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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

**DEVELOPMENT OF MEASUREMENT SYSTEM FOR INDIRECT HAND GRIP
FORCE AND WRIST ANGLE FOR BIONIC HAND**

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**A report submitted is partial fulfillment of the requirements for the degree of Mechatronic
Engineering**

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

YEAR 2015

I declare that this report entitle “Development of Measurement System for Indirect Hand Grip and Wrist Angle for Bionic Hand” is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

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ABSTRACT

In today's world, the number of physical disability people is increasing year by year. To overcome the problem, bionic hand is introduced. However, most of the bionic hands designed are complex and time consuming. Thus, in this project, a bionic hand with a designed measurement system is proposed. The first objective is to design and develop a measuring system that consist of preamplifier with DRL concept, band pass filter, full wave precision rectifier, smoothing circuit and also inverting amplifier in order to extract linear enveloped EMG signal. The second objective is to establish the relationship of EMG signal with hand grip force and wrist angle. An experiment is done which the angle considered are 60° , 90° , and 120° with the hand grip force of 20N, 60N and 100N to obtain the relationship. The last objective is to see the performance of the bionic hand in terms of repeatability and accuracy by using the designed measuring circuit. In terms of repeatability, the bionic hand is led to follow the actual human hand in terms of gripping and relaxed position to see the ability of the bionic hand to repeat and follow the human hand. From the results obtained, the bionic hand manages to yield the movement repeat ably. Finally, in terms of accuracy, the angle of each fingers of the bionic hand is test respect to the expected angle of bionic hand. From the results, the bionic hand considered as accurate as most of the fingers have lower percentage of error than 50%.

ABSTRAK

Dalam dunia hari ini, bilangan orang-orang kurang upaya fizikal semakin meningkat dari tahun ke tahun. Untuk mengatasi masalah ini, tangan bionik telah diperkenalkan. Walau bagaimanapun, kebanyakan tangan bionik yang direka adalah rumit dan memakan masa. Oleh itu, dalam projek ini, tangan bionik dengan sistem pengukuran yang direka telah dicadangkan. Objektif pertama projek ini adalah untuk mereka bentuk dan membangunkan sistem pengukuran yang terdiri daripada prapenguat dengan konsep DRL, penapis lulus jalur, gelombang penuh ketepatan penerus, melicinkan litar dan juga menyongsang penguat untuk mengekstrak linear menyelubungi EMG isyarat. Objektif kedua adalah untuk mewujudkan hubungan EMG isyarat dengan kekuatan genggam tangan dan sudut pergelangan tangan. Satu eksperimen dilakukan yang dianggap sudut 60° , 90° , dan 120° dengan kuasa cengkaman tangan 20N, 60N dan 100N untuk mendapatkan hubungan. Objektif terakhir adalah untuk melihat prestasi tangan bionik dari segi kebolehulangan dan ketepatan dengan menggunakan litar mengukur direka. Dari segi kebolehulangan, tangan bionik diketuai mengikuti tangan manusia sebenar dari segi cengkam dan kedudukan santai untuk melihat keupayaan tangan bionik mengulangi dan ikut tangan manusia. Daripada keputusan yang diperolehi, tangan bionik berjaya menghasilkan pergerakan berulang yang berupaya. Akhir sekali, dari segi ketepatan, sudut setiap jari tangan bionik adalah ujian berkenaan dengan sudut yang dijangka tangan bionik. Daripada keputusan, tangan bionik dianggap sebagai tepat kerana kebanyakan jari mempunyai peratusan lebih rendah daripada kesilapan daripada 50%.

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CHAPTER 1

INTRODUCTION

1.1 Research background

Bionic in terms of medical definition is a comprising of artificial body parts that substitute a natural biological capability. Meanwhile in terms of engineering, bionic is an application of biological principles and design of engineering systems (especially in electronic systems). Referring to Touch Bionic *et al.*, the history of touch bionics began in year 1963 at Princess Margaret Rose Hospital in Edinburgh where it start with comprehensive research in developing a prosthetic solutions for patient that affected by Thalidomide as shown in Figure 1.1. In year 1993, David Gow who joined the Bioengineering Center at the hospital, developed a partial hand system that receive international publicity and years later he achieved international profile for the world's first electrically powered shoulder. In 2007, Touch Bionics of Livingston made the i-LIMB hand that had become the world's first commercially available bionic hand that has five individually powered fingers. [1]



Figure 1.1: Patient that suffer Thalidomide

1.2 Motivation and significant of the research

Referring to the *Perangkaan Sosial Negeri/Daerah 2013*, the Table 1.1 shows the number of registered person under the department of social welfare with disabilities in Malaysia from year 2008 to 2012. In this table it shows that the number of disability people is increasing year by year.

Table 1.1: Number of Registered person with disabilities in Malaysia, from 2008 to 2012

Jenis kecacatan Type of disability	2008	2009	2010	2011	2012
Jumlah Total	248,858	283,577	314,247	359,203	445,006
Penglihatan Visually impaired	22,856	26,158	27,840	31,924	40,510
Pendengaran Hearing	34,580	37,735	39,824	43,788	53,357
Fizikal Physical	83,070	94,346	105,020	123,346 ^a	148,461 ^a
Masalah pembelajaran Learning disability	96,246	109,743	120,109	134,659	165,281
Cerebral palsy	2,890	4,071	4,068	-	-
Pertuturan Speech	-	-	334	725	1,734
Mental	-	-	3,663	8,927	14,990
Lain-lain Others	9,216	11,524	13,389	15,834	20,673

^a Termasuk Cerebral palsy
Includes Cerebral palsy

Sumber: Jabatan Kebajikan Masyarakat Malaysia
Source: Department of Social Welfare, Malaysia

For physical disabilities, in year 2008 it shows that the number of patient registered is 83070, followed by 94346 in year 2009, 105020 in 2010, 123346 in 2011 and finally 148461 in year 2012. This physical disabilities includes patient that had lost their hands, hand paralyzed and so on. For patient that facing this problem of maimed hand, their daily activities become limited and difficult for them to adapt to the daily environment. This is because they will have a difficulty to perform basic movements such as holding an object or grasping an object. To improve their daily life activities, a bionic hand by using designed measuring circuit is proposed.

1.3 Problem statement

In today's world, there are more and more amputee who had lost their body part such as hand and leg. They don't have the capability to do things like a normal person does. To improve their living ability, a bionic hand is proposed to replace their lost hands or legs. This becomes the biggest issues that surround the design and development of prostheses. Satisfaction in modern prosthetics is depends on how close a prosthetic is to reach its ideal objectives. One product has been produced by the Touch Bionic's Company which is I-Limb Ultra. This I-Limb Ultra has 14 Degree of Freedom. With 14 Degree of Freedom, the bionic hand will have more joint and parts that need to assembly together. This makes the system of this bionic hand is complex, time consuming, expensive and also hard to control. Most of the bionic hand designs used muscle kit sensor which is more expensive, to extract the EMG signal as the primary controller to control the bionic hand. The measuring circuit to extract the EMG signal is designed and developed in the project rather than muscle kit sensor as the designed measuring system cost less money and the EMG extracted is smoother compared to muscle kit sensor as it does not have a smoothing circuit in it. Thus, in this project, a bionic hand of 10 degree of freedom with designed measuring circuit which is less complex, less expensive and not time consuming is done.

1.4 Objectives

The objectives of this final year project (FYP) are to:

1. Design and develop a measurement system to extract forearm EMG signal and interface the signal with designed bionic hand.
2. Establish the relationship between forearm EMG signal and hand grip force and use this relationship to predict the hand grip force exerted and joint wrist angles when forearm EMG signals are used as input.
3. Analyze the performance of the bionic hand in term of repeatability and accuracy by using the designed measurement system.

1.5 Scope



The scopes that cover in this final year project are:

1. The EMG signal that extracted from the electrodes that attached to hand is used as the input of the system.
2. The bipolar electrodes are used in order to extract the EMG signal from Flexor Digitorum Superficialis (FDS) muscle.
3. Mohamad Fakri bionic hand designed will be used as the test bed of this project.
4. The angle considered to establish the relationship between the forearm EMG signal are 60°, 90° and 120° with hand grip force considered of 20N, 60N and 100N.

1.6 Report outline

This report consists of 5 chapters which are Introduction, Literature Review, Methodology, Preliminary Results and conclusion and recommendation. In first chapter which is Introduction, it basically talks about the objectives of project. It covers the research background of the bionic hand, motivation and significant of the research, problem statement, scope and report outline.

In chapter 2, it talks about literature review which covers the theory and basic principle, test bed of the project and also reviews of the previous related works. In this theory and basic principle, its covers the basic theory of the anatomy of hand and electromyography. The test bed of this project is developed by Mohamad Fakri which it covers the mechanical design and component selection of the bionic hand. In this chapter also, several reviews of the previous related works which taken from the journals are compared to choose the best controller and muscles to used. From the review, summary is made.

In chapter 3, it talks about methodology that used to complete the project. A flowchart is provided to see the flow on completing this project. In this chapter, it covers the objectives of the project. The first part is design and development of measuring system for forearm EMG signal extraction and interfacing to robotic hand where it covers the design measurement system and constructing the circuit. The second part covers the second objective which is the establishment of the relationship between forearm EMG signal and hand grip force. In this section, it covers the muscle selection, experimental setup for signal extraction, and establishes of the relationship. The last part covers the last objective which is to analyze the performance in term of accuracy and repeatability. Accuracy test and repeatability test is done.

In chapter 4, it covers the results obtained from each experiment that had been done. Each of the experiment is done in order to achieve every objective in this project. Analysis and discussion is made based on the results that obtained.

Finally, in chapter 5, it covers the conclusion of the whole project. Recommendation is made for further improvement for this project.



CHAPTER 2

LITERATURE REVIEW

2.1 Theory and basic principle

In this section, theory and basic principle that are related to the development of bionic hand. It covers the anatomy of human hand which it talks about the muscle in hands. This section also covers the introduction of electromyography signal, which talks about the benefits of EMG signal and the factor influence it. In this section also, it covers on the information for test bed of the bionic hand that is developed by Mohd Fakri. Finally, it covers on the previous work done in terms of bionic hand controller and muscle selection and the performance test of bionic hand.

2.1.1 Anatomy of human hand

Hand is a complex structure which adapted to perform unequalled array of movement. There are more than 60 different muscles in the hand in order to accomplish this such as Extensor Pollicis Brevis Muscle (EPB), Flexor digitorum sublimis (FDS), Flexor digitorum

profundus (FDP) and many more. However, there are two main contribution of muscle in gripping hand which are Flexor digitorum sublimis (FDS) muscle and Flexor digitorum profundus (FDP) muscle.

Referring to Innerbody *et al.* Flexor digitorum superficialis (FDS) is a large muscle that located along the bottom of the forearm from all the bones at the elbow to the four fingers as shown in Figure 2.1. It serves to flex or curl of the fingers. This muscle is divided into two distinct heads which are the radial and humeroulnar. [3] The median nerve and ulnar artery travel through these two heads. A flexor muscle is the one that decreases the angle between the two bones such as bending the arm at the elbow.



Figure 2.1.: Flexor digitorum sublimis muscle [3]

2.1.2 Electromyography (EMG)

Electromyography which is also known as EMG, is an experimental technique that concerned with the development and analysis of myoelectric signals. Myoelectric signal is an electrical impulse that produces the contraction of the muscle fibers in the human body. By placing electrodes on the skin, the myoelectric signals can be detected. Two electrodes are placed so that there is a voltage between them when the myoelectric signals are occurs.

Meanwhile, the third electrode is placed in a natural area where its output is used to cancel the noise that can interfere with the signals from the other two electrodes.

Electromyography (EMG) signal is a small electrical current that generated when there is a contraction of a muscle. Since the electromyography signal levels are too low to be captured directly by the computer, the signal is required to amplify to a TTL level that ranged between -5volts to +5volts. By amplifying the EMG signal, the computer can store and read the data in the file format. However, there are many critical factors that must be considered such as noise and artifact problems could distort the signal. Other than that, Additional DC current could also add offset to the EMG signal. Finally, the size of the device should be taken into consideration as the equipment will be attached to the forearm during the EMG recording.

Referring to Aditya Veer Singh Rana *et al.* the measurement of the electrical activity of the muscle in the hand is the results of a signal that generates in the brain which is transmitted through the nervous system to the motor neuron attached to the muscle fibers. The motor neurons resulting in a depolarization or repolarization wave throughout the muscle fiber. This wave creates action potential in the muscle fibers resulting in the movement of the electrical charge that produces an electrical signal in the muscle. This electrical signal can be picked up by the well-placed electrodes that attached on the surface of the skin. The received signal is EMG signal. The amplitude of EMG signal is depends on the amount of force delivered by the biceps. The stronger the contraction of the muscle the larger the amplitude of the EMG signal. [5]

Referring to Peter Konrad, *et al.* there are a lot of benefits of using Electromyography (EMG) such as it allows measurements of a muscular performance, helps in decision making for both before and after surgery, helps patients to find and train their muscle. Using EMG also will allow analysis to improve sport activities and detect muscle response in ergonomic studies. [6]

EMG signal can be influenced by some external factors such as tissue characteristics, external noise and electrode and amplifier. Human body is a good electrical conductor. However, the electrical conductivity varies with tissue type, temperature, thickness and physiological changes. A thicker tissue layer below the electrodes decreases the overall amplitude of the raw EMG compared to the normal condition as shown in Figure 2.2.

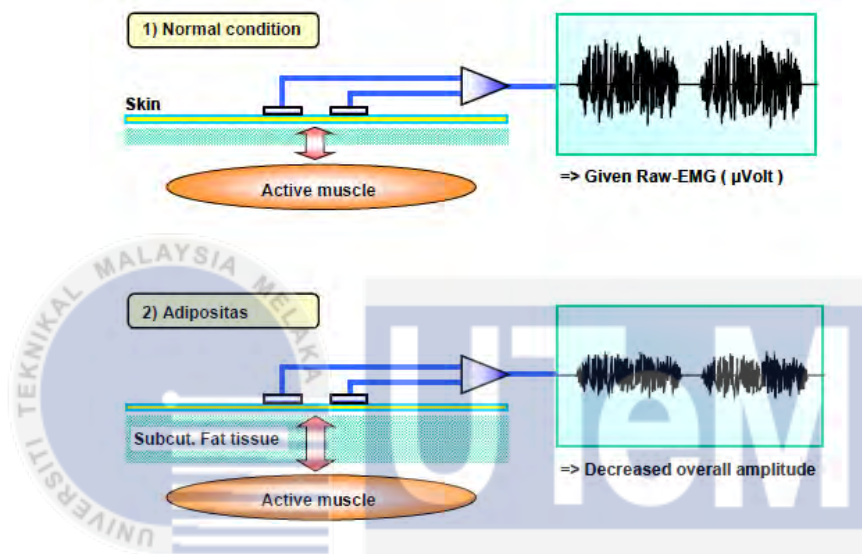


Figure 2.2: Different thickness of tissue layer produce different amplitude EMG signal (Peter Konrad, 2005)

Besides that, external noise is also one of the factors that influence the EMG signal. The selection of the electrode and internal amplifier noise might add signal content to the EMG baseline. The internal amplifier noise shouldn't exceed 5Vrms. These factors can be minimized by accurate preparation and checking the given laboratory condition.

2.2 Test bed of this project

The test bed of this research was developed by Mohamad Fakri in year 2013. The exoskeleton hand is done by using Solid Works 2014 Software which it fabricated by using Aluminum alloy 6061 from 6000 series aluminum alloy. The design is completed with the components selections which are liner DC motor for the finger movement, Servo motor for wrist movement, electrode, Arduino Uno for Controller and also V3 kit Muscle Sensor.

2.2.1 The Bionic Hand

The mechanical design of the bionic hand is done by using SolidWorks 2014 Software. It is designed follow the human hand characteristic which includes palm and fingers where each of the fingers consists of proximal, middle and distal phalanx. This bionic hand consists of 5 fingers which are thumb, index, middle, ring and also pinky. The degree of freedom of this bionic hand is 10 rather than 14. This is because the distal and middle phalanx of the fingers is combined together. Figure 2.3 shows the mechanical design of bionic hand using SolidWork software.

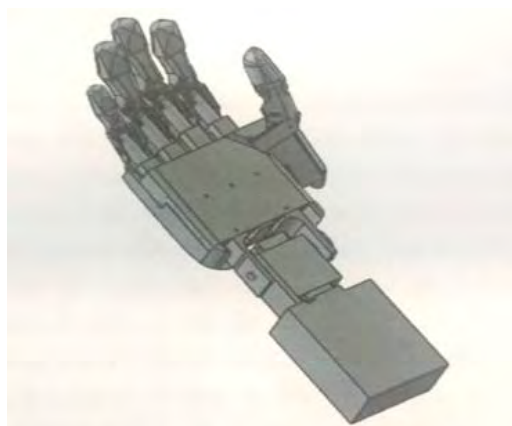


Figure 2.3: Mechanical design of bionic hand using SolidWork (Mohamad Fakri, 2014)

In designing a robotic hand, selecting components is important as it influences the performances and the structure of the bionic hand. In this component selection section, it talks about the materials and the components that used in designing and fabricating the bionic hand.

The material used to fabricate this bionic hand is by using Aluminum alloy 6061 from 6000 series aluminum alloy. According to Sapa Industrial Extrusions *et al*, this alloy 6061 is one of the most versatile of the heat-treatable alloys. It is popular for medium to high strength requirements and has a good toughness characteristic. Besides that, this material also has an excellent corrosion resistance to atmospheric conditions and has a good corrosion resistance to the seawater. Finally, this material also can be easily welded and joined by various commercial methods. [7]

The actuator used in designing the bionic hand is by using Linear DC motor, Firgelli. This is because a linear movement is needed to generate the movement of each finger. In this design, there are five linear dc motors used which is placed inside the bionic hand palm. The Linear DC motor used for the bionic hand is 100 for gearing option and 30mm for stroke option.

The bionic hand used C36R servo motor to actuate the wrist movements of the bionic hand. According to Cytron technologies, this RC servo motor has the ability to rotate and maintain at certain location, position or angle according to the control pulse from a single wire.

In order to make the movements of each fingers of the bionic hand to move smoothly, mechanical linkages are used as the mechanism to transfer the power which will generate from the linear motor to Proximal, Middle and Distal Phalanx. These mechanical linkages is connected to the palm, Proximal, Middle and Distal Phalanx part and the linear motor located

in the palm will generate the movements for the bionic hand to retract or extend the entire phalanx.

2.3 Previous work done

In this section, it covers the information that related to the previous work done in terms of bionic hand controller and the development of relationship. In bionic hand controller and muscle selection section, there are four different journals used and were compared. Meanwhile in the performance test of bionic hand, there are also four journals that had been used to compare. A summary is made into a table to summarize them.

2.3.1 Bionic hand controller and muscle selection

Referring to Paul Ventimiglia *et al.*, robotic prosthetic hands with individually articulated fingers were released onto market where these hands are completely revolutionary in their look and also functions. Touché Bionic is the first company that release one of these hands which is known as “iLimb”. The input is controlled through the myoelectric sensors that read the muscle signals remaining on the portion of an amputees arm. The control is designed so that the person should be optimally be able to open and close their hands with the same muscle signals that they would normally send them to an actual human hand. However, this ilimb bionic hand doesn’t have an actively powered positionable thumb which means the user have to use their other hand to manually rotate the angle of the thumb. Besides that, there is no force feedback provided to the user. Thus, it can be hard to perform precision tasks. As a

results, users may accidentally drop objects because they are not being gripped firmly enough. [8]

Referring to Aditya Veer Singh Rana *et al.* a robotic arm is controlled by using EMG signal acquired from the electrodes that attached to human arms. The EMG signal that acquired are from three different muscle groups of the upper forearm. The signal is then fed to the signal conditioning unit that consists of signal acquisition, rectification, amplification and final filtration. The output the signal is then being converted to digital signal by using 16-bit serial Analog to Digital converter (ADC). The digitized signal is used as feedback and control signal for final control of the robotic arm. The robotic arm is attached to the shaft of the stepper motor for motion. There may be more than one stepper motor in order to give multi-dimensional motion to the robotic arm. There are four muscle that involved in electrode positioning which are Flexor Carpi Ulnaris, Palmaris Longus, Extensor Carpi Radialis and also Extensor Digitorum muscle. [5]

According to Loredana Zollo *et al.* from the data on human behavior during motion of the fingers, these data have been used as the reference for the control system. Design goal of the control system is addressed in order to obtain a good trade-off between functionality and simplicity by optimizing proportional derivative (PD) controller with gravity compensation. There are two version of the control system that have been developed and compared which are joint space and slider space. The slider is the mechanism to produce tension in the cable transmissions. The muscle used is Flexor digitorum Profundus as its tendon runs across all the finger joints and it is attaches to the distal phalange. [9]

Jingdong Zhao *et al.* present a five fingered underactuated prosthetic hand controlled by surface Electromyographic signals. This prosthetic hand control part is based on EMG motion pattern classifier that combines Variable Learning Rate (Which also known as VLR) based neural network with the parametric Autoregressive (AR) model and wavelet transform.

By measuring the EMG signals through placing the three electrodes that mounted on the Flexor Pollicis Longus, Flexor Digitorum Profundus and Extensor Digitorum, this motion patterns classifier can identify flexion and extension of the thumb, index and middle finger. [10]

2.3.2 Performance test of bionic hand

Referring to N. S. L. Ho *et al*, in their journal of An EMG-Driven Exoskeleton Hand Robotic training device on chronic stroke subjects, in developing the relationship, the stroke subject is required to complete upper limb training task that assisted by using the exoskeleton robotic hand training device as shown in Figure 2.4. The training period for each of the tasks were given 10 minutes training period. The first task for the subject stroke to complete is by moving an object which is foam, across the table in horizontally direction for 50 cm distance. The second task is to move the foam vertically above the table for 20cm distance. The stroke subjects repeated the same task for hand opening, grasp foam and move to target position and release it at their comfortable speed for each 10 minutes. [11]



Figure 2.4: Stroke subject completing foam test (N. S. L. Ho, 2011)

Referring to Hiroshi Yokoi *et al*, through the journal of Mutual adaptation in prosthetics application, a prosthesis hand was developed with the use of finger mechanisms. In developing the relationship of EMG signal and Bionic hand, several test on the prosthetic hand were done such as grasping a cylindrical form, grasping of an elliptical case and grasping a pet bottle. The object is shaken in order to test the grasping torque. Other than that, test on holding a cup, pen and a CD case were also being done in developing the relationship. Figure 2.5 shows the tests that have been made to the EMG prosthetic hand. [12]



Figure 2.5: Test of prosthetic hand in grasping a cylindrical, elliptical form, pet bottle, holding a cup, pen and CD case. (Hiroshi Yokoi)

Referring to Jingdong Zhao *et al*. through his journal of A Five-fingered Underactuated Prosthetic Hand Control Scheme, the prosthetic hand control part is based on EMG signal pattern based on the neural network with the parametric autoregressive model and also wavelet transform. The test that is done in the project is the flexion and extension of the

thumb, index and middle finger where three electrodes were placed on three different muscles. [29] Figure 2.6 shows the prosthetic hand motion of the experiment.



Figure 2.6: Prosthetic hand motion

Finally, according to M. C. Carrozza *et al.* through his journal, the test done on the project is grasping capability. The experiment test is done to evaluate the force that the finger is able to exert on objects. The task is done 10 times to obtain the results. The force obtained is compared with the force exerted by the natural human fingers. [30]

2.3.3 Summary

In this section, the summary of the bionic hand controller and muscle selection used is summarized as in Table 2.1.

Table 2.1: Summary of bionic hand controller and muscle selection

Journal	Author	Muscle	Controller
Design of human hand prosthesis	Paul Ventimiglia (LA&E)	N/A	EMG Signal
2-d Robotic arm control using EMG Signal	Aditya Veer Singh Rana Ridhi Aggarwal	Flexor Carpi Ulnaris, Palmaris Longus, Extensor Carpi Radialis and Extensor Digitorum muscle.	EMG Signal
Biomechatronic Design and Control of an Anthropomorphic Artificial Hand for Prosthetic and Robotic Applications	Loredana Zollo Stefano Roccella Eugenio Guglielmelli M. ChiaraCarrozza Paolo Dario	Flexor digitorum Profundus	Proportional Derivative (PD) controller
A Five-fingered Underactuated Prosthetic Hand Control Scheme*	Jingdong Zhao Zongwu Xie Li Jiang Hegao Cai Hong Liu Gerd Hirzinger	Flexor Pollicis Longus, Flexor Digitorum Profundus and Extensor Digitorum	EMG Signal

From the table, the controller chosen for this project is EMG signal. The EMG signal is extracted from the hand by placing the bipolar electrode on the forearm. In this project, the muscle that used is Flexor Digitorum Profundus. This is because this muscle is a large muscle which located along the bottom of the forearm from all the bones at the elbow to the four fingers where it is easier to locate the bipolar electrode. Other than that, this muscle also has more significantly contribution to the hand grip force for the amputee to holds object.

The summary of performance test is summarized in Table 2.2.

Table 2.2: Summary of the performance test of bionic hand

Journal	Author	Types of Test
An EMG-driven Exoskeleton Hand Robotic Training Device on Chronic Stroke Subjects	N.S.K. Ho, K.Y. Tong, X.L. Hu, X.J. Rong, E.A. Susanto	Repeated the same task for hand opening, grasp foam and move to target position and release for each 10 minutes
Mutual adaptation in prosthetics application	Hiroshi Yokoi, Alejandro Hernandez Arieta, Ryu Katoh, Wenwei Yu	Test of prosthetic hand in grasping a cylindrical, elliptical form, pet bottle, holding a cup, pen and CD case.
A Five-fingered Underactuated Prosthetic Hand Control Scheme	Jingdong Zhao, Zongwu Xie, Li Jiang, Hegao Cai	The test of flexion and extension of the thumb, index and middle finger where three electrodes were placed on three different muscles.
A “Wearable” Artificial Hand for Prosthesis and Humanoid Robotics Application	M. C. Corrozza, B. Massa, S. Micera, M. Zecca, P. Dario	The test of grasping capability. The experiment test is done to evaluate the force that the finger is able to exert on objects. The force obtained is compared with the force exerted by the natural human fingers

From the table 2.2, the test that will be done in this project is accuracy test which the Flexion of each fingers of the bionic hand is tested. The test is done to get the accuracy of the bionic hand to follow the human hand motion as expected. The experiment is done 10 times to get the accuracy of the bionic hand respect to the expected results. As for the repeatability test, the bionic hand is led to follow the actual human hand which is to open and grasp for 10 times to see whether the bionic hand is able to repeat as human hand or not.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Methodology is defined as a system of method that used in a particular area of studies. Methodology in this project is mainly based on the step of how to develop a measurement system for indirect hand grip force and wrist handle measurement. It is done step by step to achieve all the objectives. With this methodology, it helps in making the project to complete in proper manner and helps to identify problem occurs when completing this project.

All the development of measurement systems for indirect hand grip force and wrist angle measurements of the bionic hand are discussed in details referring to the objectives in this methodology section. The first section covers the first objective of this project which is to design and develop measuring system for forearm EMG signal extraction and interfacing to the robotic hand. The second section covers the second objective which is the establishment of the relationship between forearm EMG signal and hand grip force. The last section covers the third objective which is to analyses the performance of the ionic hand in term of repeatability and accuracy. Figure 3.1 shows the flowchart that shows the steps on how this project can be archived all the objectives.

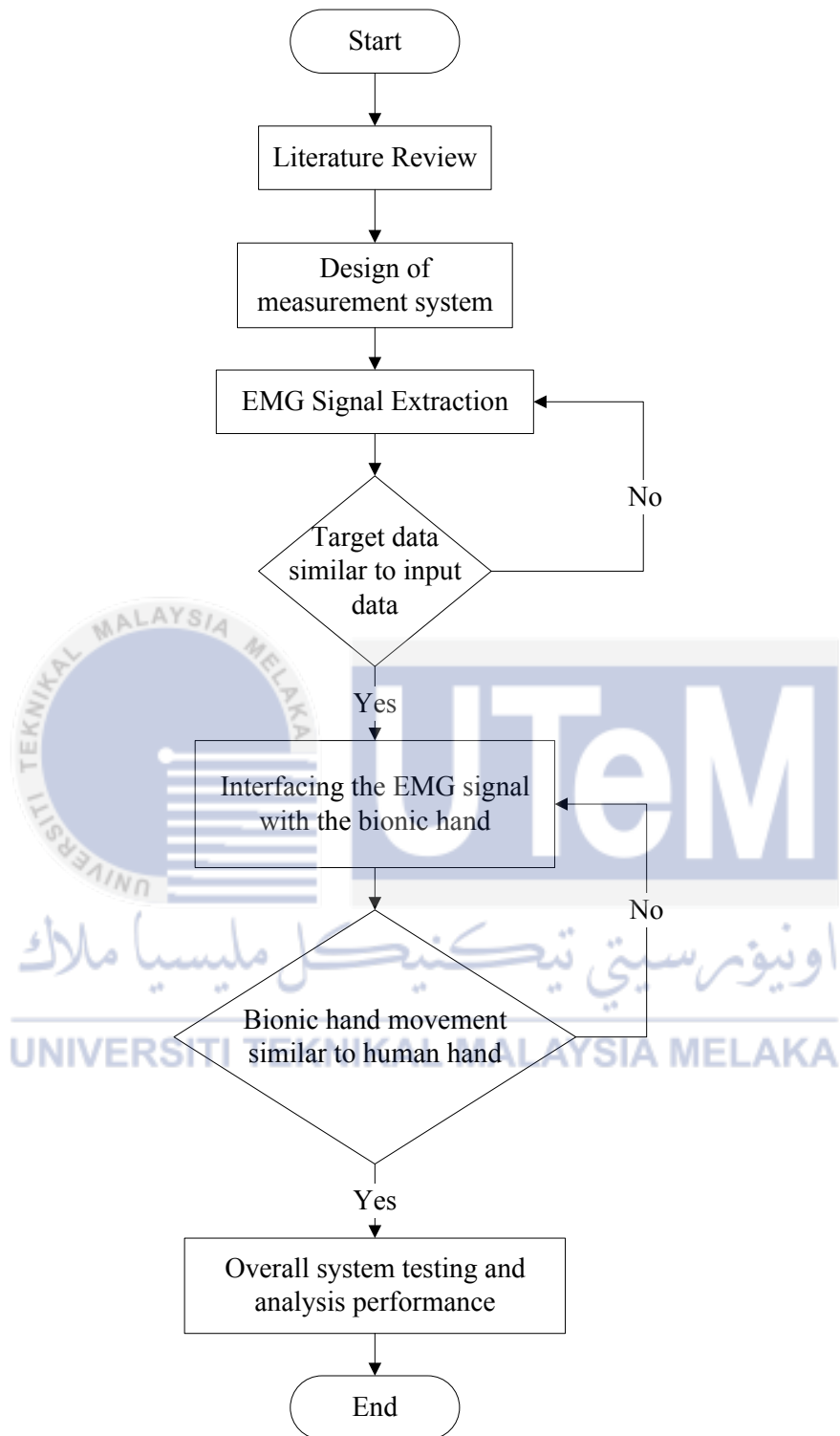


Figure 3.1: Flowchart of methodology

Based on the flowchart in figure 3.1, the project is started with literature review based on the problem statement and objectives to get clear understanding about the project. Based on the understanding and information obtained from Chapter 2, a measurement system is designed and being simulated by using Proteus 7 software. The project is being proceed with the construction of the measurement circuit on the breadboard and being analyze to get the target data similar to the input data. Once the analyzation is done, the circuit is then transferred to PCB. With the data obtained from the experiment, the results are used to interface the EMG signal with the bionic hand. The movement of the bionic hand is then being analyses to get the similar movement to human hand. Experiment is done to achieve all of the objectives.

3.2 Design and Development of Measurement System

In this section, it covers the first objective which is to design and develop a measurement system in order to extract forearm EMG signal. Then, the signal is used to interface with designed bionic hand. The system consist of circuit conditioning which is very important as the EMG signal levels are too low to be captured directly by the computer. The signal is required to amplify to a certain level that ranged between -5volts to +5volts. In this section, it divides into two sub sections. The first section covers the design of measurement system in Proteus that consist of pre-amplifier circuit with DRL concept, band pass filter, full wave precision rectifier, smoothing circuit and also inverting amplifier. The second subsection covers the development of designed EMG Measuring circuit.

3.2.1 Design of Measurement System in Proteus

The design of EMG measurement system in this project is comprises of five stages which are pre-amplifier with DRL concept, band pass filter, full wave precision rectifier, smoothing circuit and also inverting amplifier.

3. 2.1.1 Stage 1: pre-amplifier

In the first stage, a preamplifier circuit with DRL concept is designed. This stage is important as it will amplify the EMG signal and eliminate the noises in the signal. In order to eliminate noise signal from power line sources, a differential detecting configuration is employed. The signal is detected at two sites which are positive and negative input from the electrode, the electronic circuitry subtracts the two signals and amplifies the difference. Thus, any signal that is common to both detection sites will be removed and signals that are different at the two sites will be subtracted and amplified. Here, the local EMG will be amplified instead of the noise. [19] The differential amplification technique is shown schematically in Figure 3.2 below. The EMG signal is represented by 'm' and the noise signal by 'n'.

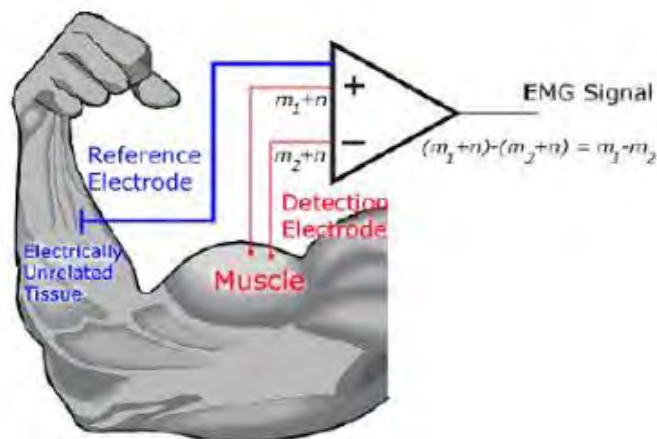


Figure 3.2: schematic of the differential amplifier configuration. [19]

The consideration in including the pre-amplifier is to have a high common mode rejection ratio (CMRR). According to A.J.H Mohideen *et. al*, higher CMMR have a higher capability of the instrumentation amplifier to subtract noise which appears as common mode signals to the instrumentation amplifier input. [14] In this pre-amplifier stage, an instrumentation amplifier which is AD620 is selected. According to the datasheet of AD620, this component has high CMRR with minimum of 100dB. The low current noise of this component allows it to use in EMG monitors. Other than that, this instrumentation amplifier also has low bias currents and low current noise, coupled with the low voltage noise of the AD620 that improves the dynamic range for better performance which makes it well suited for medical application. [20] Figure 3.3 shows the pin configuration of AD620. Thus, This AD620 is a good choice

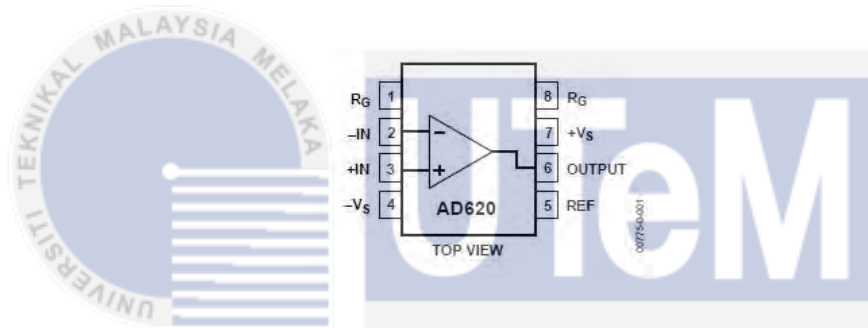


Figure 3.3: Pin configuration of AD620

The output from this pre-amplifier is then processed by a band pass filter that will be explained in the next stage. The gain of the EMG measurement circuit at this stage is lower and further amplification is needed that should be done in other part of the circuit. This is done in order to prevent from accidentally amplify the DC offset which is not desirable instead of EMG signal. The input of the preamplifier is from the electrodes that attached to the skin surface of dedicated muscle. The gain of this preamplifier is 26 with R_G value of $2k\Omega$. Each resistor R_1 and R_2 is $1k\Omega$. The selection of the value R_G is obtained by using the Equation 3.1 below.

$$Gain = \frac{50k\Omega}{R_G} + 1 \quad \text{Equation 1}$$

$$Gain - 1 = \frac{50k\Omega}{R_G}$$

$$R_G = \frac{50k\Omega}{Gain - 1}$$

$$R_G = \frac{50k\Omega}{26 - 1}$$

$$R_G = 2k\Omega$$

The leg 1 and 8 of the preamplifier circuit (AD620) is connected to the Driven Right Leg (DRL) circuit. This DRL circuit is used to have better and higher CMRR where the main noise which created due to the power lines will be removed. The output of this DRL circuit is connected to the electrode that attached to the reference bone. According to A.J.H. Mohideen *et al.* by using the Driven Right Leg (DRL) concept, the common mode noise signal is fed to a bony human body such as elbow which serves as the reference electrode in order to increase the signal to noise ratio of the preamplifier. [14] Figure 3.4 shows the preamplifier circuit with DRL concept.

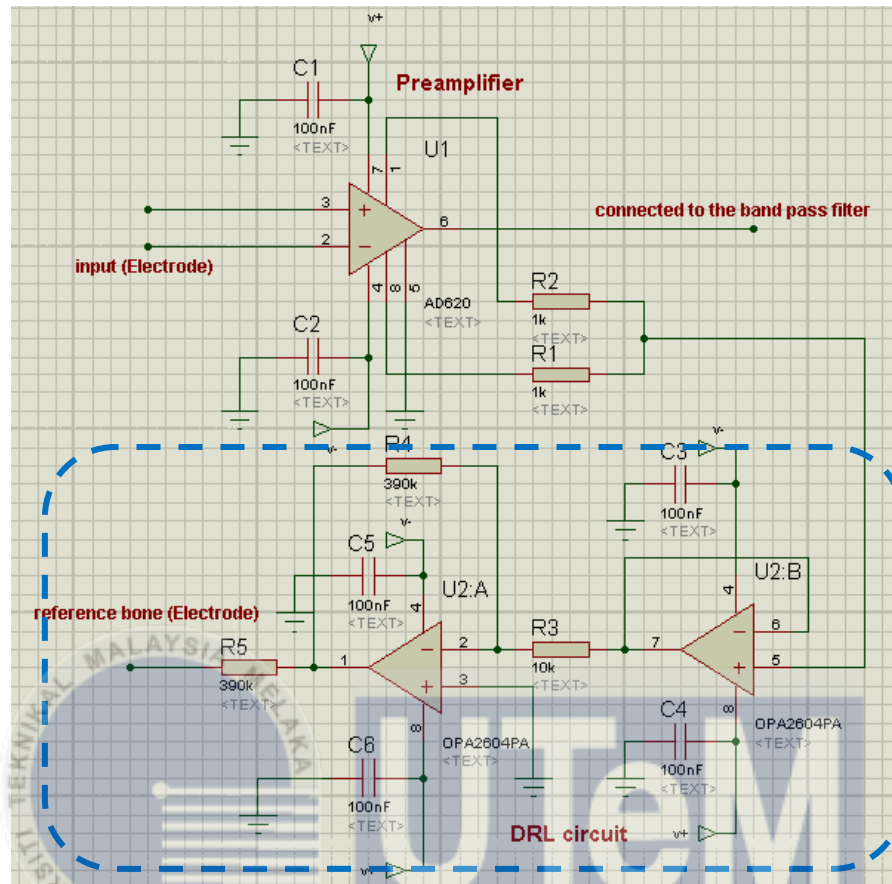


Figure 3.4: Preamplifier circuit with DRL concept.

3.2.1.2 Stage 2: Band pass filter

The second stage is band pass filter which has cut-off frequency in between 20Hz to 400Hz due to the optimum EMG signal is in between that range. According to Carlo J. De Luca, the signal to noise ratio of the EMG can be increased by having filter between 20Hz to 500Hz. The strict design characteristic could consider 400Hz as the upper bandwidth cut-off. [19] The band pass filter is divided into two parts which are Sallen Key second order high pass filter and followed by Sallen Key second order low pass filter. These both filters are cascaded to make a band pass filter. According to M. Hamza Khan *et al.*, this Sallen Key is best suited

for the application that require preservation of amplitude and linearity in the passband region which makes this filter an ideal candidate for conditioning the EMG signal. This band filter removes the motion artifact noise and the high frequency noise from the signal. [17]

Both combination of Sallen Key high pass and low pass filter used OPA2604PA as the operational amplifier. In designing the Sallen Key high pass filter, the suitable range of capacitor value for filter design purpose is range from 100pF for high frequencies to 100nF for low frequency. 20Hz considered as low frequency and thus, the value selected for C7 and C8 are 100nF. [14] In order to find the value of resistor of R6 and R7, the online Sallen key high pass filter design calculator is being used [21] The value of capacitor C7 and C8 with 100nF and cut off frequency of 20Hz are key in the online calculator and the value resistor obtained is $R_6 = 112539.5\Omega$ and $R_7 = 56269.8\Omega$ as shown in Figure 3.5.

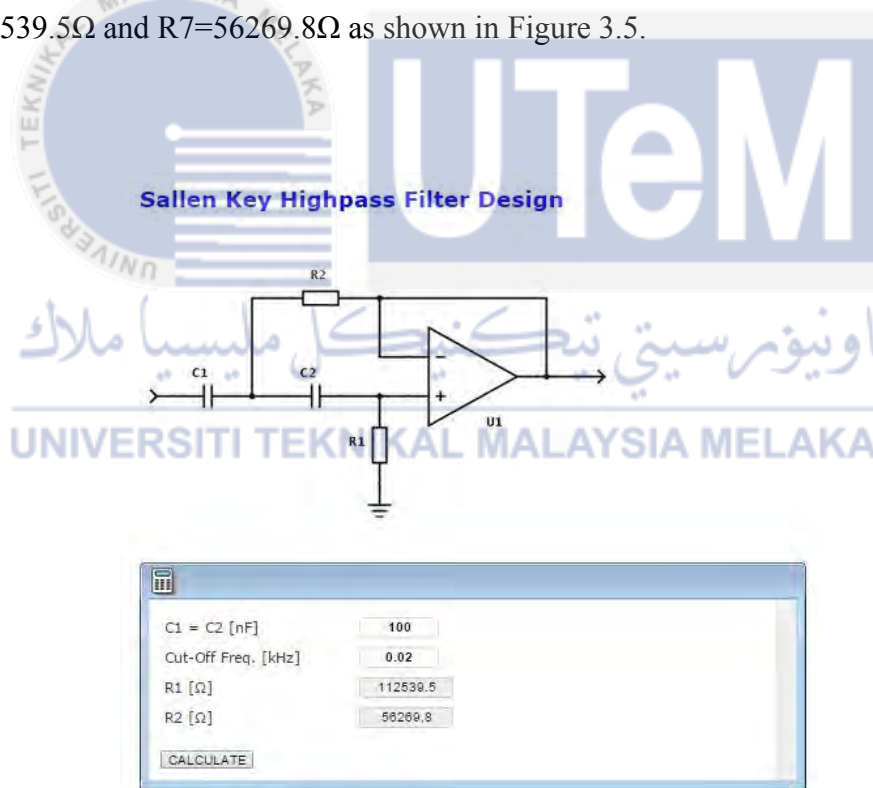


Figure 3.5: Online Calculator Sallen Key High Pass Filter

Meanwhile in designing the Sallen Key Low Pass Filter, the Online Sallen Key Low Pass Filter is being used. [22] The value of cutoff frequency of 400 kHz and C11 of 10nF are inserted and the value of C12 obtained is 20nF with the resistor value of $R8=R9$ chosen is $20k\Omega$ as shown in Figure 3.6.

Sallen Key Lowpass Filter Designer

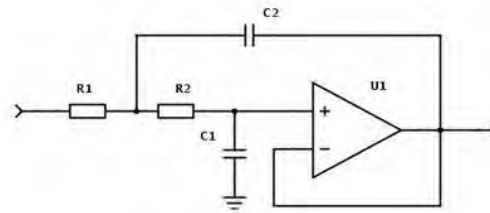


Figure 3.6: Online Calculator Sallen Key Low Pass Filter

The output for this band pass filter is connected to full wave precision rectifier circuit. Figure 3.7 shows the Sallen key second order High pass and low pass filter.

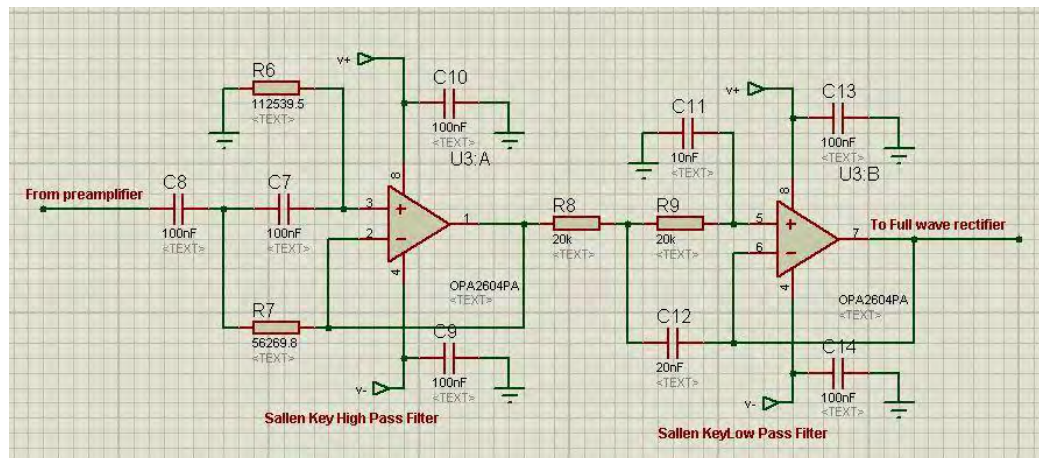


Figure 3.7: Sallen key High pass and low pass filter.

3.2.1.4 Stage 4: Smoothing circuit

The final stage in EMG signal conditioning is smoothing circuit. In this smoothing circuit design, a low pass filter is used. Low pass filter is a type of filter which passes the signal with frequency that is lower than the cutoff frequency. It attenuates the signals with frequency that higher than the cutoff frequency. Low pass filter exists in many forms such as anti-aliasing filters, digital filter for smoothing and so on. Low pass filter gives a smoother form of the signal by removing the short term fluctuation and leaves the long term trends.

According to Ahmad Jazlan Haja Mohideen *et al.* the smoothing is done in order for the EMG signal to resemble muscle force exerted by the individual. This step is important where for this application where the bionic hand movement is depends on human muscle activity. Smoothing is achieves by passing the output of the full wave rectifier in the previous stage through an active low pass filter with a very low cutoff frequency. The cut off frequency of this filter is 1.95Hz with the value capacitor C20 of 1 μ F. This cutoff frequency gives the smoothest signal. However, this cutoff frequency may be vary depends on individual. [24] Figure 3.9 show the low pass filter that used for smoothing purpose.

By using the online calculator of low pass filter [25] as shown in Figure 3.10, the resistor value obtained is 81.617k Ω . Thus, the value resistor of R16 and R15 is the same which is 82k Ω .

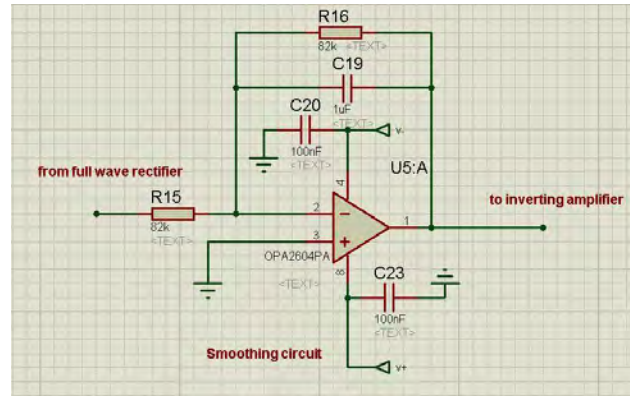


Figure 3.9: Smoothing circuit

Capacitor C	1	uF
Cutoff Frequency f	1.95	Hz
Calculate Success!		
Resistor R	81617.92	Ohm

Figure 3.10: Online calculator of low pass filter for smoothing circuit.

3.2.1.5

Stage 5: Inverting amplifier

Finally, the last part in measuring system design is inverting amplifier circuit. By referring to S.N Sidek *et al* before the EMG signal is fed into the neural network, it is full wave rectified and passed through a low pas filter as a smoothing circuit with a frequency of 1Hz in order to smoothen out the peaks and obtained an enveloped of the EMG signal. This linear enveloped EMG is suitable to be used as the input to a neural network. [15] In the entire circuit, only the operational amplifier in the first part has the gain of 26. Meanwhile both Sallen Key Low pass filter and high pass filter have the unity gain where further amplification is needed to amplify more of the signal. Thus, in this inverting amplifier, it has the gain of 100 where $1M\Omega / 10k\Omega = 100$ to amplify the signal. Therefore, the total gain of this measuring circuit is $26 \times 100 = 2600$. Different people haves different EMG signals amplitude. In order to

make this measuring circuit more flexible to accommodate with different people, R18 is replace with 1M variable resistor to enable this EMG measuring circuit to have variable value of gain. Figure 3.11 shows the inverting amplifier of the circuit.

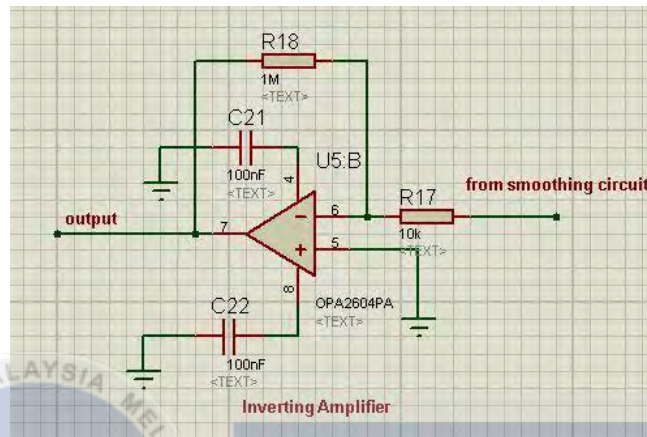


Figure 3.11: Inverting amplifier of the circuit.

The output from this inverting amplifier is connected to the oscilloscope to analyze the measurement system circuit. The analysis of the measurement system is test until the linear enveloped graph is obtained.

3.2.1.6 Power supply

Each of the IC used which are AD620 and OPA2604 is being supply with two 9V batteries to supply +9V and -9V. In AD620 IC, leg 7 and leg 4 are connected to the supply. Meanwhile for OPA2604, leg 5 and 8 are used to connect to the +9V and -9V battery. [15]

3.2.1.7 By pass Capacitor

Other than that, each IC also has two bypass capacitors with 100nF that connected to it. According to Tamara Schmitz *et al.* by using this bypass filter, it defense against unwanted perturbations on the power supply. It also helps to eliminates voltage drop on the power supply by storing electric charge to be release when a voltage spike occurs. As for the location, a bypass capacitor should be placed as near as possible to the power supply of each IC. An extra distance converts into additional series inductance which lowers the self resonant frequency of this bypass capacitor. [26] In this circuit, it has two 100nF bypass capacitors which one of it is connected between +9V power supply and ground. Meanwhile the other 100nF bypass capacitor is connected between the -9V power supply and ground.

3.2.2 Simulation on EMG Measuring Circuit

Before the EMG measuring circuit is being transferred to the breadboard, the measuring system is first being simulated by using Proteus software to test the circuit on the performance of the EMG signal. Figure 3.12 shows the full circuit of the measurement system where the input of this circuit is connected to sinusoidal 5mV (represent the EMG extracted form electrode) and the output is connected to the oscilloscope.

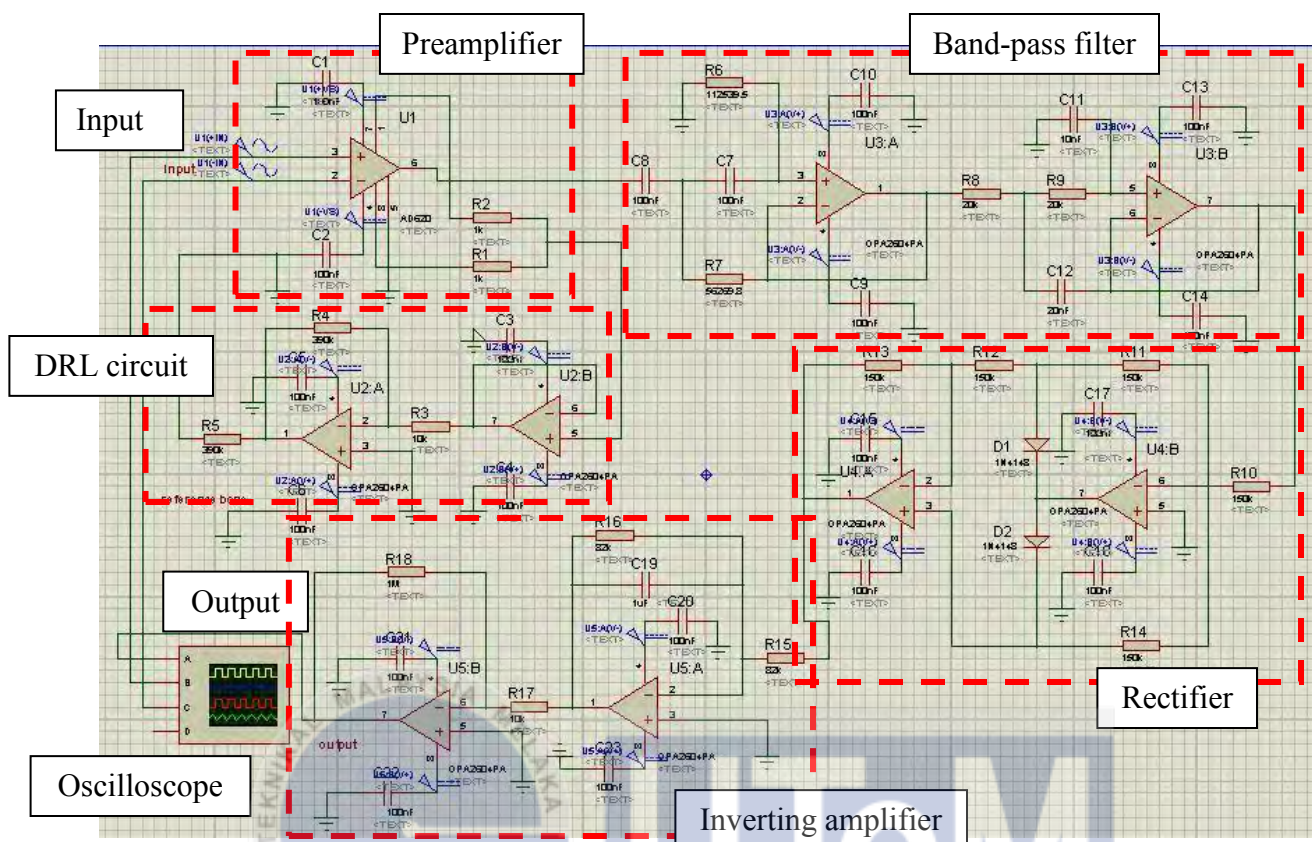


Figure 3.12: Measurement circuit for simulation in Proteus Software

From the simulation made, the graph shows in oscilloscope as shown in Figure 3.13. In the graph shown, the red line indicates the input of the system meanwhile the yellow line indicates the output from the circuit. As shown, the output from this circuit gives a linear enveloped voltage which is the signal is being rectified, smoothed and also amplified. The input channel is 5mV meanwhile the output channel is adjusted to 2V as the signal is amplified. However, the value of the amplified is depends on the circuit gain. The potentiometer is used at the inverting amplifier to have variable value of gain to make this measuring circuit more flexible to accommodate with different people as different people have different EMG signals amplitude. This linear enveloped is needed to mapped into the bionic hand. This measurement circuit design is then proceed to the next process.

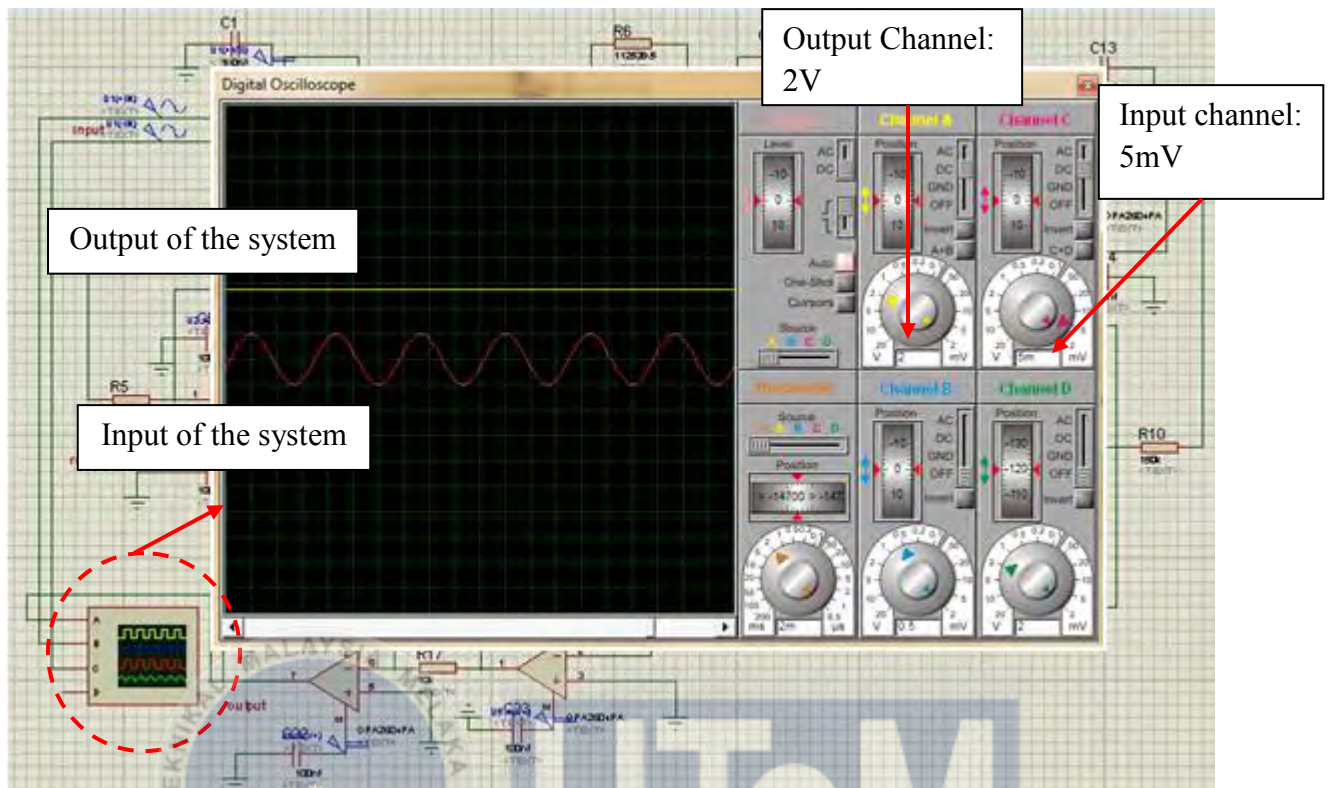


Figure 3.13: Graph obtained from the simulation

3.2.3 Developing of designed EMG Measuring circuit

The last part of achieving the first objective is to construct the measuring circuit. The circuit is constructed based on the design in the Proteus 7 software as a reference. As for the circuit prototype, all of the components used are arranged and connected on the breadboard. The reason of using this solder-less breadboard is because it doesn't require any soldering. If there is any misplaced component, it can be easily adjust. In connecting this circuit, the connection is not exactly the same as in the Proteus design. This is because one IC contains 2 operational amplifiers in it which means it only use 1 AD620 and 4 OPA2604 instead of 1AD620 and 8 OPA26054. The circuit on the breadboard is then tested to see the performance

of the EMG signal by using oscilloscope. Figure 3.14 shows the measuring circuit on the breadboard.

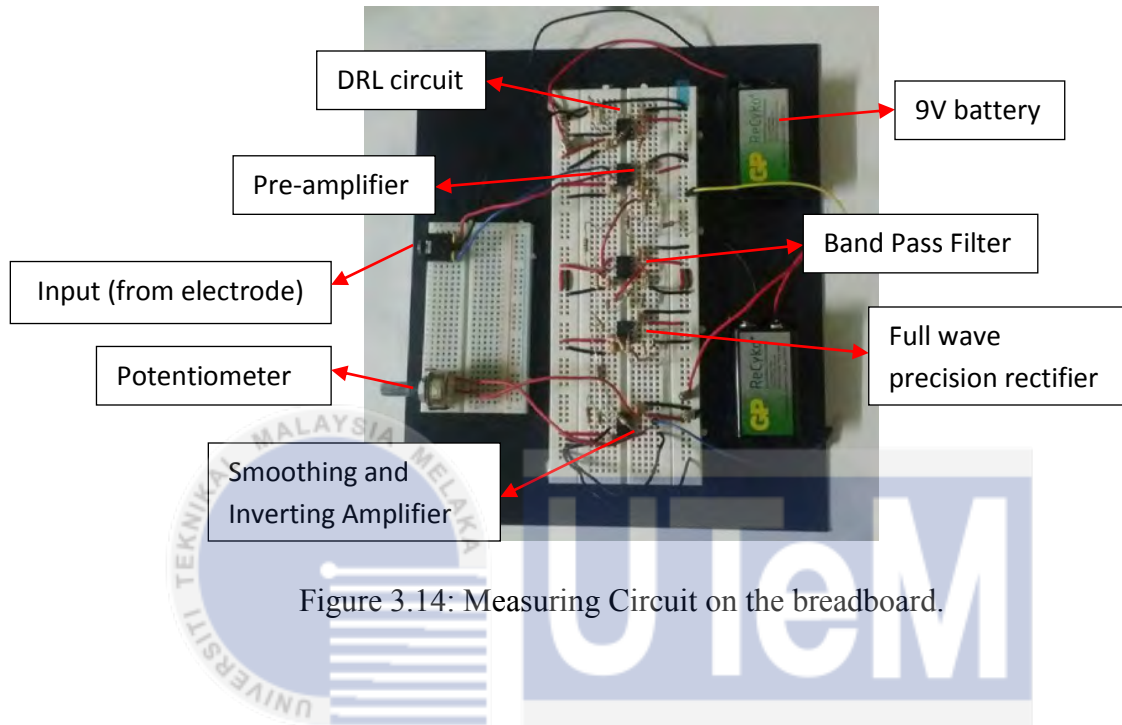


Figure 3.14: Measuring Circuit on the breadboard.

Once the circuit is performed and tested as expected (EMG signal is extracted) as shown in Figure 4.2 in Chapter 4, the circuit is then being transferred to PCB. The PCB is designed by using Proteus ARES software. Figure 3.15 shows the front side of the PCB design meanwhile Figure 3.16 Shows the back side of the PCB design in Proteus ARES software.

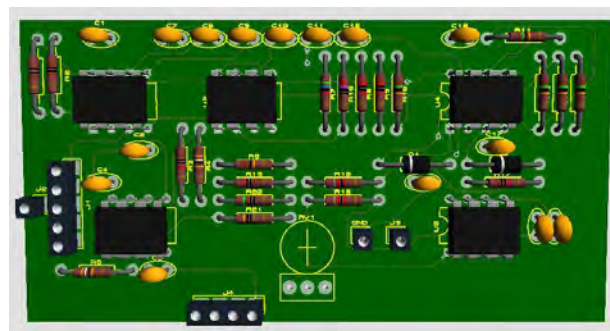


Figure 3.15: Front side of measuring circuit PCB design using Proteus ARES software.

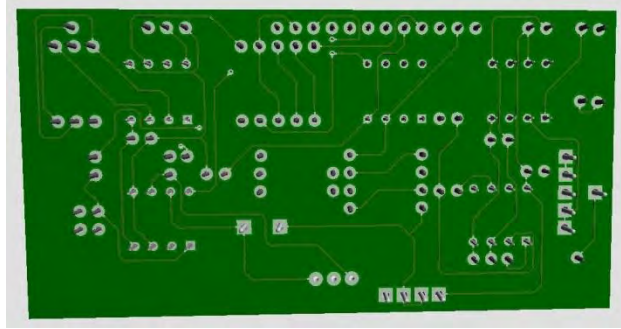


Figure 3.16: Back side of measuring circuit PCB design using ARES Proteus

Once the design is complete, the PCB layout is then being processed to be the real PCB. All of the components are placed on the real PCB in their position according to the PCB layout design. The leg of the component is then being soldered to keep them in a place. Figure 3.17 shows the front side of measuring circuit on the real PCB. Meanwhile Figure 3.18 shows the back side of measuring circuit on the real PCB.

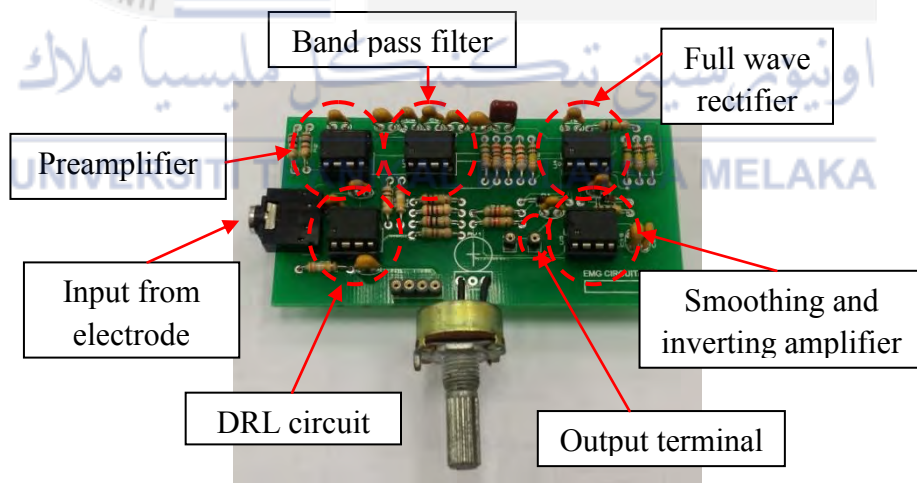


Figure 3.17: Front side of measuring circuit on the real PCB

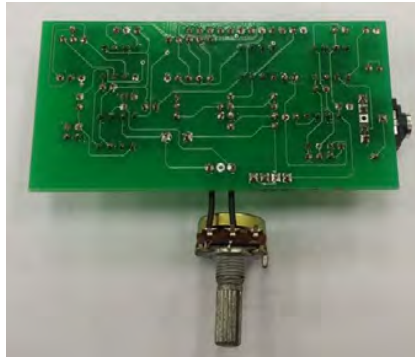


Figure 3.18: Back side of measuring circuit on the real PCB.

3.3 Establishment Relationship of hand grip force and wrist angle

In this section, it covers the second objectives which is to establish the relationship between forearm EMG signal and hand grip force and use this relationship to predict the hand grip force exerted and joint wrist angles when forearm EMG signals are used as input. It divided into three sub sections which are muscle selection, experiment setup for signal extraction and establishment of the relationship . The designed measuring system is used to achieve the objective. The electrode that attached to the hand is connected to the measuring system and the output of this measuring circuit is then connected to the oscilloscope. Figure 3.19 shows the overall system in achieving the second objective.

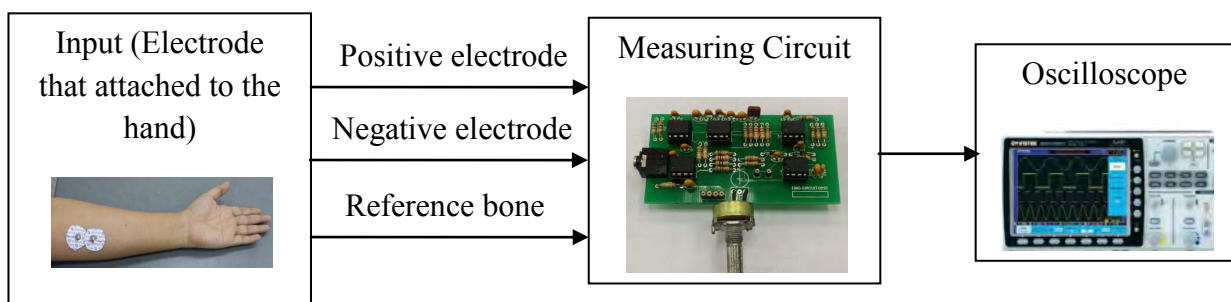


Figure 3.19: Overall system in achieving the second objective

3.3.1 Muscle selection

Muscle selection is very important as it is play an important role to know the best location for the EMG signal to be extracted. There are three muscles that are located in the forearms which are Flexor Digitorum Profundus muscle, Flexor Digitorum Sublimis Muscle and Extensor Pollicis Brevis Muscle.

From the research study, Flexor Digitorum Sublimis (FDS) Muscle is selected for this project. This is because this muscle has more significantly contribution to hand grip force. The method to determine the location of this muscle is by placing the other hand palm on the medial epicondyle and extended thumb and fingers down the forearm as shown in Figure 3.20 [13] The ring finger represents a Flexor Digitorum Superficialis muscle. Thus, the electrodes are placed on the hand skin below the ring finger as shown in Figure 3.21.



Figure 3.20: Hand palm on the medial epicondyle

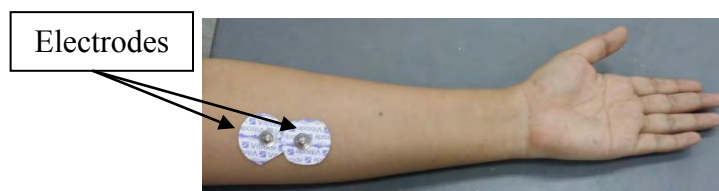
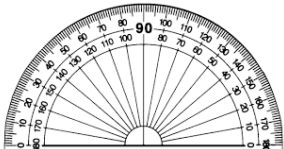


Figure 3.21: Electrodes are placed on the hand skin below the ring finger

3.3.2 Components used

In achieving the second objective, there are many components that were used other than measuring circuit. All of the components used are summarized in Table 3.1 below.

Table 3.1: Summary of components selection

Components	Diagram	Function
AgCl Electrode		Act as a transducer that sense ion distribution on the surface of the tissue and converts them to electron current [27] in order to measure the EMG signal
Vernier Hand dynamometer		Used to measure the grip strength of the hand. this sensor amplifies the force applied by converting it to a voltage that is monitored by the lab interface. [28]
Digital oscilloscope		Four channel color digital storage oscilloscope that used to display the electrical signal based on the input probes that display graphs on its screen.
Printed protractor		Used to measure the angle of the hand wrist in degrees ($^{\circ}$)

3.3.3 Pre-task procedure

Before proceeding to the experiment, a pre-task procedure about the preparation is explained. Firstly, all of the subjects selected are explained briefly on the experiment that is going to conduct. Then, all of the respondent undergo skin preparation before proceeding with the experiment. Electrode is attached to the skin and multi-meter is used to check the skin impedance to make sure that the resistance on the surface area is low as shown in Figure 3.21 in section 3.3.4.

3.3.4 Skin preparation procedures

According to Peter Konrad in his journal of The ABC of EMG, he stated that the quality of an EMG measurement is depends on a proper skin preparation and electrode position. Proper skin preparation is important to get a good signal and avoid artifacts. The main purpose of skin preparation is to stable electrode contact and to have low skin impedance. Usually, it is needed to perform some skin preparation before applying the electrodes. There are two procedures that may be considered for skin preparation before attaching the electrodes. [6]

The first step is by removing the hairs on the skin. This way, it can improve the adhesion of the electrodes, especially under humid condition or for sweaty skin types. The second step is through cleaning the skin surface. There are three methods of cleaning of the skin. The first method to clean the skin is by braded the skin with an abrasive cream such as NuPrep, which removes the dead skin cells which produce high impedance. The second method is by sweeping 3 or 4 times on the skin by using a very find sand paper. The use of

sand paper should be combined skin with the alcohol pad. The last method is by rubbing the skin with alcohol pad. It may be sufficient for static muscle function test in easy condition. [6]

In this project, the third method of the second step which is by rubbing the skin with alcohol pad is chosen for the skin preparation procedure to run all of the experiments.

3.3.5. Impedance Test

According to Peter Konrad in his journal of The ABC of EMG, when the skin preparation is done properly, the skin typically gets a light red color. It indicates a good skin impedance condition. In order to verify it, the ohm-resistance between both electrodes is measured by using multi-meter as shown in Figure 3.22. This step is recommended for beginners and also for sophisticated research studies. Normally, the application area need about 5 minutes in order for it to reach stable electrical condition. In the first minutes, it can see a decrease of electrical resistance over 50%, which mainly due to the chemical changes within the skin layers. Skin impedance range can be classified into 5 ranges. Table 3.2 shows the recommendation for electrode/skin impedance range. [6]

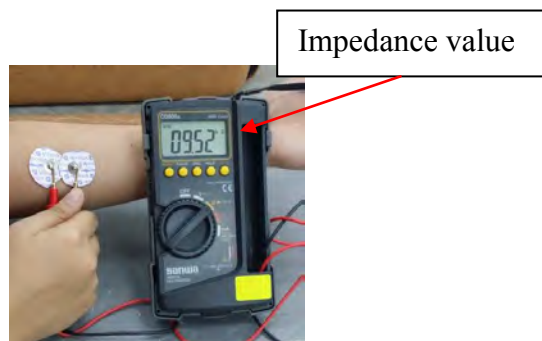


Figure 3.22: Impedance test using Multi-meter

Table 3.2: Recommendation for electrode/skin impedance range [6]

Impedance Range ($k\Omega$)	Recommendation
1-5	Very good condition
5-10	Good and recommended (if feasible)
10-30	Acceptable for easy conditions
30-50	Less good
>50	Should be avoided or requires second cleaning

3.3.6 Electrode Selection

In the most cases, surface electrodes are used in kinesiological studies due to its non-invasive character. For surface electrode, silver or silver chloride pre-gelled are the most common used electrodes and is recommended for the general us. Besides than it is easy and quick handling, hygienic aspects are also not a problem when disposal electrode type is used. The electrode diameter which is the conductive area should be sized to 1cm or smaller. [6] There are several general guidelines on electrode application. Following are the list of general guidelines in electrode application.

- i. Wet gel electrodes have better skin impedance values
- ii. Use small electrodes in order to increase the selectivity of measures (to avoid cross-talk)
- iii. Smaller electrode (active detection area) has the higher impedance value
- iv. Select the closest inter-electrode distance in order to increase selectivity
- v. The general recommendation for inter-electrode distance is 2cm from center point to center point)

- vi. Electrode is apply in parallel to the muscle fiber direction
- vii. Use the dominant middle portion of the muscle belly for best selectivity
- viii. Avoid the region of motor points

3.3.7 Experiment 1: Experiment Setup for Signal Extraction

There are several steps in extracting the EMG signal. Firstly, an amount of electrolyte gel is put on the skin surface. The AgCl electrodes are placed accurately on the Flexor Digitorum Superficialis (FDS) muscle. The subject is then asked to keep a standard position such as sitting straight up while forearm is flexed to horizontal and supported. Then, the hand dynamometer is placed on the hand palm. The wrist is moved to 90° based on the printed protector as shown in Figure 3.23.

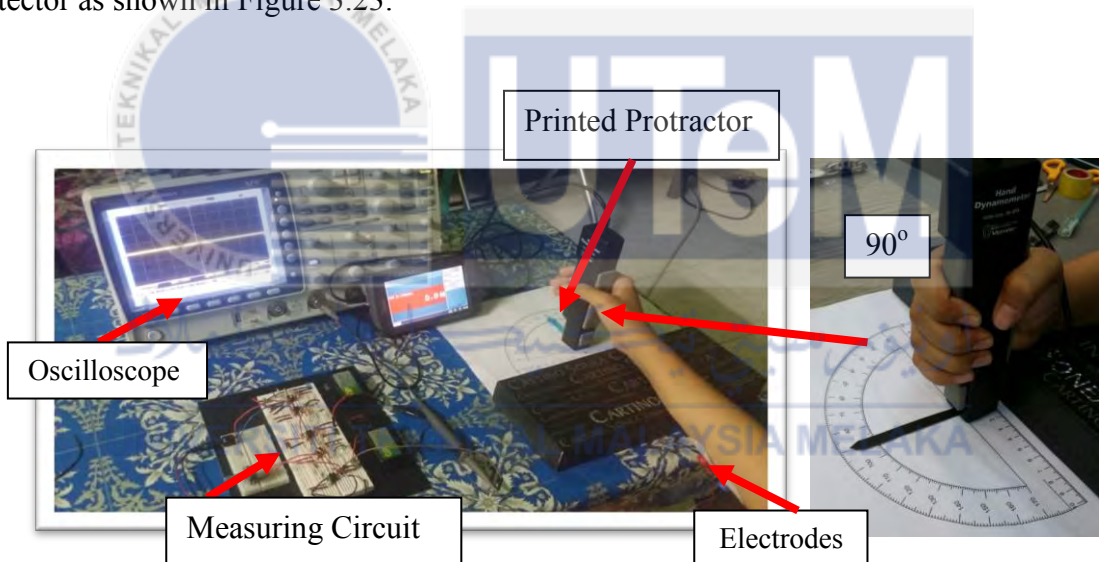


Figure 3.23: Wrist is moved to 90 degree based on the printed protector

While the wrist is in 90° position the subject is then asked to grip the hand dynamometer with 20N of hand grip strength for 10 seconds. The subject is then let to be in relaxing position and rested for 5 minutes to avoid fatigue. The steps are repeated with different hand grip strength of 60N and 100N. The experiment for each of the hand grip test will be repeated for 10times. Finally, the experiment is then repeated with different wrist angle

of 60 and 120 degree as shown in Figure 3.24. All of the results obtained are recorded. The experiment is done for 3 subjects.

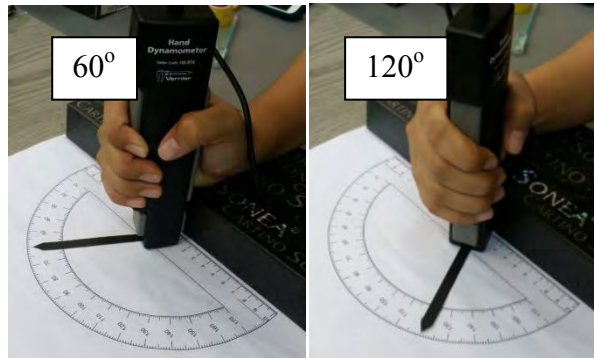


Figure 3.24: Wrist is moved to 60° and 120° based on the printed protector

3.3.8 Establishment relationship of Hand Grip Force and Wrist Angle

The graph of EMG Average Power versus Hand grip force of Flexor Digitorum Sublimis for different angle is plotted to see the relationship between the EMG signal and Hand grip force. The data is taken for the wrist angle of 60°, 90° and 120° for 20N, 40N and 100N. The linear enveloped generated from the various hand grip force and wrist angle are then mapped to control the movement or grasping of the exoskeleton hand respectively. From the reading obtained by measuring the EMG signal, the Arduino Uno is being coded referring to the reading range obtained to move the exoskeleton hand. refer Appendix C.

3.4 Analysis of performance

This section covers the third objective which is to analyze the performance of the bionic hand in term of repeatability and accuracy. In this section, it contains the procedure of the experiment to achieve the objectives. The first experiment is done to analyze the bionic hand in terms of repeatability. In repeatability experiment, the human hand is grasps and release for 10 times and let the bionic hand to repeat and follow the movement of human hand. Meanwhile, the second experiment is done to analyze the bionic hand in terms of accuracy. In this accuracy experiment, the joint angle for each finger is compared to get the accuracy of bionic hand for each finger. The system is started with the electrodes that attached to the hand as the input is connected to the measuring circuit. The output from the measuring circuit is connected to the Arduino Uno. From the Arduino Uno, it will send the signal to the motor driver according to the programming. From the motor driver, it will connect to the motor that will make the bionic hand to move. Figure 3.25 shows the overall system in achieving the third objective.

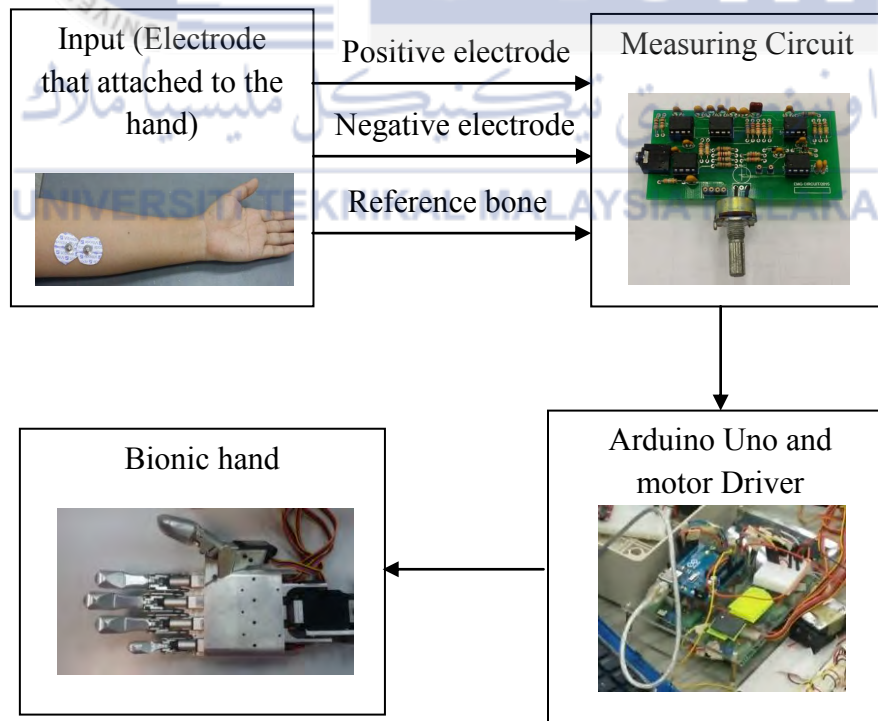


Figure 3.25: Overall system in achieving the third objective.

3.4.1 Performance of Bionic Hand in terms of Repeatability.

In this experiment, to test the bionic hand in terms of repeatability, the bionic hand is led to follow the human hand to grasp and relaxed. This experiment is conducted to see whether the bionic hand is able to repeat and follow the human hand or not. The experiment is repeated for 10 times and observation is taken to see the performance of the bionic hand while it follows the human hand. The data is taken to analyze the performance of bionic hand in terms of repeatability.

3.4.2 Experiment 2: Repeatability experiment.

There are several steps of experimental procedure to perform the experiment in terms of Repeatability. Firstly, all of the devices are set up neatly on a table as shown in Figure 3.26.

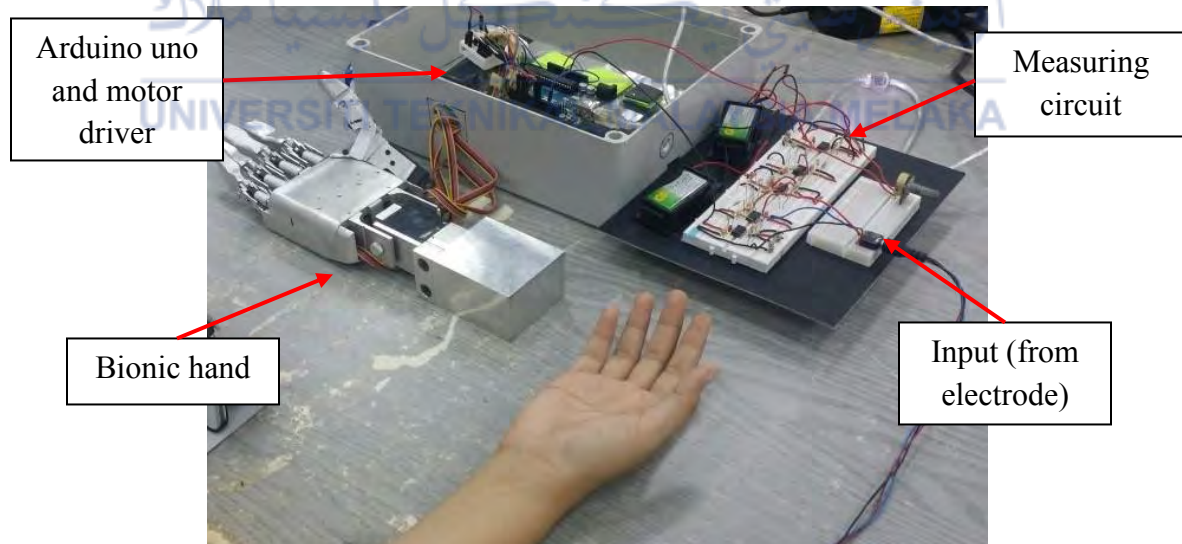


Figure 3.26: Experimental set up for Repeatability test

When the bionic hand and the other device are ready, the human hand is then being relaxed in a straight position. Once the hand starts to grasps, the bionic hand is led to move and the timer is start. The data is taken for one cycle which is started when the hand is in relaxed position to the grasping position and back to relaxed position. All of the observations are taken. Human hand is then let to be in a relaxed position. Finally, the experiment is repeated for 10 times to see the ability of bionic hand to repeat the same action by following the action of human hand.

3.4.3 Performance of Bionic hand in terms of Accuracy.

In this experiment, to test the accuracy of the bionic hand, the angle of joint of each finger of bionic hand is analyzed to see the accuracy of the fingers of the bionic hand to bend at the certain angle. The camera is used to capture the movement for each of the joint finger of the bionic hand. The camera is place on the stable and fixed position during the experiment. There are 50 different frames that acquired during the experiment where 10 frames for each finger. The relative position is measured by using the protractor. The data for the angle of flexion joint of the bionic hand finger is taken and tabulated into a table. From the data, a graph is constructed to evaluate and analyze the accuracy of the bionic hand as shown in Chapter 4.

3.4.4 Experiment 3: Performance of Bionic hand in terms of Accuracy.

There are several steps of experimental procedure to perform the experiment in terms of Accuracy. Firstly, all of the device and components are set up neatly on the table as shown in Figure 3.27.

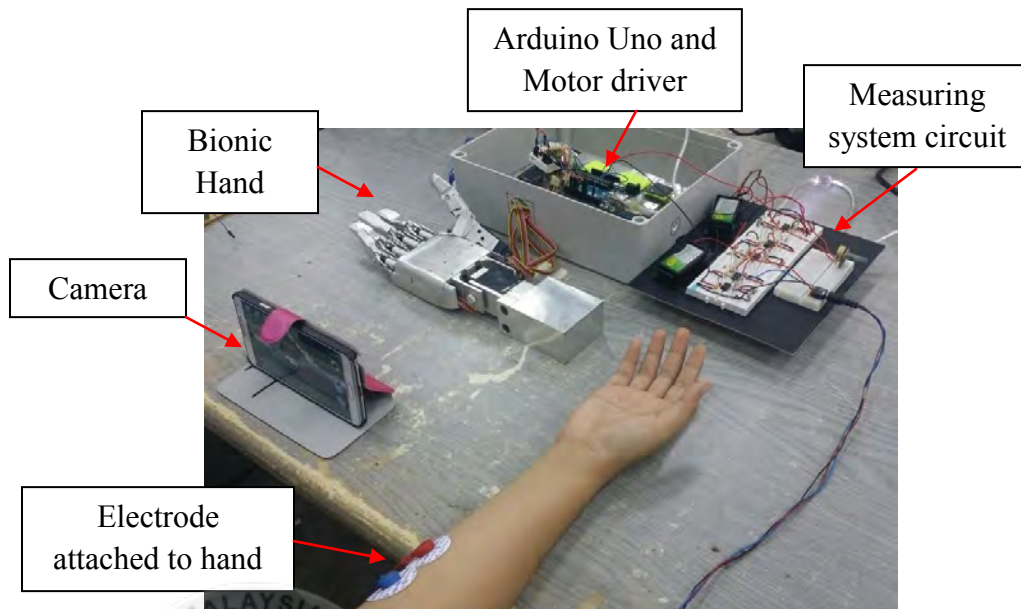


Figure 3.27: Experiment set up for Accuracy test.

The camera is made sure that it placed at the fixed and stable position. The bionic hand is set only the pinky finger to move and the rest of the fingers are in relaxed state. Once the bionic hand and the device are ready, human hand is then being grasps to let the bionic hand to follow. Once the pinky finger of the bionic hand is fully bend as shown in Figure 3.28, the camera is started to take the pictures. The human hand is then being relaxed and let the finger of the bionic hand to follow.



Figure 3.28: Pinky finger of the bionic hand bends

The steps are repeated for 10 times. Then, the experiment is then repeated for the rest of 4 fingers as in Figure 3.29. Once done, the frame is then measured using protractor to get the data of the angle of flexion (angle 1 and angle 2) of each finger of the bionic hand as shown in figure 3.30.

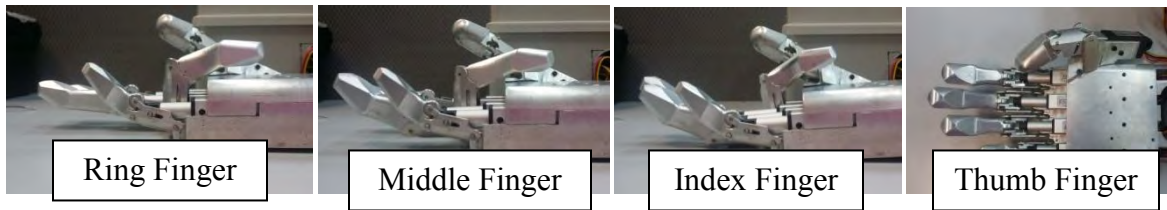


Figure 3.29: Others finger of bionic hand bend.

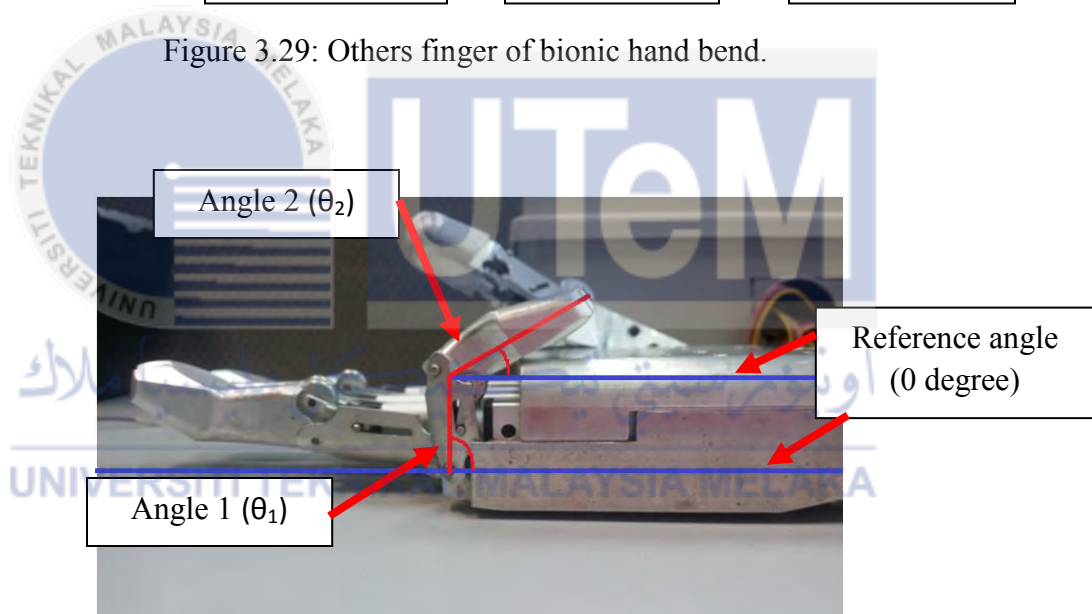


Figure 3.30: Frame of pinky finger measured.

3.5 Summary

The methodology to archive the first objective which is to design and developed a measurement system to extract forearm EMG signal and interface the signal with

designed bionic hand is divided into three sub sections. The first sub sections cover the design and development of measurement system which includes design of measurement system in Proteus software, simulation on measuring circuit and developing the design circuit. The main component used in designing this measurement circuit is AD620 and OPA2604. The design includes the pre-amplifier, Driven Right Leg circuit, Sallen Key high pass filter, Sallen key Low Pass Filter, Full wave Precision Rectifier, Smoothing circuit and also inverting amplifier. The circuit is first developed in breadboard and then it being transferred to PCB board.

For the second objectives which is to establish the relationship between forearm EMG signal and hand grip force and use this relationship to predict the hand grip force exerted and joint wrist angles, the methodology to archive this is divided into several sub section. The first section is muscle selection which is FDS muscle is being selected. The second section is the component used in the experiment followed by pre-task procedures, skin preparation procedures, impedance test, electrode selection and experimental setup for the signal extraction and finally the establishment of the relationship of hand grip force and wrist angle. In establishing the relationship of the hand grip force and wrist angle, the value of peak-to-peak voltage shown in the oscilloscope is taken. The data is then being analyzed and a graph is constructed to see the relationship.

Lastly, the methodology for the third experiment which is to analyze the performance of bionic hand in terms of repeatability and accuracy is divided into 2 experiments. The first experiment done is on the repeatability test, where the bionic hand is led to repeat and follow the human hand to see the whether the bionic hand is able to repeat and follow the human hand in terms of grasping and relaxing or not. Meanwhile in experiment 2, the joint angle for each finger is compared to the expected angle of bionic fingers in order to get the accuracy of bionic hand for each finger. These two experiments are done to achieve the third objective.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, it describes the results and analysis referring to the experiment that had done in this project. The first section of this chapter covers the first objectives which is the design of measurement system. The measurement circuit which comprises of pre-amplifier with DRL circuit, band pass filter, full wave rectifier, smoothing circuit and also inverting amplifier is design and constructed on a PCB. The second section of this chapter covers the first experiment to achieve the second objective which is to establish the relationship between forearm EMG signal and hand grip force and use this relationship to predict the hand grip force exerted and joint wrist angles. The last section comprises of two experiments to achieve the third objective which is to analyze the performance of bionic hand in terms of repetability and accuracy. The data obtained is then tabulated and graphs are constructed in both experiment 2 and experiment 3 to analyze in order to achieve the objectives.

4.2 Designed and development of measuring system

In this section, it covers the first objective which is to design and develop a measuring system. The design of measuring system in this project are consist of preamplifier circuit with DRL concept, band pass filter, full wave precision rectifier, smoothing circuit and also inverting amplifier. Figure 4.1 shows the full circuit that constructed in PCB for measuring system.

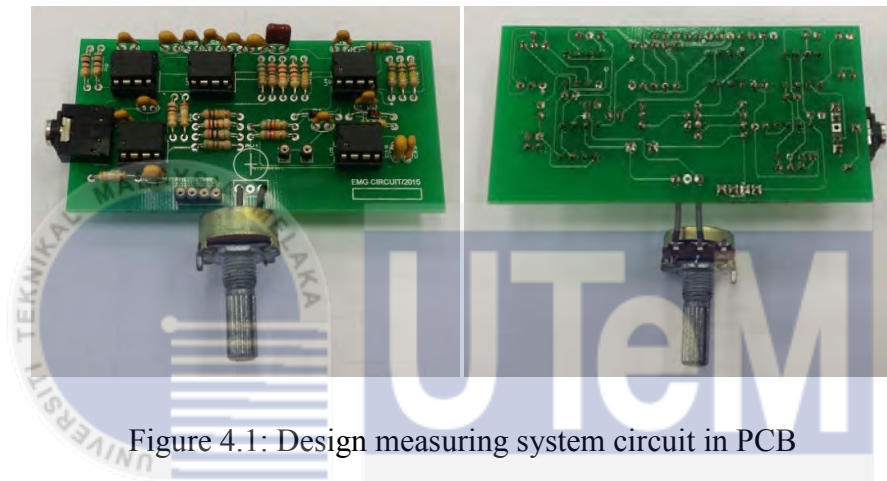


Figure 4.1: Design measuring system circuit in PCB

In Figure 4.2, the yellow line in the graph indicated the output of the system after the EMG signal being filtered, rectified, smoothed and also amplified. The graph obtained is in linear enveloped graph. The graph shown is taken from the digital oscilloscope. In the Figure 4.2, the graph shows the output of the EMG signal when the hand is in relaxed state and grasped state. The peak-to-peak value can be obtained easily from the screen of the oscilloscope which the average value will be used to map into the bionic hand through programming of the Arduino Uno.

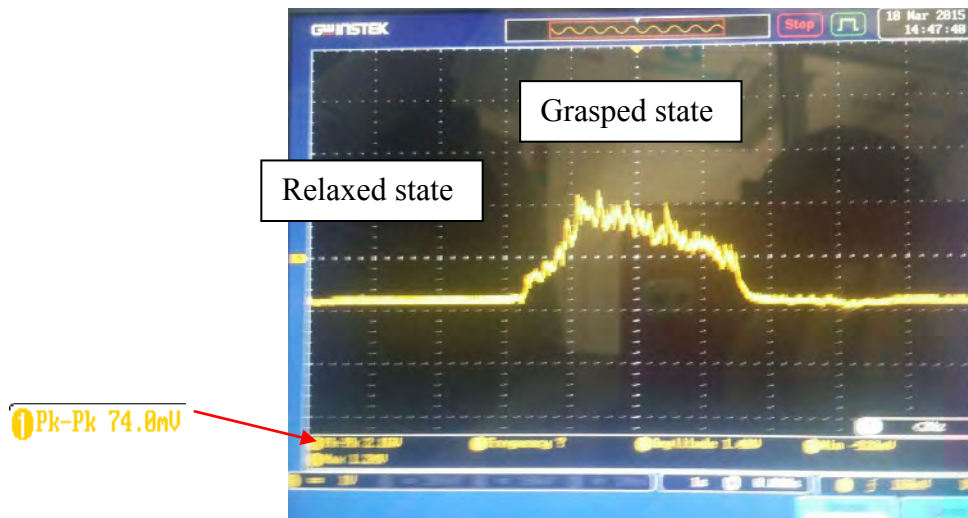


Figure 4.2: EMG signal taken from oscilloscope.

4.3 Establishment of the relationship between forearm EMG signal with hand grip force and wrist angle (EXPERIMENT 1)

In this section, it covers the second objective which is to establish the relationship between forearm EMG signal with hand grip force and wrist angle. A table of results is constructed for the experiment of signal extraction which the angle considered to establish the relationship between the forearm EMG signal are 60°, 90° and 120° with hand grip force considered of 20N, 60N and 100N. The data collected is the peak-to-peak voltage when the hand dynamometer is grasps to certain grip force and at certain wrist angle for 10 times. Table 4.1 shows the table of results for hand grip force of 20N for wrist angle of 60°, 90° and 120°. Meanwhile in Table 4.2, it shows the EMG power varies to wrist angle for 60N grip force. Finally, in Table 4.3 shows the EMG power varies to wrist angle for 100N grip force. The result obtained is for the first subject.

Table 4.1: EMG power varies to wrist angle for 20N grip force.

No. of experiment	peak to peak of EMG voltage (mV)		
	60°	90°	120°
1	26.6	46.5	80.2
2	22.8	40.2	70.5
3	20.2	37.9	72.7
4	26.3	38.2	67.3
5	18.7	36.4	66.2
6	20.3	32.9	65.1
7	18.2	30.9	59.2
8	16.9	29.1	50.2
9	11.3	27.6	49.5
10	20.5	23.0	40.1
Average EMG voltage	20	34	59

From the data obtained, a graph is constructed. Figure shows the graph of average peak-to-peak EMG voltage against wrist angle at 20N grip force.

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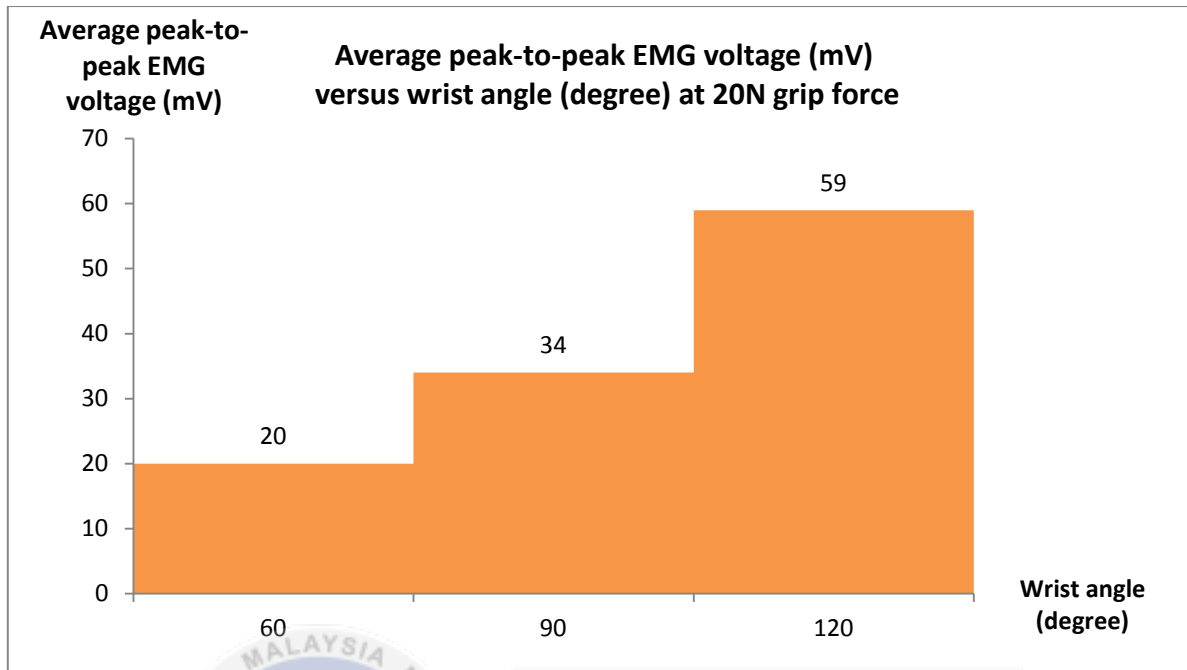


Figure 4.3: Average peak-to-peak EMG voltage (mV) versus wrist angle (degree) at 20N grip force

Table 4.2: EMG power varies to wrist angle for 60N grip force.

No of experiment	peak to peak of EMG voltage		
	60°	90°	120°
1	47.2	70.1	91.5
2	46.1	68.3	90.2
3	40.2	65.6	86.4
4	39.2	48.2	79.2
5	39.9	49.0	80.4
6	35.0	42.3	76.1
7	34.7	51.9	81.4
8	31.5	40.1	70.9
9	23.7	39.2	67.7
10	33.4	26.4	67.1
Average EMG voltage	37	50	79

From the data obtained, a graph is constructed. Figure shows the graph of average peak-to-peak EMG voltage against wrist angle at 60N grip force.

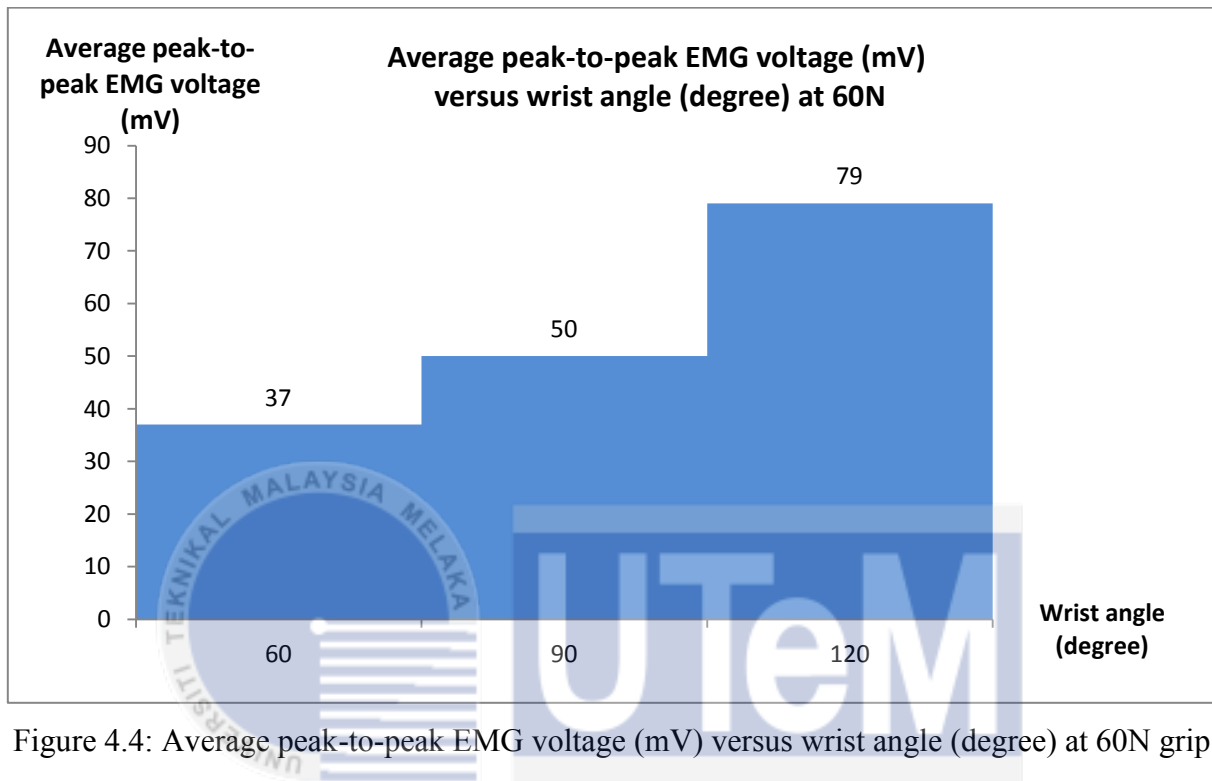


Figure 4.4: Average peak-to-peak EMG voltage (mV) versus wrist angle (degree) at 60N grip force

Table 4.3: EMG power varies to wrist angle for 100N grip force.

No of experiment	peak to peak of EMG voltage		
	60°	90°	120°
1	80.2	102.7	150.0
2	77.1	90.1	131.6
3	74.3	91.3	133.9
4	66.4	86.9	120.4
5	65.4	74.3	118.6
6	59.0	70.2	114.2
7	53.1	68.5	96.7
8	48.2	67.3	88.1
9	41.3	51.1	86.3
10	36.0	49.0	81.9
Average EMG voltage	60	75	112

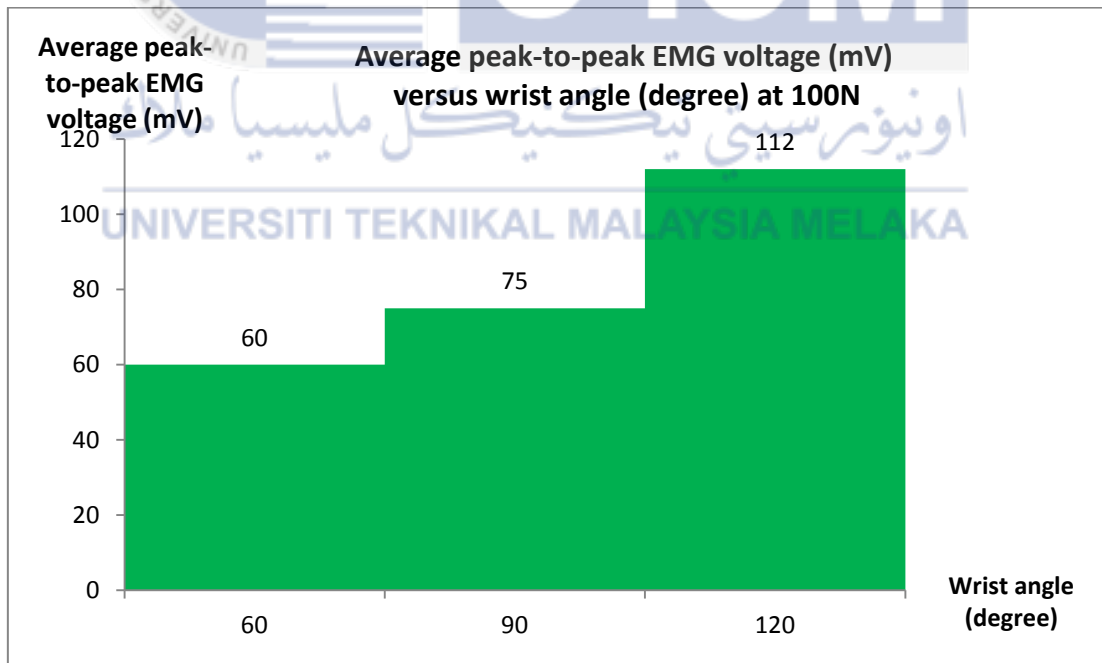


Figure 4.5: Average peak-to-peak EMG voltage (mV) versus wrist angle (degree) at 100N grip force

Referring to Table 4.1, Table 4.2 and Table 4.3, the value of peak-to-peak EMG voltage obtained for all wrist angles respect to hand grip force have the same pattern which is decreasing with the number of experiment. This is due to the muscle fatigue of the subject as the experiment run. Thus, the value of EMG voltage obtained is decreasing with no of experiments.

A graph of Average value peak-to-peak enveloped EMG voltage varies to hand grip force and wrist angle is then constructed to give more clear pictures of the relationship of forearm EMG signal and hand grip varies to wrist angle. Figure 4.6 shows the graph of Average value peak-to-peak enveloped EMG voltage varies to hand grip force and wrist angle.

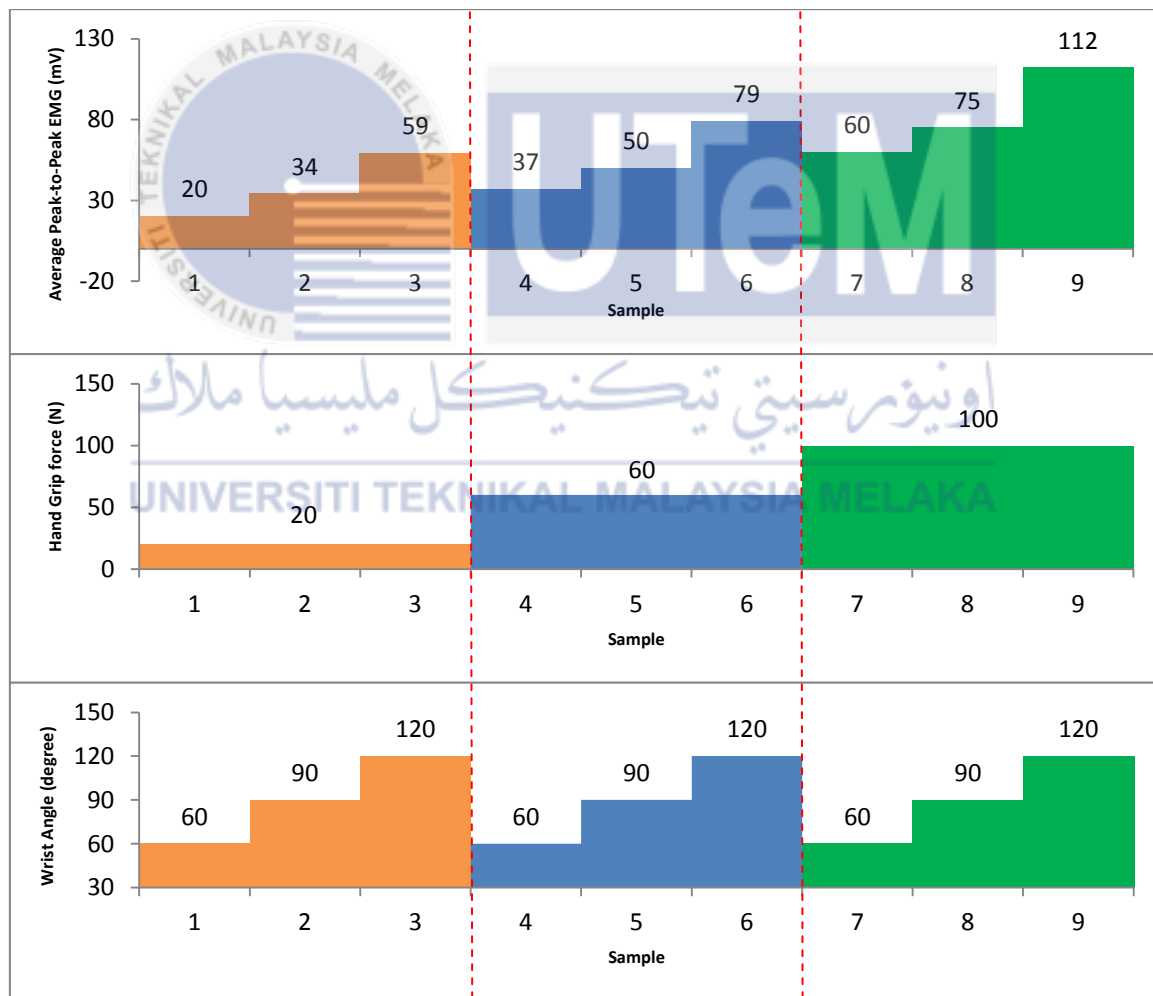


Figure 4.6: Average value peak-to-peak enveloped EMG voltage varies to hand grip force and wrist angle

From the graph plotted in Figure 4.3, Figure 4.4 and Figure 4.5, it can be clearly seen that at 60° of wrist angle, the average value of peak-to-peak EMG voltage obtained is 20mV, followed by 34mV for 90° and 59mV for 120° wrist angle at 20N hand grip force. Meanwhile at constant 60N hand grip force, the value of average peak-to-peak obtained at 60° is 37mV, followed by 50mV at 90° wrist angle and 79mV at 120° wrist angle. Finally, at constant 100N grip force, the value of the average peak-to-peak EMG voltage obtained at 60° wrist angle is 60mV, followed by 75mV for 90° wrist angle and 112mV for wrist angle of 120°. From the graph, at 120° of wrist angle gives the highest value of average peak-to-peak EMG voltage, followed by 90° and finally 60° wrist angle. It can be conclude that the value of average peak-to-peak EMG voltage is increased with the increasing of wrist angle. This happened due to the muscle contribution respect to the wrist angle movement. At 120° of wrist angle, the FDS muscle gives the greatest contribution of the wrist movement to move at 120° angle. Thus, at that position (120° wrist angle), it gives the biggest reading value of EMG voltage compared to 90° and 60° wrist angle. However, at 60° wrist angle, the value of EMG voltage obtained is the lowest compared to 120° and 90° wrist angle. This happened is because the muscle that contributes to move the wrist to 60° wrist angle is not FDS muscle. At this position, the biggest muscle contribution is Extensor Carpi Ulnaris muscle which located at the back of the hand forearm. Thus, the value of EMG voltage obtained is the lowest compared to 90° and 120° wrist angle.

Meanwhile from the graph plotted in Figure 4.6, it shows that the value of average peak-to-peak EMG voltage is increased when the hand grip force applied is increased. At 60° of wrist angle, the value of average peak-to-peak EMG voltage obtained is 20mV at 20N, 37mV at 60N and 60mV at 100N grip force. Meanwhile at 90° of wrist angle, the value of average peak-to-peak EMG voltage obtained is 34mV at 20N, 50mV at 60N and 75mV at 100N grip force. Finally, at 120° wrist angle, the value of average peak-to-peak EMG voltage obtained is 59mV at 20N followed by 79mV at 60N and 112mV at 120N. Here, it can be clearly seen that with the increasing of hand grip force will increased the EMG voltage obtained. This happened as we apply stronger grip force, the EMG signal extracted by the electrode will be more and thus the reading obtained will be higher. [31] The results obtained

for the rest of 2 subjects have the same pattern of graph with the first subject. However, subject 2 and 3 have a higher average peak-to-peak EMG voltage compared to the first subject. Different people have different EMG voltage amplitude. Referring to the journal of ABC of EMG, this might be due to the position of the electrode that attached to the skin. Other than that, it might be due to the fat tissue of the second and third subject that is thinner compared to the first subject. From the journal, it stated that different thickness of tissue layer gives different amplitude EMG signal. Thicker tissue layers gives smaller EMG amplitude compared to the subject that has thinner tissue layer. [6] Thus, the value of EMG voltage is not the same. Refer Appendix A and B for the results obtained for the rest 2 subjects.

4.4 Performance of Bionic Hand in terms of Repeatability.

Table 4.4 shows the data obtained when the bionic hand is led to follow the human hand to analyze the capability of the bionic hand to repeat and follow according to the human hand when the measurement circuit is used. The data is taken for one cycle which is started when the hand is in relaxed position to the grasping position and back to relaxed position. All of the observations are taken and tabulated into the table.

Table 4.4: Performance of Bionic Hand in terms of Repeatability

Experiment	Description
1	- It takes 2 seconds delay for bionic hand to move according to actual hand - the bionic hand manage to fully grip and open the hand
2	- It takes 2 seconds delay for bionic hand to move according to actual hand - The index finger stuck, where the linkage of the index finger slipped from its original position. The bionic hand is fully grip except the index finger.
3	- It takes 1 seconds delay for bionic hand to move according to actual hand - The bionic hand is fully grip.

	- The index finger stuck, where the linkage of the index finger slipped from its original position while in opening hand movement.
4	- It takes 1 seconds delay for bionic hand to move according to actual hand - bionic hand manage to fully grip and open the hand
5	- It takes 1 seconds delay for bionic hand to move according to actual hand - bionic hand manage to fully grip and open the hand
6	- It takes 1 seconds delay for bionic hand to move according to actual hand - bionic hand manage to fully grip and open the hand
7	- It takes 1 seconds delay for bionic hand to move according to actual hand - The index finger stuck, where the linkage of the index finger slipped from its original position. The bionic hand is fully grip except the index finger.
8	- It takes 1 seconds delay for bionic hand to move according to actual hand - bionic hand manage to fully grip and open the hand
9	- It takes 1 seconds delay for bionic hand to move according to actual hand - bionic hand manage to fully grip and open the hand
10	- It takes 2 seconds delay for bionic hand to move according to actual hand - bionic hand manage to fully grip and open the hand



From the observations made from the experiment, most of the time, the bionic hand manage to fully grip and open the hand according to the actual hand repeatably. It shows that the system is functioning with the designed measuring circuit used as the controller. However, there are some delays happened while opening and gripping the bionic hand. This might be due to the signal is not strong enough to move the bionic fingers without delaying time. There are some problem that occurs during the Experiment 2, 3 and 7 where the index finger linkage slipped from its original position caused the index finger of bionic hand not to fully gripped or opened. From the observation, it is concluded that the rest of the finger (Thumb, middle, ring and pinky finger) are manage to yield the movement repeatably which reassemble the human hand.

4.5 Performance of Bionic hand in terms of Accuracy.

The results of accuracy test of joint angle for each of the fingers of bionic hand based on reference line are illustrated into table 4.5 below. The results of joint angle for all five fingers are obtained with two movements of angle of each finger which are θ_1 and θ_2 . The flexion angle that is considered is θ_1 and θ_2 as shown in Figure 3.30 in Chapter 3. Figure 4.7 shows the example frame of pinky finger to measure the angle of finger joint θ_1 and θ_2 .

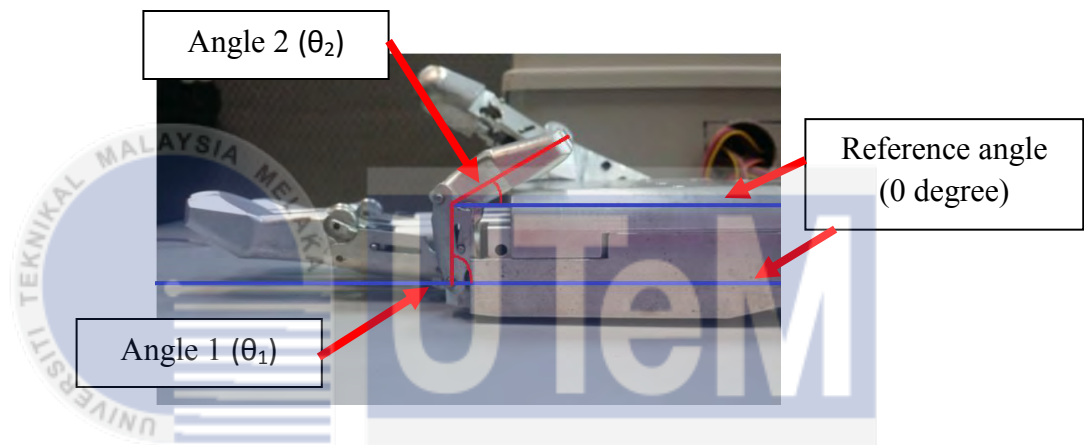


Figure 4.7: Example frame of Pinky finger

Table 4.5: Flexion angle of θ_1 and θ_2 for accuracy test

No of experiment	Angle of finger joints (°)									
	Thumb		Index		Middle		Ring		Pinky	
	θ_1	θ_2	θ_1	θ_2	θ_1	θ_2	θ_1	θ_2	θ_1	θ_2
1	31	26	91	30	84	26	87	24	89	30
2	32	27	90	30	84	25	87	24	89	29
3	32	27	88	28	85	25	84	18	90	29
4	31	26	91	30	86	26	85	20	89	30
5	31	27	90	29	84	24	83	22	90	31
6	30	27	90	30	84	25	83	20	89	29
7	32	26	91	31	85	25	84	23	89	28
8	32	27	90	31	84	24	83	20	89	28
9	31	27	89	29	86	25	82	20	90	29
10	32	27	90	31	85	24	84	22	89	30

From the data obtained, the graph for each finger is plotted to analyze. Figure 4.8, Figure 4.9, Figure 4.10, Figure 4.11 and Figure 4.12 shows the finger angle accuracy test versus number of test.

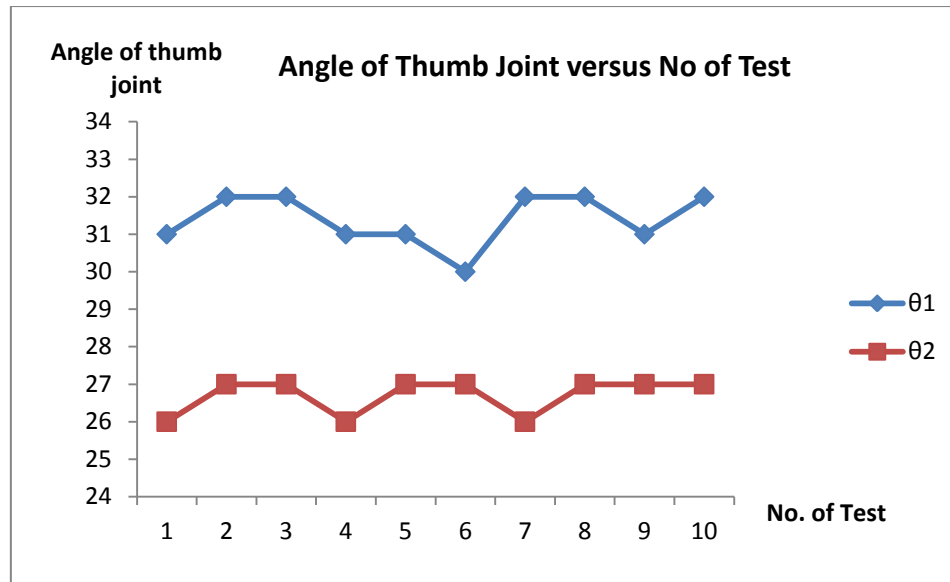


Figure 4.8: Graph of Angle of Thumb Joint versus No of Test

From the graph plotted in Figure 4.8, it shows that there are four test data obtained have the same result which is test 2, 3, 8 and 10 with 32 degree for angle of θ_1 and 27 degree for angle of θ_2 . Meanwhile the test of number 5, 6, 7 and 9 gives uneven results. This is due to the movement of the mechanical linkage which is not too smooth that cause by the distance between mechanical linkages and Proximal Phalanx of the finger is too close. Effect from this situation, the finger of the bionic hand is stuck and cause the reading obtained to have slightly different reading.

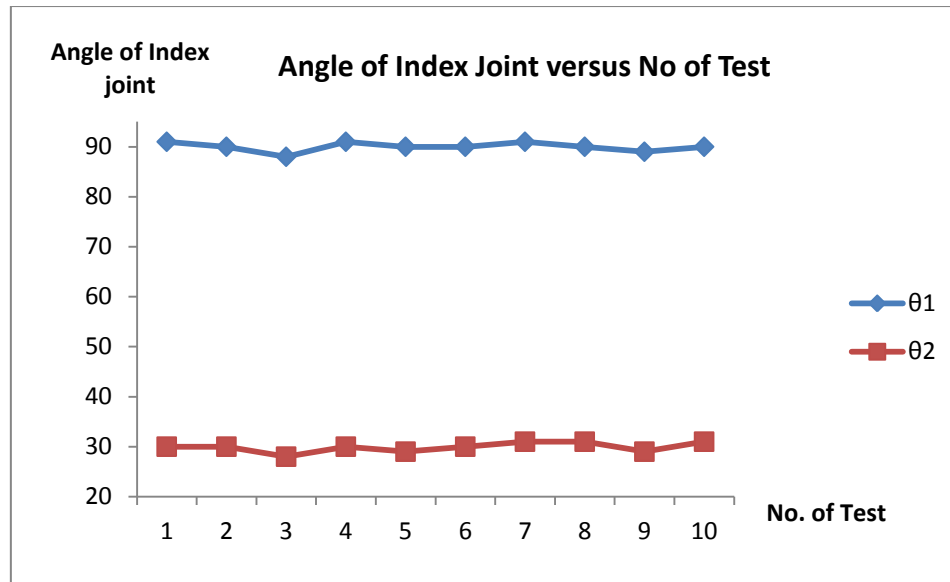


Figure 4.9: Graph of Angle of Index Joint versus No of Test

From the graph plotted in Figure 4.9, there are two test data obtained have the same result which is test 1 and 4 with 91 degree for angle of θ_1 and 30 degree for angle of θ_2 . Meanwhile the rest of the test of number gives uneven results. This is due to the movement of the mechanical linkage which is not too smooth that caused by the mechanical linkages and Proximal Phalanx of the finger that is not really function well and cause it not to bend smoothly.

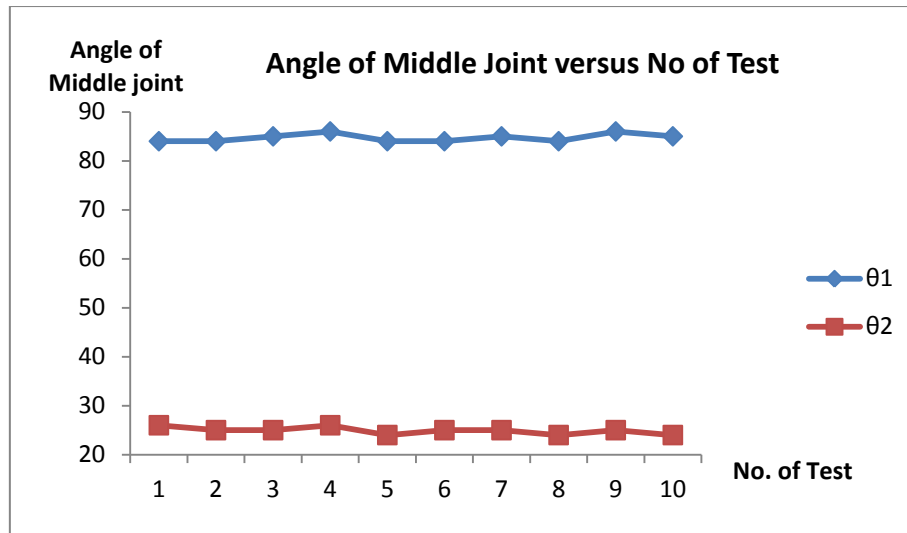


Figure 4.10: Graph of Angle of Middle Joint versus No of Test

From the graph plotted in Figure 4.10, it shows that the graph obtained for the θ_2 is smooth as there is not much fluctuation on the graph obtained. There are two data obtained that have the same results which is test 2 and 6 with 84 degree angle of θ_1 and 25 degree for angle of θ_2 . The rest of the tests have uneven results that might be cause from the mechanical linkage that is not too smooth.

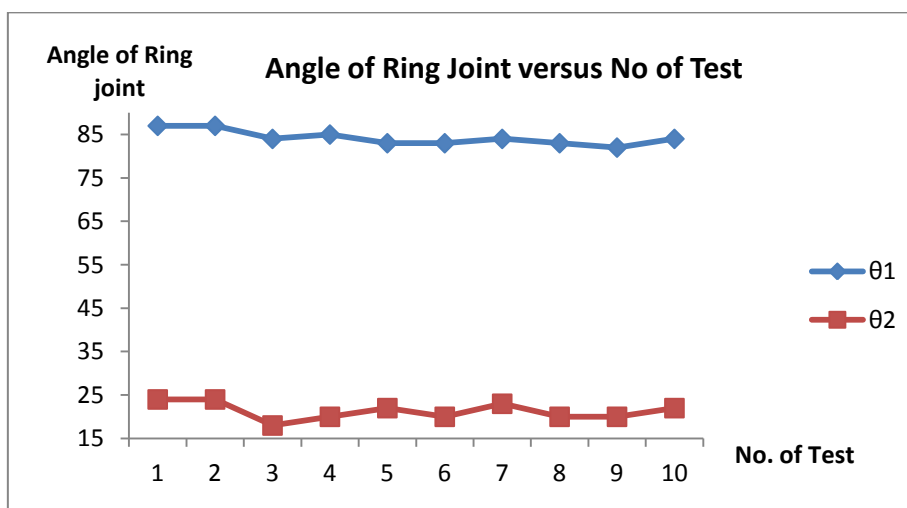


Figure 4.11: Graph of Angle of ring Joint versus No of Test

From the graph obtained in Figure 4.11, the angle of θ_2 gives a fluctuated graph pattern. Test 1 and test 2 gives the same results which are 87 degree for angle of θ_1 and 24 degree for angle of θ_2 . The rest of the tests have uneven results that might be caused from the mechanical linkages. From the design of this bionic hand, the dimension of ring and finger is the same. In terms of theoretical understanding, the results obtained should be the same with the index finger.

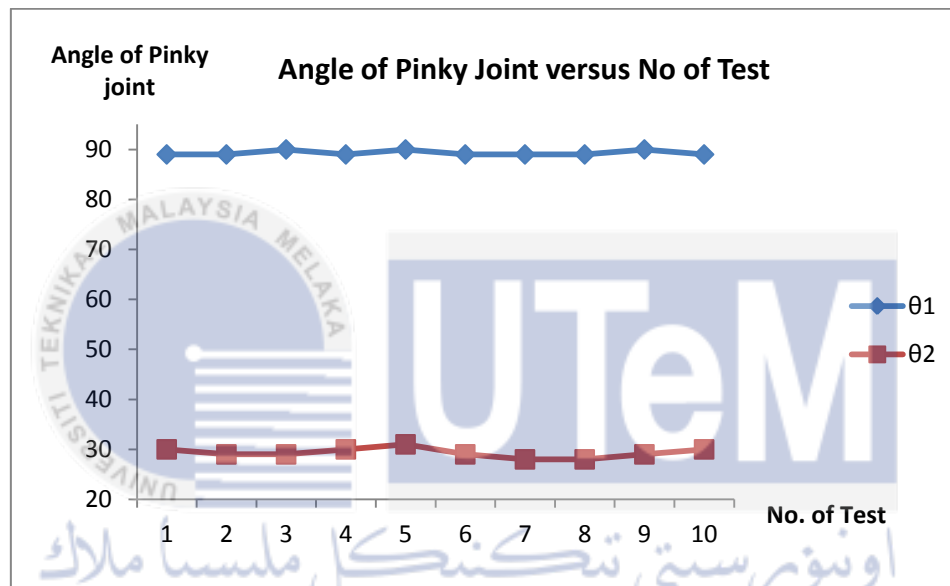


Figure 4.12: Graph of Angle of pinky Joint versus No of Test

From the graph obtained in Figure 4.12, the graph showed that data obtained almost gives a consistent measurement. Among all of the fingers, this pinky test gives the most consistent measurements compared to the others. The angle of θ_1 that is recorded has the near identical value with the different angle of 1 degree. This might caused from the design of mechanical linkages that has the best among all five fingers.

From the data obtained for all five finger test, the average results of the angle of θ_1 and angle of θ_2 is calculated and tabulated into a table as shown in table 4.6 below.

Table 4.6: Measured average angle of all finger joints

Measured average Angle of finger joints (°)									
Thump		Index		Middle		Ring		Pinky	
θ_1	θ_2	θ_1	θ_2	θ_1	θ_2	θ_1	θ_2	θ_1	θ_2
31.4	26.7	89.9	29.9	84.7	27.4	84.2	21.3	89.3	29.3

For the analysis of accuracy of each finger, the percentage error formula is used as below.

$$\text{Percentage Error (\%)} = \frac{\text{Measured} - \text{Expected}}{\text{Expected}} \times 100$$

The expected value of angle for each finger joints is as shown in Table 4.7 below.

Table 4.7: Expected average angle of all finger joints

Expected Angle of finger joints (°)									
Thump		Index		Middle		Ring		Pinky	
θ_1	θ_2	θ_1	θ_2	θ_1	θ_2	θ_1	θ_2	θ_1	θ_2
30	30	90	20	90	20	90	20	90	30

From all the data that obtained from this experiment, the percentage error is calculated for each finger. Table 4.8 shows the percentage error for each of the finger.

Table 4.8: Percentage error for each of the finger

Percentage error for each of the finger (%)									
Thump		Index		Middle		Ring		Pinky	
θ_1	θ_2	θ_1	θ_2	θ_1	θ_2	θ_1	θ_2	θ_1	θ_2
4.67	11.00	0.10	48.50	5.89	37.00	6.40	6.50	0.78	2.33

From the percentage of error calculated in Table 4.8, the accuracy of each finger can be found. Referring to the Table 4.8, the percentage error for θ_1 of thumb, index, middle, ring and pinky finger are 4.67%, 0.10%, 5.98%, 6.40% and 0.78%. Meanwhile the percentage error for θ_2 of thumb, index, middle, ring and pinky finger are 11.00%, 48.50%, 37.00%, 6.50% and 2.33%. Referring to the table, the index finger at joint θ_2 has the highest value of percentage error with 48.5%. This happened is due to the mechanical linkage that is always slipped from the original position. Thus it gives readings that is far from expected angle and caused it to have the highest value of percentage error. However, the joint θ_1 for this index finger has the lowest percentage error compared to the others with only 0.10%. Among all of the fingers, pinky finger considered as the finger that is the most accurate compared to the others as the value of the percentage error of both joint θ_1 and θ_2 is the lowest with 0.78% for θ_1 and 2.33% for θ_2 . As conclusion, this bionic hand considered as accurate as most of the percentage error of the fingers are lower than 50%.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

In conclusion, all of the objectives are achieved. The first objective which is to design and developed the measurement circuit is done where the circuit is designed and constructed with preamplifier, Sallen Key second Order high pass filter, Sallen Key second Order low pass filter, full wave precision rectifier, smoothing low pass filter, and also inverting amplifier were used in design and develop the measuring circuit. Meanwhile the second objective which is to establish the relationship between forearm EMG signal and hand grip force and use this relationship to predict the hand grip force exerted and joint wrist angles when forearm EMG signals are used as input is achieve by measuring and analyzed the the results of the value obtained that viewed on the escilloscope. There are many factors that caused the reading of EMG voltage obtained is different from others. From the results obtained, it shows that the higher the hand grip force will gives higher value of EMG voltage. Other than that, it also shows that with the increasing of wist angle will also increase the value of EMG voltage. Finally, the third objective which is to analyze the performance of the bionic hand in term of repeatability and accuracy by using the designed measuring circuit is archive. In terms of repeatability, it is concluded that thumb, middle, ring and pinky finger are manage to yield the movement repeatably which reassemble the human hand. Meanwhile in terms of accuracy, the bionic hand is said to be accurate as the percentage of error for the angle of flexion for each finger is small. Among all of the fingers, pinky finger considered as the finger that is the most accurate compared to the others as the value of the percentage error of both joint θ_1 and θ_2 is the lowest with 0.78% for θ_1 and 2.33% for θ_2 .

As a recommendation, it is recommended to use better IC in designing measuring circuit in order to improve the performance of the EMG signal extracted. Designing the circuit that use less components will also makes the measurement circuit on the PCB smaller and can fit into the bionic hand. Next, the design of the bionic hand should be improved especially to the mechanical linkages to make it perform more accurate. Finally, the material selection of the designed bionic hand can be changed into another material that is lighter and strong instead of using Aluminum Alloy 6061.



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APPENDIX A

Table A.1: EMG power varies to wrist angle for 20N grip force.

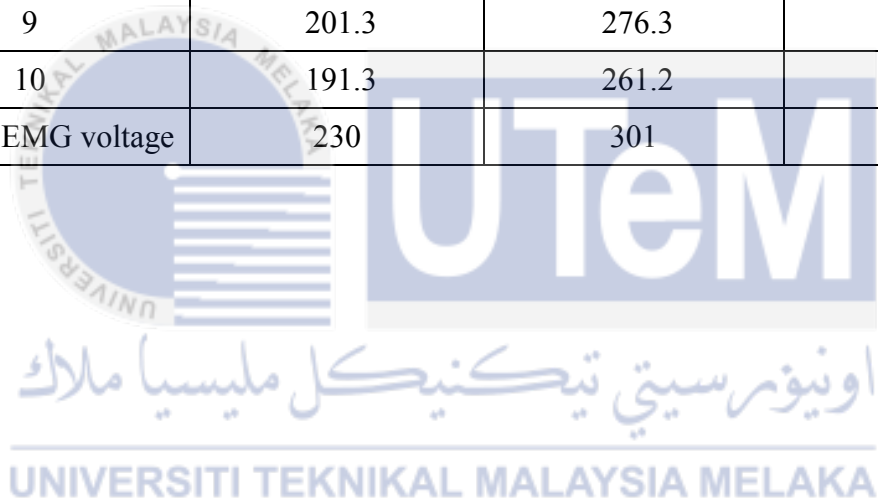
No. of experiment	peak to peak of EMG voltage (mV)		
	60°	90°	120°
1	140.2	234.3	381.2
2	141.1	232.1	370.2
3	136.2	221.9	361.7
4	128.4	220.1	352.1
5	124.3	218.1	342.4
6	119.7	217.3	331.2
7	118.2	209.2	329.4
8	107.8	205.3	323.5
9	92.1	189.1	320.9
10	91.3	172.3	306.9
Average EMG voltage	120	212	342

Table A.2: EMG power varies to wrist angle for 60N grip force.

No. of experiment	peak to peak of EMG voltage (mV)		
	60°	90°	120°
1	152.3	215.2	502.3
2	150.4	207.3	495.3
3	143.5	198.3	482.6
4	142.3	188.3	472.1
5	140.5	187.4	470.3
6	139.3	173.3	445.2
7	132.3	171.5	430.2
8	130.4	169.3	421.5
9	129.4	156.2	420.3
10	110.2	153.5	419.5
Average EMG voltage	137	182	456

Table A.3: EMG power varies to wrist angle for 100N grip force.

No. of experiment	peak to peak of EMG voltage (mV)		
	60°	90°	120°
1	263.2	332.5	541.2
2	261.5	329.2	532.7
3	257.3	318.7	528.5
4	252.4	309.5	520.7
5	232.8	307.9	507.3
6	221.3	302.5	502.3
7	218.9	288.1	493.2
8	201.2	286.5	492.3
9	201.3	276.3	487.2
10	191.3	261.2	470.3
Average EMG voltage	230	301	508



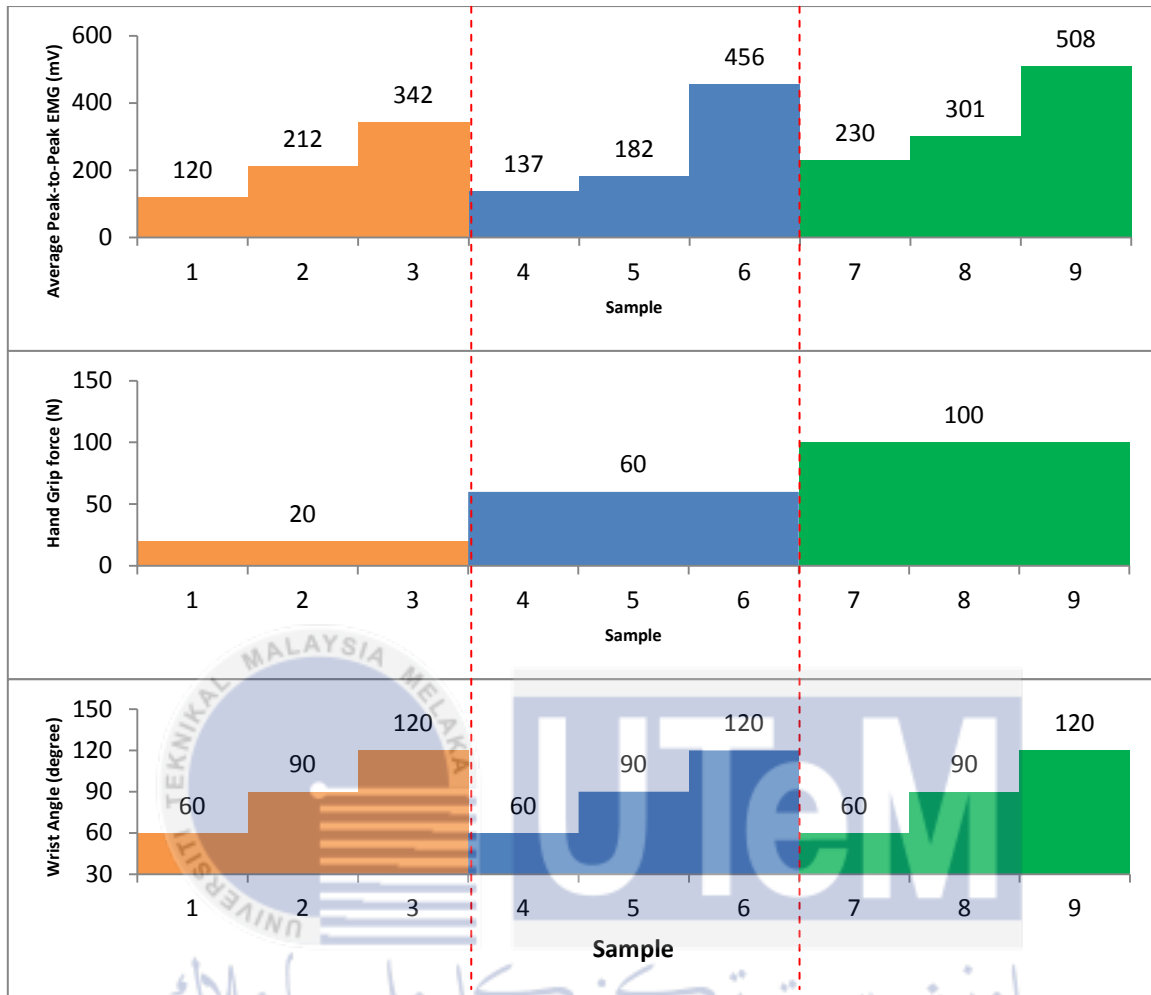


Figure A.1: Average value peak-to-peak enveloped EMG voltage varies to hand grip force and wrist angle (second subject)

APPENDIX B

Table B.1: EMG power varies to wrist angle for 20N grip force.

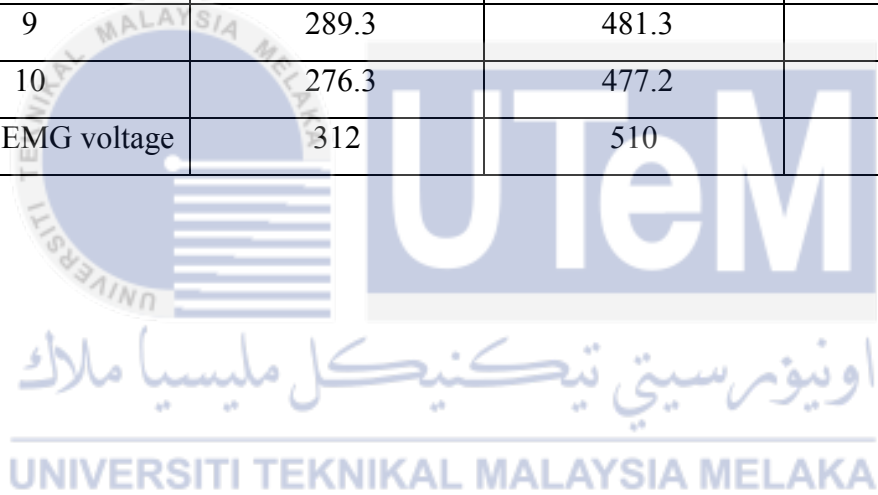
No. of experiment	peak to peak of EMG voltage (mV)		
	60°	90°	120°
1	256.1	453.2	525.7
2	243.7	447.2	521.2
3	233.6	235.2	511.2
4	230.7	421.2	501.4
5	221.8	391.2	497.2
6	215.7	382.7	482.3
7	215.1	279.3	476.7
8	210.8	377.1	472.1
9	203.5	374.1	459.7
10	201.1	361.2	453.9
Average EMG voltage	223	402	490

Table B.2: EMG power varies to wrist angle for 60N grip force.

No. of experiment	peak to peak of EMG voltage (mV)		
	60°	90°	120°
1	312.5	518.7	612.7
2	310.7	507.1	607.3
3	301.5	502.8	592.3
4	290.1	481.7	581.2
5	281.1	476.3	579.3
6	278.1	462.1	561.2
7	275.3	451.3	558.3
8	260.1	441.2	541.0
9	254.3	435.3	532.0
10	251.2	421.5	529.1
Average EMG voltage	281	470	570

Table B.3: EMG power varies to wrist angle for 100N grip force.

No. of experiment	peak to peak of EMG voltage (mV)		
	60°	90°	120°
1	350.2	552.3	662.3
2	341.7	541.3	651.7
3	329.5	532.7	641.2
4	320.5	523.5	631.5
5	312.5	510.1	621.2
6	309.8	502.3	611.5
7	299.3	492.5	602.7
8	292.1	488.7	596.9
9	289.3	481.3	593.6
10	276.3	477.2	591.2
Average EMG voltage	312	510	620



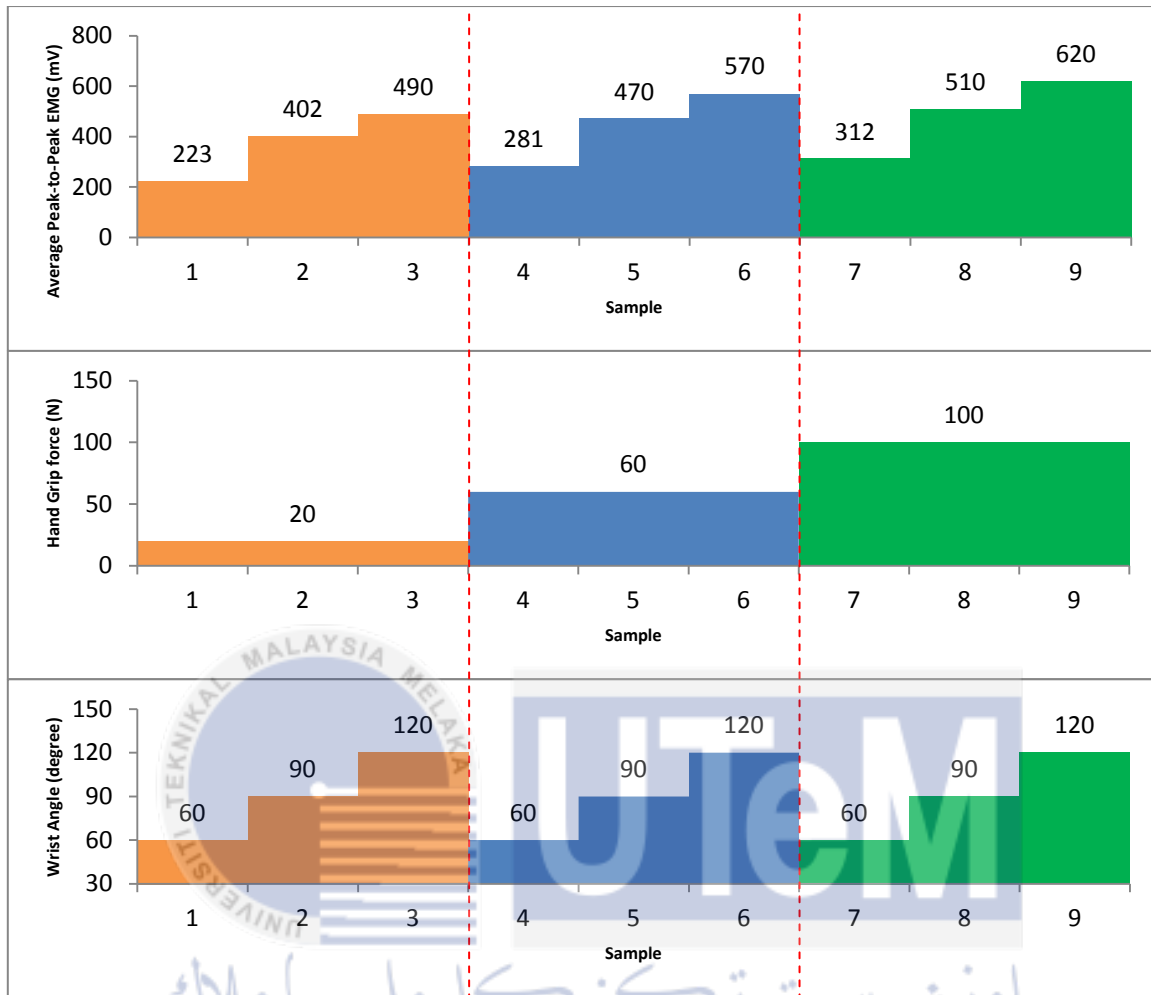


Figure B.1: Average value peak-to-peak enveloped EMG voltage varies to hand grip force and wrist angle (Third subject)

APPENDIX C

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

```
Servo myservo1; // create servo object to control a servo
```

```
Servo myservo2;
```

```
Servo myservo3;
```

```
Servo myservo4;
```

```
Servo myservo5;
```

```
const int sensorPin = 0; // analog pin used to connect the potentiometer
```

```
int val= 0; // variable to read the value from the analog pin
```

```
int sensorValue = 0;
```

```
void setup()
```

```
{
```

```
Serial.begin(9600); //initial serial communication
```

```
myservo1.attach(3); // attaches the servo on pin 3 to the servo object
```

```
myservo2.attach(5);
```

```
myservo3.attach(6);
```

```
myservo4.attach(9);
```



```

myservo5.attach(10);

}

void loop()

{

sensorValue = analogRead(sensorPin); // reads the value of the potentiometer (value between
0 and 1023)

if(sensorValue<=180) // sensor range
{
myservo5.write(150);
delay(2000);
myservo1.write(150);
myservo2.write(150);
myservo3.write(150);
myservo4.write(150);

Serial.print(" sensor ="); // Print the result of sensor value and output value

Serial.print(sensorValue);Serial.print("\n");

Serial.print(" Output =");

Serial.print(" extand")

;delay(1000);Serial.print("\n");

}

```

```
if(sensorValue>=180) // sensor range

{

myservo1.write(20);

myservo2.write(20);

myservo3.write(20);

myservo4.write(20);

delay(2000);

myservo5.write(20);

Serial.print(" sensor ="); // Print the result of sensor value and output value

Serial.print(sensorValue);Serial.print("\n");

Serial.print(" Output =");

Serial.print(" retract")

;delay(1000);Serial.print("\n");

// waits for the servo to get there

}

}
```