# FAKULTI KEJURUTERAAN ELEKTRIK

# UNIVERSITI TEKNIKAL MALAYSIA MELAKA

## FINAL YEAR PROJECT

**DEVELOPMENT OF TELE-OPERATED ANIMATRONIC HAND**

**Azlina binti Md Amin Teng**

**Bachelor of Mechatronics Engineering**

**June 2015**

Supervisor's Endorsement

"I hereby declare that I have read through this report entitle "Development of Tele-Operated Animatronic Hand" and found that it has comply the partial fulfilment for awarding the degree of Bachelor of Mechatronics Engineering"

Signature : ..........................................................

Supervisor's Name : ..........................................................

Date : ..........................................................

# DEVELOPMENT OF TELE-OPERATED ANIMATRONIC HAND

**AZLINA BINTI MD AMIN TENG**

**A report submitted in partial fulfilment of the requirements for the degree of**

**BACHELOR OF MECHATRONICS ENGINEERING**



**Faculty of Electrical Engineering**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**YEAR (2014/2015)**

Student Declaration

I declare that this report entitle “Development of Tele-Operated Animatronic 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 : ........................................................

Name : ........................................................

Date : ........................................................

Specially dedicated to my beloved mother and father

## ACKNOWLEDGEMENT

Bismillahirrahmannirrahim,

Praise to Allah SWT, whom with His Willingness to give me chance to complete my Final Year Project. Firstly, I would like to express my deepest thanks and my deepest appreciation to my project supervisor for first semester, Puan Norafizah Binti Abas and my project supervisor for second semester, DR. Muhammad Fahmi Bin Miskon for their encouragement, guidance, time and willingness to teach, support and help me throughout this whole process from beginning until completing this report.

Next, I would like to thank Universiti Teknikal Malaysia Melaka (UTeM) for providing me enough equipment and tools for me to carry on with my project. Without tools and equipment provided, I may not be able to complete this project successfully.

Finally, I would like to express my deepest thanks to my family members especially to my beloved mother and father for their financial and continuous support, advices and encouragement for me to keep on going until this report is done. Not to forget, my friends, whom always give me ideas and full support until this report is completed.

# ABSTRACT

Robotic hands create safe working environment especially in industries and eventually help to avoid injuries in handling hazardous items or objects. The importance of doing this project is to come out a hand that able to handle object better for industry. The early design of this gripper has only 2 fingers where the tendency of slippage might occurs in which accident or unwanted things may happen. The significant of doing this project is to create an animatronic hand via glove that can substitute real human hand and reduce the tendency of slippage where it eventually reduce accidents. Thus, the ideas of highly accurate tele-operated 14 DOF animatronic hand that able to handle items or objects well and the ability to imitate human hand is proposed. The experiment will be analysed in terms of tele-operation accuracy and repeatability which will be carried out in lab. In this project, this tele-operated animatronic hand will have 5 fingers and have the ability to copy human hand movement. Plastic is used to fabricate this hand and flex sensor will be used to sense the movement of human hand. The expected result of this project is that the design hand is able to imitate the real human hand with a high accuracy value of 85.32% for pinky finger, 89.25% for ring finger, 89.83% middle finger, 91.03% index finger and 90.34% thumb. In conclusion, the tele-operated animatronic hand accuracy can be achieved by increasing the length of the crank and is verified in the accuracy test. Thus, the objectives are achieved.

## ABSTRAK

Tangan robotik mewujudkan persekitaran kerja yang selamat terutamanya dalam industri dan akhirnya membantu untuk mengelakkan kecederaan dalam mengendalikan perkara berbahaya atau objek. Kepentingan melakukan projek ini adalah untuk menghasilkan tangan robot yang mampu untuk mengendalikan objek yang lebih baik bagi industri. Reka bentuk awal penggenggam hanya mempunyai 2 jari di mana kecenderungan kekuatan untuk tergelincir boleh berlaku di mana kemalangan yang tidak diingini atau perkara boleh berlaku. Projek ini adalah untuk mewujudkan satu tangan animatronic melalui sarung tangan yang boleh menggantikan tangan manusia sebenar dan mengurangkan kecenderungan gelinciran di mana ia akhirnya dapat mengurangkan kemalangan. Oleh itu, idea-idea yang dicadangkan untuk projeck ini ialah 14 DOF tangan animatronik yang tele dengan tangan manusia yang mampu menangani perkara atau benda-benda yang baik dan mempunyai keupayaan untuk meniru tangan manusia. Sistem keseluruhan akan dianalisis dari segi ketepatan tele-operasi dan kebolehulangan. Eksperimen akan dianalisis dari segi ketepatan tele-operasi dan kebolehulangan yang akan dijalankan di dalam makmal. Dalam projek ini, ini tangan animatronik tele yang beroperasi mempunyai 5 jari dan mempunyai keupayaan untuk meniru pergerakan tangan manusia. Plastik biasa digunakan untuk membuat tangan ini dan flex sensor akan digunakan untuk mengesan pergerakan tangan manusia. Keputusan yang dijangka dari projek ini adalah bahawa tangan reka bentuk mampu meniru tangan manusia sebenar dengan nilai ketepatan yang tinggi 85.32% untuk jari pinky, 89.25% untuk jari manis, 89.83% jari tengah, 91.03% jari telunjuk dan ibu jari 90.34%. Kesimpulannya, ketepatan tangan animatronik yang tele dengan tangan manusia yang beroperasi boleh dicapai dengan menambah kepanjangan engkol dan dibuktikan dalam ujian ketepatan. Oleh itu, objektif tercapai.

## TABLE OF CONTENTS

# LIST OF TABLES

## LIST OF FIGURES

## LIST OF APPENDICES

# CHAPTER 1

# INTRODUCTION

## 1.1 Research Background

In today's world, robots have become part and parcel of human life. The population of robots have tremendously increasing year by year which can be clearly seen when Arturo Baroncelli, the President of the International Federation of Robotics (IFR) [1] stated that Year 2013 has shown another record in the sales of robot with 168,000 of units. This quantities of robots sales has a high magnificent demand in the Asian market which can be referred to Metra Martech's report "Positive Impact of Industrial Robots on Employment Updated in January 2013". The growth of industrial robots will continue to accelerate.

Robotic hands are widely used because of its abilities to perform and do more tasks in many aspects like medical, research, industries and many more than human can do. It is widely used especially in industrial processes and has replaced numerous operators or workers due to its speed, product quality, more accurate, more productivity and low tendency of making mistakes compare to humans.

## 1.2 Motivation and Significant of the Research

Robots have the ability to imitate or copy human movement like hands, legs, body and other parts of body. According to Peter Gorle, "Positive Impact of Industrial Robots on Employment Updated in January 2013" [2], human unable to make products with precision or consistency like robots, working conditions of robots are more ideal than human and the labour cost imbalanced can be well-balanced when robots are used.

Robots have the abilities to perform and do more tasks in many aspects like industries, chemical, medical and many more than human can do. According to Mathias Wiklund, COO Comau, Robotics, Italy [3], robots are widely used due to its abilities which resulted in lots of new applications needed to be explored. He added that in automotive business especially will likely be the biggest in worldwide that use robots for a long period of time in terms of quality, productivity and many more.

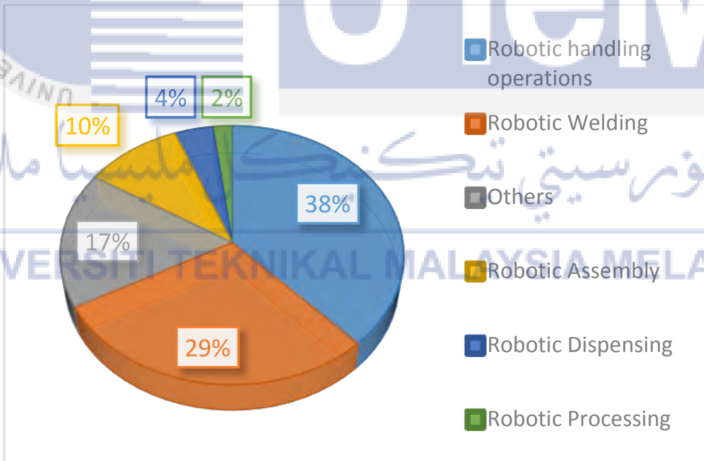


Figure 1.1: Applications of Industrial Robots [4]

According to a survey made by the IFR Statistical Department, World Robotics, 2010 [4] shown in Figure 1.1, Robotic handling operations (38%), Robotic Welding (29%), Robotic Assembly (10%), Robotic Dispensing (4%) and Robotic Processing (2%) are 5 top applications used in industry.

In robotic hand handling section, there are many problems that occurs while handling items, products or objects. Sometimes, it can affect the product, objects, tools or human itself (workers) especially in Industries. For example like slippage of a hazardous chemical products or any objects which sometimes may lead to death. To overcome this problem, many technology has been used to developed robotic hand which focus more on the end effectors (grippers). Different robots used different types of grippers. The grippers or end effectors plays an important role to hold or place an items, thus, the grippers must be designed in the best design.

The importance of doing this project is to create an animatronic hand via glove that can substitute real human hand and reduce the tendency of slippage where it eventually reduce accidents. Thus, this project is going to propose the ideas of animatronic hand for industries which can handle the object, tools or products better.

## 1.3 Problem Statement

Robots have helped many industries especially in the areas of safety. This statement can be supported when Marlin Steel, Baltimore, MD, USA [2], stated the advantages of using robots makes the working environment safe. He added that, robot not only helps to create a safe working environment, but also benefit the company and workers. Robot hands helps to avoid injuries especially in handling hazardous things. This can be seen in Figure 1.2 where the injury is cause by hydrofluoric acid (used for metal cleaning, glass etching and many more) [5]. Many injuries like back pain (ergonomic issues) and many more types of injuries can lead to fatal error or maybe worse, death if it is not well treated. Thus, the ideas of animatronic hand is proposed.



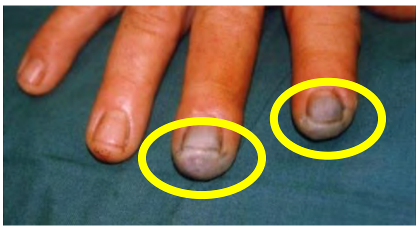

Figure 1.2: The injury of hands cause by hydrofluoric acid [5]

Robot hands especially the end effectors is the most crucial parts of robots hands in handling process. The Design of a Robotic Arm with Gripper & End Effector for Spot Welding developed by Puran Singh, Anil Kumar, Mahesh Vashisth from the Department of Mechanical and Automation Engineering, Amity School of Engineering and Technology Delhi, India, 2013 [6], designed a gripper with 2 DOF with 2 fingers to pick, hold and grasped various types of objects (shapes).

The disadvantages of using gripper is that the handling is not as secured as normal hand (five fingers) due to its number of fingers (two). Thus, this project is going to propose the ideas of animatronic hand for industries which can handle the object, tools or products better. This animatronic hand imitates the movement of human hand so that the work done is better.

In order to make the animatronic hand better in handling the product, the challenges faced in designing this hand is to make every designed fingers movement to be accurate and no delay. In order to make the designed animatronic hand more accurate in movement and no delay, the idea is proposed by increasing the length of the crank. By increasing the length of the crank, the movement will be more precise as it will pull the string farther which will make the fingers to bend more compared to shorter crank. However, by increasing the length of the crank, the force required for the shaft to move is greater when it pulls further due to the weight of the added load. In order to find balance solution between accuracy and force, I assume by using a lighter object to extend the length of crank. When lighter object is used to extend the crank, the accuracy can be achieved, thus the force due to the weight of added load can be lessen.

## 1.4 Objective

The objective of this research are:-

1. To design highly accurate tele-operated 14 DOF animatronic hand (prototype)
2. To analyse overall system performance in terms of tele-operation accuracy and repeatability

### 1.5 Scope

This project involves two parts which are hardware and software. The scopes of this project are:-

i. To fabricate the tele-operated animatronic hand for grasp purposes that has 14 DOF
ii. Each finger used only one actuator with limited movement and it do not have any ball joint
iii. The glove only able to control one movement of each finger
iv. To produce animatronic hand by using piping tube with the size of 5.5cm - 7.5cm which will be used as fingers thus it does not have the ability to carry a heavy object
v. Size of the palm is from the range of 8cm – 9.5cm
vi. The experiment will be analysed in terms of tele-operation accuracy and repeatability which will be carried out in lab

### 1.6 Report Outline

The first chapter is about a brief explanation on the research background of animatronic hand on the reason why robot hands are required in industries. Motivation is the main idea of making this project and problem statement is included to identify and solved the problem in making of animatronic hand. The objective is included to see whether it is achieved at the end of the animatronic hand project and the scope is also included in this report to limit certain criteria that is unable to achieve due to some reason.

The second chapter is about the literature review of animatronic hand. It is mainly about the theory and basic principles of animatronic hand, anatomy of human hands, review of previous works or journal and the summary and the discussion of the review.

The third chapter is about methodology and is divided into four which are the introduction, the design highly accurate tele-operated 14 DOF animatronic hand and the analysis of overall performance in terms of accuracy and repeatability. Introduction in this section is mainly about the method used to achieve all objectives. Next is the design highly accurate tele-operated 14

DOF animatronic hand which consists of the design parameter, the components selection of the animatronic hand and tele-operated hand, electronic circuit for animatronic hand and tele-operated and component selection for the design circuit. Finally, the analysis which is about the complete procedure of the experiment and safety precautions.

The fourth chapter is about the result and discussion. In this chapter, the result of the test in terms of accuracy and repeatability is shown and discussed.

Finally, the last chapter is about conclusion and recommendation. This chapter will conclude all the tele-operated animatronic hand project whether it achieved the objective or not. Recommendation will be made to proposed other advanced idea or materials that can be added in the tele-operated animatronic hand.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Theory and Basic Principles

This section covers about the theory and the basic principles of animatronic hand that are related to the development of animatronic hand. It covers with three subsection which are animatronic hand, anatomy of human hand and basic principles. Animatronic hand covers the theory of animatronic hand and how it works. Anatomy of human hand covers about the basic theory of human hand and basic principles is mainly about the principle on how the material like sensor works.



### 2.1.1 Animatronic Hand

According to Macmillan Dictionary, 2009-2014 [7], animatronic means a technology that use an electronic system to operate a puppets like models of an animals or people or can be simplified as the combination of animation and electronic.

Animatronic hand has many different types of design and various ways to control the hand not to mention, the types of sensors and actuator used. There are many types of Animatronic hand like shadow dexterous hand, dexterous robotic hand and many more. Animatronic hand [8] shown in Figure 2.1 is one of the types of animatronic hand that uses a glove to move a design hand where the design hand imitates the movement of real human hand. The glove uses flex sensors as the sensors and servo motors as an actuator. When the glove (flex sensors are attached on the glove) moves, the servo motors will pull the wires that attached to each fingers of the design hand.

Figure 2.1: Animatronic Hand [8]

### 2.1.2 Anatomy of Human Hand

According to Oxford Dictionary, 2014 [9] states that hand is defined as the end part of an individual arm beyond the wrist including the thumb, fingers and palm.

According to Aristotle, Di partibus animalium: 687a 7, ca. 340 BC [10], hand is the key of human intelligence which only humans are gifted with the hands that capable of doing different tasks such as handling and sensing. Our hands are one of the most complex part of our bodies that consist of fifty four bones in different variation of sizes and able to accomplish a wide range of tasks. When it comes to robotic hand, it cannot compete with actual hands due to its structure, materials used and many more. Brand and Hollister 1999; Kry et al. 2002 [11] states that human hand consist of bones, muscles, skin, tendon and complicated relationships between them. According to Orthogate and the Internet Society of Orthopaedic Surgery and Traumatology (I.S.O.S.T), 1999-2014 [12], Human hand consists of twenty seven bones and twenty seven joints shown in Figure 2.2, thirty four muscles, countless blood vessels, nerves and soft tissue with a hundred over ligaments and tendons shown in Figure 2.3. Human hand can be classified into three groups which are wrist, carpal and digital bones shown in Figure 2.4.

Figure 2.2: A picture of hand with twenty seven bones and twenty seven joints [12]

Figure 2.3: A picture of hand with thirty four muscles, countless blood vessels, nerves and soft tissue with a hundred over ligaments and tendons [12]



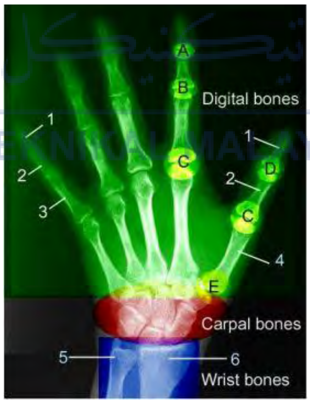


Figure 2.4: Human hand is classified into three groups which are wrist, carpal and digital bones [13]

According to Mufa T. Ghadiali, M.D., F.A.C.S ,Diplomate of American Board of Surgery [13], Carpal bones is situated at wrist that consist of eight bones that connected to five metacarpal bones where each metacarpal bone linked to finger. Each of our fingers has three phalanges and two joints except thumb which has two phalanges and one joint. Our hands and bone at wrist are clenched by different types of soft tissues which are tendons, ligaments, cartilage and muscles. MCP or Metacarpophalangeal joint (metacarpals and phalanges) is the joint that work as a hinge when there is a bending or fingers straighten. There are various types of movement of hands which are flexion (move base finger to palm), extension (move base finger away from palm), adduction (move all fingers to middle finger), abduction (move all fingers away from the middle finger) and many more.

### 2.1.3 Basic Principles

Flex sensors will be used as a controller for the design hand. Flex sensors shown in Figure 2.5 [14] are one type of sensor that are made by resistive elements of carbon. Flex sensors are usually used in many technology like in automotive industries, devices, games and many more. Flex sensor works when bending of fingers are made when an electrical resistance is produced. Flex sensor give variable reading of resistance shown in Figure 2.6 where, the more bending one's made, the higher the value of the electrical resistance [14]. Flex sensors are usually in thin shape with 2.54cm to 12.7cm long. The values of resistors is in the range of 1kΩ to 200kΩ. Flex sensors uses voltage divider shown in Figure 2.7 [14] to identify the changes of the resistance value made when one move the finger. Flex sensors are widely used because of its high repeatability, consistency, reliability, flexible and many more.



Figure 2.5: Flex Sensor [14]

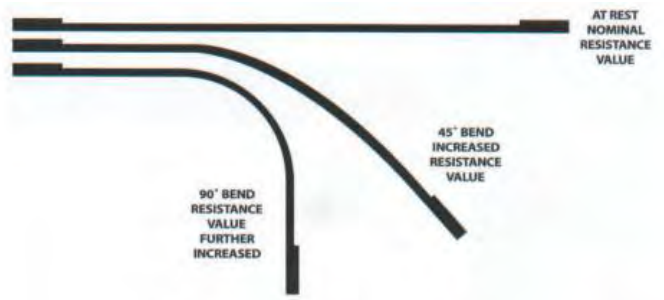


Figure 2.6: Variable reading of resistance [14]

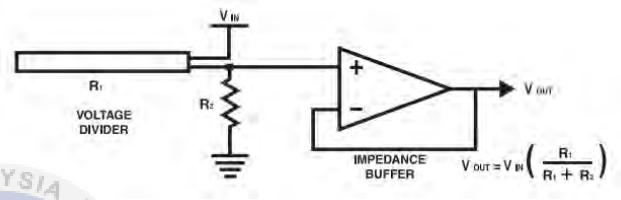


Figure 2.7: Voltage Divider [14]

## 2.2 Review of Previous Related Work

This section covers the review of previous related work, configuration of hand, device to control the robotic hand and modelling, controlling and performance used for animatronic hand. Review of previous related work is mainly about the history of the development of robotic hand which began on the eras of 70. Configuration of hand on the other side, is mainly about the component and actuator used. Device used to control the animatronic hand is about types of sensor used to control the designed hand. Finally, modelling, controlling and performance used for animatronic hand were about the analysis of the robotic hand.

A summary is made to summarise the journal referred to have a good understanding in the configuration of animatronic hand and its functions, information regarding these hand are gathered.

### 2.2.1 Development of Robotic Hand

Referring to Shigeo Hirose *et al.,* a robotic hand named Hirose Soft Gripper (with one Degree of Freedom) was developed and the robot hands started at early of 1970 shown in Figure 2.8 [15].

Figure 2.8: Hirose Soft Gripper [15]

Rajko Tomovic and George Bekey *et al.,* developed a robotic hand (their first prototypes after the World War II) that had four Degree of Freedom for each pair of fingers and two Degree of Freedom for thumb named Belgrace or USC hand shown in Figure 2.9. The development of robot hand continued in the late 1980's [15].

Figure 2.9: Belgrace or USC hand [15]

Barrett Technology, Inc *et al.,* developed a robotic hand named Barett hand where it had the ability to hand had the ability to maintain about one in the half kilograms of force at fingertips. The price of this hand was approximately about thirty thousand US dollar. It had four motors per finger (three finger) and one motor for the palm spread. The technology used was breakaway where it allowed the fingers to adjust to object geometry [15].

Figure 2.10: Barrett Hand [15]

Kawasaki and Mouri *et al.,* developed robotic hand named Gifu Hand shown in Figure 2.11 which had sixteen controlled Degree of Freedom (the last two joints are coupled together except the thumb). This robotic hand was sold by a company called Dainichi. It used a pressure sensor but there is no accurate in sensing position. It had about three hundred kilograms of fingertip force with the hand weight of one in the half kilograms. The sizes of this hand is larger than human size [15].

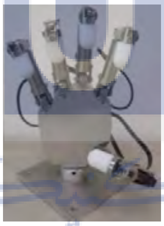

Figure 2.11: Gifu Hand [15]



Shadow Robot Company *et al.,* developed a Shadow Hand shown in Figure 2.12 that had twenty controlled Degree of Freedom (the last two joined was coupled except the thumb). It used Hall Effect sensor, air pressure and tactile array. The weight of this hand was about four kilograms and the fingertips force was half of kilograms. This hand was added with the best features where pneumatic actuators add compliance, wear and a control issues [15].

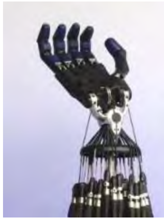

Figure 2.12: Shadow Hand [15]

Robert Ambrose and colleagues (NASA) *et al.,* developed a Robonaut hand shown in Figure 2.13 where this hand was used for space operation. It can controlled fourteen Degree of Freedom including at wrist and had motor in forearm. The sensor used was tactile sensing glove with QTC and FSR element at the last two fingers mounted at the angle and rotate at CMC joint [15].

Figure 2.13: Robonaut hand [15]



### 2.2.2 Configuration of Hand

Shamsheer Verma and Bharati Vidyapeeth *et al.,* developed a Hand Gestures Remote Controlled Robotic Arm shown in Figure 2.14. It had 3 DOF with 6 servo motors. It used Accelerometer to get the angles of all directions of hands and transfer the signal to Arduino which the value gained will be processed accordingly. The actuator used was 6 servo motors and gears [16].

Figure 2.14: Hand Gestures Remote Controlled Robotic Arm [16]

Shadow Robot Company Ltd *et al.,* developed a humanoid robot with advanced system that able to move in 24 DOF called Shadow Dexterous Hand shown in Figure 2.15. It is used for research in in handling dangerous materials, grasping, brain computer interface, quality control of industry and neural control. Shadow Dexterous Hand is divided into two models which are C5 and C6M. The first model, C5, 40 air muscles attached on forearm and the muscle acted like the same human muscle. Each muscle is moved by integrated electronics. It used pneumatic as actuator. For the second model, C6M, the actuator used is "Smart Motor" where 20 motors were used and was attached at below wrist. C6M was controlled by using PC robot interface or CyberGlove and C6M is the most advanced Dexterous Hand [17].



Figure 2.15: Shadow Dexterous Hand C5 (back) and C6M (front) [17]

Cristian *et al.,* developed a Hand Gesture Control for 5-Axes Prototype Manipulator shown in Figure 2.16. This project used hand gesture to control the movement of this 5-Axes Prototype Manipulator. Flex sensor was used to control the movement of gripper while 5-Axes Prototype Manipulator used accelerometer to moved. 4 DC servo motors are used due to its sizes and weight [18].

Figure 2.16: Hand Gesture Control for 5-Axes Prototype Manipulator [18]

Maryanto *et al.,* developed a robotic hand called Dexterous Robotic Hand shown in Figure 2.17, where it used 11 RC Servo to move 5 fingers and it had 11 DOF. It had the ability to grasped different objects and can act naturally and exactly like human hand. It was made by using Acryl Sheet. It used wire to move the each fingers. The Microcontroller used for this hand is AT89S52. The sensor used for this hand is potentiometers [19].

Figure 2.17: Dexterous Robotic Hand [19]

Tetsuya M, Haruhisa K, Keisuke Y, Jun T, and Satoshi I *et al.,* developed a Gifu Hand III shown in Figure 2.18. This hand had 16 DOF with 20 joints. The actuator used were servo motor and each servo motor has magnetic encoder (16 pulses for every revolution). The thumb and fingers had 4 joint each with 4 DOF and 3 DOF respectively. Tactile sensors and force sensors were used as sensors. The improvements made were in terms of response which had become higher, reduced backlash in transmission and many more [20].

Figure 2.18: Gifu Hand III [20]

Ikuo Yamano *et al.,* developed **a** Five-fingered Robot Hand using Ultrasonic Motors and Elastic Elements shown in Figure 2.19. This hand was almost the same as human hand and it had 20 DOF which every finger had 4 DOF. The actuator used for this hand was ultrasonic motors and potentiometers were used as the sensor. Elastic elements were used as the driving methods [21].

Figure 2.19: Five-fingered Robot Hand using Ultrasonic Motors and Elastic Elements [21]

Klaus Schmidt *et al.,* developed a robotic hand called a Palm Improvement and a Robotic Hand-Arm Interface shown in Figure 2.20. This hand had 3 fingers with 10 DOF. This hand abled to do 8 different grasps. This hand used 1 servo motor and 3 DC motor. The sensor used was force sensors. The materials used to make this hand were aluminium, plastic, titan and steel [22].

Figure 2.20: Palm Improvement and a Robotic Hand-Arm Interface [22]

Matthew J. Rowell *et al.,* developed a Design and Analysis of a Robotic Hand for Prosthetic Device shown in Figure 2.21. This hand imitated the movement of a human finger. The sensors used for this hand were pressure sensor, position sensor, and force sensors. The actuator used was 2 servo motors [23].

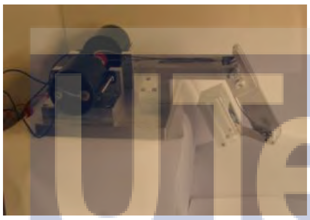

Figure 2.21: Design and Analysis of a Robotic Hand for Prosthetic Device [23]



Ichiro Kawabuchi *et al.,* developed a Designing of Humanoid Robot Hands in Endoskeleton and Exoskeleton Styles shown in Figure 2.22. This hand had 15 DOF. The sensor used for this hand was force sensor while the actuator used for this hand were 1 large motor (Faulhaber, type 1724SR) and 2 small DC motors. This hand has the same function and motion of human hand and same weight and size.

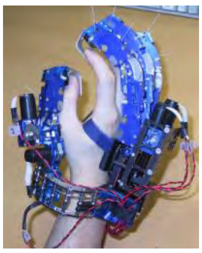

Figure 2.22: A Designing of Humanoid Robot Hands in Endoskeleton and Exoskeleton Styles[24]

Dongwoon Choi, Dong-Wook Lee, Woonghee Shon and Ho-Gil Lee *et al.,* developed a 5 D.O.F Robot Hand with an Artificial Skin for an Android Robot shown in Figure 2.23. This hand had 5 DOF which is used for android robot and the skin made was artificial. This hand shape and fingers were based on the female hand in Korea. Linear potentiometers and proximity were used as sensors for this hand while the motor used for this hand was DC motors [25].

Figure 2.23: Design of 5 D.O.F Robot Hand with an Artificial Skin for an Android Robot [25]

### 2.2.3 Device Used to Control the Animatronic Hand

John KangChun Perng et.al developed a sensing glove for controlling the hand named as Acceleration Sensing Glove (ASG) shown in Figure 2.24. It used accelerometer to defined fingers and motion made by hand to computer to interpret the signal gained. This acceleration sensing glove had a wrist controller with 6 accelerometer where 5 was attached at fingertips and the other one was attached at the back of the hand. This glove used Atmel AVR AT90LS8535 microcontroller attached on forearm to convert signal (analog signal made by accelerometer) to digital [26].


Figure 2.24: Acceleration Sensing Glove [26]

Dr WILLIAM C. SHIEL JR *et al.,* EMG is a test of measuring the changes voltage made by the skeletal muscle when it contract [14]. The signal was taken by implanting electrodes in the arm (Intramuscular EMG) or by the attaching electrodes on the surface of the arm (Figure 2.25). This EMG is usually used for medical to detect an abnormal nerves or muscles from patience. EMG is usually used to make Prosthesis Bionic Hand [27].

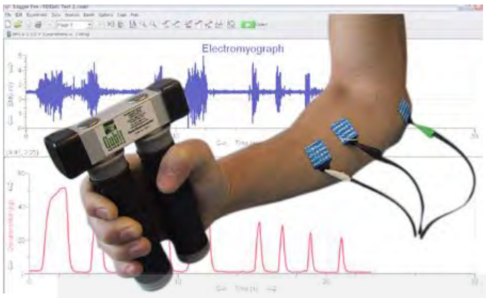


Figure 2.25: Electrodes is attached on the surface of the hand [27]



Cyber Glove Systems *et al.,* developed a controlling glove named Cyberglove II shown in Figure 2.26. This glove used the technology of Bluetooth. It had the ability to detect many distances from an object. This CyberGlove hand had 10 sensor located at fingers, palm, and other parts to sense abduction and flexion. Each sensor used is exceptionally thin and it is very flexible in the light stretchy glove. It has the ability to allow one to write, grasp different objects and typing [28].

Figure 2.26: CyberGlove II [28]

Nazrul H. Adnan, Khairunizam Wan, Shahriman A.B., M. Hazwan Ali, M. Nasir Ayob and Azri A. Aziz *et al.,* developed a Flex sensor glove shown in Figure 2.27. This glove used and act the exact ways of potentiometer glove. It used voltage divider shown in Figure 2.7 to identify the changes of the resistance value made when one move the finger. The flex sensor produced an electrical resistance when bending of fingers are made. The more bending made, the higher the value of the electrical resistance [29].

Figure 2.27: Flex sensor glove [29]

Maryanto *et al.,* developed Dexterous Robotic Hand shown Figure 2.17 that used potentiometer as sensors which are attached on every finger. It applied the same as flex sensor, the resistance value will change if there is a movement made. Once the finger move, the voltage produced will be delivering the value to controller which make the system identified the location of the finger [19].



### 2.2.4 Performances Test of Robotic Hand

Martin Jagersand *et al.,* developed Utah/MIT Hand [30] with 16 Degree of Freedom. The experiment done to test the performance of the robotic hand is by repeating the hand position for 50 times (repeatability). It is tested to see whether the position of the hand measured is accurate by marking the hand near the end of the fingers using marker as it give a better visual when the hand do the bending movement.

Figure 2.28: Setup for repeatability test of Utah Hand [30]

Nazrul H. Adnan, Khairunizam Wan, Shahriman A.B., M. Hazwan Ali, M. Nasir Ayob and Azri A. Aziz *et al.,* developed a Flex sensor glove [29] shown in Figure 2.27. The experiment to test out the performance of this hand is accuracy test where the finger bending is taken and data is transferred using Matlab.

Magnus Johnsson *et al.,* developed a LUCS Haptic hand I [31] to study the haptic perception. The experiment done to analyse the performance of this robot hand is by grasping test. The test is done by letting the robot hand to grasp any different object with different sizes, shapes and the signal produced from the sensors.



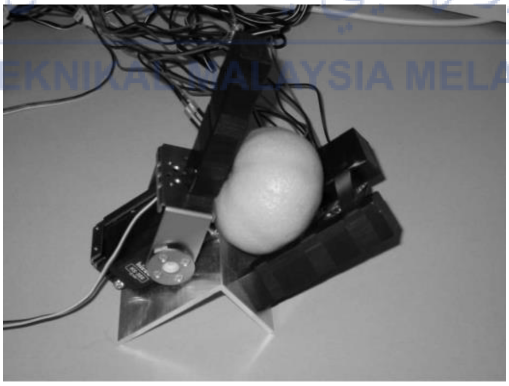

Figure 2.29: LUCS Haptic Hand I holding orange (grasping test) [31]

## 2.3 Summary and Discussion of the Review

The ideas of the researches and students of making Robotic hand are extracted to help in completing this Smart Animatronic Hand project.

### 2.3.1 The Design of Robotic Hand

Table 2.1: The design of robotic hand

| Types of Glove | Author | Sensor | Actuator Used | Movement or DOF |
|---|---|---|---|---|
| Hand Gestures Remote Controlled Robotic Arm | Shamsheer Verma, B.Tech (ICE), Bharati Vidyapeeth College Of Engineering, New Delhi [16] | Accelerometer | Servo Motors | 3 DOF |
| Shadow Dexterous Hand | Shadow Robot Company Ltd, 2008 [17] | CyberGlove | C5 :- Pneumatic C6M :- "Smart Motor" | 24 DOF |
| Hand Gesture Control for 5-Axes Prototype Manipulator | Cristian, 2010 (SGU) [18] | Flex Sensor | DC Servo Motor | 5-axes |
| Dexterous Robotic Hand | Maryanto (2006) [19] | Potentiometers | RC Servo | 11 DOF |
| Gifu Hand III | Tetsuya Mouri, Haruhisa Kawasaki, Keisuke Yoshikawa, Jun Takai, and Satoshi Ito [20] | Tactile sensors, Force sensors | Servo motors | 16 DOF |

| | | | | |
|---|---|---|---|---|
| Five-fingered Robot Hand using Ultrasonic Motors and Elastic Elements | Ikuo Yamano, Keio University of Japan [21] | Potentiometers | Ultrasonic motors | 4 DOF |
| Palm Improvement and a Robotic Hand-Arm Interface | Klaus Schmidt [22] | Force sensors | 1 Servo motor, 3 DC motor | 10 DOF |
| Design and Analysis of a Robotic Hand for Prosthetic Device | Matthew J. Rowell [23] | Pressure sensor, Position sensor, Force sensors | 2 Servo motor | Not stated |
| A Designing of Humanoid Robot Hands in Endoskeleton and Exoskeleton Styles | Ichiro Kawabuchi [24] | Force sensor | 1 large motor (Faulhaber , type 1724SR), 2 small DC motors | 15 DOF |
| Design of 5 D.O.F Robot Hand with an Artificial Skin for an Android Robot | Dongwoon Choi, Dong-Wook Lee, Woonghee Shon and Ho-Gil Lee, Korea Institute of Industrial Technology, Republic of Korea [25] | Linear Potentiometer, Proximity | DC Motors | 5 DOF |

**Summary of Mechanical Design**

By comparing all the information gathered from many projects above shown in Table 2.1, Dexterous Hand is the most suitable design to be used compared to others. This is because the other design has a complex design. Thus, Dexterous Hand is the best design since the designed has the closest characteristic to animate human hand.

### 2.3.2 Device to Control

Table 2.2: Device to Control with Various Types of Sensor Used

| Types of Glove | Author | Sensor |
|---|---|---|
| Acceleration Sensing Glove (ASG) | John Kangchun Perng, Brian Fisher, Seth Hollar, Kristofer S. J. Pister from the University of California, Berkeley [26] | Accelerometer |
| A Multigrasp Hand Prosthesis for Transradial Amputees | Skyler A. Dalley, Tuomas E. Wiste, Huseyin Atakan Varol, and Michael Goldfarb [27] | EMG |
| Cyberglove II | Cyber Glove Systems [28] | Bluetooth |
| Development of Low Cost "GloveMAP" Based on Fingertip Bending Tracking Techniques for Virtual Interaction | Nazrul H. ADNAN, Khairunizam WAN, Shahriman A.B., M. Hazwan ALI, M. Nasir Ayob and Azri A. AZIZ [29] | Flex Sensor |
| Dexterous Robotic Hand | Maryanto (2006) [19] | Potentiometer |

**Summary of Control Glove with Various Types of Sensor Used**

Based on the table 2.2, the most suitable sensor used for glove is Flex Sensor. Flex sensor is chosen because it is affordable, flexible, robust, thin and easy to operates.

### 2.3.3 Performances Test of Robotic Hand

Table 2.3: Performances test

| Types of Test | Description |
| --- | --- |
| Repeatability [30] | Repeating the hand position for 50 times (repeatability) |
| Accuracy [29] | Test of finger bending and data is transferred using Matlab |
| Grasping [31] | Letting the robot hand to grasp any different object with different sizes, shapes and the signal produced from the sensors |

**Summary of the Types of Tests**



Based on the table 2.3 above, the suitable types of test for the animatronic hand is accuracy and repeatability test. The grasping test is unable to be done because of the material used (plastic tube) to make the animatronic hand as it is unable to carry or hold heavy items or objects.

## 2.4 Summary of the Design

After referring and gathering the ideas and information from the researches and students (based on Literature Review), the design of this project will be using flex sensor as the sensor and servo motor as actuator. The experiment to test out the performance of the animatronic hand is accuracy and repeatability by assuming that when these tests are carried out, accuracy and the ability for the animatronic hand to repeat many times will be achieved.

# CHAPTER 3

# METHODOLOGY

## 3.1 Introduction

This chapter will be divided into three sub-chapter which is the introduction, the design of highly accurate tele-operated 14 DOF animatronic hand and the analysis of overall system performance in terms of tele-operated accuracy and repeatability. The first sub-chapter will be discussed about the methodology to achieve all the objectives.

The second sub-chapter is about the design of highly accurate tele-operated animatronic hand, component selection of the animatronic hand and tele-operated hand, electronic circuit design for animatronic hand and tele-operated hand and the component selection for the designed circuit.

The third and last sub-chapter is about the analysis experiment of accuracy and repeatability test and the safety and precautions.

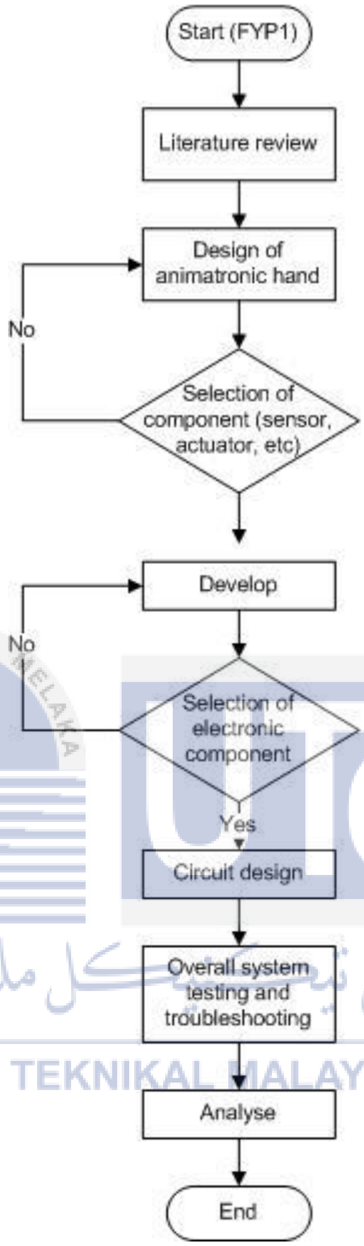


Figure 3.1: Project Methodology flowchart (overall)

The method used to achieve all the objectives are by using flowchart shown in Figure 3.1 where each section will be later further discussed in details. To prove out the assumptions above, the experiments will be done in lab.

## 3.2 Design of Tele-Operated Animatronic Hand

This section covers the first objective which is to design highly accurate tele-operated 14 DOF animatronic hand. This section is divided into several subsection which are the design of the animatronic hand, component selection for the animatronic hand and the tele-operated hand (glove), circuit design for the animatronic hand and the tele-operated hand and component selection for the design circuit.

### 3.2.1 Design of the Animatronic Hand

In order to design the animatronic hand, firstly, the design parameter of the fingers needed to be determined. The size of each fingers and palm is desirable to resemble human hand. The design of the fingers are 3DOF for each finger and 2DOF for thumb shown in Figure 3.2. To achieve the accurate movement of the fingers, the length of the crank is increased with a light object shown in Figure 3.3. The reason on the increase length of the crank is because it actually help in making the fingers to bend more. This is because when the length of crank increased, the movement (radius) of the crank will be bigger, and thus the string pulled by the servo motors will be greater.



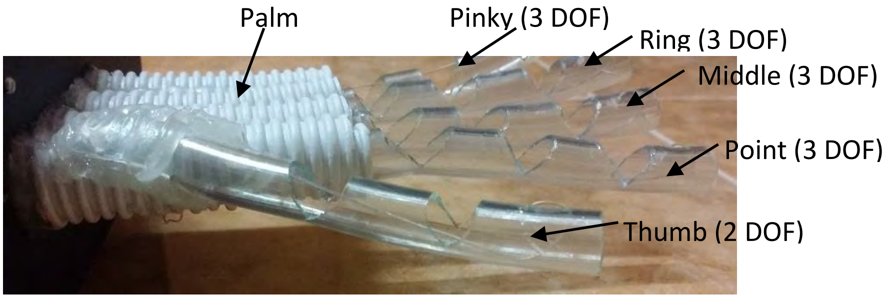


Figure 3.2: The Design of 14 DOF Tele-Operated Animatronic Hand

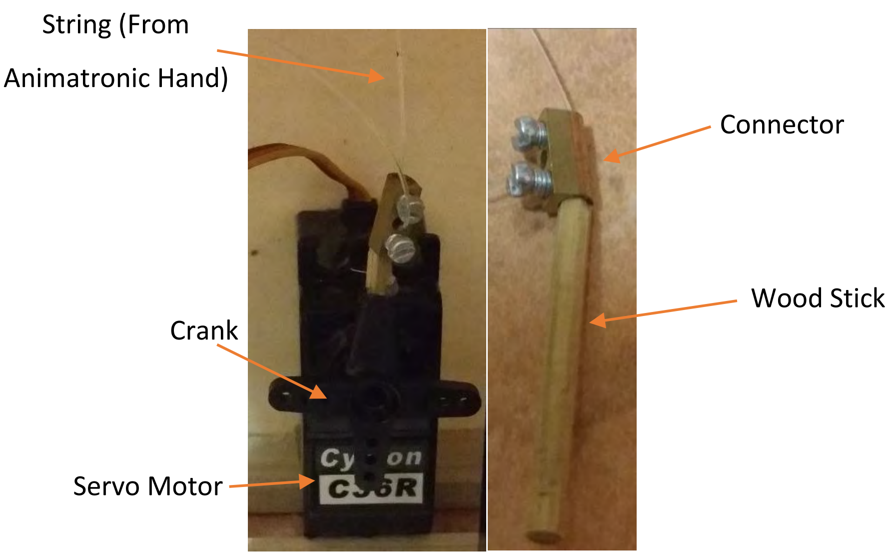


Figure 3.3: Crank with the increase of length (wood stick)

### 3.2.2 Component Selection for the Animatronic Hand and Tele-Operated Hand

The component selection for the design animatronic hand is very important as it will affect the overall structure of this animatronic hand. This section mainly discussed about the material, actuator and sensors used to complete the design of animatronic hand. The components chosen for this animatronic hand as discussed in chapter 2.4 are servo motor and flex sensors. Servo motor will act as actuator and move the animatronic hand. The material used for this design animatronic hand is a tube that made out of plastic, thus it does not have the ability to carry heavy items or objects. The fingers dimensions (long) are from the size of 5.5cm - 7.5cm and the palm will be 9.5cm×8.cm in size.

The first actuator used is servo motor. Servo motors shown in Figure 3.4 are type of actuator that can be used in creating the movement of the robot and many more. Servo motor [32] has the ability to make a rotation and static at certain position. Servo motor is controlled by Pulse Width Modulation [32] with its width range of 0.5ms to 2.5ms. Figure 3.5 shows how PWM controlled the position (angle) of servo motor. The specification of servo motor can be referred in Table 3.1 [32].


Figure 3.4: Servo motor [32]

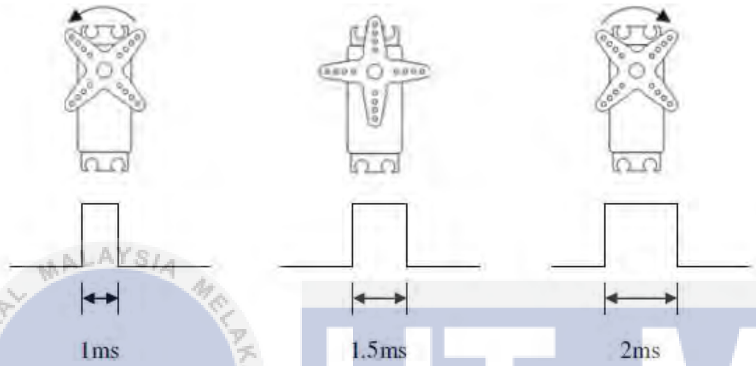


Figure 3.5: Position control by using PWM [32]

Table 3.1: Servo motor specification [32]

| RC Servo Code | | C36R |
|---|---|---|
| 4.8V | Speed (s/60°) | 0.16 |
| | Torque (Kg.cm) | 3.50 |
| 6.0V | Speed (s/60°) | 0.14 |
| | Torque (Kg.cm) | 4.50 |
| 7.2V | Speed (s/60°) | - |
| | Torque (Kg.cm) | - |
| Pulse Width Range (ms) | | 0.5ms to 2.35ms |
| Weight (g) | | 36 |
| Gear material | | Plastic |
| Servo Type | | Standard |

Flex sensor is the sensor used to control the animatronic hand using human hand to control the movement of the finger. Referred 2.1.3 for the basic principle of flex sensor.

### 3.2.3 Electronic Circuit Design for the Animatronic Hand and Tele-Operated Hand

There are two types of circuit used in the circuit design for the animatronic hand and the tele-operated hand. The first circuit which is used for the animatronic hand is the servo motor circuit. This circuit is important to deliver the output signal to the microcontrollers. The second circuit which is used for the tele-operated hand is flex sensor circuit. In this circuit, flex sensors act as a signal conditioning. The electronic circuit for the PCB is done by using Protheus.

#### 3.2.3.1 Servo Motors

5 servo motors used to represent 5 fingers for the animatronic hand. Servo motors have 3 connectors which are for signal, input voltage and ground.

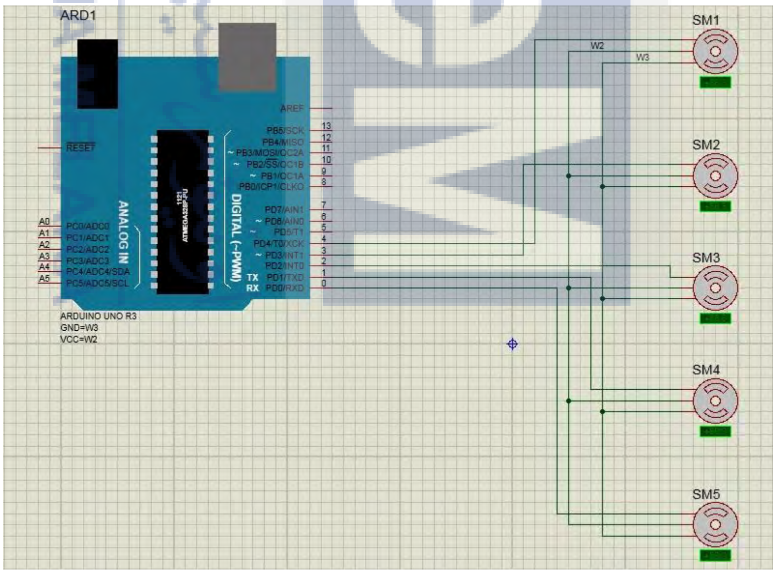


Figure 3.6: Servo motor circuit

#### 3.2.3.2 Flex Sensor

The flex sensors require a circuit in order for them to be compatible with Arduino. It's a voltage divider: the flex sensors are variable resistors, and when paired with resistors of a static value, change in resistance (in this case bending the sensor) can be sensed through the change in voltage between the resistors. This can be measured by the Arduino through its analogue inputs.

Example:

$$V_{out} = V_{in}\left(\frac{R_1}{RV1 + R_1}\right)$$

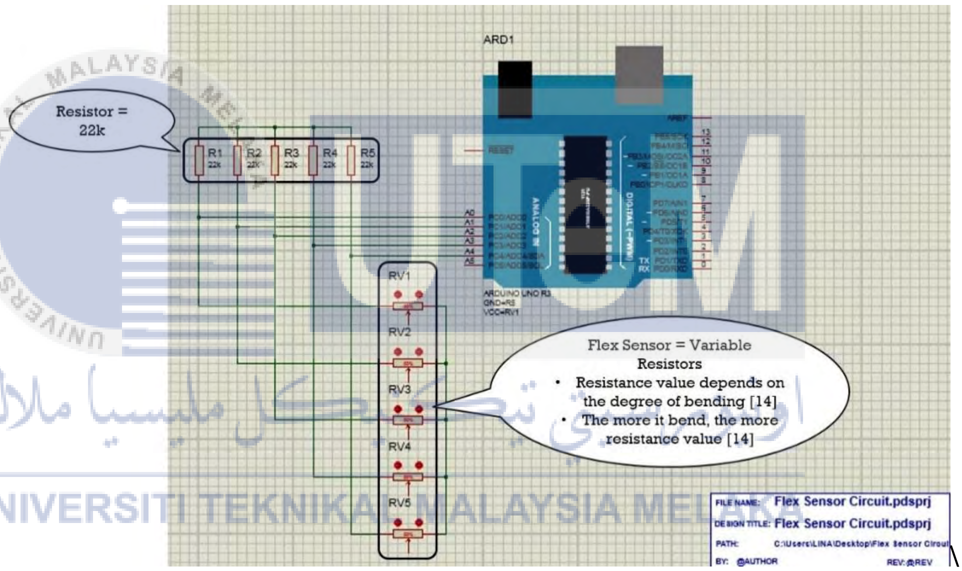




Figure 3.7: Flex sensor circuit

### 3.2.4 Component Selection for the Design Circuit

The component selection for the designed circuit is crucial to make the project complete. There are many components can be used for the designed circuit, but, this section will discussed in detail on the component selection used for the designed circuit.

Arduino Uno shown in Figure 3.8 is a microcontroller used for the animatronic hand. The Arduino operating voltage is 5V with the digital input/output of 14 (6 provide

PWM output). This Arduino Uno has 6 analog input pins with 16MHz clock speed. This Arduino Uno comes with USB interface, reset button, power jack and ICSP button. Arduino Uno power can either from AC-to-DC adapter or from battery [33].

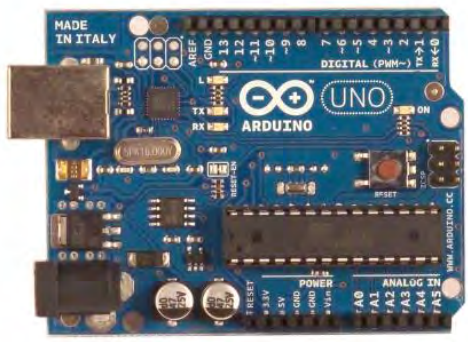


Figure 3.8: Arduino Uno [33]



## 3.3 Analysis of Performance of Animatronic Hand

This section covers the second objective which is to analyse overall system performance of animatronic hand in terms of accuracy and repeatability. This section is about the procedure or method of experiment in order to achieve the objectives. The first experiment is completed by analysing the accuracy of animatronic hand with human hand where the angle of every fingers of the animatronic hand are compared with the angle of the every fingers of the human hand. The second experiment is done by comparing the animatronic hand and human hand in terms of repeatability. The experiment will be repeated three times by relaxed and grasping each fingers to see whether the animatronic hand able to cope the movement of the human hand.

### 3.3.1 Experiment of Accuracy Test

In this experiment, to test the accuracy of the animatronic hand, the angle (when the pinky finger is in extension and flexion) of the animatronic hand and human hand (pinky finger) are compared at certain angle by using Tracker software. Two cameras (put side by side) are used and are made sure to be in a static position. The cameras are used to capture the video for the movement of the animatronic hand and human hand. The steps are repeated for ring finger, middle finger, index finger and thumb. The data for the animatronic hand and human hand in extension and flexion is taken and tabulated into table. From the data gained, graph is then constructed and the accuracy is analysed shown in Chapter 4.

**Equipment**

1. Camera
2. Tracker Software
3. Glove (stitched with flex sensor for human hand)



**Apparatus**

1. Multimeter
2. Animatronic hand

**Materials**

1. Arduino Uno
2. Batteries
3. Resistor
4. Jumper

## Experiment Procedure

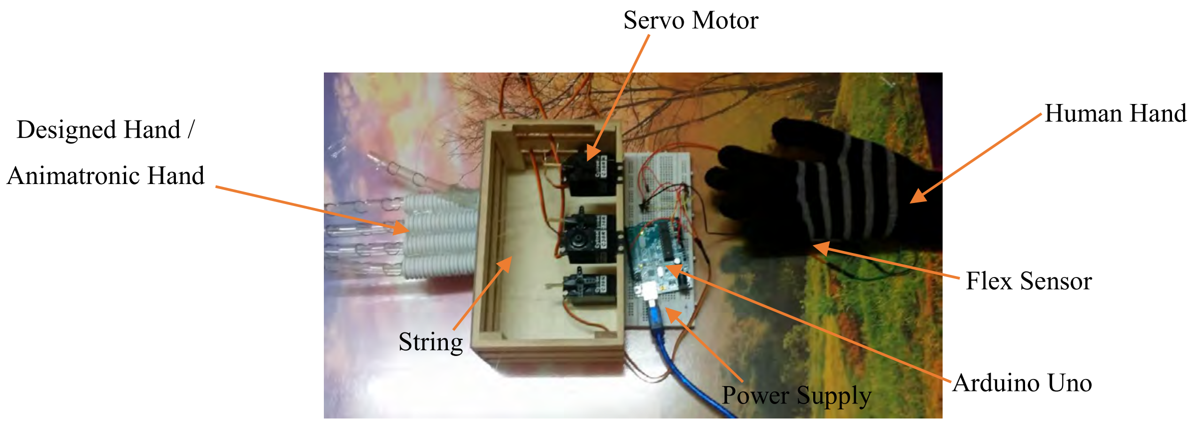


Figure 3.9: Experiment setup

To perform the accuracy test, all the materials and equipment are set up shown in Figure 3.9. The cameras are placed in a static position. The animatronic hand (pinky finger) and the human hand (pinky finger) must be in a relaxed position. Once everything is ready, the cameras (in video mode put side by side) are pressed. Then, the pinky finger of human hand is move (fully bend) to let the animatronic hand move. Once the finger (animatronic hand) move accordingly shown in Figure 3.10 (a), the human finger is then relaxed followed by the animatronic hand shown in Figure 3.10 (b). Once the experiment is done, the button 'stop' is pressed on the camera. The steps are repeated for ring finger, middle finger, index finger and thumb. The videos of both finger is analysed by using Tracker software. The data gain is taken and tabulated. The graph is plotted.


Figure 3.10 (a): Human hand relaxed

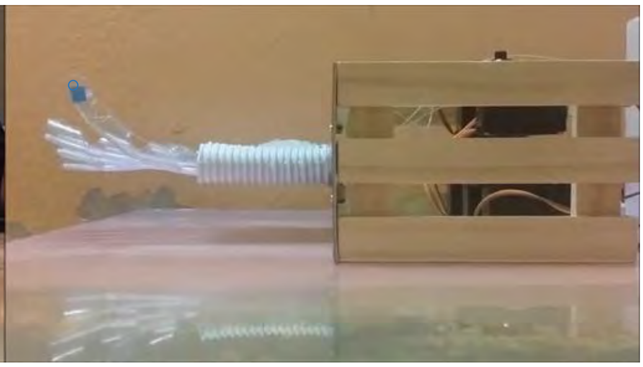

Figure 3.10 (b): Robot hand relaxed

### 3.3.2 Experiment of Repeatability Test

In this experiment, to test the repeatability of the animatronic hand, the animatronic hand fingers are let to follow the movement of the human hand fingers (relaxed and grasped). This experiment is executed to compare the whether the animatronic hand fingers are able to cope the movement of the human fingers. This experiment will be repeated three times continuously with all fingers involved and two cameras (put side by side) are used to capture the video. The data taken from Tracker software is tabulated. From the data gained, the graph is constructed and repeatability is analysed shown in Chapter 4.

**Equipment**

1. Camera
2. Tracker Software
3. Glove (stitched with flex sensor for human hand)

**Apparatus**

1. Multimeter
2. Animatronic hand



**Materials**

1. Arduino Uno
2. Batteries
3. Resistor
4. Jumper

**Experiment Procedure**

To perform the repeatability test, all the materials and equipment are set up shown in Figure 3.9. The cameras are placed in a static position. The animatronic hand and the human hand pinky fingers are in a relaxed position. Once everything is ready, the cameras (in video mode put side by side) are pressed. The human hand pinky finger is move (bend) to let the animatronic hand move. Once the animatronic hand move accordingly shown in Figure 3.10 (a), the human hand pinky finger is then relaxed followed by the animatronic hand shown in Figure 3.10 (b). Once the experiment is done, the button 'stop' is pressed on the camera. The steps are repeated for ring finger, middle finger, index finger and thumb. The videos of both hands are analysed by using Tracker software. The data gain is taken and tabulated. The graph is plotted.

## 3.4 Safety and Precautions



There are some steps needed to be taken before and after the operation of tele-operated animatronic hand to avoid electronic damaged / burned, injuries and many more. Below are some

1. Make sure that the external power used does not exceed the requirement power (example: the maximum voltage of Arduino Uno is 7V-12V)
2. Make sure that the polarity of the components are placed on the breadboard correctly
3. Do not exert excessive force to any parts of the animatronic hand

# CHAPTER 4

# RESULT AND DISCUSSION

## 4.1 Introduction

This chapter is going to discuss on the result and analysis of experiment that had been done. The first section is the design of highly accurate tele-operated 14 DOF animatronic hand and is separated into several subsections. The first subsection is the component selection of the animatronic hand and tele-operated hand. Next, electronic circuit for animatronic hand and tele-operated hand which two circuits have been developed. The last subsections covers the component selection for the design circuit. The second section covers the analysis of performance of the two experiments which are accuracy test and repeatability test. The data gained is tabulated and the graph is plotted.

## 4.2 Design of Highly Accurate Tele-Operated 14 DOF Animatronic Hand

The design of the highly accurate tele-operated animatronic hand is achieved and explained in Chapter 3. The full design of the tele-operated 14 DOF animatronic hand are shown below.

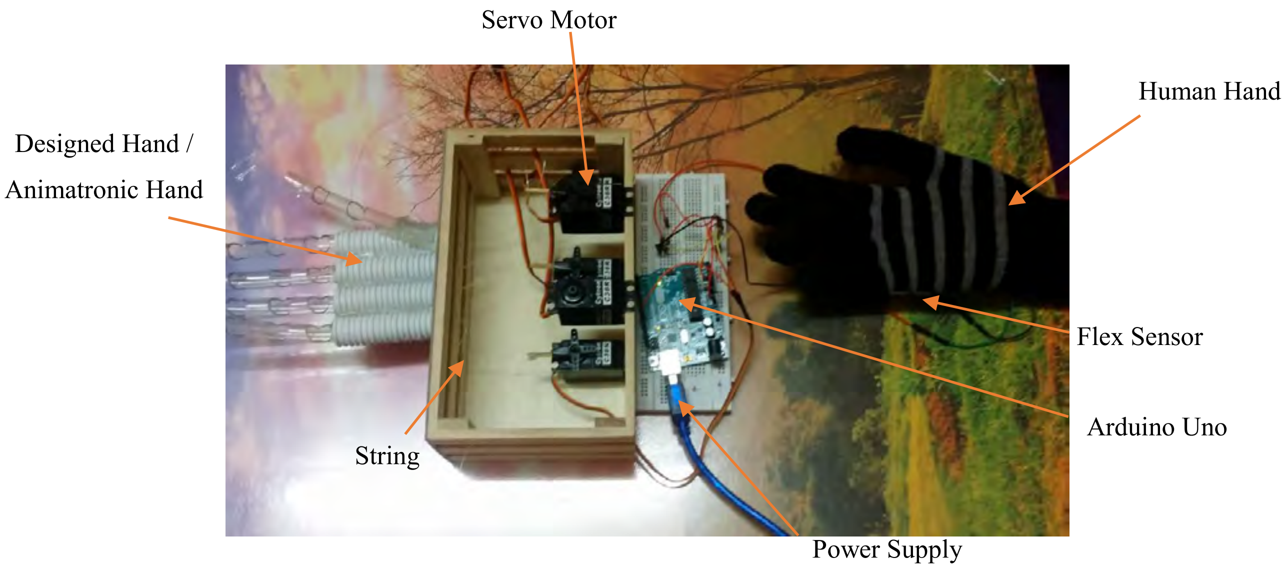


Figure 4.1: The Overall Design of Tele-Operated 14 DOF Animatronic Hand (with wire)

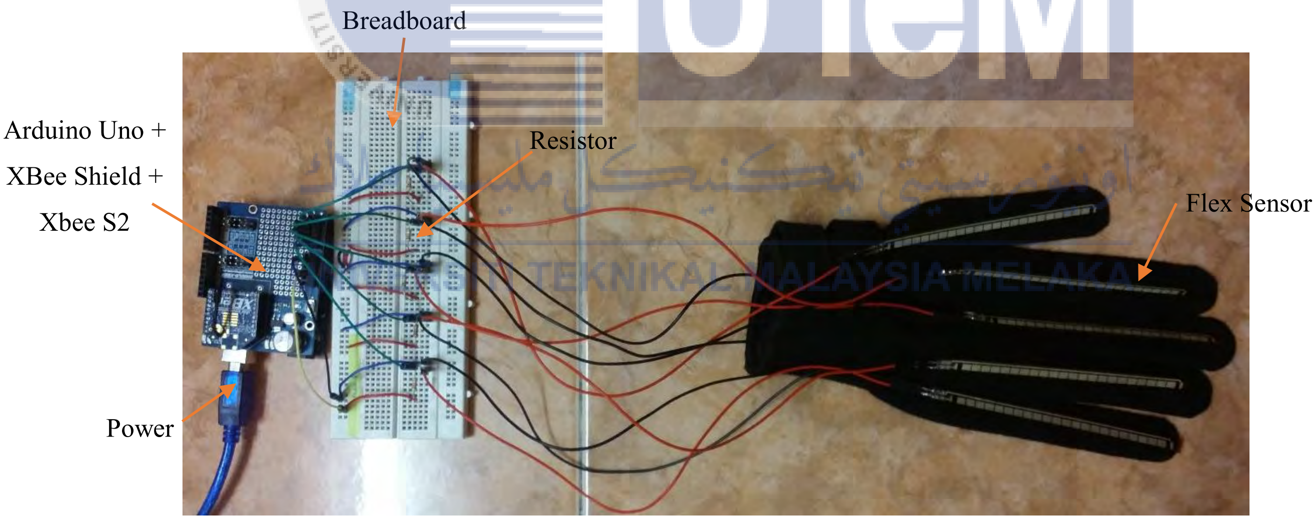


Figure 4.2: The Design of Tele-Operated Hand (wireless)

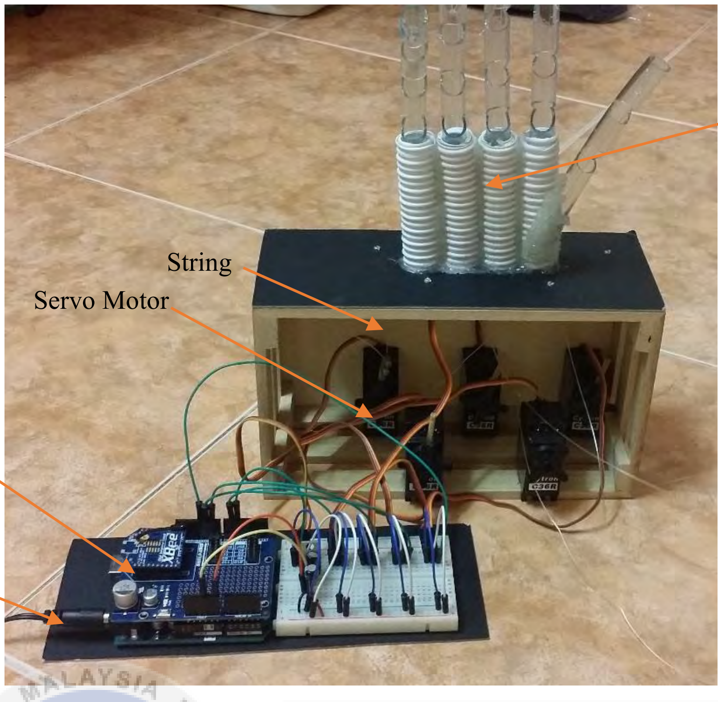


Figure 4.3: The Design of 14 DOF Animatronic Hand (wireless)

## 4.3 Analysis of Performance

The analysis of performance done for this project is accuracy and repeatability test. The data gained is tabulated and the graph is then plotted.

### 4.3.1 Accuracy Test

In this experiment, accuracy test data is gained by using Tracker software. Figure 4.4 and Figure 4.5 shows the position of the axes (purple colour) and the point (red and blue) of human hand and animatronic hand accordingly. Table 4.1 shows the data obtained which are the angle of the pinky finger of human hand and the time taken for the pinky finger to relaxed, fully bend and back to its original position (refer Appendices) and Table 4.2 shows the data obtained of the pinky finger of animatronic hand angle and the time taken for the pinky finger to relaxed, fully bend and back to its original position (refer Appendices). Figure 4.6 shows the overlapped graph of both human pinky finger and designed pinky finger plotted.


Figure 4.4: The axes (purple colour) and point (red colour) of human hand


Figure 4.5: The axes (purple colour) and point (blue colour) of animatronic hand

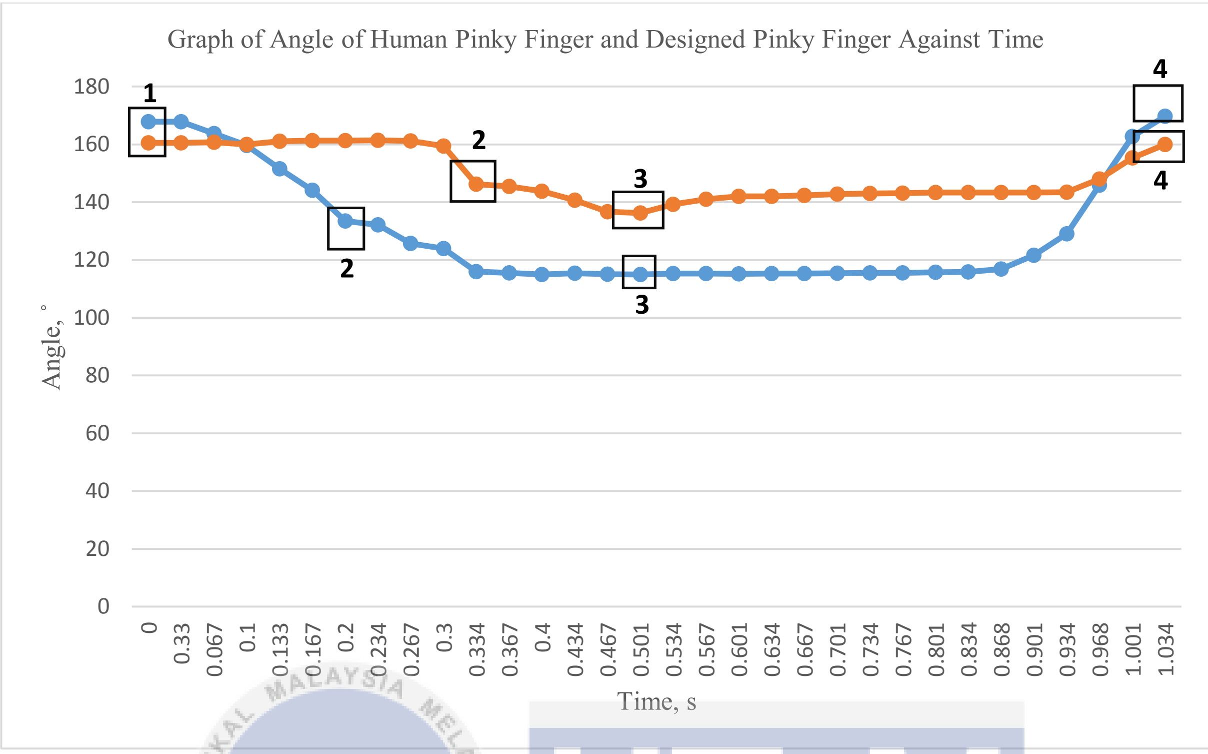


Figure 4.6: The overlapped graph of both human pinky finger (blue colour) and designed pinky finger (orange colour) plotted.

From the graph shown in Figure 4.3, the blue line shows the graph of angle of human finger. 167.8˚ is the starting angle which is in relaxed mode of the pinky finger of the human hand. From the angle of 115˚ to 116˚, the pinky started to bend and at the time of 0.501s, the pinky finger is fully bend. After that, the pinky started to back at its original position which are 169.7˚, slightly different from when it started. On the other hand, the orange line shows the graph of angle of animatronic hand pinky finger. 160.5˚ is the starting angle of the animatronic hand pinky finger is in relaxed mode. From the angle of 159.4˚ to 139.2˚, the pinky started to bend and at the time of 0.501s, the pinky finger is fully bend. After that, the pinky started to back at its original position which are 160˚, slightly different from when it started.

Point 1:

Based on the point 1 which is when the hand is in the relaxed mode (start) shown in Figure 4.6, the angle of the human hand pinky and the animatronic hand pinky finger are slightly different with 7.3˚ (refer in Figure 4.7). The angle of the animatronic hand pinky finger is slightly different with the human hand is because the string tied on the servo motor is tight.

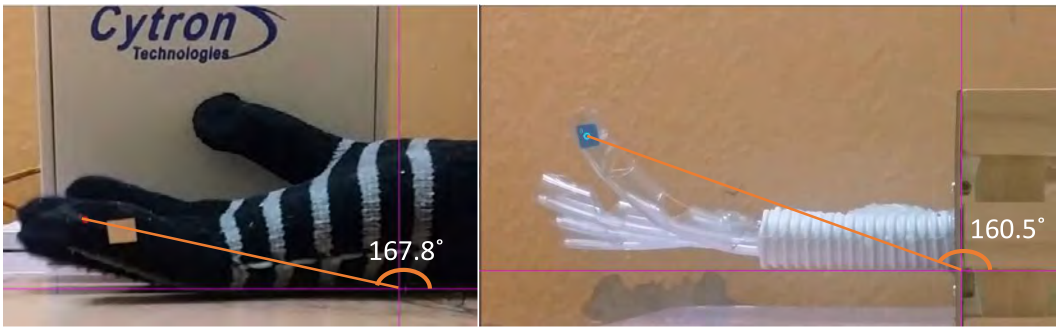


Figure 4.7: The angle of the human hand pinky and the animatronic hand pinky finger in relaxed mode (start)

Point 2:

Based on the point 2 which is when the pinky finger started to bend shown in Figure 4.6, the angle of the human hand pinky and the animatronic hand pinky finger are different with 34.2˚ (refer in Figure 4.8). The angle of the animatronic hand pinky finger is different with the human hand pinky finger due to length of the animatronic hand pinky finger (longer) and the delay of the signal transfer from flex sensor to servo motor.


Figure 4.8: The angle of the human pinky finger and the animatronic hand pinky when started to bend

Point 3:

Based on the point 3 which is when the pinky finger is fully bend shown in Figure 4.6, the angle of the human hand pinky and the animatronic hand pinky finger are different with 21.2˚ (refer Figure 4.9). The angle of the animatronic hand pinky finger is different with the human hand pinky finger due to the tightness of the string tied at servo motor. When the string tied is too tight and the servo motor move accordingly, it forces the tube (animatronic hand) to touch the palm.


Figure 4.9: The angle of the human pinky finger and the animatronic hand pinky finger when fully bend



Point 4:

Based on the point 4 which is when the hand is in the relaxed mode (end) shown in Figure 4.6, the angle of the human hand pinky and the animatronic hand pinky finger are slightly different with 9.7˚ (refer in Figure 4.10). The angle of the human pinky finger and animatronic hand pinky finger is slightly different from the angle when in relaxed mode (start).


Figure 4.10: The angle of the human pinky finger and the animatronic hand pinky finger in relaxed mode (end)

From the graph shown in Figure 4.6, the error, relative error and the percentage error of the human pinky finger and the animatronic hand pinky finger can be calculated by taking the average values of both data. Below are the calculation:-



$$\text{Absolute Error} = \text{animatronic hand} - \text{human hand}$$

$$= 149.13125 - 130.0375 = 19.09375$$

$$\text{Relative Error} = \frac{\text{Error}}{\text{human hand}} = \frac{19.09375}{130.0375} = 0.1468$$

$$\text{Percentage Error} = \text{Relative Error} \times 100\% = 14.68\%$$

$$\text{Accuracy} = 1 - \text{Relative Error} = 0.8532$$

$$\text{Percentage Accuracy} = 0.8532 \times 100 = 85.32\%$$

Table 4.11: Table of absolute error, relative error, percentage error, accuracy and percentage accuracy of ring finger, middle finger, index finger and thumb

| Finger | Absolute Error | Relative Error | Percentage Error | Accuracy | Percentage Accuracy |
|---|---|---|---|---|---|
| Ring | 14.471 | 0.1075 | 10.75% | 0.8925 | 89.25% |
| Middle | 13.8193 | 0.1017 | 10.17% | 0.8983 | 89.83% |
| Index | 12.2484 | 0.0897 | 8.97% | 0.9103 | 91.03% |
| Thumb | 1.6516 | 0.0966 | 9.66% | 0.9034 | 90.34% |

Based on the calculation above, there are some errors between human fingers and the animatronic hand fingers. These errors may due to the elasticity of the tube used for making the animatronic hand fingers. This is because the properties of the plastic tube is not as elastic as human hand. Next, these errors occurred due to the string tied to the servo motor which the string tied was too tight which result in error. Lastly, the length of the pinky finger of animatronic hand differs from human hand may contribute these errors. In this experiment, we can conclude that all fingers of animatronic hand (refer Table 11) have high value of percentage accuracy which are 85.32% for pinky finger, 89.25% for ring finger, 89.83% middle finger, 91.03% index finger and 90.34% thumb.

### 4.3.2 Repeatability Test

In this experiment, repeatability test data is gained by using Tracker software and the axes and point are the same like accuracy test shown in Figure 4.1 and 4.2. This experiment is repeated three times continuously with all fingers involved. The data gained is tabulated shown in Table 4.12, Table 4.14, Table 4.16, Table 4.18 and Table 4.20 (refer appendices) are for pinky, ring, middle, index and thumb of human hand while Table 4.13, Table 4.15, Table 4.17, Table 4.19 and Table 4.21 (Refer Appendices) are for animatronic hand of pinky, ring, middle, index and thumb.

Figure 4.11 and Figure 4.12 are the overlapped graph of angle of three experiment of the human pinky finger and pinky finger of the animatronic hand accordingly against the time taken for the pinky finger to relaxed, fully bend and back to its original position.

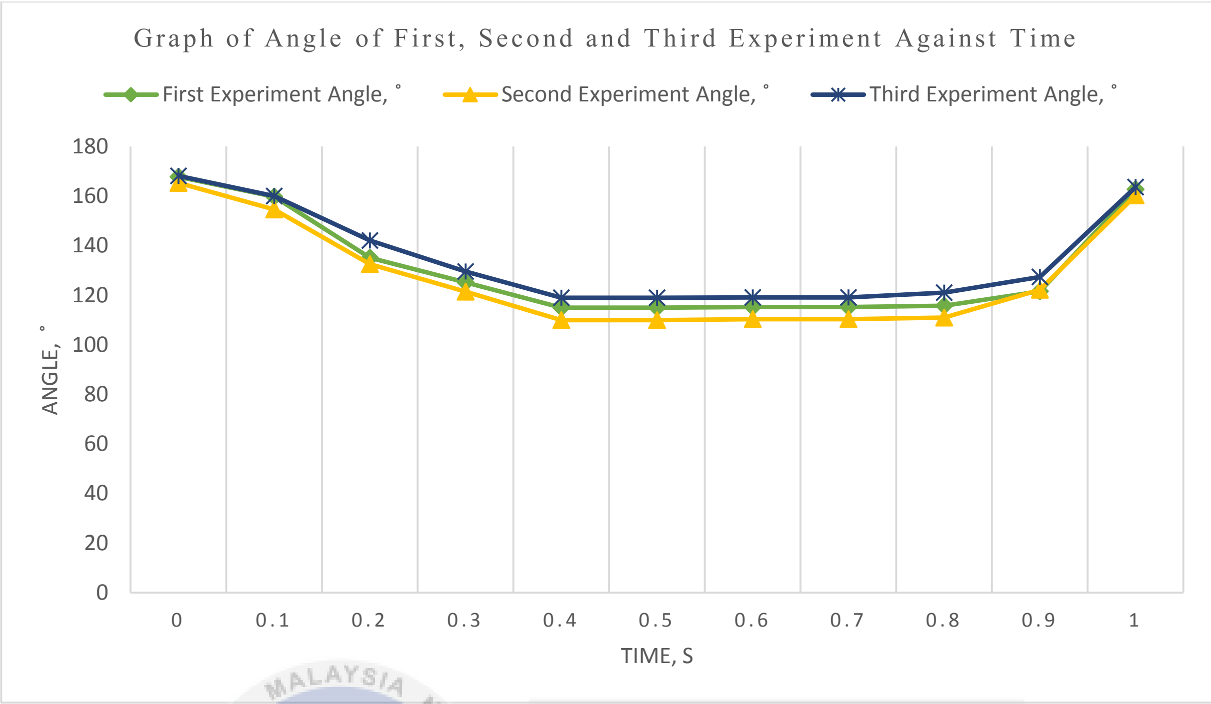


Figure 4.11: The overlapped graph of angle of three experiment of the human pinky finger against the time

In Figure 4.11 which is the graph of human hand pinky, all the three experiment shows the data gain is consistent. In the first experiment, second and third experiment, the starting angle is 167.8˚, 165.3˚ and 168.1˚ accordingly. Next is the angle of the first experiment, second and third experiment started to bend to fully bend is when the angle started at 115˚ to 115.7˚, 110˚ to 111˚ and 119˚ to 121˚ accordingly. Lastly, the angle of the first experiment, second and third experiment back to their original position when the angle end at 162.7˚, 160.3˚ and 163.6˚ accordingly.

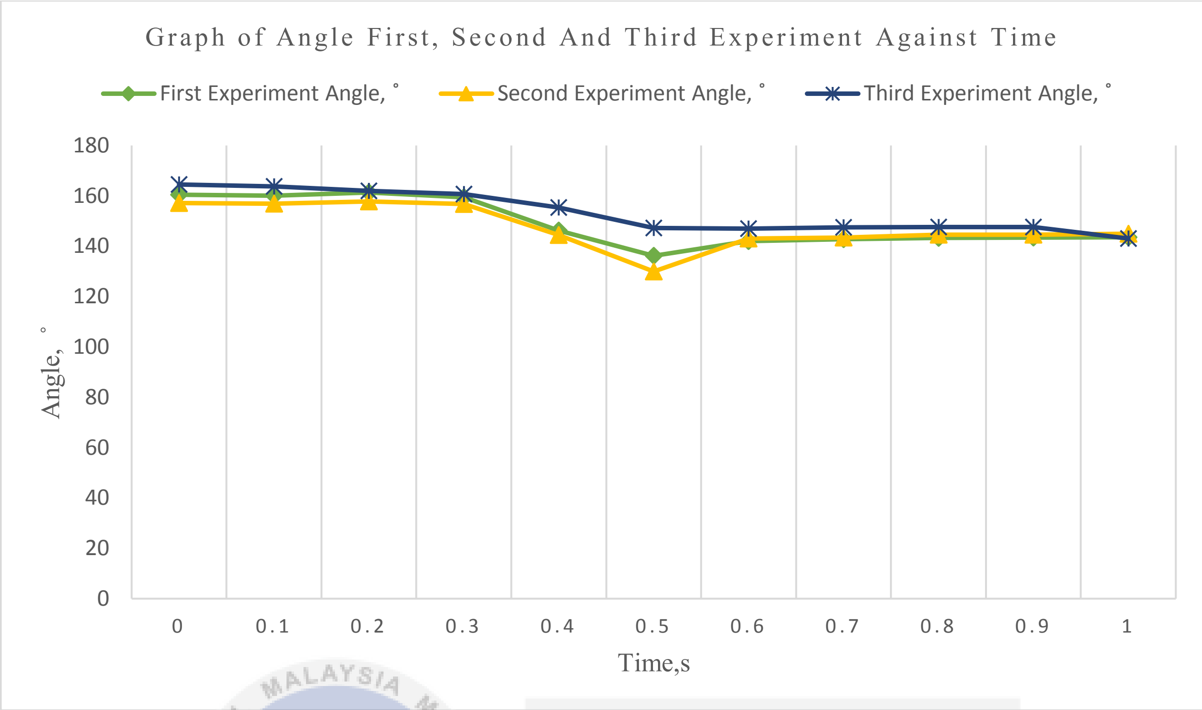


Figure 4.12: The overlapped graph of angle of three experiment of the animatronic hand pinky finger against the time taken



In Figure 4.12 which is the graph animatronic hand pinky finger, all the three experiment shows the data gain is inconsistent. In the first experiment, second and third experiment, the starting angle is 160.5˚, 157.1˚ and 164.5˚ accordingly. Next is the angle of the first experiment, second and third experiment started to bend to fully bend is when the angle started at 146.2˚ to 142˚, 144.4˚ to 143˚ and 155.4˚ to 147˚ accordingly. Lastly, the angle of the first experiment, second and third experiment back to their original position when the angle end at 143.6˚, 145˚ and 143˚.

By comparing both graphs in Figure 4.11 and 4.12, we can conclude that human hand pinky is more flexible and the angle will not differ even it is repeated for several times. All fingers of the animatronic hand on the other side is not consistent in flexibility. This is because, the tube needed time to go back to its original position when string is pulled for several time. As shown in Table in Appendices, when the experiment are repeated three times continuously, the angle of all fingers of animatronic hand are nearer to the axes which means that the tube of the animatronic hand of all fingers are unable to flex back to its starting point.

# CHAPTER 5

# CONCLUSION AND RECOMMENDATION

In conclusion, the design of highly accurate 14DOF tele-operated animatronic hand is achieved. The overall system performance in terms of accuracy and repeatability are valid based on the result gained where the accuracy of all fingers of animatronic hand have high value of percentage accuracy which are 85.32% for pinky finger, 89.25% for ring finger, 89.83% middle finger, 91.03% index finger and 90.34% thumb. .

For recommendation, there are many addition can be made to increase the accuracy of the system performance. For example, use a better material for the animatronic hand like aluminium. Make sure that the length of the hand are similar to the designed hand. Finally, make sure that the string used are not too tightly when tied on the crank.

## REFERENCES


[1] J. Burnstein, R. I. Association, and M. Ifr, "*Kommentare von Geschäftsführern aus der Robotik- branche zur Pressemitteilung World Robotics 2014 Kommentare von Geschäftsführern aus der Robotik- branche zur Pressemitteilung World Robotics 2014*," pp. 1-4, 2014.

[2] M. Martech, "*Positive Impact of Industrial Robots on Employment*", pp. 1.2013

[3] G. Litzenberger, "*IFR : Weiterhin steigende Nachfrage bei Industrierobotern 2014 : Verkauf von Industrierobotern steigt um mindestens 15 Prozent 2015-2017 : Jährlicher Anstieg der Nachfrage um durchschnittlich 12 Prozent*," 2015.

[4] The International Federations of Robotics, "*World Robotics 2005 Statistics, Market Analysis, Case Studies and Profitability of Robot Investment", 2005*

[5] Garry Wilkes, MBBS, FACEM Director of Emergency Medicine, Calvary Hospital, Canberra, ACT; Adjunct Associate Professor, Edith Cowan University, Western Australia, Medscape, "*Hydrofluoric Acid Burns",* [online], http://emedicine.medscape.com/article/773304-overview 1994 – 2014

[6] P. Singh, A. Kumar, and M. Vashisth, "*Design of a Robotic Arm with Gripper & End Effector for Spot Welding,*" vol. 1, no. 3, pp. 92–97, 2013.

[7] Macmillandictionary.com, (2014). Macmillan Dictionary and Thesaurus Free English Dictionary Online. [online] Available at httpwww.macmillandictionary.com\

[8] Department of EEE, Ahsanullah University of Science and Technology, Bangladesh, "*Project Final Report Animatronic Hand Controller*," vol. 5, pp. 15

[9] [online] 2014, http://www.oed.com (Accessed: 20 October 2014)

[10] Aristotle, "*De partibus animalium*", 687a 7, ca. 340 BC

[11] Brand and Hollister, “*Human Hand Modeling from Surface Anatomy”,* 1999; Kry et al. 2002, pp. 3

[12] Anon, “*Hand Anatomy”,* [online] 2014, http://www.orthogate.orgpatient-educationhandhand-anatomy [Accessed 17 Dec 2014].

[13] Mufa T. Ghadiali, M.D., F.A.C.S ,Diplomate of American Board of Surgery, “*Normal Hand Anatomy”,* pp. 3-8

[14] [online] 2014, Available at httptutorial.cytron.com.my20120810method-to-interface-and-use-flexibend-sensor (Accessed: 20 October 2014)

[15] [online] 2014, http:// graphics.cs.cmu.edu/nsp/course/16 899/slides/1.HandsOverview.pdf (Accessed: 20 October 2014)

[16] S. Verma, “*Hand Gestures Remote Controlled Robotic Arm*,” vol. 3, no. 5, pp. 601–606, 201

[17] S. Dexterous and H. Technical, “*Shadow Dexterous Hand E1 Series Table of Contents,*” no. January, pp. 1–14, 2013.

[18] Sgu.ac.id, (2014). SGU Thesis Garuda. [online] 2014, http://www.sgu.ac.idlibrarygarudaread.phpcode=691 (Accessed: 20 October 2014)

[19] Sgu.ac.id, (2014). [online] 2014 http://www.sgu.ac.idlibrarygarudaswfMT2011Ryan.swf (Accessed: 20 October 2014)

[20] T. Mouri, H. Kawasaki, K. Yoshikawa, J. Takai, and S. Ito, “*Anthropomorphic Robot Hand : Gifu Hand III,*” pp. 1288–1293.

[21] I. Yamano, “*Five-fingered Robot Hand using Ultrasonic Motors and*,” no. April, pp. 73–78, 2005.

[22] H. Interface and K. Schmidt, “*ROBOT HAND DESIGN -PALM IMPROVEMENT AND A ROBOTIC*,” 2008.

[23] Matthew J. Rowell, Doughlas D. Whitecomb, “DESIGN AND ANALYSIS OF A ROBOTIC HAND FOR USE AS A PROSTHETIC DEVICE”, 2006, pp. 24

[24] I. Kawabuchi, "*A Designing of Humanoid Robot Hands in Endoskeleton and Exoskeleton Styles,"*2007

[25] D. Choi, D. Lee, W. Shon, and H. Lee, "*Design of 5 D . O . F Robot Hand with an Artificial Skin for an Android Robot,*" 2005.

[26] John KangChun Perng, Brian Fisher, Seth Hollar, Kristofer S. J. Pister,*"Acceleration Sensing Glove (ASG)",* 1999, California.

[27] S. Micera, J. Carpaneto, and S. Raspopovic, "*Control of hand prostheses using peripheral information.*," *IEEE Rev. Biomed. Eng.*, vol. 3, pp. 48–68, Jan. 2010.

[28] [online] 2014, http://www.cyberglovesystems.comproductscyberglove-IIoverview (Accessed: 20 October 2014)

[29] N. H. Adnan, K. Wan, A. B. Shahriman, M. H. Ali, M. N. Ayob, and A. A. Aziz, "*Development of Low Cost ' GloveMAP ' Based o n Fingertip Bending Tracking Techniques for Virtual Interaction*," no. 04, 2012.

[30] Martin J¨agersand, Olac Fuentes, Randal Nelson, "*Acquiring Visual-Motor Models for Precision Manipulation with Robot Hands,"* 1996, p. 603-612

[31] Magnus Johnsson, Robert Pallbo, Christian Balkenius, "*Experiments with Haptic Perception in a Robotic Hand*," Sweden

[32] [online] 2014, http://www.warf.com/download/5687_9948_1.pdf (Accessed: 20 October 2014)

[33] [online] 2014, http://www.cytron.com.my/p-arduino-uno (Accessed: 20 October 2014)

## APPENDICES

Appendix A Gantt Chart

Appendix B Coding for Flex Sensors and Servo Motors (with wire)

```
#include <Servo.h>



Servo servo1;

Servo servo2;

Servo servo3;

Servo servo4;

Servo servo5;



const int flexpin1 = 0;

const int flexpin2 = 1;

const int flexpin3 = 2;

const int flexpin4 = 3;

const int flexpin5 = 4;



void setup()

{
```

```
  Serial.begin(9600);

  servo1.attach(9);

  servo2.attach(10);

  servo3.attach(11);

  servo4.attach(12);

  servo5.attach(13);

}



void loop()

{

  int flexposition1;   // Input value from the analog pin.

  int flexposition2;

  int flexposition3;

  int flexposition4;

  int flexposition5;


  int servoposition1;   // Output value to the servo.

  int servoposition2;

  int servoposition3;

  int servoposition4;

  int servoposition5;


  flexposition1 = analogRead(flexpin1);
```

```
  flexposition2 = analogRead(flexpin2);
```

Appendix C Coding for Flex Sensors (Wireless)

```
int Finger1 = A0;
int Finger2 = A1;
int Finger3 = A2;
int Finger4 = A3;
int Finger5 = A4;

void setup()
{
  Serial.begin(9600);
}
void loop()
{
  byte servoValue1;
  byte servoValue2;
  byte servoValue3;
  byte servoValue4;
  byte servoValue5;

  int FingerValue1 = analogRead(Finger1);
  int FingerValue2 = analogRead(Finger2);
  int FingerValue3 = analogRead(Finger3);
```

```
  int FingerValue4 = analogRead(Finger4);
```

APPENDIX D   Coding for Servo Motors (Wireless)

```
#include <Servo.h>

int servoPin1 =11;
int servoPin2 =10;
int servoPin3 =9;
int servoPin4 =6;
int servoPin5 =5;

Servo Servo1;
Servo Servo2;
Servo Servo3;
Servo Servo4;
Servo Servo5;

void setup()
{
  Serial.begin(9600);

  Servo1.attach(servoPin1);
  Servo2.attach(servoPin2);
  Servo3.attach(servoPin3);
```

Servo4.attach(servoPin4);

Table 4.1: Angle of pinky finger of human hand and the time taken

| Angle, ° | Time, s |
|---|---|
| 167.8 | 0 |
| 167.8 | 0.33 |
| 163.7 | 0.067 |
| 159.7 | 0.1 |
| 151.5 | 0.133 |
| 144.1 | 0.167 |
| 133.5 | 0.2 |
| 131.2 | 0.234 |
| 125.7 | 0.267 |
| 124 | 0.3 |
| 116 | 0.334 |
| 115.5 | 0.367 |
| 115 | 0.4 |
| 115.4 | 0.434 |
| 115.1 | 0.467 |
| 115 | 0.501 |
| 115.3 | 0.534 |
| 115.3 | 0.567 |
| 115.2 | 0.601 |
| 115.3 | 0.634 |
| 115.3 | 0.667 |
| 115.4 | 0.701 |
| 115.5 | 0.734 |
| 115.5 | 0.767 |
| 115.7 | 0.801 |
| 115.9 | 0.834 |
| 116.8 | 0.868 |
| 121.6 | 0.901 |
| 129.1 | 0.934 |
| 145.9 | 0.968 |
| 162.7 | 1.001 |
| 169.7 | 1.034 |

Table 4.2: Angle of pinky finger of animatronic hand and the time taken

| Angle, ° | Time, s |
|---|---|
| 160.5 | 0 |
| 160.5 | 0.33 |
| 160.7 | 0.067 |
| 160 | 0.1 |
| 161.1 | 0.133 |
| 161.3 | 0.167 |
| 161.3 | 0.2 |
| 161.4 | 0.234 |
| 161.2 | 0.267 |
| 159.4 | 0.3 |
| 146.2 | 0.334 |
| 145.5 | 0.367 |
| 143.8 | 0.4 |
| 140.7 | 0.434 |
| 136.7 | 0.467 |
| 136.2 | 0.501 |
| 139.2 | 0.534 |
| 141 | 0.567 |
| 142 | 0.601 |
| 142 | 0.634 |
| 142.4 | 0.667 |
| 142.8 | 0.701 |
| 143 | 0.734 |
| 143.1 | 0.767 |
| 143.3 | 0.801 |
| 143.3 | 0.834 |
| 143.4 | 0.868 |
| 143.4 | 0.901 |
| 143.5 | 0.934 |
| 148 | 0.968 |
| 155.3 | 1.001 |
| 160 | 1.034 |

Table 4.3: Angle of ring finger of human hand and the time taken

| Angle, ° | Time, s |
|---|---|
| 165 | 0 |
| 165 | 0.33 |
| 161.3 | 0.067 |
| 158.3 | 0.1 |
| 150 | 0.133 |
| 143.1 | 0.167 |
| 133.2 | 0.2 |
| 130.3 | 0.234 |
| 125.1 | 0.267 |
| 124.3 | 0.3 |
| 117.2 | 0.334 |
| 116.7 | 0.367 |
| 116.1 | 0.4 |
| 116.7 | 0.434 |
| 116.5 | 0.467 |
| 116.4 | 0.501 |
| 116.8 | 0.534 |
| 116.8 | 0.567 |
| 116.6 | 0.601 |
| 116.8 | 0.634 |
| 116.8 | 0.667 |
| 116.9 | 0.701 |
| 117.1 | 0.734 |
| 117.1 | 0.767 |
| 117.2 | 0.801 |
| 117.5 | 0.834 |
| 118.1 | 0.868 |
| 122.5 | 0.901 |
| 130.4 | 0.934 |
| 146.1 | 0.968 |
| 162.2 | 1.001 |
| 170 | 1.034 |

Table 4.4: Angle of ring finger of animatronic hand and the time taken

| Angle, ° | Time, s |
|---|---|
| 160 | 0 |
| 160 | 0.33 |
| 160.5 | 0.067 |
| 158 | 0.1 |
| 158.1 | 0.133 |
| 158.3 | 0.167 |
| 158.3 | 0.2 |
| 158.4 | 0.234 |
| 159.2 | 0.267 |
| 159.4 | 0.3 |
| 148.2 | 0.334 |
| 147.5 | 0.367 |
| 145.8 | 0.4 |
| 144.7 | 0.434 |
| 140.7 | 0.467 |
| 138.2 | 0.501 |
| 139.2 | 0.534 |
| 143 | 0.567 |
| 144 | 0.601 |
| 143.7 | 0.634 |
| 143.4 | 0.667 |
| 143.9 | 0.701 |
| 143.5 | 0.734 |
| 144.1 | 0.767 |
| 144.6 | 0.801 |
| 144.6 | 0.834 |
| 144.6 | 0.868 |
| 144.8 | 0.901 |
| 144.9 | 0.934 |
| 149 | 0.968 |
| 157.1 | 1.001 |
| 153 | 1.034 |

Table 4.5: Angle of middle finger of human hand and the time taken

| Angle, ° | Time, s |
|---|---|
| 165.3 | 0 |
| 165.3 | 0.33 |
| 161 | 0.067 |
| 159.2 | 0.1 |
| 151.3 | 0.133 |
| 143.8 | 0.167 |
| 134.2 | 0.2 |
| 131.7 | 0.234 |
| 126.7 | 0.267 |
| 124.9 | 0.3 |
| 116.2 | 0.334 |
| 126.1 | 0.367 |
| 125.3 | 0.4 |
| 125.9 | 0.434 |
| 125.7 | 0.467 |
| 125.6 | 0.501 |
| 125.9 | 0.534 |
| 125.9 | 0.567 |
| 125.7 | 0.601 |
| 125.8 | 0.634 |
| 125.9 | 0.667 |
| 126.1 | 0.701 |
| 126.2 | 0.734 |
| 126.5 | 0.767 |
| 126.7 | 0.801 |
| 127.2 | 0.834 |
| 131.8 | 0.868 |
| 139.1 | 0.901 |
| 152 | 0.934 |
| 157 | 0.968 |
| 163.1 | 1.001 |
| 171.2 | 1.034 |

Table 4.6: Angle of middle finger of animatronic hand and the time taken

| Angle, ° | Time, s |
|---|---|
| 162 | 0 |
| 162 | 0.33 |
| 162.3 | 0.067 |
| 160 | 0.1 |
| 159.1 | 0.133 |
| 159.3 | 0.167 |
| 159.3 | 0.2 |
| 159.4 | 0.234 |
| 159.2 | 0.267 |
| 158.4 | 0.3 |
| 150.2 | 0.334 |
| 149.5 | 0.367 |
| 147.8 | 0.4 |
| 146.7 | 0.434 |
| 144.7 | 0.467 |
| 140.2 | 0.501 |
| 139.2 | 0.534 |
| 140 | 0.567 |
| 141 | 0.601 |
| 141.9 | 0.634 |
| 142.2 | 0.667 |
| 142.6 | 0.701 |
| 143 | 0.734 |
| 143.5 | 0.767 |
| 143.8 | 0.801 |
| 144.3 | 0.834 |
| 144.4 | 0.868 |
| 144.9 | 0.901 |
| 144.8 | 0.934 |
| 150 | 0.968 |
| 157.3 | 1.001 |
| 161 | 1.034 |

Table 4.7: Angle of index finger of human hand and the time taken

| Angle, ° | Time, s |
|---|---|
| 166.4 | 0 |
| 166.4 | 0.33 |
| 162.8 | 0.067 |
| 158.6 | 0.1 |
| 150.7 | 0.133 |
| 143.7 | 0.167 |
| 144.2 | 0.2 |
| 141.3 | 0.234 |
| 134.2 | 0.267 |
| 132.9 | 0.3 |
| 127.3 | 0.334 |
| 126.1 | 0.367 |
| 125.3 | 0.4 |
| 125.9 | 0.434 |
| 125.7 | 0.467 |
| 125.6 | 0.501 |
| 125.9 | 0.534 |
| 125.9 | 0.567 |
| 125.7 | 0.601 |
| 125.8 | 0.634 |
| 125.9 | 0.667 |
| 126.1 | 0.701 |
| 126.2 | 0.734 |
| 126.4 | 0.767 |
| 126.6 | 0.801 |
| 127 | 0.834 |
| 127.2 | 0.868 |
| 131.8 | 0.901 |
| 139.1 | 0.934 |
| 152 | 0.968 |
| 163.1 | 1.001 |
| 171.2 | 1.034 |

Table 4.8: Angle of index finger of animatronic hand and the time taken

| Angle, ° | Time, s |
|---|---|
| 159.4 | 0 |
| 159.4 | 0.33 |
| 159 | 0.067 |
| 158.9 | 0.1 |
| 158.6 | 0.133 |
| 158.4 | 0.167 |
| 158.3 | 0.2 |
| 158 | 0.234 |
| 157.8 | 0.267 |
| 155.4 | 0.3 |
| 150.1 | 0.334 |
| 150 | 0.367 |
| 148.4 | 0.4 |
| 146.1 | 0.434 |
| 140 | 0.467 |
| 138.2 | 0.501 |
| 138.8 | 0.534 |
| 141 | 0.567 |
| 142.3 | 0.601 |
| 142.9 | 0.634 |
| 143.1 | 0.667 |
| 143.3 | 0.701 |
| 143.6 | 0.734 |
| 143.7 | 0.767 |
| 143.7 | 0.801 |
| 143.9 | 0.834 |
| 143.9 | 0.868 |
| 144 | 0.901 |
| 144.5 | 0.934 |
| 146 | 0.968 |
| 155.9 | 1.001 |
| 156.1 | 1.034 |

Table 4.9: Angle of thumb of human hand and the time taken

| Angle, ° | Time, s |
|---|---|
| 120 | 0 |
| 120 | 0.33 |
| 121 | 0.067 |
| 121.1 | 0.1 |
| 121 | 0.133 |
| 122 | 0.167 |
| 122 | 0.2 |
| 122 | 0.234 |
| 122.3 | 0.267 |
| 122.4 | 0.3 |
| 122.5 | 0.334 |
| 122.5 | 0.367 |
| 122.5 | 0.4 |
| 122.6 | 0.434 |
| 122.6 | 0.467 |
| 122.7 | 0.501 |
| 122 | 0.534 |
| 122.1 | 0.567 |
| 122.2 | 0.601 |
| 122.5 | 0.634 |
| 123.7 | 0.667 |
| 123.7 | 0.701 |
| 123.9 | 0.734 |
| 124.1 | 0.767 |
| 124.8 | 0.801 |
| 125 | 0.834 |
| 128 | 0.868 |
| 129 | 0.901 |
| 133.6 | 0.934 |
| 137.4 | 0.968 |
| 133 | 1.001 |
| 140 | 1.034 |

Table 4.10: Angle of thumb of animatronic hand and the time taken

| Angle, ° | Time, s |
|---|---|
| 140 | 0 |
| 140 | 0.33 |
| 139.7 | 0.067 |
| 139.4 | 0.1 |
| 139.2 | 0.133 |
| 139.1 | 0.167 |
| 138.9 | 0.2 |
| 138.7 | 0.234 |
| 138.4 | 0.267 |
| 138 | 0.3 |
| 136.3 | 0.334 |
| 136.3 | 0.367 |
| 136.2 | 0.4 |
| 135.7 | 0.434 |
| 135.7 | 0.467 |
| 134.9 | 0.501 |
| 134.6 | 0.534 |
| 134.4 | 0.567 |
| 133.9 | 0.601 |
| 133.5 | 0.634 |
| 133.3 | 0.667 |
| 135 | 0.701 |
| 135.1 | 0.734 |
| 135.2 | 0.767 |
| 135.3 | 0.801 |
| 135.3 | 0.834 |
| 135.7 | 0.868 |
| 135.9 | 0.901 |
| 136.5 | 0.934 |
| 138 | 0.968 |
| 138.8 | 1.001 |
| 140.6 | 1.034 |

Table 4.12: Human hand pinky finger

| First Experiment | | Second Experiment | | Third Experiment | |
|---|---|---|---|---|---|
| Angle, ° | Time, s | Angle, ° | Time, s | Angle, ° | Time, s |
| 167.8 | 0 | 165.3 | 0 | 168.1 | 0 |
| 159.7 | 0.1 | 154.6 | 0.1 | 160 | 0.1 |
| 135.1 | 0.2 | 132.5 | 0.2 | 142.1 | 0.2 |
| 125.2 | 0.3 | 121.4 | 0.3 | 129.5 | 0.3 |
| 115 | 0.4 | 110 | 0.4 | 119 | 0.4 |
| 115 | 0.5 | 110 | 0.5 | 119 | 0.5 |
| 115.2 | 0.6 | 110.3 | 0.6 | 119.1 | 0.6 |
| 115.2 | 0.7 | 110.3 | 0.7 | 119.1 | 0.7 |
| 115.7 | 0.8 | 111 | 0.8 | 121.0 | 0.8 |
| 121.6 | 0.9 | 122.2 | 0.9 | 127.3 | 0.9 |
| 162.7 | 1.0 | 160.3 | 1.0 | 163.6 | 1.0 |



Table 4.13: Pinky finger of the animatronic hand

| First Experiment | | Second Experiment | | Third Experiment | |
|---|---|---|---|---|---|
| Angle, ° | Time, s | Angle, ° | Time, s | Angle, ° | Time, s |
| 160.5 | 0 | 157.1 | 0 | 164.5 | 0 |
| 160 | 0.1 | 156.9 | 0.1 | 163.8 | 0.1 |
| 161.3 | 0.2 | 157.8 | 0.2 | 162 | 0.2 |
| 159.4 | 0.3 | 156.7 | 0.3 | 160.7 | 0.3 |
| 146.2 | 0.4 | 144.4 | 0.4 | 155.4 | 0.4 |
| 136.2 | 0.5 | 130 | 0.5 | 147.2 | 0.5 |
| 142 | 0.6 | 143 | 0.6 | 147 | 0.6 |
| 142.8 | 0.7 | 143.4 | 0.7 | 147.5 | 0.7 |
| 143.3 | 0.8 | 144.6 | 0.8 | 147.6 | 0.8 |
| 143.4 | 0.9 | 144.6 | 0.9 | 147.6 | 0.9 |
| 143.6 | 1.0 | 145 | 1.0 | 149 | 1.0 |

Table 4.14: Human hand ring finger

| First Experiment | | Second Experiment | | Third Experiment | |
|---|---|---|---|---|---|
| Angle, ° | Time, s | Angle, ° | Time, s | Angle, ° | Time, s |
| 165 | 0 | 163.1 | 0 | 168.3 | 0 |
| 158.3 | 0.1 | 157.2 | 0.1 | 159.3 | 0.1 |
| 133.2 | 0.2 | 136.8 | 0.2 | 136.1 | 0.2 |
| 124.3 | 0.3 | 125.4 | 0.3 | 128.2 | 0.3 |
| 116.1 | 0.4 | 120 | 0.4 | 123.4 | 0.4 |
| 116.4 | 0.5 | 120.4 | 0.5 | 122.1 | 0.5 |
| 116.6 | 0.6 | 121 | 0.6 | 122.5 | 0.6 |
| 116.9 | 0.7 | 122.1 | 0.7 | 130 | 0.7 |
| 117.2 | 0.8 | 130.4 | 0.8 | 133.3 | 0.8 |
| 122.5 | 0.9 | 156.3 | 0.9 | 152.6 | 0.9 |
| 162.2 | 1.0 | 165.9 | 1.0 | 169 | 1.0 |

Table 4.15: Ring finger of the animatronic hand

| First Experiment | | Second Experiment | | Third Experiment | |
|---|---|---|---|---|---|
| Angle, ° | Time, s | Angle, ° | Time, s | Angle, ° | Time, s |
| 160 | 0 | 158.2 | 0 | 161.7 | 0 |
| 158 | 0.1 | 157.7 | 0.1 | 159.9 | 0.1 |
| 158.3 | 0.2 | 157.3 | 0.2 | 159.3 | 0.2 |
| 159.4 | 0.3 | 157.4 | 0.3 | 158.6 | 0.3 |
| 145.8 | 0.4 | 144.2 | 0.4 | 148.5 | 0.4 |
| 138.2 | 0.5 | 136.9 | 0.5 | 141.3 | 0.5 |
| 144 | 0.6 | 142.7 | 0.6 | 147.2 | 0.6 |
| 144.5 | 0.7 | 142.9 | 0.7 | 147.9 | 0.7 |
| 144.6 | 0.8 | 143 | 0.8 | 150.3 | 0.8 |
| 144.8 | 0.9 | 146.5 | 0.9 | 151.2 | 0.9 |
| 157.1 | 1.0 | 155.4 | 1.0 | 153 | 1.0 |

Table 4.16: Human hand middle finger

| First Experiment | | Second Experiment | | Third Experiment | |
|---|---|---|---|---|---|
| Angle, ° | Time, s | Angle, ° | Time, s | Angle, ° | Time, s |
| 165.3 | 0 | 165.1 | 0 | 166.4 | 0 |
| 159.2 | 0.1 | 158.8 | 0.1 | 160.3 | 0.1 |
| 134.2 | 0.2 | 134.0 | 0.2 | 135.2 | 0.2 |
| 124.9 | 0.3 | 124.2 | 0.3 | 130.6 | 0.3 |
| 125.3 | 0.4 | 124.9 | 0.4 | 126.7 | 0.4 |
| 125.6 | 0.5 | 125.0 | 0.5 | 125.7 | 0.5 |
| 125.7 | 0.6 | 125.2 | 0.6 | 125.4 | 0.6 |
| 126.1 | 0.7 | 126.0 | 0.7 | 129.1 | 0.7 |
| 126.7 | 0.8 | 126.6 | 0.8 | 130.6 | 0.8 |
| 139.1 | 0.9 | 139.8 | 0.9 | 145 | 0.9 |
| 163.1 | 1.0 | 162.8 | 1.0 | 163.6 | 1.0 |

Table 4.17: Middle finger of the animatronic hand

| First Experiment | | Second Experiment | | Third Experiment | |
|---|---|---|---|---|---|
| Angle, ° | Time, s | Angle, ° | Time, s | Angle, ° | Time, s |
| 162 | 0 | 160 | 0 | 164.4 | 0 |
| 160 | 0.1 | 158.4 | 0.1 | 162.3 | 0.1 |
| 159.3 | 0.2 | 158.2 | 0.2 | 155.4 | 0.2 |
| 158.4 | 0.3 | 157.3 | 0.3 | 151.6 | 0.3 |
| 147.8 | 0.4 | 146.1 | 0.4 | 144.2 | 0.4 |
| 140.2 | 0.5 | 138.6 | 0.5 | 139.4 | 0.5 |
| 141 | 0.6 | 140.4 | 0.6 | 138.2 | 0.6 |
| 142.6 | 0.7 | 141.4 | 0.7 | 139.5 | 0.7 |
| 143.8 | 0.8 | 143.2 | 0.8 | 140 | 0.8 |
| 144.9 | 0.9 | 144.3 | 0.9 | 140.5 | 0.9 |
| 157.3 | 1.0 | 158.5 | 1.0 | 153.4 | 1.0 |

Table 4.18: Human hand point finger

| First Experiment | | Second Experiment | | Third Experiment | |
|---|---|---|---|---|---|
| Angle, ° | Time, s | Angle, ° | Time, s | Angle, ° | Time, s |
| 166.4 | 0 | 163.5 | 0 | 166.8 | 0 |
| 158.6 | 0.1 | 159.3 | 0.1 | 162.4 | 0.1 |
| 144.2 | 0.2 | 148.4 | 0.2 | 146.2 | 0.2 |
| 132.9 | 0.3 | 136.9 | 0.3 | 134.8 | 0.3 |
| 125.3 | 0.4 | 135.3 | 0.4 | 129.1 | 0.4 |
| 125.6 | 0.5 | 135.1 | 0.5 | 129.5 | 0.5 |
| 125.7 | 0.6 | 138.4 | 0.6 | 133.4 | 0.6 |
| 126.1 | 0.7 | 140 | 0.7 | 136.9 | 0.7 |
| 126.6 | 0.8 | 143.6 | 0.8 | 139.5 | 0.8 |
| 131.8 | 0.9 | 155.5 | 0.9 | 149.6 | 0.9 |
| 163.1 | 1.0 | 164.2 | 1.0 | 164.3 | 1.0 |

Table 4.19: Point finger of the animatronic hand

| First Experiment | | Second Experiment | | Third Experiment | |
|---|---|---|---|---|---|
| Angle, ° | Time, s | Angle, ° | Time, s | Angle, ° | Time, s |
| 159.4 | 0 | 162.5 | 0 | 160 | 0 |
| 158.9 | 0.1 | 161.2 | 0.1 | 158.9 | 0.1 |
| 158.3 | 0.2 | 161.1 | 0.2 | 158.2 | 0.2 |
| 155.4 | 0.3 | 158.4 | 0.3 | 156.3 | 0.3 |
| 148.4 | 0.4 | 150.2 | 0.4 | 149.7 | 0.4 |
| 138.2 | 0.5 | 142.9 | 0.5 | 139.6 | 0.5 |
| 142.3 | 0.6 | 136.5 | 0.6 | 142.5 | 0.6 |
| 143.3 | 0.7 | 139.9 | 0.7 | 143.6 | 0.7 |
| 143.7 | 0.8 | 144.7 | 0.8 | 143.9 | 0.8 |
| 144 | 0.9 | 153.8 | 0.9 | 144.7 | 0.9 |
| 155.9 | 1.0 | 132 | 1.0 | 150.2 | 1.0 |

Table 4.20: Human hand thumb

| First Experiment | | Second Experiment | | Third Experiment | |
|---|---|---|---|---|---|
| Angle, ° | Time, s | Angle, ° | Time, s | Angle, ° | Time, s |
| 120 | 0 | 125.1 | 0 | 125.8 | 0 |
| 121.1 | 0.1 | 125.9 | 0.1 | 123.6 | 0.1 |
| 122 | 0.2 | 126.7 | 0.2 | 124.1 | 0.2 |
| 122.4 | 0.3 | 127 | 0.3 | 124.6 | 0.3 |
| 122.5 | 0.4 | 127.2 | 0.4 | 125.1 | 0.4 |
| 122.7 | 0.5 | 127.5 | 0.5 | 125.6 | 0.5 |
| 122.2 | 0.6 | 126.9 | 0.6 | 126 | 0.6 |
| 123.7 | 0.7 | 128.3 | 0.7 | 127.2 | 0.7 |
| 124.8 | 0.8 | 128.4 | 0.8 | 128.4 | 0.8 |
| 129 | 0.9 | 128.7 | 0.9 | 128.9 | 0.9 |
| 133 | 1.0 | 129 | 1.0 | 129 | 1.0 |



Table 4.21: Thumb of the animatronic hand

| First Experiment | | Second Experiment | | Third Experiment | |
|---|---|---|---|---|---|
| Angle, ° | Time, s | Angle, ° | Time, s | Angle, ° | Time, s |
| 140 | 0 | 139.8 | 0 | 142 | 0 |
| 139.4 | 0.1 | 139.1 | 0.1 | 140.7 | 0.1 |
| 138.9 | 0.2 | 138.7 | 0.2 | 139.2 | 0.2 |
| 138 | 0.3 | 138.1 | 0.3 | 139 | 0.3 |
| 136.2 | 0.4 | 136.7 | 0.4 | 138.7 | 0.4 |
| 134.9 | 0.5 | 134.5 | 0.5 | 135.6 | 0.5 |
| 133.9 | 0.6 | 134 | 0.6 | 134.3 | 0.6 |
| 135 | 0.7 | 136.1 | 0.7 | 136.7 | 0.7 |
| 135.3 | 0.8 | 136.5 | 0.8 | 138.5 | 0.8 |
| 135.9 | 0.9 | 136.9 | 0.9 | 140.9 | 0.9 |
| 138.8 | 1.0 | 144 | 1.0 | 148 | 1.0 |