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"I hereby declare that I have read through this report entitle *"Identification and Parameter Estimation of Multifunctional Prosthetic Hand "* and found that it has complied the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Control, Instrumentaion and Automation)"

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IDENTIFICATION AND PARAMETER ESTIMATION OF MULTIFUNCTIONAL PROSTHETIC HAND

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

BACHELOR OF ELECTRICAL ENGINEERING CONTROL, INSTRUMENTATION AND AUTOMATION

Faculty of Electrical Engineering

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YEAR 2016

DECLARATION

I declare that this thesis entitled "Identification and Parameter Estimation of Multifunctional Prosthetic Hand" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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DEDICATION

To my beloved mother and father,

Rohana binti Ahmad and Bahran bin Ismail

ACKNOWLEDGEMENT

In the name of Allah S.W.T the most merciful, Alhamdulillah, with His bless I manage to complete this research, entitled: "Identification and Parameter Estimation of Multifunctional Prosthetic Hand". I would like to thank to everyone who have involved in preparing this research. Thanks to my supervisor Dr Rozaimi bin Ghazali, that has given me a lot of encouragement and motivation as well as brilliant ideas during the development of this research.

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Thank you.

ABSTRACT

Nowadays, number of patients with forearm amputations have been increased tremendously due to trauma, surgery coma or prolonged constriction. Many problems and challenges occurred for the patients who suffer with these issues especially in their daily life. The evolution of prosthetic hand is written in history, it happens from primitive beginning until the future. Some ideas and inventions have been worked and expanded for example the fixed-position foot became the use of iron in prosthesis. The main objective of this study is to create and develop nonlinear mathematical modelling of prosthetic hand. There are three phase of purposed methodology in order to complete this project which started with developing the model of prosthetic hand with grasping force which taking Electromyography (EMG) signal as input reference signal. Then, system identification and parameter estimation using voltage signal and position will be designed and implemented in the prosthetic hand. Lastly, validation on the real data from experimental works has been conducted by using the data obtained from mathematical modelling design. The system identification is a technique which can provides more accurate data and efficient of prosthetic hand. There are two type of mathematical model used in experimental including ARX for linear model and Hammerstein-Wiener for nonlinear model. For conclusion, the Hammerstein-Wiener mathematical model is acceptable because the Final Prediction Error (FPE) and Mean Square Error (MSE) are lower than ARX mathematical model.

ABSTRAK

Pada masa kini, jumlah pesakit yang kehilangan tangan telah meningkat dengan ketara disebabkan oleh trauma, pembedahan atau penyempitan berpanjangan. Pelbagai masalah dan cabaran telah dihadapi pesakit yang menderita dengan isu-isu ini terutamanya dalam kehidupan seharian mereka. Evolusi tangan prostetik telah ditulis dalam sejarah, ia berlaku dari awal primitif sehingga masa kini. Beberapa idea dan ciptaan telah dicetus dan berkembang sebagai contohnya; kaki palsu tanpa pergerakan tetap menjadi penggunaan besi dalam prostesis. Objektif utama kajian ini adalah untuk mewujud dan membangunkan pemodelan matematik yang tak linear terhadap tangan prostetik. Terdapat tiga fasa yang telah dirangka dalam meteologi untuk melengkapkan projek ini,dimana pada mulanya tangan protetik telah dimodel dengan mengambil isyarat Electromyography (EMG) sebagai rujukan dalam daya genggaman. Kemudian, sistem pengenalan dan anggaran parameter dengan menggunakan isyarat voltan dan kedudukan akan menjadi reka bentuk dalam pelaksanaan tangan palsu. Akhir sekali, pengesahan data sebenar dari eksperimen telah dijalankan dengan menggunakan data dari reka bentuk model matematik. Pengenalan sistem adalah teknik yang boleh menyediakan lebih banyak data yang tepat dan tangan palsu yang cekap. Terdapat dua jenis model matematik yang telah digunakan dalam eksperimen termasuklah ARX untuk model linear dan Hammerstein-Wiener untuk model tak linear.Kesimpulannya, model matematik Hammerstein-Wiener boleh diterima kerana Final Prediction Error (FPE) dan Mean Square Error (MSE) adalah lebih rendah daripada ARX model matematik.

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CHAPTER 1

INTRODUCTION

1.1 Introduction and Motivation

People with disabilities (PWDs) in Malaysia can be considered as one of minority group in Malaysia population [1]. In 2011, World Bank and Word Health Organization (WHO) estimated that are 15 % of the word population having some form disabilities. The total number of disable peoples in Malaysia are 3055640 and 106252 who encountered disable physical problem [2]. Refer to Department of Social Welfare, Malaysia statistic 2013, there are 8,289 men, and 5,465 women, registration of disabilities at the physical department.

Table 1.1 :Number of New Registration of PWDs by Category of Disabilities, Age Group and Sex, 2013

Kumpulan Umur	PENGLIHATAN		PENDENGARAN		FIZIKAL		MASALAH PEMBELAJARAN		PERTUTURAN		MENTAL		PELBAGAI		JUMLAH	
	L	P	L	P	L	P	L	P	L	P	L	P	L	P	L	P
Kurang dari 6 tahun	101	73	144	116	413	329	859	594	119	74	3	1	277	199	1,916	1,386
7 - 12 tahun	199	155	240	194	511	404	1,774	1,141	253	167	2	5	318	228	3,297	2,294
13 - 18 tahun	266	187	264	257	588	397	1,292	866	184	121	47	22	225	176	2,866	2,026
Jumlah (a)	**566**	**415**	**648**	**567**	**1,512**	**1,130**	**3,925**	**2,601**	**556**	**362**	**52**	**28**	**820**	**603**	**8,079**	**5,706**
19 - 21 tahun	154	99	128	123	455	279	795	504	103	65	99	51	114	73	1,848	1,194
22 - 35 tahun	590	388	624	535	1,520	917	1,343	1,111	193	168	883	500	463	320	5,616	3,939
36 - 45 tahun	603	350	385	366	1,447	835	831	668	135	108	934	573	293	227	4,628	3,127
46 - 59 tahun	884	604	602	499	1,877	1,307	647	610	107	95	814	613	338	247	5,269	3,975
60 tahun ke atas	732	412	516	356	1,478	997	272	212	33	18	188	189	182	102	3,401	2,286
Jumlah (b)	**2,963**	**1,853**	**2,255**	**1,879**	**6,777**	**4,335**	**3,888**	**3,105**	**571**	**454**	**2,918**	**1,926**	**1,390**	**969**	**20,762**	**14,521**
Jumlah (a + b)	**3,529**	**2,268**	**2,903**	**2,446**	**8,289**	**5,465**	**7,813**	**5,706**	**1,127**	**816**	**2,970**	**1,954**	**2,210**	**1,572**	**28,841**	**20,227**

Table 1.1 shows the age group from 46 – 59 years is highest of physical disabilities of man which is 1877. For patient that facing this problem especially handicapped have difficult to adapt daily environment. Losing all 5 fingers, it will be difficult for them to perform basic movement such as grasp the object.

Human hand is a complex system. It has large number of freedom, sensor embedded in structure, complex hierarchical control, actuator and tendon. Therefore the development of prosthetic hand is very demanding endeavour. It can become support equipment for amputated people to support daily life activities.

Identification is a powerful technique for develop accurate models of complex system from noisy data [8]. Identification is the methods to measure the data by build mathematical models of dynamic system. There are three steps to develop system identification [8]:

I. The design of an experiment
II. The construction of a model, black box or physical laws
III. The estimation of the model parameters from the measurements.

Therefore the identification technique is used for measure data which applied in Multifunction of prosthetic hand. This technique is to measure electromyogram (EMG) signal for the input, force and position for the output. The MATLAB/ Simulink software is provided application such as System Identification Toolbox, for construct mathematical models of dynamic systems from measured data. This toolbox provides detail data like hood, prediction-error minimization (PEM) and subspace system. It also represents nonlinear model system dynamic which is Hammerstein-Wiener model and nonlinear ARX models with wavelet network, sigmoid network and tree partition [9].

1.2 Problem Statement

It has been addressed in many researchers about multifunction prosthetic hand, it more focusing to develop functionality and controllability of prosthetic hand [3]. Generally the researcher use transfer function equation and combine with any controller to control the movement of prosthetics hand. A linear mathematical modelling can express a certain psychical situation without include the independent variable. However it cannot operate with the flexible and unpredictable data. For system identification, the nonlinear mathematical modelling is more suitable for mapping the unpredictable data from input or output. In order to bury present prosthesis limitation and augment the level acceptable of the artificial limb, the mathematical modelling must be developing to measure the input and output system of multifunctional prosthetic hand.

1.3 Objective

The objectives of the study included:

I. To design the prosthetic hand which capable to control degree position
II. To develop mathematical equation modelling using system identification for multifunctional prosthetic hand
III. To validate and verify the nonlinear mathematical modelling and linear mathematical modelling.

1.4 Project Scope

This project will focuses on identification and parameter estimation of multifunctional prosthetic hand. The scopes of study are follows:

I. The mechanical design of prosthetic hand focused in five fingers.
II. The input data from MATLAB applied to the system and be mapping for identification system.
III. Determine and collecting position data from one finger of prosthetic hand.
IV. MATLAB software will be implemented in collecting the data and develop identification system.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the previous works on identification and parameter estimation for multifunction prosthetic hand will be discussed. The research more focuses in the development of nonlinear mathematical modelling and parameter estimation. The studies on the design of prosthetic hand also will be assessed in order to develop the hardware platform where the hardware model of prosthetic hand is crucial part in the analysis of mathematical modelling.

2.2 Design of Prosthetic Hand

The researcher use bio mechatronic approach in the design of an anthropomorphic artificial hand [4]. The objective of the journal is to mimic the motion of the human finger. The design of bionic hand consists of three fingers with three of freedom (DOF) for each finger and degree of freedom for ubanation. The modelling prototype which is design by Pro-Engineer is constructed by using aluminium alloy while the finger is shell of carbon fibre like Figure 2.1. The prototype has ten DOF and 4 degree of movement.

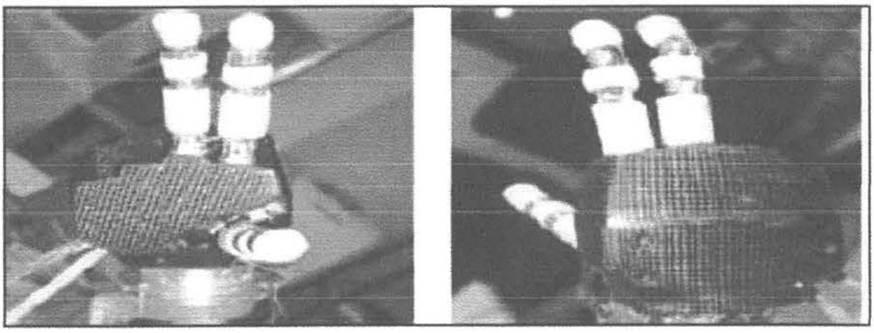

Figure 2.1: Design of Bionic hand [4]

In [5], the researcher has introduced the multi-fingered anthropomorphic robotic hands that have fourteen degree of freedom (DOF).The objective of his journal is to mimic the functionality of the biological hand, especially in handling the object. The design of robotic hand consists of five finger where each finger has three different phalanxes which is proximal, middle and distal phalanxes. The prosthetic hand is designed by using CATIA and fabricated by using In Vision XT-3D Modeller. The Acrylic Plastic material is chosen to fabricate robotic hand with the tensile modulus and 1772MPa and 34MPa of tensile strength. Figure 2.2 is the example of complete design of researcher.

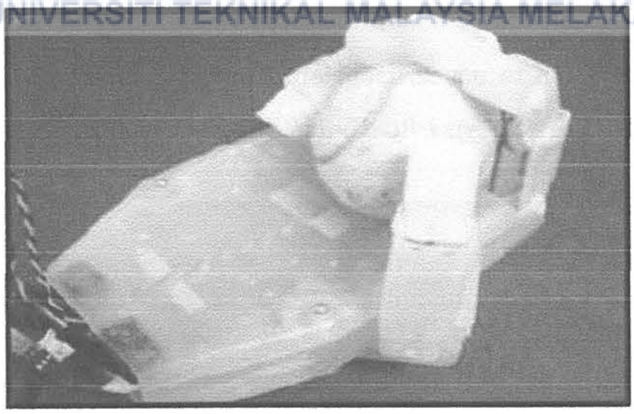

Figure 2.2: Design of Robotic hand [5]

In [6], the design of prosthetic hand consists of the two degree of freedom (DOF) for each finger where it has three fingers. The objective of this paper is to develop an upper limb prosthesis that can be fielded as a part of the body by amputee [6]. This paper also represents the design and fabrication of novel prosthetic hand by used a bio mechatronics and cybernetic approach. The prototype of prosthetic hand is fabricated by using Fused Deposition Modelling (FDM) process. Meanwhile acrylonitrile/ butadiene/ styrene (ABS) plastic is used to construct the body structure. Figure 2.3 show the design of Prosthetic hand. MP joints represented metacarpo-phalangeal and PIP joints represented proximal interphalangeal joints. The distal interphalangeal joints is represented as DIP joints.

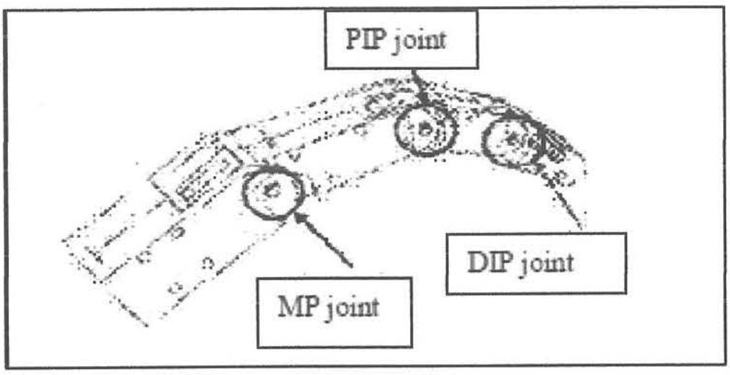

Figure 2.3: Design of Prosthetic hand [6]

Three fingered gripper can be designed and stimulate to provide both gross motion and fine motion of the finger [7]. The objective of this paper is to copy the human hand in term of dexterity and adaptive capabilities to function as either a manipulator or as prosthetic device [7]. This prosthetic hand is designed with three finger which is thump, middle, and index like Figure 2.4. It also designed seven of degree freedom. All part of prosthetic hand is assembly by using SolidWorks software.

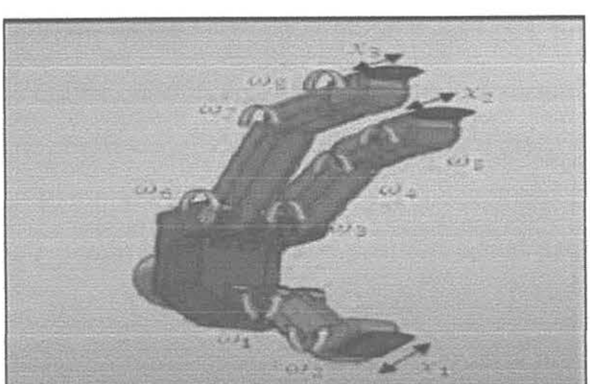

Figure 2.4: Design of Prosthetic hand [7]

In 2013, the researchers in [8] have developed of prosthetic hand which perform hand opposition and reposition action (clasp and release) base of the real EMG signal from an elbow amputee [8]. The objective of these studies is to develop human hand which can provide natural haptic functionality .The prosthetic hand is design with two freedom of degree (DOF) below elbow amputee like shows Figure 2.5.

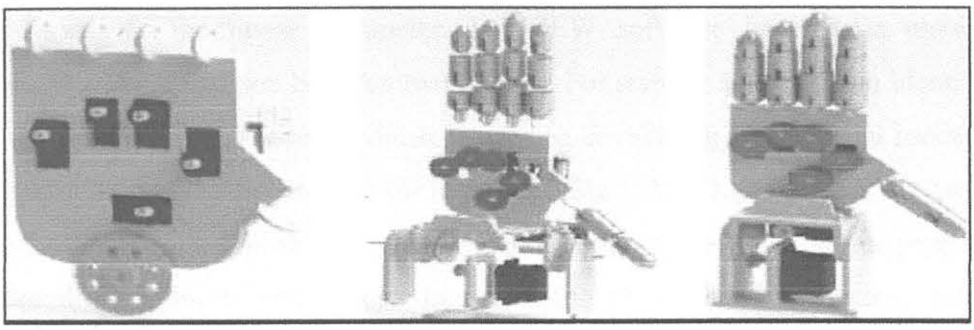

Figure 2.5: Design of Prosthetic hand [8]

2.3 System Identification

System Identification is a method to build models of dynamical systems from measured data. It also includes the optimal design of the experiment for efficiently generate information data for fitting. There are two common model to start measurements of the behaviour of the system which is grey box model and black box model. The white box model is known as complex and impossible to obtain in reasonable time because the complexity of nature. For studies about system identification, many of researchers applied the system identification to mapping EMG signal. The concept and method the researcher can be applied to estimate parameter of force and position signal data.

2.3.1 Identification of EMG signal.

In 2015, the researchers in [11] write the journal about mapping EMG signal using System Identification technique. The aim of the journal is to develop a mathematical modelling with surface EMG (sEMG) signal from the biceps and triceps muscle as input and velocity of motion of fore arm as output [11]. The researcher uses two model identification systems which is ARX Model for linear parameter and Hammerstein-Wiener Model for nonlinear parameter. LabVIEW software is used as platform to development and comparison between two models. For starting study system identification system techniques, ARX Model as linear is used to developing EMG signal model. Then Hammerstein Wiener Model is used for more accurate sEMG signal. There are two stage in this study; data acquisition and system identification stage. For data acquisition, the EMG signal form bicep and triceps is processing meanwhile the second stage, the mathematical model relating sEMG are used.

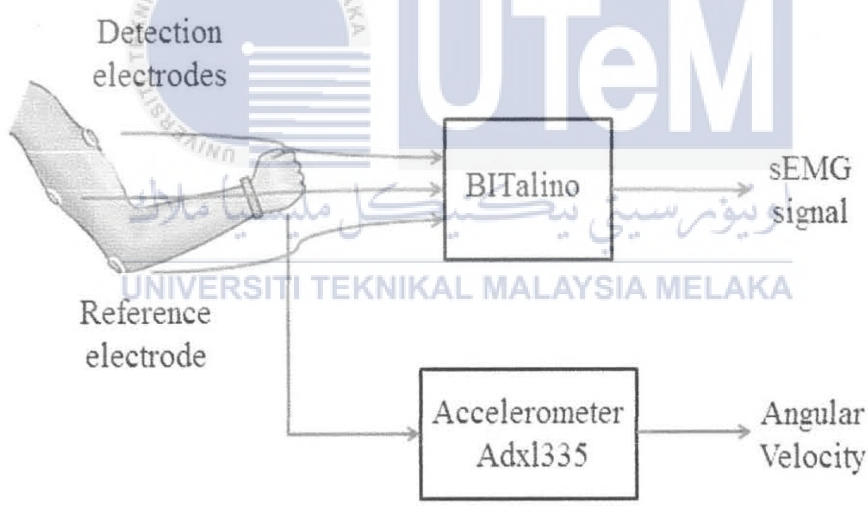

Figure 2.6: Block Diagram of Data Acquisition stage [11]

Figure 2.6 represents the data acquisition block diagram where the flexion and extension in bidirectional movement are considered for acquisition of sEMG signal [11]. There are four study conditions is considered in the experimental setup which is represented as follows:

I. Fast Flexion

II. Fast Extension

III. Slow Flexion

IV. Slow Extension

Three surface electrodes are connected at the arm, one reference electrodes on the elbow and two detection electrodes at bicep and triceps. ADXL335 is a 3 axis accelerometer and used for acquisition acceleration of fore arm angular velocity which is to measure output. BITalino is a biomedical data acquisition device which is used for acquired sEMG signal.

Table 2.1: Comparison between ARX and Hammerstein models [11]

sEMG- Angular Velocity Model		ARX Model	Hammerstein Model
Cases	RMSE		
Fast Flexion	Estimation	0.09655	0.09139
	Validation	0.152385	0.13970
Fast Extension	Estimation	0.11552	0.09505
	Validation	0.15139	0.14149
Slow Flexion	Estimation	0.117059	0.09797
	Validation	0.141825	0.11436
Slow Extension	Estimation	0.12369	0.09685
	Validation	0.2243	0.1903

Table 2.1 shows the result of comparison between performance of ARX model and Hammerstein model in different case studies.

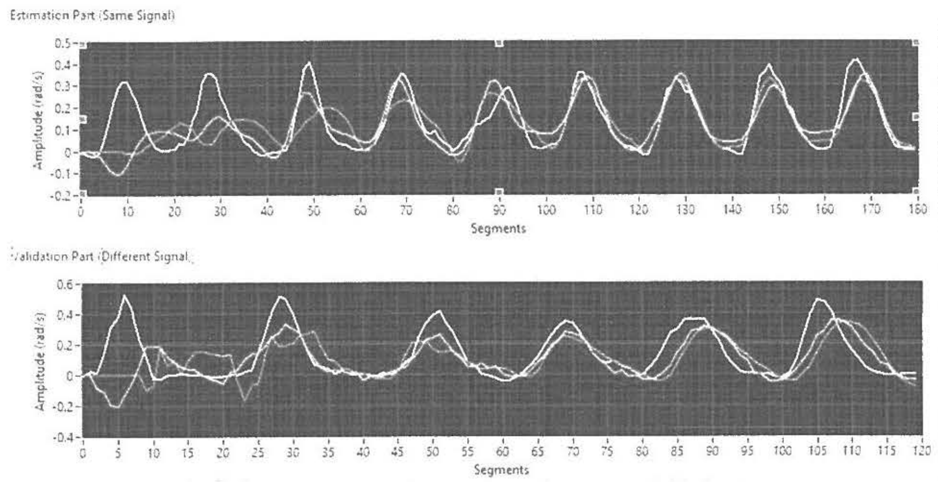

Figure 2.7: Fast flexion model response [11]

Figure 2.7 shows the result of fast flexion model response. The upper panel for the estimation input and the lower for validation input. The white signal represent actual response, red represent ARX model response and green represent Hammerstein model response. For each 10 segment, the amplitude graph for actual signal is in fast flexion modes which have a little different from 0.29 to 0.41 rad/sec. The validation of ARX input signal unpredicted for starting and after segment 35, the signal return to normal state.

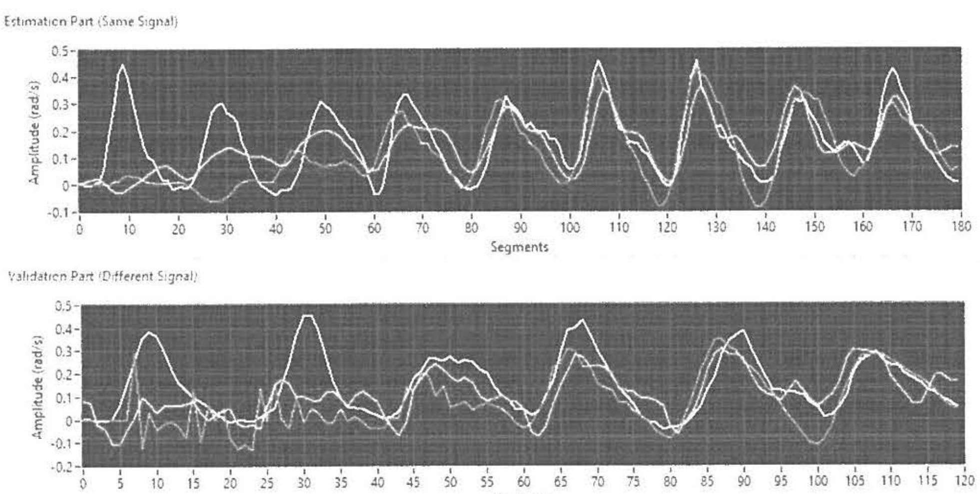

Figure 2.8: Slow flexion model response [11]

Figure 2.8 shows the slow flexion condition for ARX model and Hammerstein model. The upper panel shows an estimation input response and the lower panel shows validating input response. The white signal represent actual response, red represent ARX model and green represent Hammerstein model. It can be seen that overall response of the Hammerstein signal is an estimation response is more identical to actual signal. The estimation of ARX signals showing inaccurate response from starting and to 60. After the segment 60 the data signal can estimate identically with actual signal compare to Hammerstein model. The ARX model in slow flexion is not validating from 0 to 44 segments. After that, the signal is validate with actual signal.

The muscle is a source producing force and the basic function unit of muscle is motor unit, when applied some force the electrical signal is generated on muscle surface and it called electromyogram (EMG) [11].The objective of this research is to purpose the new mathematical model which obtained through identification system to mapping EMG to joint torque by use EMG sensor. The EMG signal has physiologic signal, real time, non-stationary, non-linear, non-Gaussian, and continuous [11]. These properties provided easier way to modelling of the EMG signal. There are traditional approaches which assume the surface of EMG can be modelled as band limited white nose modulated by the level of muscle contraction. Muscle tension can be determined by controlling length and activation level of muscle. EMG signal are used as indirect measure of force and joint torque.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describe the project methodology on system identification development and estimate parameters of Prosthetic Hand. The ideas for the design and analysis have been planned. In other ways, with the method planned, it can help to make the project goes smooth and able to determine the error. At the early stage on this section shows the flow chart represented the overview of methodology which is used to achieve the objective of this study.

The methodology in this project is classified into three sections. The first section is discussed detailed about prosthetic hand design which can control the position of finger. The second section will be discussing the development of mathematical equation modelling for ARX model as linear and Hammerstein-Wiener model as nonlinear equation. The last section will be more explanation method used to validate the mathematical equation modelling.

3.1.1 Flow Chart

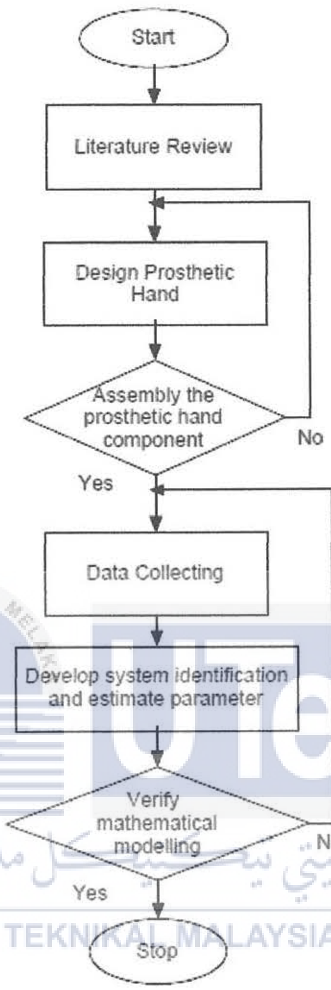

Figure 3.1 : Flow chart of methodology

Figure 3.1 shows the flow chart on the development of system identification and estimate parameter mathematical modelling. The main method to develop system identification can be divided for significant sections. First section is the design Prosthetic Hand which the assembly process is included. The second section will be focus to development of system identification and the last section will be discussed the verification of mathematical equation modelling.

3.2 Design of Prosthetic Hand Mechanism.

The mechanical design of multifunctional prosthetic hand is done by using the SolidWORKS 2014 software. The design more focus in one finger which following the characteristic of human finger. For full prosthetic hand design will be conducted after the mathematical equation of identification and estimate parameter has been done. There are five fingers which consist of Proximal, Middle and Distal Phalanx.

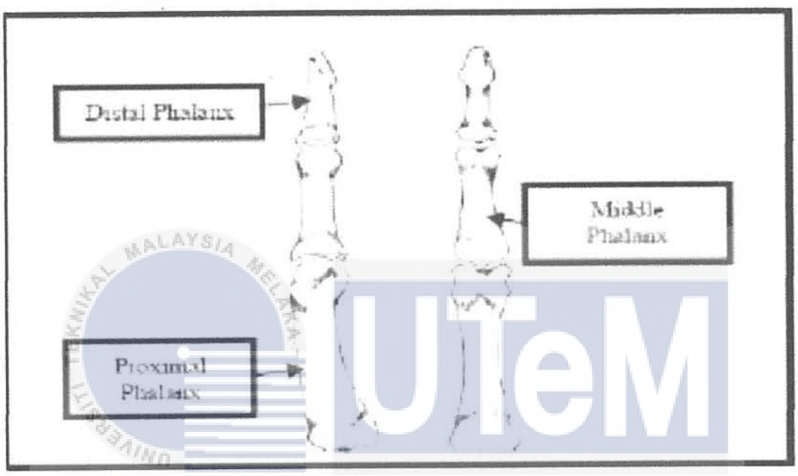

Figure 3.2 : Human Finger structure [5]

Figure 3.2 shows the combination of the human phalanx for each of the finger. Based on this information the finger of prosthetic hand will be designed.

3.2.1 Mechanical Linkages

The mechanical design for this prosthetic hand is done by Gael Langevin who is a French sculptor and designer. His personal project collect INMOOV was initiated in January 2012 as the first Open Source prosthetic hand. INMOOV is the first Open Source 3D printed life- size robot.

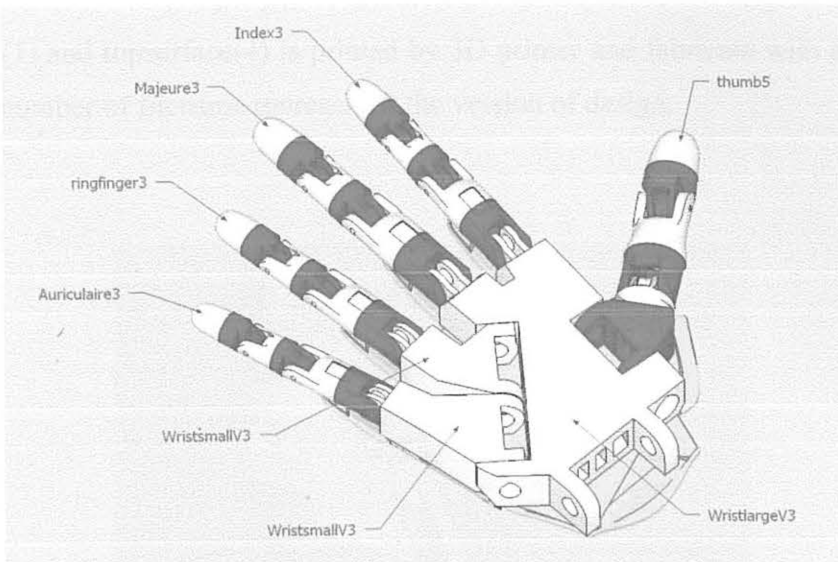

Figure 3.3: Lower view of INMOOV hand

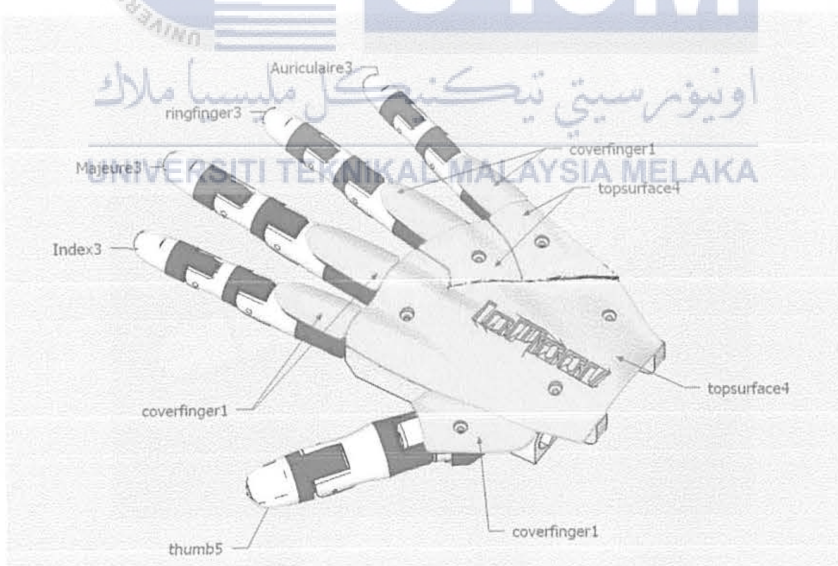

Figure 3.4: Upper view of INMOOV hand

Figure 3.3 and 3.4 shows the lower and lower view of INMOOV hand. All the part is Auriculaire(3), ringfinger(3), Majeure(3), Index(3), coverfinger(1), thumb(5), coverfinger(1) and topsurface(4) is printed by 3D printer and fabricate with the procedure given. The number of filename represented the version of design.

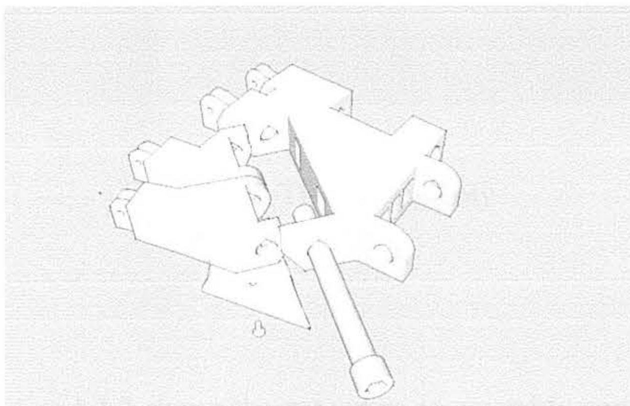

Figure 3.5: Palm assembly

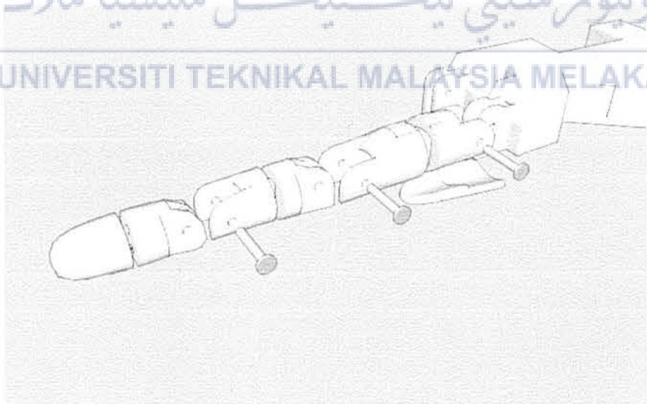

Figure 3.6: Finger assembly

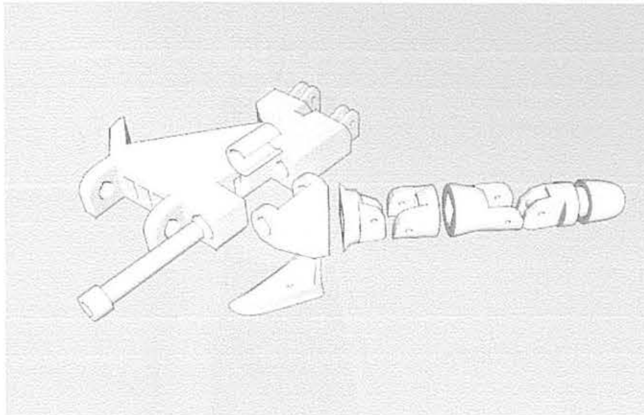

Figure 3.7: Thumb assembly

Figure 3.5, 3.6 and 3.7 shows the procedure to assembly part of INMOOV hand. For the rest of the finger can be assembly according the example in Figure 3.6. First, the palm of INMOOV hand must be assembly before assembly the finger part. The top cover finger and top cover palm is glued after the palm and finger complete fabricate. For top part at each finger should not attach to make installation of fishing line easier.

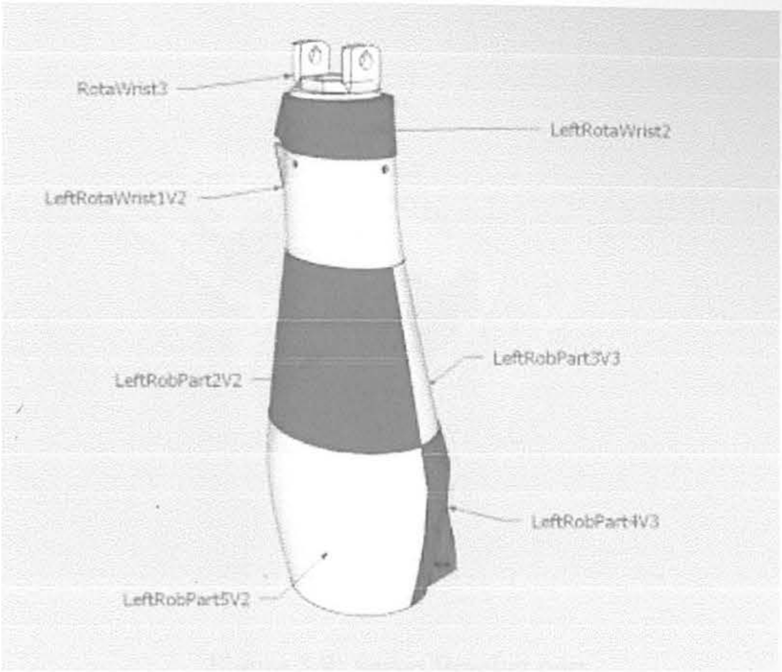

Figure 3.8: Forearm part

Figure 3.8 shows the forearm part from the wrist and before to elbow. This part is important because the servo motor bed for control finger is placed in this part. The parts are RotaWrist(3), LeftRotaWrist1V(2), LeftRobPart2V(2), LeftRobPart5V(2), LeftRobPart4V(3), LeftRobPart3V(3) and LeftWrist(2). There are part not mention in this figure which is BedservoV3, TopBed1 and MiddleBed1. This part is implementing inside forearm InMoov to placed servo motor and fishing line route from servo motor to each finger.

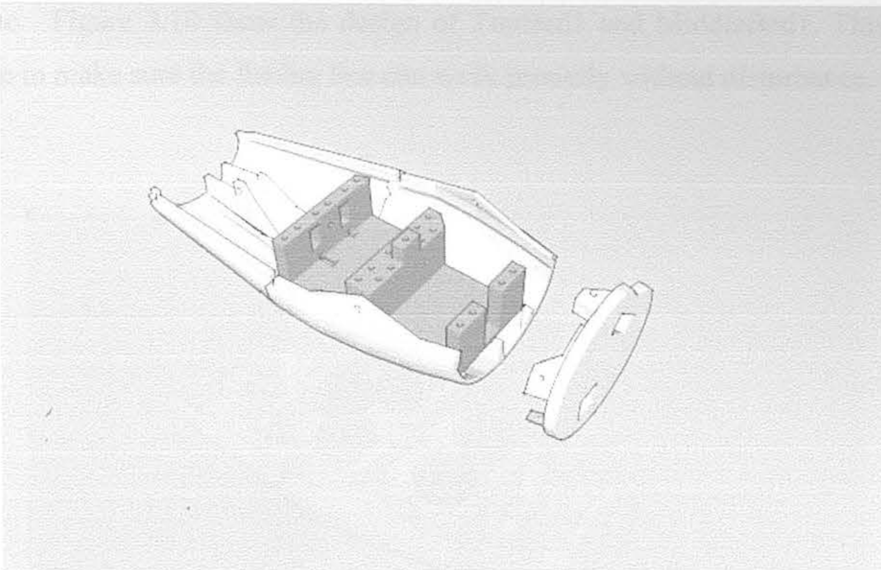

Figure 3.9: Servo Bracket part

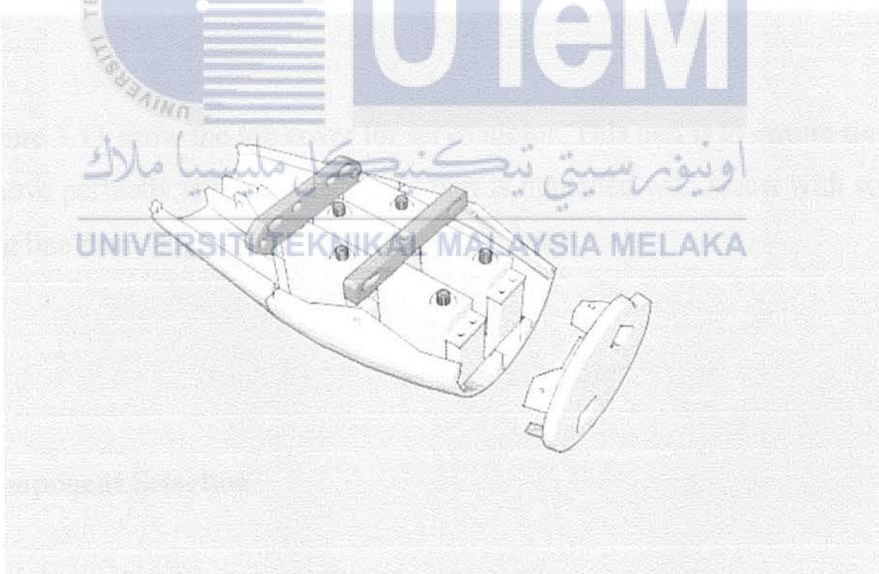

Figure 3.10: Servo Bracket with TopBed1 and MiddleBed1 part

Figure 3.9 shows the design of servo bracket which implement in forearm INMOOV. There are many version of servo bracket but for this project the third design (Known as ServoBedV3) have been choose because more compatible and easy to install fishing line. Figure 3.10 show the design of TopBed1 and MiddleBed1. This design is importance to make sure the fishing line can work properly without disturbance.

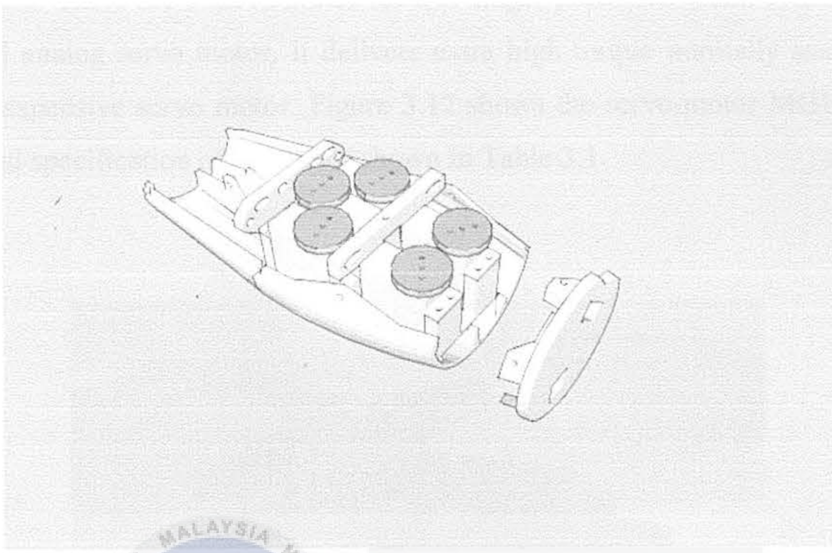

Figure 3.11: Servo motor with Cover top part

Figure 3.11 show the top cover for servo motor. This part is to ensure tie the fishing line and move perfectly without loose. This part is tightened with screw with servo motor. The fishing line from finger will be tied up with this part.

3.2.2 Component Selection

The component selection is the importance procedure to complete design prosthetic hand because each component is influence in prosthetic hand design. In this section will be discussed about selecting component to make the prosthetic hand complete and perform very well.

3.2.2.1 Servo Motor

The servo motor is used to control the movement of finger which placed in forearm prosthetic hand. There are 5 servo motor for five finger prosthetic hand. The MG1501 is a metal geared analog servo motor. It delivers extra high torque normally associated with much more expensive servo motor. Figure 3.12 shows the servo motor MG1501 and the parameter and specification of the motor shown in Table 3.1.

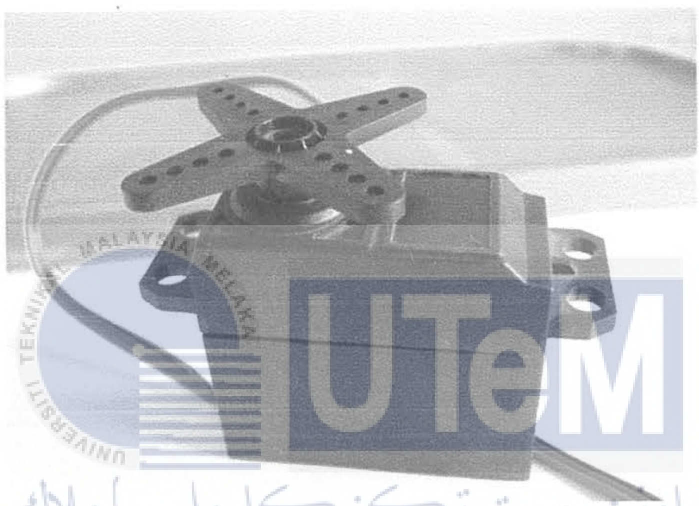

Figure 3.12: Servo Motor MG1501

Table 3.1: General Specification MG1501

Size	40.7 x 20.5 x 39.5 mm
Weight	60g
Speed of 6V	0.14 sec/60°
Stall torque of 6V	17 kg.cm
Speed of 4.8V:	0.16 sec/60°
Stall torque of 4.8V:	15.5 kg·cm

3.2.2.2 Fishing Line

Fishing line is the most important component for ensuring the finger of prosthetic hand can be controlled by servo motor. The fishing line will be tied to servo motor and knotted at the prosthetic fingertips. It is supposed to be 200lbs unfortunately because of some limited factor, the project will carry on with 150lbs. Figure 3.13 represented the fishing line 150lbs.

Figure 3.13: Fishing line 150lbs

3.2.2.3 Arduino Mega

Microcontroller Arduino Mega 2560 is selected to control prosthetic hand. Arduino Mega has 54 Digital input/output pins and provided 15 pin for PWM output. It also has limit voltage limit from 6 V to 12 V. Figure 3.14 shows the example of Arduino Mega 2560.

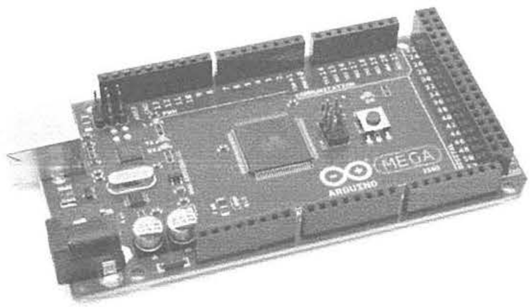

Figure 3.14: Arduino Mega 2560

3.2.2.4 Flex Sensor

Figure 3.15 shows the flex sensor. As the sensor flexed, the resistance across the sensor increases. The resistance of the flex sensor changes when the metal pads are on the outside of the bend (text on inside the bend). The flex sensor is used to estimate the value of output and installed with glove to control the prosthetic hand.

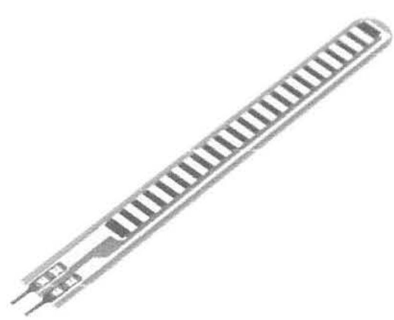

Figure 3.15: Flex Sensor

3.2.2.5 Acetone

Acetone is the organic compound with the formula $(CH_3)_2CO$ which is colourless, volatile, flammable liquid and is the simplest ketone. Figure 3.16 shows the acetone, use as solvent for prosthetic hand, which good solvent for many plastics. It also used as superglue to combine the part of prosthetic hand design during assembly.

Figure 3.16: Example of Acetone

3.2.2.6 Electrical Component

The accessories electrical component such as jumper wire and resistor is needed to complete the electrical circuit to give supply servo motor, flex sensor and microcontroller Arduino Mega 2560. The connection of electrical component is simplified for one flex sensor and one motor and represented as Figure 3.17.

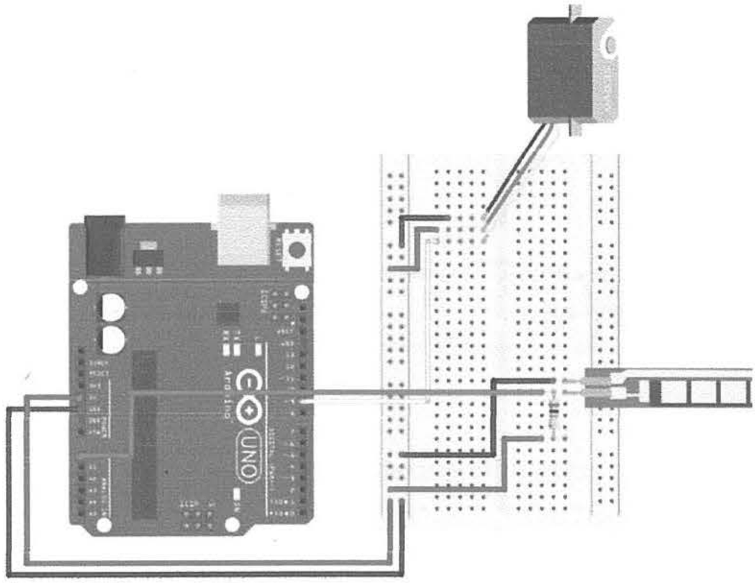

Figure 3.17: Connection of electrical component

3.3 Mathematical Modelling Development

This section discusses to on the design mathematical model to identification and estimate parameter of prosthetics hand. System identification models used in this project are: ARX model for linear model and Hammerstein model for nonlinear model. There are stages to design mathematical equation which is:

3.3.1 Data Acquisition

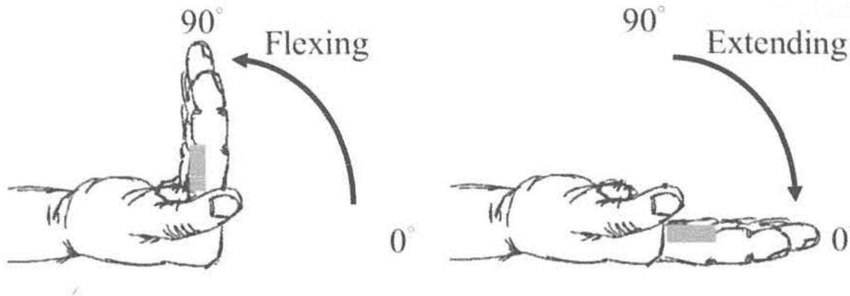

Figure 3.18: The flexing of fingers

The output data is taken from flexing movement between the proximal phalanx and palm such as orange shaded area shown in Figure 3.18. The degree of movement is from 0° until 90°. The flex sensor is replaced at proximal phalanx as shown in Figure 3.19.

Figure 3.19: The position of flex sensor

The flex sensor will read resistance value during bending. The value of resistance can be change to voltage value by using equation in gain from MATLAB or coding in Arduino Software. Before stimulate the value input from MATLAB, the value of position degree must calibrate manually according to value of voltage output from flex sensor. The value of position degree based on value of voltage is recorded like Table 3.2 below;

Table 3.2: Value Degree of position and Voltage output

Position (Degree)	Voltage (V)
0	1.9
10	1.75
20	1.64
30	1.47
40	1.38
50	1.25
60	1.14
70	1.08
80	0.96
90	0.9

Based on Table 3.1, when the value of voltage is 1.9V, the value of degree of position is 0^{o}. Meanwhile when the value voltage is 0.9 V, the value of degree of position is 91^{o}. This table can use as reference to convert the value of voltage output to degree of position. The reference data that has been recorded can generate mathematical linear equation which can apply in Simulink MATLAB.

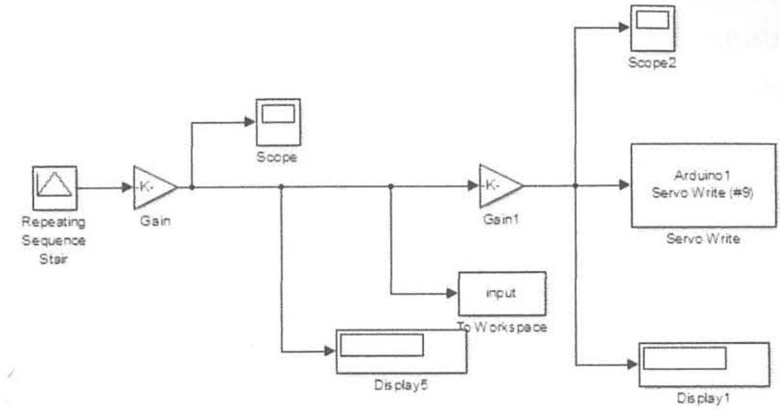

Figure 3.20: Simulink diagram of voltage input

Figure 3.20 shows the design of bock Simulink to operate the servo motor via using Repeating Sequence Stir as input. The function of first gain is to convert the value of degree from 0^{o} until 180^{o} to voltage input. Then the input voltage data will transfer and save into workspace. Second gain is to convert back the voltage value into degree of position to command movement of servo motor.

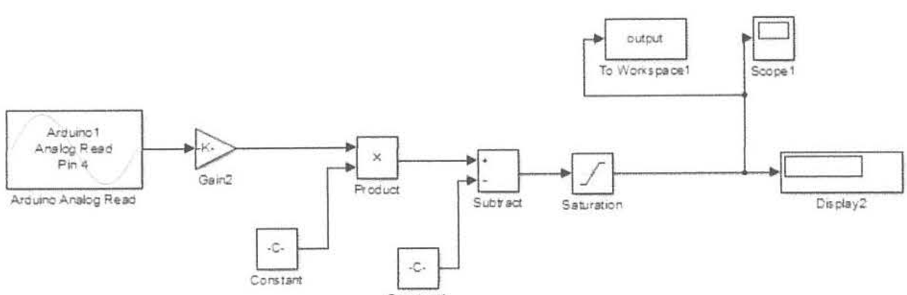

Figure 3.21: Simulink diagram of voltage output

The voltage output data from flex sensor will me measure via using Simulink MATLAB as shown in Figure 3.21. Arduino Analog Read data will measure data in bits value, the gain convert into voltage value. The block Product and Subtract is linear equation operation and the value of constant is the value from linear equation from reference data. The linear equation will convert the voltage into degree of position based on the value from calibration before. The accuracy of flex sensor is so poor; therefore saturation block is to provide limitation the value from 0^{o} until 90^{o}. The data will save into workspace and can proceed to data processing.

3.3.2 Data Processing

System identification also can be defined as the process of deriving a mathematical model of a system by observing the data [10]. There are three steps to measure voltage data signal and position [10].

I. Split the data

In this step, the input and output of measured data divided into two sets. One measured data for model estimation and the other for model validation. The figure 3.22 showed the example System Identification app to split the data. Select Pre-process > Select Range and estimate the value of range for estimate and validate data. The range for estimate and validate cannot be the same.

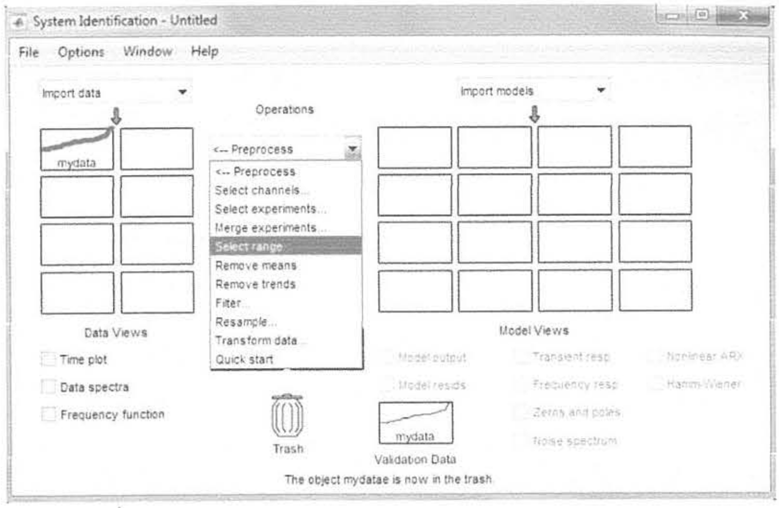

Figure 3.22: System Identification split data

II. Model Estimation

In this step, the system model based on different system identification is created.

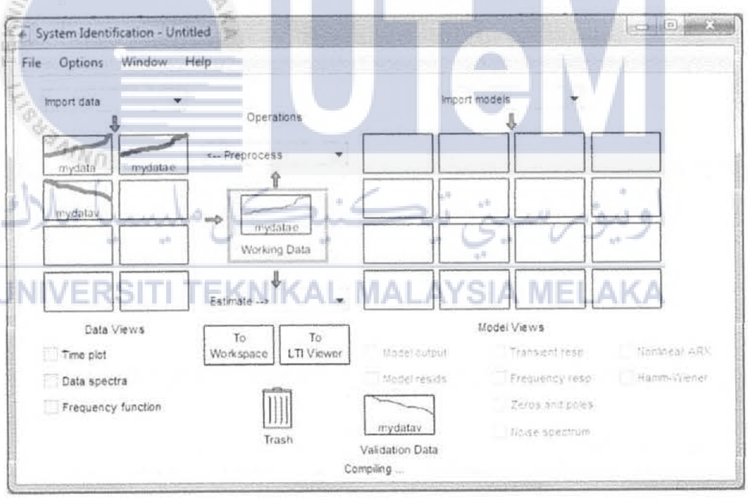

Figure 3.23: System Identification estimate data

After the data have been split to estimate and validate data. Drag the estimate data into Working Data box like shown in Figure 3.23. The location of Working Data box is highlight with orange line in rectangle form.

III. Model Validation

In this step, system model estimated is validated by using model validation data.

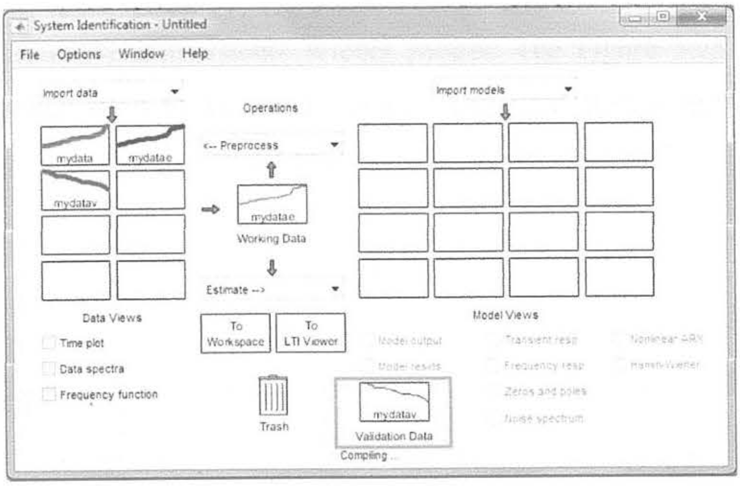

Figure 3.24: System Identification estimate data

Figure 3.24 shown the validate data drag into Validation Data box. The location of Validation Data box is highlight with orange line in rectangle form. This method of validate called as cross validate.

For the next step, choose Estimate > Nonlinear Model at System Identification apps to design identification nonlinear model system.

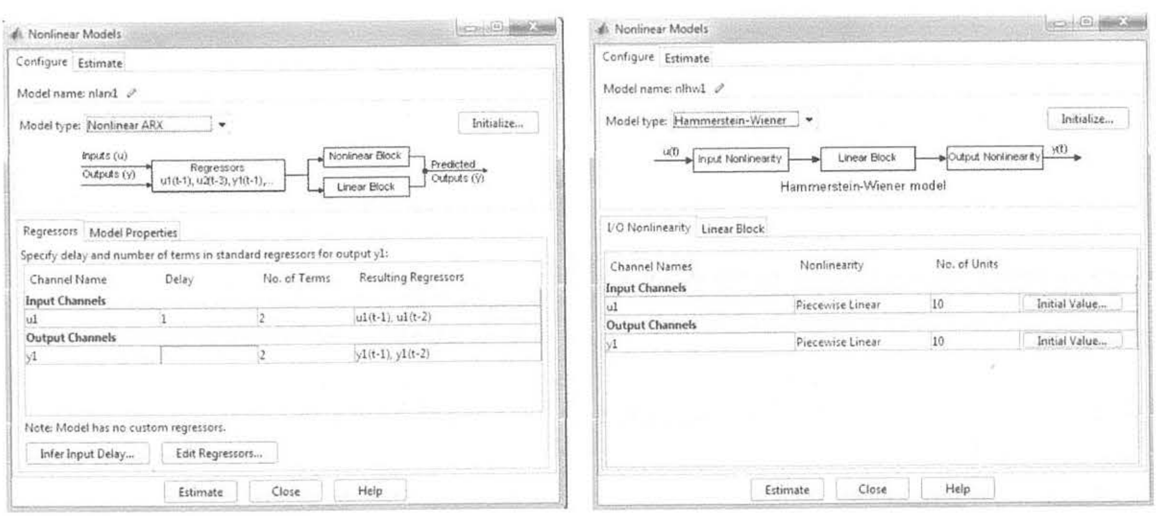

Figure 3.25: System Identification Nonlinear configuration box

For this simulation only two types System Identification model has been selected which is ARX model and Hammerstein- Wiener Model. The Figure 3.25 showed the Nonlinear Model configuration to design the model. The right side is for design ARX model and the left side is to design Hammerstein Wiener model.

3.3.3 System Identification

ARX model is the simplest linear parametric model. ARX stands for Autoregressive (depending on past values) with Exogenous Input (input along with disturbance) model. The different equation of ARX SISO model is like below;

$$y[t] + a_1 y[t-1] + \cdots + a_{n_a} y[t-n_a] = b_0 u[t-d] + b_1 u[t-1-d] + \cdots + b_{n_b-1} u[t-(n_b-1)-d] + e[t] \quad (3.1)$$

Where A and B are the unknown model parameter, n_a and n_b are the order of model coefficients a and b meanwhile e(t) is the zero mean Gaussian white noise and d is the system delay.

Assume,

$$A(q) = 1 + a_1 q^{-1} + \cdots + a_{na} q^{-na} \quad (3.2)$$

$$B(q) = b_0 q^{-d} + b_1 q^{-1} + \cdots + b_{n_b-1} q^{-(n_b-1)-d} \quad (3.3)$$

where q is shift operator.

Combine equation (3.1), (3.2) and (3.3), it provided the complete ARX model equation.

$$y(t) = \frac{B(q)}{A(q)}u(t) + \frac{1}{A(q)}e(t) \tag{3.4}$$

The value n_a, n_b and d (known as n_k in MATLAB) will be determine by using System Identification Toolbox.

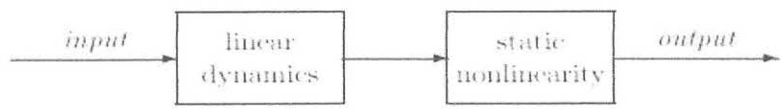

Figure 3.26: Hammerstein Wiener block diagram

Figure 3.26 above shows the general block diagram representation of Hammerstein Model. The main difference from linear models is that it contains a static nonlinear function along with the linear dynamic function. The nonlinear function describes the nonlinearities present in the system. There are nonlinear function used is a polynomial nonlinearity;

Static nonlinear function (Polynomial Nonlinearity)

$$w(t) = f[u(t)] = \beta_1 u(t) + \beta_2 u^2(t) + \cdots + \beta_m u^m(t) = \sum_{k=1}^{m} \beta_k u^k(t) \tag{3.5}$$

Where β is the coefficients of polynomial nonlinear function and m is the order of the nonlinear function.

Linear dynamic function,

$$G(q) = \frac{b_0 q^{-d} + b_1 q^{1-d} + \cdots + b_{n_b-1} q^{-(n_b-1)d}}{1 + f_1 q^{-1} + \cdots + f_{n_f} q^{-n_b}} = \frac{B(q)}{F(q)} \tag{3.6}$$

Where b and f are the unknown parameter of linear function, n_b and n_f are the order of coefficients b and f. Combine the equation (3.5) and (3.6), complete Hammerstein model

$$y(t) = \frac{B(q)}{F(q)} \sum_{k=1}^{m} \beta u^k(t) + v(t) \tag{3.7}$$

The value of n_a , n_b and n_k for ARX model and the value of n_a , n_b and n_k for Hammerstein will be given after the model is validate.

3.4 Mathematical Model Validation

In this section will give explanation about the method use to verify the mathematical equation model. There are many methods to use to verify and validate the mathematical model. For this project, the best fit method is selected because it's more easy to understand and to analysis. This method can apply in System Identification apps.

CHAPTER 4

RESULTS AND DICUSSION

4.1 Introduction

This chapter describe about the result and analysis referring to the objective of this project. The first section discussed about result of prosthetic hand design. The second section more explanation of development mathematical equation modelling and the third section the explanation about the validation of mathematical equation modelling. The result with analysis of capabilities of ARX Model and Hammerstein-Wiener based of different number of coefficient model and the same value of system delay.

4.2 Design of Prosthetic Hand

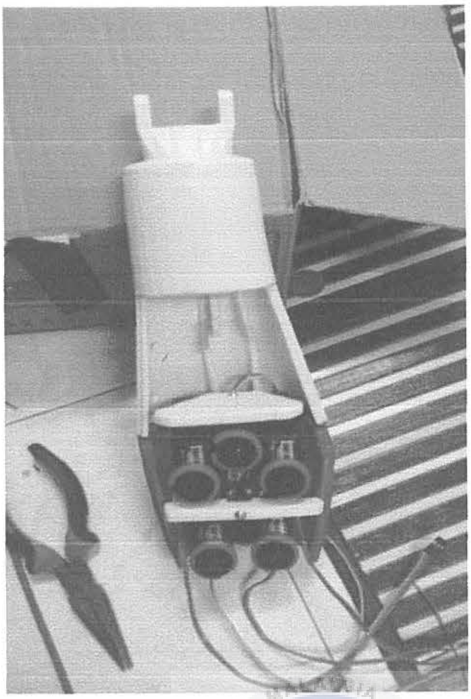

Figure 4.1: Forearm INMOOV

Figure 4.2: Forearm INMOOVcover

Figure 4.3: INMOOV 3D printed robot with glove

Figure 4.1 representing the INMOOV forearm without the cover and hand. All the five servo motor is replace at servo bracket in the forearm. When the fishing line has been installed, the cover of forearm put together like the figure 3.2. Figure 4.3 shows the result after the INMOOV prosthetic hand complete with integration electrical equipment.

4.3: Development of Mathematical Modelling

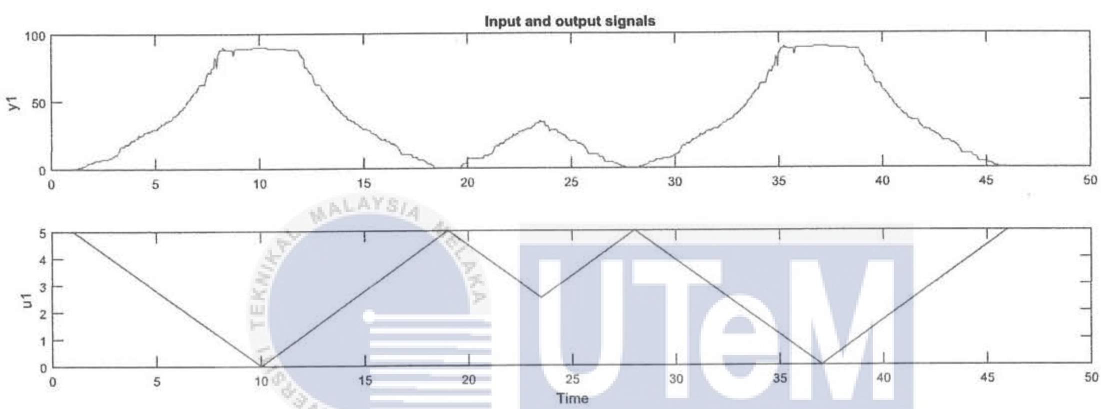

Figure 4.4: Input and Output signal

Figure 4.4 shown the input and output signal of prosthetic hand. The upper side is position output data meanwhile the lower side is voltage input data. The figure 4.5 is the input and output data after split data. Yellow colour for estimate data and green colour for validate data.

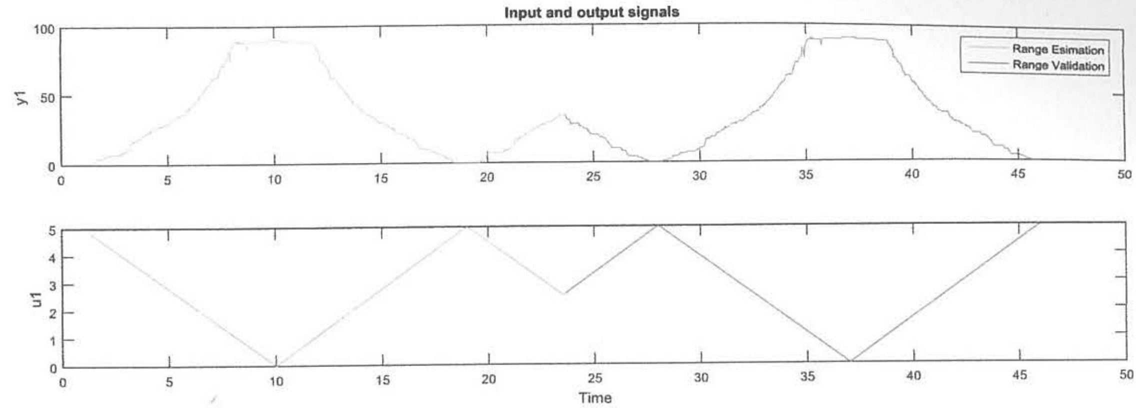

Figure 4.5: Input and Output signal after split data

The mathematical equation modelling for Prosthetic Hand is like below;

$$\frac{0.6858\,s\,+\,1.172}{s^2+\,1.225e-10\,s\,+\,0.06855} \tag{4.1}$$

From simulation in MATLAB, the value of ARX model of coefficient and system delay is obtained like below;

$n_a = 1$

$n_b = 1$

$n_k = 1$

Therefore applied this value into equation (3.4) and generate the ARX mathematical equation model like below;

$$y(t) = \frac{b_0 q^{-1}}{1 + a_1 q^{-1}} u(t) + \frac{1}{1 + a_1 q^{-1}} e(t) \tag{4.2}$$

The a and b known as unknown parameter model.

Meanwhile for Hammerstein Wiener mathematical equation model, the value of order of coefficient and system delay is obtained like below;

$n_b = 2$

$n_f = 3$

$n_k = 1$

The value of m (order of the nonlinear function) is 2. All the value is applied in equation (3.7) and generate Hammerstein-Wiener mathematical equation model like below;

$$y(t) = \frac{b_0 q^{-1} + b_1 q^{-2}}{1 + f_1 q^{-1} + f_2 q^{-2} + f_3 q^{-3}} \sum_{k=1}^{2} \beta u^k(t) + v(t) \tag{4.3}$$

4.4 Validation of Mathematical Model

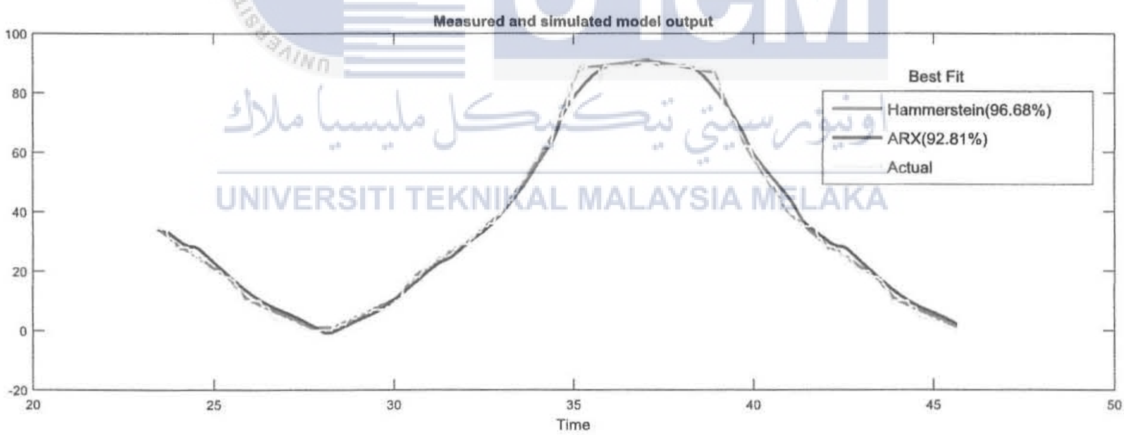

Figure 4.6: Comparison of Best fits

Based on Figure 4.6 the value best fit for Hammerstein-Wiener is 96.68% for red line and ARX model best fit is 92.81% for yellow line. The graph of black line is the actual data output. According the value of best fits obtain, the value of error for Hammerstein- Wiener model is smaller than ARX model. Therefore the Hammerstein-Wiener model is more acceptable for mathematical modelling for prosthetic hand.

4.5 Analysis of Mathematical Modelling

In this section, two mathematical modelling which is Hammerstein and ARX model is discussed through a set of experiment. ARX model will be analysis for capabilities for estimation data of prosthetic hand in the first part. While in the second part is analysis and discussed about capabilities of Hammerstein-Wiener model for estimate data of prosthetic hand.

4.5.1 Analysis ARX Model

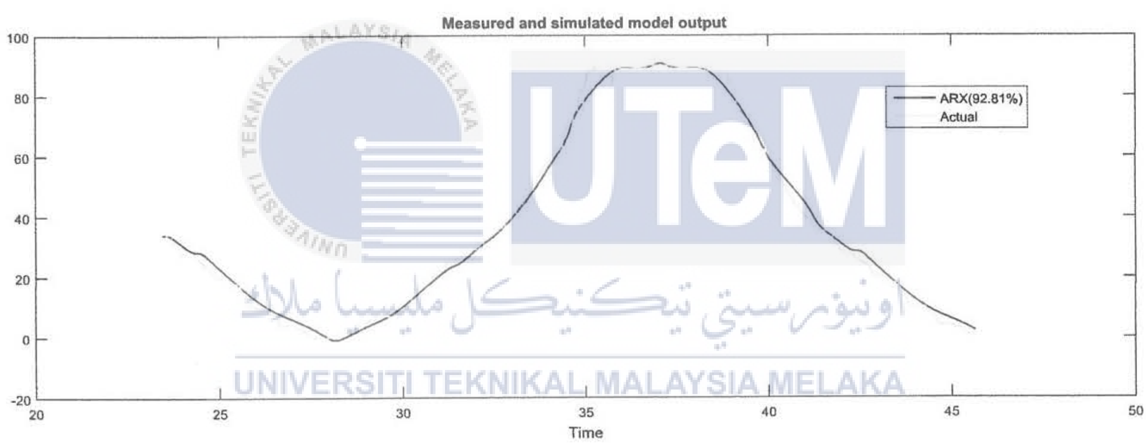

Figure 4.7: Comparison of Best fits of ARX and actual data

Figure 4.7 shows the comparison of ARX model for the yellow line with actual data for the black line. The percentage of best fit for the ARX model is 92.81% and the error is 7.29%. The ARX model capabilities will be analysis with a set of experiment which the value of model coefficient is change and the delay of system is the same value as 1.

Table 4.1: Result of ARX model

Model Name	n_a	n_b	n_k	Best fits (%)	Final Prediction Error (FPE)	Mean Square Error (MSE)	Loss Function (LF)
larx1	1	1	1	92.81	1.158	1.058	1.06
larx2	2	2	1	75.01	1.127	1.073	1.07
larx3	3	3	1	73.91	1.142	1.068	1.075
larx4	4	4	1	76.23	1.16	1.07	1.08
larx5	5	5	1	78.76	1.17	1.06	1.072
larx6	6	6	1	78.93	1.101	0.9663	0.9796
larx7	7	7	1	78.53	1.134	0.9863	1.002
larx8	8	8	1	80.98	1.142	0.9755	0.9934
larx9	9	9	1	80.26	1.149	0.9593	0.9791

The result of capabilities experiment for ARX model is recorded and shows as Table 4.1. The experiment is estimate the same input and output data of prosthetic hand with different value of coefficient. There are nine models for ARX model and name as larx1, larx2, larx3, nlarx4, larx5, larx6, narx7, larx8 and larx9. The result data of best fits, final prediction error (PDE), mean square error (MSE) and loss function (LF) is recorded to make the comparison.

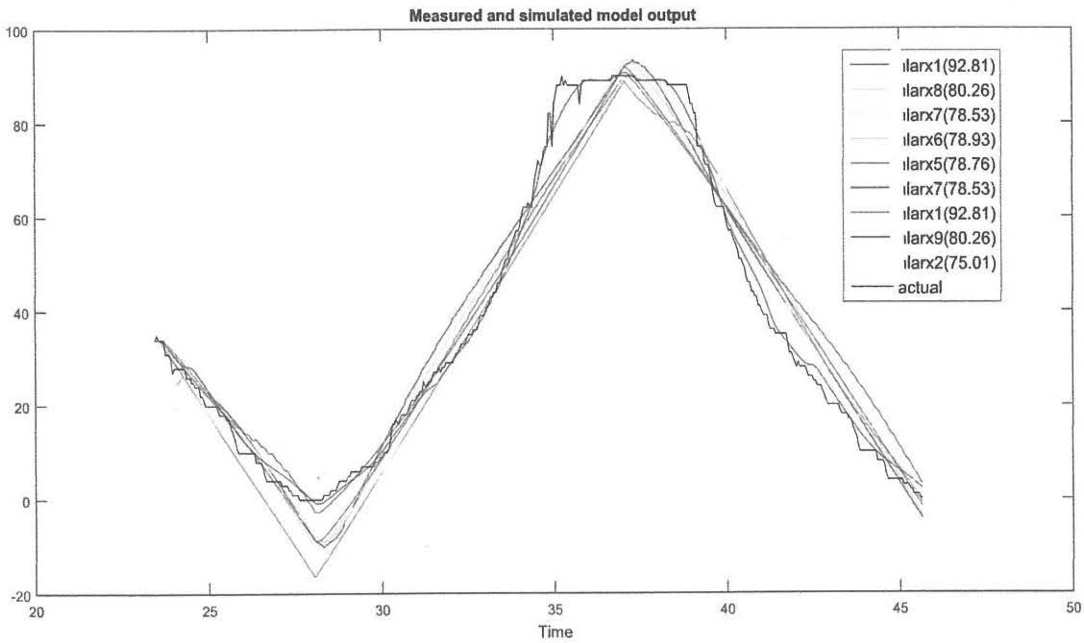

Figure 4.8: ARX model best fits

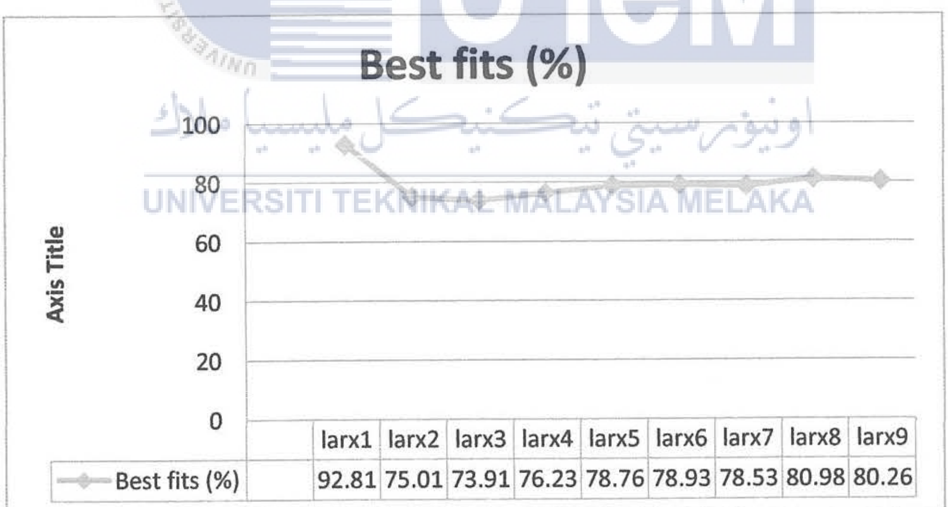

Figure 4.9: ARX model Best Fits graph

Figure 4.8 is the result of best fit for ARX model from MATLAB software. Referring the capabilities of ARX model as represented at Figure 4.9, nlarx1 is the highest best fits among the other models where the value is 92.81%. The lowest best fit is 73.91% and named as larx3 model. The average best fits for all model experiment is 79.49.

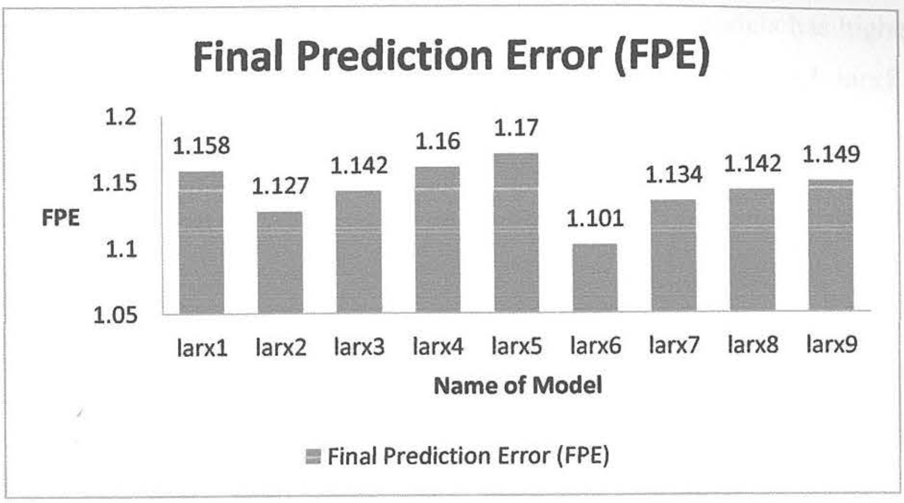

Figure 4.10: ARX model Final Prediction Error

Final Prediction Error Criterion known as FPE is estimates the model fitting error when use the model to predict new outputs. Figure 4.10 represent the Final Prediction Error for ARX model. The highest value FPE is nlarx5, 1.17 and nlarx1 is the second highest which 1.158. While the larx6 model obtained the lowest FPE and larx2 model is the second highest.

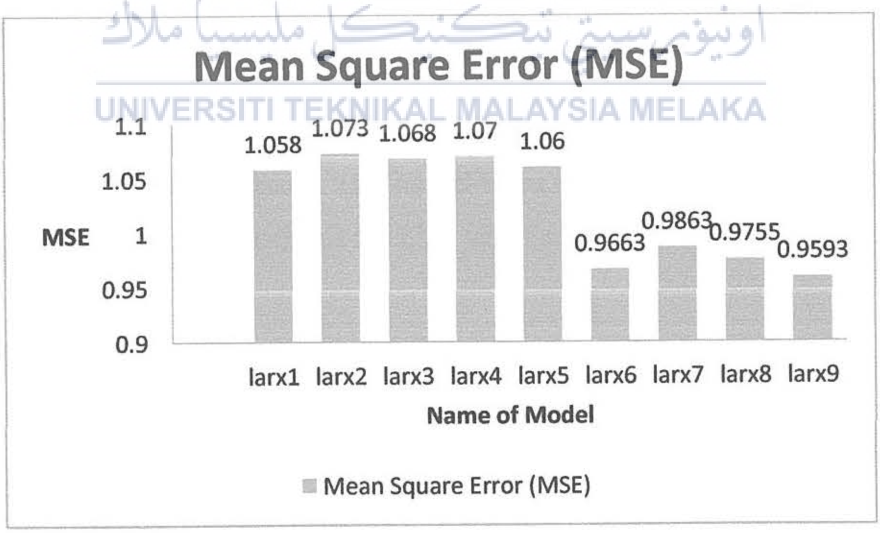

Figure 4.11: ARX model Mean Square Error

Mean Square Error or in the other name known as Means squared deviation (MSD). MSE is an estimator measures the average of the errors or the difference between the estimator and what estimated. Referring Figure 4.11 there are 5 models has higher value of MSE which is larx1, larx2, larx3, larx4, and larx5 meanwhile larx6, larx7, larx8 and larx9 is lower value of MSE.

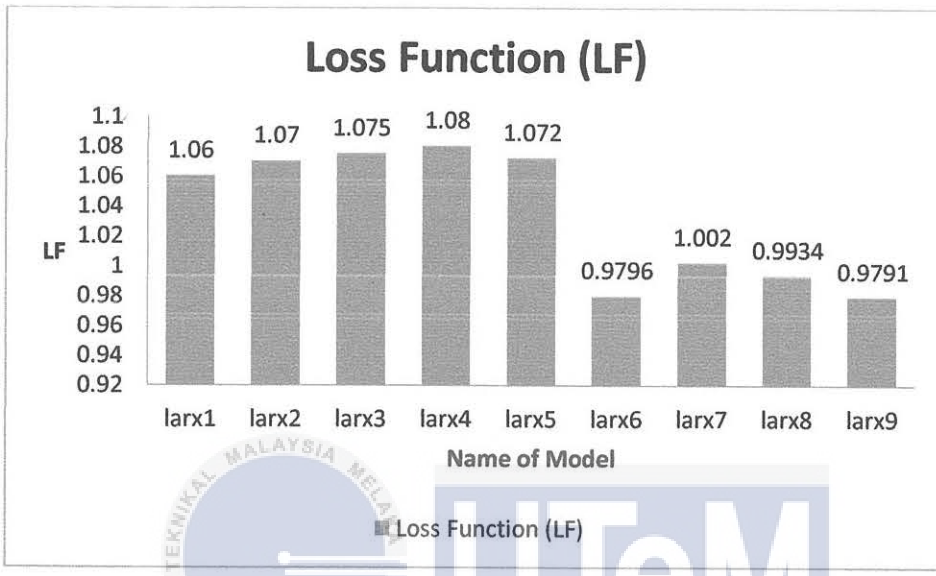

Figure 4.12: ARX model Loss Function

Loss Function or known as cost function is a function that maps an event or values of the one or more variables onto a real number intuitively based in mathematical optimization. Figure 4.12 shows the bar chart of Loss function of ARX model. The highest LF value is 1.08 for model nlarx4. The model nlarx3 and nlarx2 only has 0.05 different values. Model nlarx1 until nlarx5 has the high value and the rest of model has lower value of LF.

4.5.2 Analysis Hammerstein Wiener Model

Hammerstein-Wiener is the simple nonlinear dynamical models that configuration of linear dynamic block and nonlinear memory less blocks.

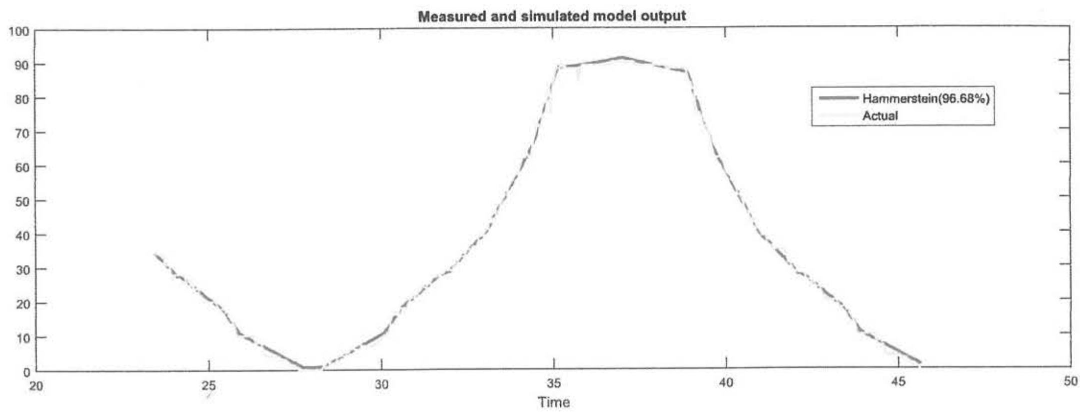

Figure 4.13: Comparison of Best fits of Hammerstein –Wiener and actual data

Figure 4.13 represented the comparison of Best Fits between Hammerstein-Wiener and actual input and output data. The yellow line is represented the actual data meanwhile the red line represented Hammerstein-Wiener model estimation. Based on this figure, the best fit for Hammerstein-Wiener is 96.68% that make the error for this model is 3.32%.

Table 4.2: Result of Hammerstein-Wiener model

Model Name	n_a	n_b	n_k	Best fits (%)	Final Prediction Error (FPE)	Mean Square Error (MSE)	Loss Function (LF)
nlhw1	1	1	1	32.48	488.2	405.9	405.9
nlhw2	1	2	1	94.04	4.253	3.52	3.52
nlhw3	2	2	1	73.7	107	88.77	88.17
nlhw4	2	3	1	96.68	1.2	0.9841	0.9841
nlhw5	3	3	1	39.94	533	451.4	451.4

The result of analysis capabilities of Hammerstein-Wiener model is recorded in Table 4.2. There only have 5 models with different number of coefficient model in this experiment. The number of zero plus one, n_b and the number of pole n_f is assume different value and delay system n_k assume the same value for all model

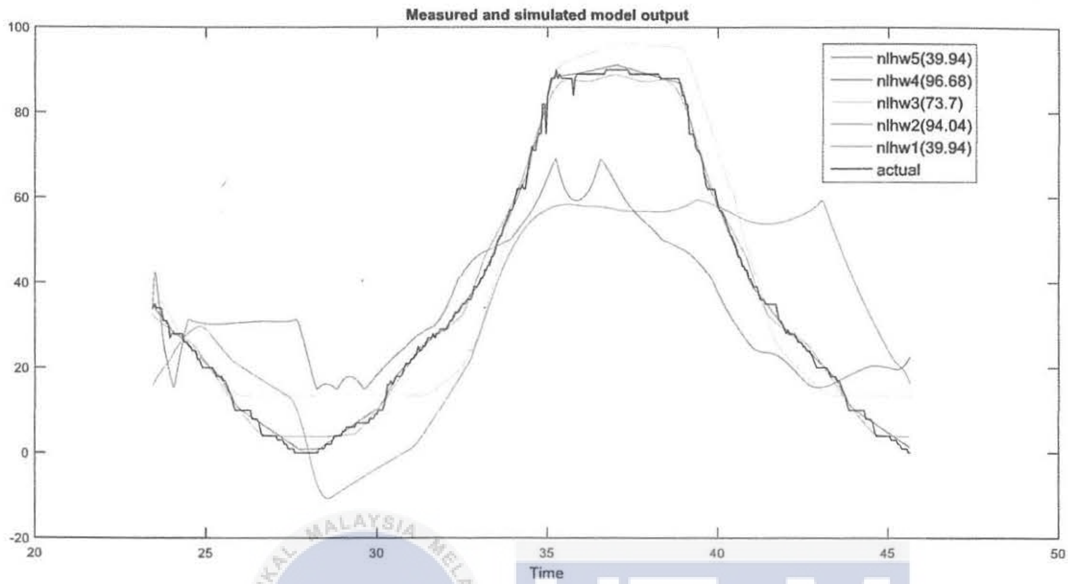

Figure 4.14: Hammerstein- Wiener model best fits

There are represented the Best Fits from MATLAB software from Figure 4.14. The graph for analysis between the models like Figure 4.15 can be done from information obtains from MATLAB.

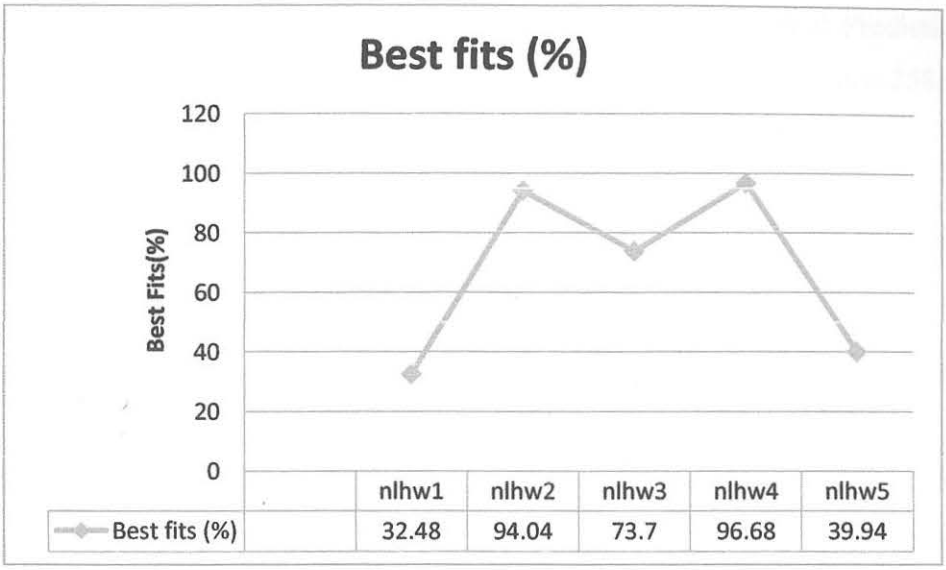

Figure 4.15: Hammerstein- Wiener model Best Fits graph

Referring Figure 4.15 the graph is not uniform because from the model nlhw1 to model nlhw2 is increase sharply and decrease when to model nlhw3. The graph starts increase again from nlhw3 to nlhw4 and decrease dramatically from model nlhw4 to model nlhw5.

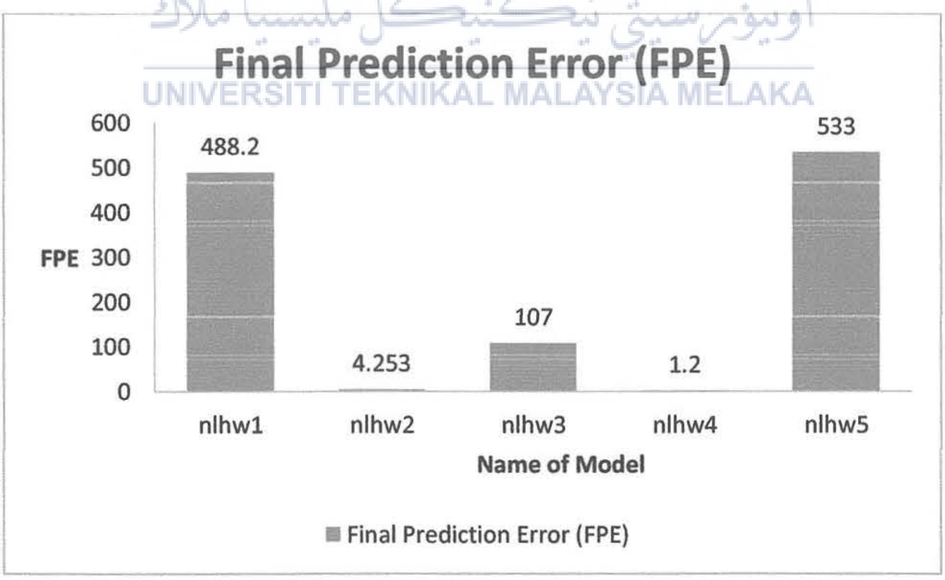

Figure 4.16: Hammerstein- Wiener model Final Prediction Error

Based on Figure 4.16, the nlhw5 has the highest value of Final Prediction Error (FPE). Meanwhile model nlhw2 and nlhw4 has the lower of FPE which is 4.258 and 1.2. The differentiation value of FPE for each model is so high.

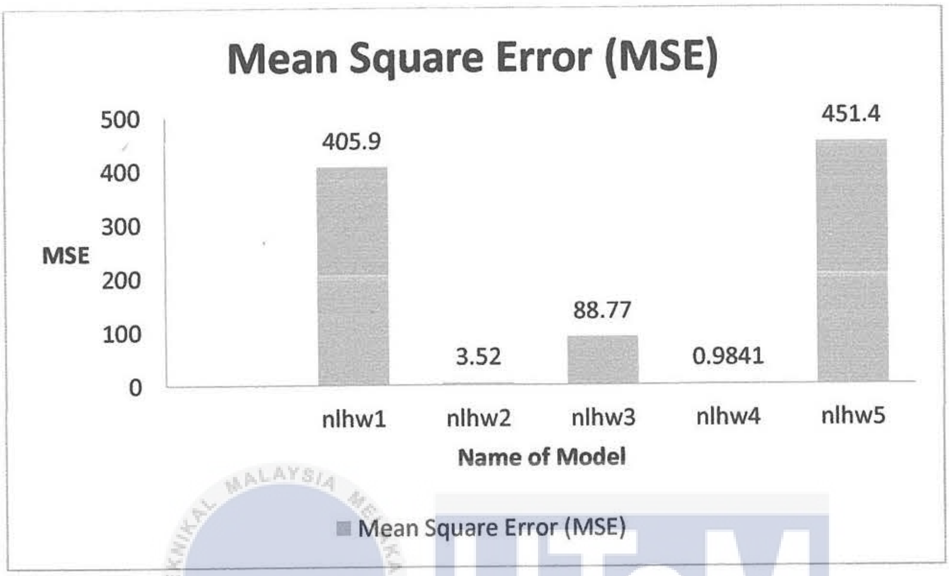

Figure 4.17: Hammerstein- Wiener model Final Prediction Error

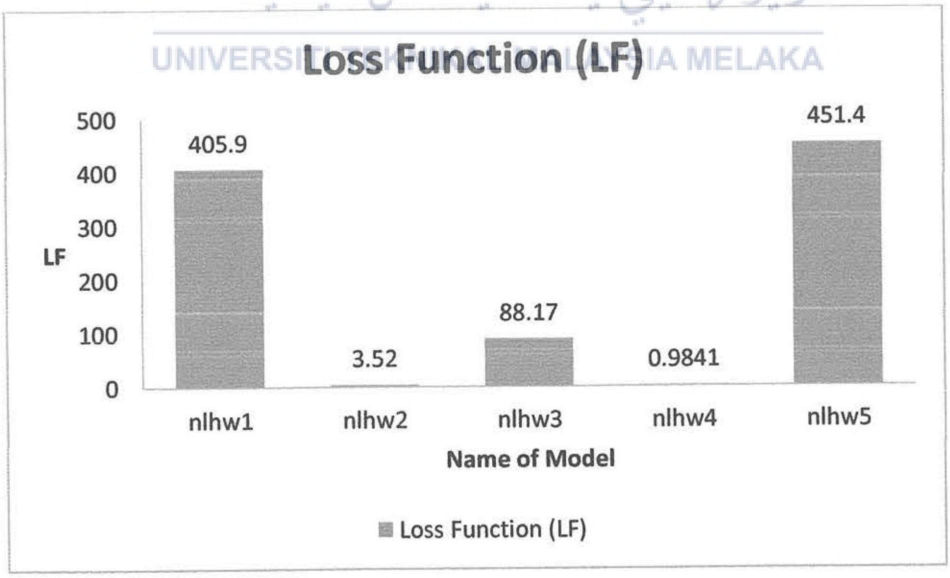

Figure 4.18: Hammerstein- Wiener model Loss Function

The same situation happens in Figure 4.17 Means Square Error (MSE) and Figure 4.18 for Loss Function (LF). Model nlhw1 and nlhw5 is the higher value meanwhile nlhw2 and hlhw4 have the lower value for both bar charts. Based Figure 4.17, the different value of nlhw1 and nlhw5 is 45.5 while the difference value of model nlhw2 and nlhw4 is 2.54. The difference of Loss Function for nlhw1 and nlhw5 is same Mean Square Error weather the difference of nlhw2 and nlhw4.

4.6 Summary of Analysis and Discussion

In this section two model of mathematical equation model have been analyse which is ARX model and Hammerstein-Wiener. The mathematical model capabilities are analyse with four factors which is Best Fits, Final Predictor Error (FPE), Mean Square Error (MSE) and Loss Function (LF). For conclusion, the Hammerstein-Wiener mathematical equation model is acceptable and more accurate compare to ARX mathematical equation model. Hammerstein-Wiener model has highest Best Fits (96.68%) and smallest value of Final Prediction Error. The smallest the value of FPE is the higher the accuracy of the model.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

For conclusion, the first objective to design prosthetic hand which can control degree position of this project is achieved. The discussion in detail of the prosthetic hand design already takes part in previous chapter. The limit of time to explore the science of mechanical design is became the first problem to create the prosthetic hand that suitable and practical to the patient.

The second objective to develop mathematical equation modelling using system identification for multifunctional prosthetic hand is achieved. The explanations for the mathematical equation modelling have been discussed in previous chapter. This mathematical equation modelling can be start after the prosthetic hand complete assembly and ready for estimate the data.

The last objective to validate and verify the nonlinear mathematical modelling and linear mathematical modelling also have been achieved. The linear and nonlinear mathematical modelling have been validate during to estimation process in System Identification app from MATLAB software. The experiment to analyse the mathematical modelling are conducted to analysis the capabilities of linear and nonlinear mathematical equation modelling. In the last conclusion, all objective for this project have been achieved.

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5.2 Recommendation

During to completion the prosthetic hand design, the limitation of time of time to explore the science of mechanical design is became the main issue for complete the first objective. There also the limit knowledge to improve the linkages of mechanical prosthetic hand make a lot of time to make the prosthetic hand movement smooth. Therefore the student should study with someone which has knowledge about mechanical design should make the main problem solved. The open source for prosthetic hand also can help student to complete the design. The hardware also can be improved with put same sticky grip at the palm and finger to estimate parameter of force for the output.

The second improvement can be made is make the comparison the linear and nonlinear mathematical modelling with the controller. Theoretically, the nonlinear mathematical modelling only use simple controller to get desire input compare to controller for linear mathematical equation.

The third improvement is estimate parameter and identification system of five finger of prosthetic hand. The analysis identification and parameter estimation of one finger is the first step to understand the step should do during design mathematical modelling equation.

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APPENDIX

A.Input Voltage and Output Degree Position.

Voltage	Position	Voltage	Position	Voltage	Position	Voltage	Position
5	0	3.61	17	2.22	40	0.83	88
4.97	0	3.58	18	2.19	41	0.81	88
4.94	0	3.56	18	2.17	41	0.78	88
4.92	0	3.53	18	2.14	43	0.75	88
4.89	0	3.5	18	2.11	43	0.72	88
4.86	0	3.47	19	2.08	44	0.69	84
4.83	1	3.44	20	2.06	44	0.67	88
4.81	1	3.42	21	2.03	46	0.64	89
4.78	1	3.39	21	2	46	0.61	89
4.75	1	3.36	21	1.97	47	0.58	89
4.72	2	3.33	22	1.94	49	0.56	89
4.69	2	3.31	22	1.92	50	0.53	89
4.67	2	3.28	23	1.89	51	0.5	89
4.64	2	3.25	23	1.86	51	0.47	89
4.61	3	3.22	25	1.83	53	0.44	89
4.58	4	3.19	24	1.81	54	0.42	89
4.56	4	3.17	24	1.78	55	0.39	89
4.53	4	3.14	25	1.75	56	0.36	89
4.5	4	3.11	25	1.72	57	0.33	89
4.47	4	3.08	26	1.69	57	0.31	89
4.44	5	3.06	27	1.67	58	0.28	89
4.42	5	3.03	27	1.64	60	0.25	89
4.39	6	3	27	1.61	62	0.22	89
4.36	6	2.97	28	1.58	62	0.19	89
4.33	6	2.94	27	1.56	62	0.17	90
4.31	6	2.92	28	1.53	63	0.14	90
4.28	6	2.89	28	1.5	62	0.11	90
4.25	6	2.86	29	1.47	62	0.08	90

4.22	7	2.83	29	1.44	65	0.06	90
4.19	7	2.81	29	1.42	68	0.03	90
4.17	7	2.78	29	1.39	70	0	90
4.14	7	2.75	29	1.36	72	0.03	90
4.11	7	2.72	30	1.33	71	0.06	90
4.08	7	2.69	31	1.31	71	0.08	90
4.06	7	2.67	31	1.28	74	0.11	90
4.03	7	2.64	32	1.25	75	0.14	90
4	8	2.61	33	1.22	75	0.17	90
3.97	8	2.58	33	1.19	82	0.19	90
3.94	8	2.56	33	1.17	82	0.22	89
3.92	9	2.53	34	1.14	75	0.25	89
3.89	9	2.5	35	1.11	84	0.28	89
3.86	10	2.47	35	1.08	86	0.31	89
3.83	10	2.44	35	1.06	88	0.33	89
3.81	10	2.42	36	1.03	88	0.36	89
3.78	11	2.39	36	1	88	0.39	89
3.75	13	2.36	36	0.97	90	0.42	89
3.72	16	2.33	37	0.94	88	0.44	89
3.69	16	2.31	39	0.92	89	0.47	89
3.67	17	2.28	39	0.89	88	0.5	89
3.64	16	2.25	39	0.86	88	0.53	89

Voltage	Position	Voltage	Position	Voltage	Position	Voltage	Position
0.56	89	1.94	49	3.33	22	4.72	0
0.58	89	1.97	47	3.36	20	4.75	0
0.61	89	2	46	3.39	20	4.78	0
0.64	89	2.03	46	3.42	20	4.81	0
0.67	89	2.06	44	3.44	20	4.83	0
0.69	89	2.08	44	3.47	19	4.86	0
0.72	88	2.11	43	3.5	18	4.89	0
0.75	88	2.14	43	3.53	18	4.92	0
0.78	88	2.17	41	3.56	18	4.94	0

0.81	88	2.19	41	3.58	18	4.97	0
0.83	88	2.22	40	3.61	17	5	0
0.86	88	2.25	39	3.64	17	4.97	0
0.89	88	2.28	39	3.67	16	4.94	0
0.92	88	2.31	39	3.69	15	4.92	0
0.94	88	2.33	37	3.72	14	4.89	0
0.97	88	2.36	36	3.75	13	4.86	0
1	88	2.39	36	3.78	11	4.83	0
1.03	88	2.42	36	3.81	10	4.81	0
1.06	86	2.44	35	3.83	10	4.78	0
1.08	84	2.47	35	3.86	10	4.75	0
1.11	84	2.5	35	3.89	10	4.72	0
1.14	82	2.53	34	3.92	10	4.69	0
1.17	82	2.56	33	3.94	10	4.67	0
1.19	75	2.58	33	3.97	10	4.64	0
1.22	75	2.61	33	4	10	4.61	1
1.25	75	2.64	32	4.03	10	4.58	2
1.28	74	2.67	31	4.06	10	4.56	3
1.31	72	2.69	31	4.08	8	4.53	3
1.33	71	2.72	30	4.11	8	4.5	3
1.36	71	2.75	29	4.14	8	4.47	3
1.39	70	2.78	29	4.17	8	4.44	7
1.42	68	2.81	29	4.19	8	4.42	7
1.44	65	2.83	29	4.22	7	4.39	7
1.47	63	2.86	29	4.25	6	4.36	7
1.5	62	2.89	28	4.28	6	4.33	7
1.53	62	2.92	28	4.31	6	4.31	7
1.56	62	2.94	28	4.33	6	4.28	7
1.58	62	2.97	26	4.36	6	4.25	7
1.61	62	3	26	4.39	6	4.22	7
1.64	60	3.03	26	4.42	5	4.19	7
1.67	58	3.06	25	4.44	5	4.17	7
1.69	57	3.08	25	4.47	4	4.14	7

1.72	57	3.11	25	4.5	3	4.11	7
1.75	56	3.14	23	4.53	3	4.08	7
1.78	55	3.17	23	4.56	3	4.06	7
1.81	54	3.19	22	4.58	3	4.03	7
1.83	53	3.22	22	4.61	2	4	9
1.86	51	3.25	21	4.64	2	3.97	9
1.89	51	3.28	21	4.67	0	3.94	9
1.92	50	3.31	21	4.69	0	3.92	9

Voltage	Position	Voltage	Position	Voltage	Position	Voltage	Position
3.89	9	2.5	35	3.89	10	4.72	2
3.86	10	2.53	34	3.92	10	4.69	2
3.83	10	2.56	34	3.94	10	4.67	2
3.81	10	2.58	34	3.97	10	4.64	2
3.78	11	2.61	34	4	10	4.61	3
3.75	13	2.64	31	4.03	10	4.58	4
3.72	16	2.67	31	4.06	10	4.56	4
3.69	16	2.69	31	4.08	8	4.53	4
3.67	17	2.72	30	4.11	8	4.5	4
3.64	16	2.75	27	4.14	8	4.47	4
3.61	17	2.78	28	4.17	8	4.44	5
3.58	18	2.81	28	4.19	7	4.42	5
3.56	18	2.83	28	4.22	5	4.39	6
3.53	18	2.86	28	4.25	4	4.36	6
3.5	18	2.89	28	4.28	4	4.33	6
3.47	19	2.92	28	4.31	4	4.31	6
3.44	20	2.94	28	4.33	4	4.28	6
3.42	21	2.97	26	4.36	4	4.25	6
3.39	21	3	26	4.39	4	4.22	7
3.36	21	3.03	26	4.42	4	4.19	7
3.33	22	3.06	25	4.44	4	4.17	7
3.31	22	3.08	25	4.47	4	4.14	7
3.28	23	3.11	24	4.5	3	4.11	7

3.25	23	3.14	24	4.53	3	4.08	7
3.22	25	3.17	24	4.56	3	4.06	7
3.19	24	3.19	22	4.58	3	4.03	7
3.17	24	3.22	22	4.61	2	4	8
3.14	25	3.25	21	4.64	2	3.97	8
3.11	25	3.28	20	4.67	1	3.94	8
3.08	26	3.31	20	4.69	1	3.92	9
3.06	27	3.33	20	4.72	1	3.89	9
3.03	27	3.36	20	4.75	1	3.86	10
3	27	3.39	20	4.78	0	3.83	10
2.97	28	3.42	20	4.81	0	3.81	10
2.94	27	3.44	20	4.83	0	3.78	11
2.92	28	3.47	19	4.86	0	3.75	13
2.89	28	3.5	18	4.89	0	3.72	16
2.86	29	3.53	18	4.92	0	3.69	16
2.83	29	3.56	18	4.94	0	3.67	17
2.81	29	3.58	18	4.97	0	3.64	16
2.78	29	3.61	17	5	0	3.61	17
2.75	29	3.64	17	4.97	0	3.58	18
2.72	30	3.67	16	4.94	0	3.56	18
2.69	31	3.69	15	4.92	0	3.53	18
2.67	31	3.72	14	4.89	0	3.5	18
2.64	32	3.75	13	4.86	0	3.47	19
2.61	33	3.78	11	4.83	1	3.44	20
2.58	33	3.81	10	4.81	1	3.42	21
2.56	33	3.83	10	4.78	1	3.39	21
2.53	34	3.86	10	4.75	1	3.36	21

Voltage	Position	Voltage	Position	Voltage	Position	Voltage	Position
3.33	22	1.94	49	0.56	89	0.83	88
3.31	22	1.92	50	0.53	89	0.86	88
3.28	23	1.89	51	0.5	89	0.89	88
3.25	23	1.86	51	0.47	89	0.92	88

3.22	25	1.83	53	0.44	89	0.94	88
3.19	24	1.81	54	0.42	89	0.97	88
3.17	24	1.78	55	0.39	89	1	88
3.14	25	1.75	56	0.36	89	1.03	88
3.11	25	1.72	57	0.33	89	1.06	86
3.08	26	1.69	57	0.31	89	1.08	84
3.06	27	1.67	58	0.28	89	1.11	84
3.03	27	1.64	60	0.25	89	1.14	82
3	27	1.61	62	0.22	89	1.17	82
2.97	28	1.58	62	0.19	89	1.19	75
2.94	27	1.56	62	0.17	90	1.22	75
2.92	28	1.53	63	0.14	90	1.25	75
2.89	28	1.5	62	0.11	90	1.28	74
2.86	29	1.47	62	0.08	90	1.31	72
2.83	29	1.44	65	0.06	90	1.33	71
2.81	29	1.42	68	0.03	90	1.36	71
2.78	29	1.39	70	0	90	1.39	70
2.75	29	1.36	72	0.03	90	1.42	68
2.72	30	1.33	71	0.06	90	1.44	65
2.69	31	1.31	71	0.08	90	1.47	63
2.67	31	1.28	74	0.11	90	1.5	62
2.64	32	1.25	75	0.14	90	1.53	62
2.61	33	1.22	75	0.17	90	1.56	62
2.58	33	1.19	82	0.19	90	1.58	62
2.56	33	1.17	82	0.22	89	1.61	62
2.53	34	1.14	75	0.25	89	1.64	60
2.5	35	1.11	84	0.28	89	1.67	58
2.47	35	1.08	86	0.31	89	1.69	57
2.44	35	1.06	88	0.33	89	1.72	57
2.42	36	1.03	88	0.36	89	1.75	56
2.39	36	1	88	0.39	89	1.78	55
2.36	36	0.97	90	0.42	89	1.81	54
2.33	37	0.94	88	0.44	89	1.83	53

2.31	39	0.92	89	0.47	89	1.86	51
2.28	39	0.89	88	0.5	89	1.89	51
2.25	39	0.86	88	0.53	89	1.92	50
2.22	40	0.83	88	0.56	89	1.94	49
2.19	41	0.81	88	0.58	89	1.97	47
2.17	41	0.78	88	0.61	89	2	46
2.14	43	0.75	88	0.64	89	2.03	46
2.11	43	0.72	88	0.67	89	2.06	44
2.08	44	0.69	84	0.69	89	2.08	44
2.06	44	0.67	88	0.72	88	2.11	43
2.03	46	0.64	89	0.75	88	2.14	43
2	46	0.61	89	0.78	88	2.17	41
1.97	47	0.58	89	0.81	88	2.19	41
Voltage	Position	Voltage	Position				
2.22	40	3.61	17				
2.25	39	3.64	17				
2.28	39	3.67	16				
2.31	39	3.69	15				
2.33	37	3.72	14				
2.36	36	3.75	13				
2.39	36	3.78	11				
2.42	36	3.81	10				
2.44	35	3.83	10				
2.47	35	3.86	10				
2.5	35	3.89	10				
2.53	35	3.92	10				
2.56	35	3.94	10				
2.58	35	3.97	10				
2.61	35	4	10				
2.64	33	4.03	10				
2.67	31	4.06	10				
2.69	31	4.08	8				
2.72	30	4.11	8				

2.75	29	4.14	8
2.78	28	4.17	8
2.81	29	4.19	7
2.83	28	4.22	5
2.86	28	4.25	4
2.89	28	4.28	4
2.92	28	4.31	4
2.94	27	4.33	4
2.97	26	4.36	4
3	26	4.39	4
3.03	26	4.42	4
3.06	25	4.44	4
3.08	25	4.47	4
3.11	24	4.5	3
3.14	24	4.53	3
3.17	24	4.56	3
3.19	23	4.58	3
3.22	22	4.61	2
3.25	21	4.64	2
3.28	20	4.67	1
3.31	20	4.69	1
3.33	20	4.72	1
3.36	20	4.75	1
3.39	20	4.78	0
3.42	20	4.81	0
3.44	20	4.83	0
3.47	19	4.86	0
3.5	18	4.89	0
3.53	18	4.92	0
3.56	18	4.94	0
3.58	18	4.97	0

B. Collaboration with myvista Company.