FAKULTI KEJURUTERAAN ELEKTRIK

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

CONTROL OF MOVABLE PLATFORM FOR SURGICAL ILLUMINATION SYSTEM

PRASSHANTH A/L S.SELVERAJOOR

Bachelor of Mechatronics Engineering

December 2017

SUPERVISOR ENDORSEMENT

" I hereby declare that I have read through this report entitle **"CONTROL OF MOVABLE PLATFORM FOR SURGICAL ILLUMINATION SYSTEM**" and found that it has comply the partial fulfilment for awarding the degree of Bachelor of Mechatronics Engineering"

Signature : ....

Supervisor's Name : ....

Date : ....

CONTROL OF MOVABLE PLATFORM FOR SURGICAL ILLUMINATION SYSTEM

PRASSHANTH A/L S.SELVERAJOOR

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

2018

DECLARATION

"I declare that this report entitle" **CONTROL OF MOVABLE PLATFORM FOR SURGICAL ILLUMINATION SYSTEM** "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 : ....

DEDICATION

To my beloved mother and father

ACKNOWLEDGEMENT

First of all, I am grateful to God for giving me the strength and health all the time, especially during the process of doing my Final Year Project in my final semester.

To progress in this project, I was in contact with many seniors from UTeM, researchers, academicians, and practitioners. They had contributed towards my understanding and thought. I would like to take this chance to express my sincere appreciation to my project supervisor, Pn. Nurdiana Binti Nordin, for encouragement, guidance, and motivation. Without her continued support and interest, this project would not have been same as presented here.

I would also like to thank my friends and housemates and others who have helped on various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. Last but not least, I am grateful to all my family members who trust and support me all the time.

Last but not least, I would like to thank my family members, for supporting me 24 years in mentality or physically. Without them, I cannot perform so well to reach this stage. They always trust me and give me the strength to move forward without any fear.

ABSTRACT

Surgical illumination is an essential element in a surgical room. To illuminate an area of interest, surgeons have to manually orient the surgical light which may interrupt the work flow especially during a delicate surgical operations. Hence, the aim of this project to develop an automated movable surgical light which illuminated area of interest automatically without human intervention. A statistical linear controller was designed at both pan and tilt joints to control the movement of actuator for the automated movable surgical light based on the detection of localized markers. Since the localization algorithm is out of the scope of this project, the goal is directed to ensure the movable platform moves to the desired location. In multiple experiments presented, movable platform was proven to be able to move within the desired angle precisely. The angular position of the actuator is analyzed within 25 to 155 degree in 2 significant figures using Monte-Carlo simulation. It was shown that the mechanism was able to be directed to the desired location at 45 degrees with accuracy of 98.5% and with error 1.5% using the proposed control strategy. These results confirmed that the control strategy for the platform built fulfills the objective of this project.

ABSTRAK

Pencahayaan pembedahan adalah elemen penting dalam bilik pembedahan. Untuk menerangi bidang minat, pakar bedah harus mengarahkan secara manual cahaya pembedahan yang mungkin mengganggu aliran kerja terutama semasa operasi pembedahan yang halus. Oleh itu, matlamat projek ini untuk membangunkan lampu pembedahan bergerak automatik yang diterangi kawasan kepentingan secara automatik tanpa intervensi manusia. Satu pengawal linear statistik telah direka pada kedua-dua kuali dan tilt sendi untuk mengawal pergerakan penggerak untuk cahaya mudah alih yang mudah alih alih berdasarkan pengesanan penanda setempat. Oleh kerana algoritma penyetempatan adalah daripada skop projek ini, matlamat diarahkan untuk memastikan platform alih bergerak ke lokasi yang dikehendaki. Dalam pelbagai eksperimen yang dibentangkan, platform bergerak terbukti mampu bergerak dalam sudut yang dikehendaki dengan tepat. Kedudukan sudut penggerak dianalisis dalam 25 hingga 155 derajat dalam 2 angka penting menggunakan simulasi Monte-Carlo. Telah ditunjukkan bahawa mekanisme tersebut dapat diarahkan ke lokasi yang dikehendaki pada 45 darjah dengan ketepatan 98.5% dan dengan ralat 1.5% menggunakan strategi kawalan yang dicadangkan. Keputusan ini mengesahkan bahawa strategi kawalan untuk platform yang dibina memenuhi objektif projek ini.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	SUPERVISOR ENDORSEMENT	**I**
	ACKNOWLEDGEMENT	**V**
	ABSTRACT	**Vi**
	ABSTRAK	**Vii**
	TABLE OF CONTENTS	**Vii**
	LIST OF TABLES	**Xi**
	LIST OF FIGURES	**Xii**
	LIST OF SYMBOL	**Xiv**
	LIST OF ABBREVIATIONS	**Xv**
1	**INTRODUCTION**	**1**
	1.1 Introduction	1
	1.2 Motivation	2
	1.3 Problem Statement	5
	1.4 Objective	6
	1.5 Scope	6
	1.6 Report Outline	7
2	**LITERATURE REVIEW**	**8**
	2.1 Introduction	8
	2.1.1 Overview Of Pan-Tilt Mechanism	9
	2.1.2 Automated Voice Controlled Surgical light	10
	2.1.3 Remotely Operated Surgical Light	11
	2.2 Related Project	12

	2.2.1	Method Of Angular Positioning In A System	12
2.3	Overview On Method Used To Control The Angular Positioning Of The System		21
2.4	Summary Of Method Used To Control The Angular Positioning Of A System		22
2.5	Type Of Actuator		28
2.6	PID Controller		30
	2.6.1	PID Tuning	31
2.7	Fuzzy Logic Controller		32
2.8	Artificial Neural network controller		33
2.9	Summary		35
3	**METHODOLOGY**		**36**
3.1	Introduction		36
3.2	FYP Flowchart		38
3.3	FYP GANTT CHART		40
3.4	Mathematical modelling		41
3.5	Selection Of Simulation Tool		45
	3.5.1	Matlab 2017	45
	3.5.2	Monte Carlo Simulation	46
3.6	Actuator Selection		46
3.7	Proposed Hardware Implementation		47
3.8	Development Of Open Loop System		48
3.9	Development Of Closed Loop System		48
3.10	Statistical Verification		49
3.11	Experiment Setup		50
	3.11.1	Experiment On Motor Rotation	50
	3.11.2	Experiment On accuracy and precision of the pan-tilt manipulator	51
	3.12.3	Experiment On accuracy and precision with various speed of the pan-tilt manipulator	52

4	**RESULT AND DISCUSSION**		**53**
	4.1	Introduction	53
	4.2	Experiment Of Motor Rotation	54
	4.3	Experiment on determining the accuracy and precision of the pan-tilt manipulator	67
	4.4	Root mean square error (RMSE)	73
	4.5	Trajectory Generation	74
	4.6	Comparison between linear movement path and trajectory generation movement path	80
5	**CONCLUSION AND NEXT STEP**		**81**
	5.1	Conclusion	81
	5.2	Recommendation	82
6	**REFERENCES**		**83**
7	**APPENDIX**		**87**

LIST OF TABLES

TABLE	TITLE	PAGE
2.1	Summary Of Method Used To Control The Angular Positioning Of A System	22
2.2	Comparison Of The Actuators	29
3.1	Gantt Chart For FYP 1	40
3.2	Gantt Chart For FYP 2	41
4.1	Data Collected From The Experiment For Pan Joint For Day 1	55
4.2	Data Collected From The Experiment For Pan Joint For Day 2	55
4.3	Data Collected From The Experiment For Tilt Joint For Day 1	56
4.4	Data Collected From The Experiment For Tilt Joint For Day 2	57
4.5	Test Hypothesis Of Each Day For Pan Joint (Yaw)	60
4.6	Paired Sample Test For Pan Joint	61
4.7	Test Hypothesis Of Each Day For Tilt Joint (Roll)	63
4.8	Paired Sample Test For Tilt Joint	64
4.9	Data Collected For Measured Angle From Experiment For Pan Axis	69
4.10	Data Collected For Measured Angle From Experiment For Pan Axis	71
4.11	Data collected from the rotary encoder reading for pan axis	75
4.12	Data collected from the rotary encoder reading for tilt axis	78

LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1	Percentage Of The Mental Workload In The Operating Room	3
1.2	Types Of Medical Error In 1997 [2]	4
2.1	Pan-Tilt Mechanism [6]	10
2.2	Permanent Magnet Dc Motor Control System Block Diagram [12]	13
2.3	Position Of Angular Axis [16]	14
2.4	Servomotor System Block Diagram [18]	16
2.5	Servomotor Simulink Model System [18]	16
2.6	Robotic Arm Servo Drive Block Diagram [19]	17
2.7	Self –Regulation PID System Block Diagram [20]	18
2.8	1st Link Controller Block Diagram [21]	19
2.9	2nd Link Controller Block Diagram [21]	19
2.10	Proportional Controller Cascaded System Block Diagram [22]	20
2.11	Servo Motor	29
2.12	Stepper Motor	29
2.13	Dc Motor With Encoder	29
2.14	PID System Plant [25]	30
2.15	The Block Diagram Of The Fuzzy Logic Controller [28]	32
2.16	Artificial Neural Network Controller Block Diagram [29]	34
2.17	ANN Controller Block Diagram For Robot Arm (Dc Motor Position Control) In Matlab Simulink [29]	34
3.1	Overall Flowchart For FYP 1 And FYP 2	38
3.2	Free Body Diagram Of The System	41
3.3	Free body Diagram With Dimension	42
3.4	Datasheet of the motor	43
3.5	Hardware Design Of The Surgical Illumination System	46

3.6	HD1501-MG Servo Motor	47
3.7	Open Loop System Block Diagram	48
3.8	Closed System Block Diagram	48
4.1	Experiment Setup Of The Servo Motor Rotation	54
4.2	Experimental Setup Of The Accuracy And Precision Test For Pan Axis	67
4.3	Experimental Setup Of The Accuracy And Precision Test For Tilt Axis	68
4.4	Graph of measured angle vs desired angle of the pan axis rotation of the manipulator.	70
4.5	Graph of measured angle vs desired angle of the tilt axis rotation of the manipulator.	71
4.6	Graph of rotary encoder data vs desired angle up to range of 65 degrees for pan axis	76
4.7	Graph of rotary encoder data vs desired angle up to range of 110 degrees for pan axis	76
4.8	Graph of rotary encoder data vs desired angle up to range of 155 degrees for pan axis	77
4.9	Graph of comparison rotary encoder data vs desired angle from the range of 65 to 155 degrees for pan axis	77
4.10	Graph of rotary encoder data vs desired angle up to range of 60 degrees for tilt axis	79
4.11	Graph of rotary encoder data vs desired angle up to range of 100 degrees for tilt axis	79

LIST OF SYMBOL

º	-	Degree
e	-	Error
s	-	second

LIST OF ABBREVIATIONS

PID	-	Proportional-Integral-Derivative
PMDC	-	Permanent Magnet Direct Current
SMC	-	Sliding Mode Controller
SCPT	-	Saturation Constraints and Performance Technique
FFNN	-	Forward Neural Network
DOF	-	Degree of Freedom
TWMR	-	Two-Wheeled Mobile Robot
FLC	-	Fuzzy Logic Controller
ANN	-	Artificial Neural network
PWM	-	Pulse Width Modulation
ANOVA	-	Analysis Of The Variance
SPSS	-	Statistical Package For The Social Sciences
RMSE	-	Root Mean Square Error

CHAPTER 1

INTRODUCTION

1.1 Introduction

The most important element in the surgical room is the illumination of the light. In recent years the surgeon needs to adjust the surgical lighting manually on their own. Therefore, the surgeons move the position of the lamp by holding the lamp body at sterile hand cover and pushed the handle of the lamp to the desired position and orientation. So surgeons required to adjust the surgical light in a proper direction in a continuous during the surgery. During a surgery, it is required the hand of the surgeons is not become unhygienic by placing their hands on this object. This has distracted the focus of surgeons during the operation [1]. In recent years, many surgical illuminations have been developed such automated movement of the surgical bed, surgical robots and so on. At times it is inconvenient to reposition the position of the illumination system whenever the surgeon changes his posture. To overcome this problem an automated movable surgical illumination with the function of several degrees of freedom and precise control of positioning system to be developed.

Generally, the surgical light has two links with a single joint, which one on it able move rotate about the z-axis (yaw) and another one is able to rotate about the x-axis (roll). This mechanism is mounted directly to the ceiling of the operating room. So this project is about to design and developed an automated movement of surgical light based on the movement of the surgical tool. Moreover, each link has an actuator which allows the mechanism to moves in the desired direction. The mechanism moves based on the torque emitted from the actuators. The movement of the surgical light needs to be precise and accurate in order the system to be more efficient. The movement of the surgical lamp, depends on the positioning of the actuators.

Therefore, for precise positioning and accuracy of the actuators, a controller is very much needed in the system. A linear controller will be developed and be tuned to improve the system performance.

1.2 Motivation

Surgical illumination tools are being invented especially to perform a specific action or carrying out a desired outcome during the surgery. This type of modern tools may assist the doctor and reduce the work on considering the lighting factor during surgery or operation. Over time, many different kinds of surgical instruments and tools have been invented.as the need to do wonders continuous, so does the complexity of the tools.

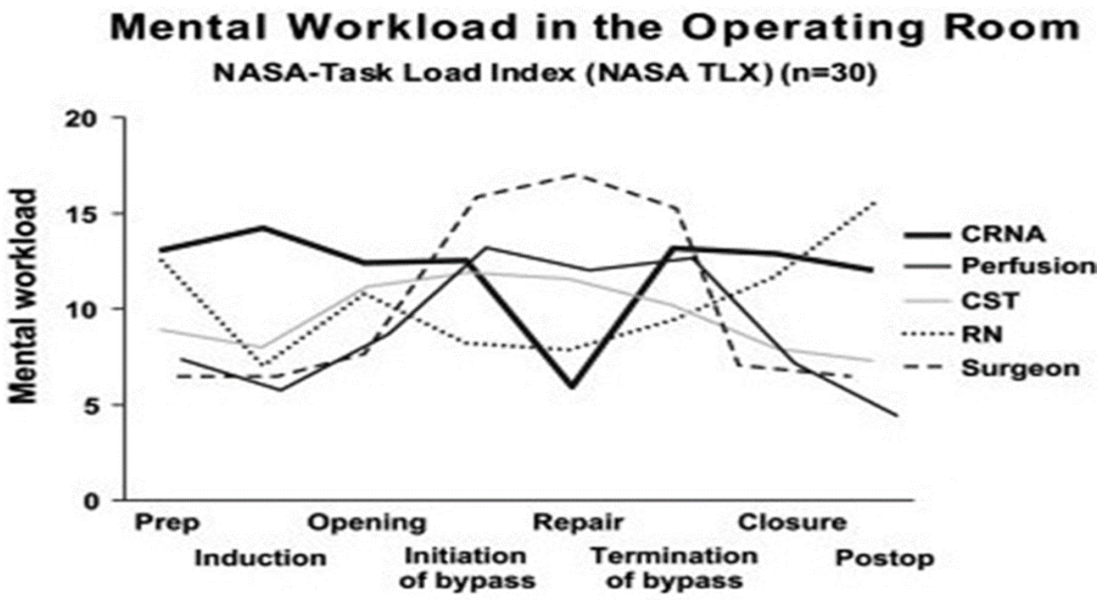


Figure1.1: Percentage Of The Mental Workload In The Operating Room

Figure 1.1 shows the mental workload that has carried by the doctor during the surgery. Doctors have always been needed to perform at their optimum whenever needed. According to the graph, it could be seen that surgeon has the highest mental workload and they do need better equipment to assist them in their daily tasks. A simple thin line is a difference between a successful and failed surgery. A modern equipment may help to reduce their pressure during the surgery and operation, perhaps help them to be more focus in their work.

As they are handling delicate parts of the body, illumination is also a very important so that they could focus on their work. As in the early 18th century, surgeries always takes place in the day due to make full use of natural sunlight. Bad weather conditions may affect the progress of surgery. Moving on, using natural lighting can easily be blocked by tools, nurses or even doctors themselves. This results in higher failure risks to be assessed. Since then the surgical procedure is done in a closed dark room without any light penetration of outside. The necessary light source is provided from the surgical light that is mounted together with the ceiling of the operating room. This mechanism needs to be moved manually by the surgeons or nurses.

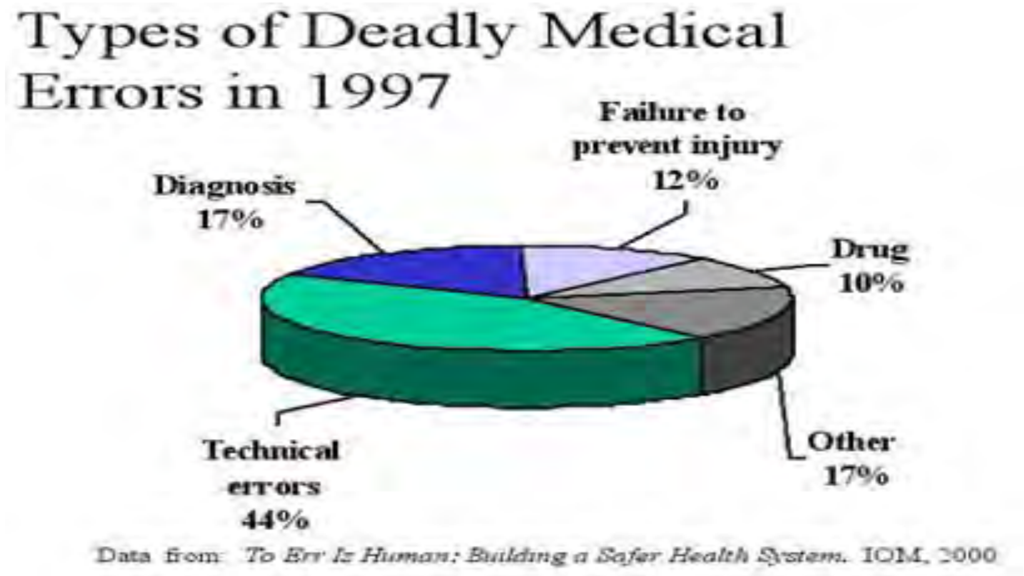


Figure 1.2: Types Of Medical Error In 1997 [2]

Figure 1.2 indicates that in the year 1997, 44% of the death in a hospital are caused by technical error. Technical error falls due to the failure of the surgical instrument, tools and etc. so one of the important elements in an operation room is the surgical light. The focus of the light towards the patient surgical part plays a key role in the surgery or operation. So during a surgery or operation, doctors or nurse have to relocate the surgical light to the required position until they get a good focus of light [3]. This will distract the focus of the doctor on their work if they did not receive a good light source to the surgery part at the right time and may cause an error. So an automated control of a surgical lamp may east the doctor job. Moreover, to reduce the number surgeons and nurses required during the surgical procedure is done, which there are no needs of a person for handling the orientation of the surgical light. Perhaps the person can be utilized in other ways during the surgery. Besides that to limit the disturbance produce from surgical lighting mechanism. So a control system with surgical lighting mechanism can limit the disturbance produce from the mechanism. Therefore, a control movable platform for surgical illumination is beneficial, so it can assist the doctor in achieving greater heights in a successful surgery.

1.3 Problem Statement

A movable platform for the surgical lamp is very useful in surgical work environment instead of shifting it manually. So in this project, an automated movable platform for surgical illumination prototype was designed where the surgical lamp was mounted with a pan-tilt mechanism model. However, mounting the pan-tilt mechanism with surgical lamp might produce some problem in the system.one of the main concerns in this prototype is suffer from external disturbance [4]. The external disturbance occurs due to the connection of the parts between the link joints and surgical lamp. For example, a loose part of mechanism could weaken the stability and performance of the system. Generally, the noise produced by a mechanical vibration could differ the performance of the system. External disturbance also happens at the joints of the mechanism. The friction produce between one link joint with another link joint will cause the delay in movement of the surgical illumination mechanism.

Furthermore, it also suffers from high-frequency vibration. High-frequency vibration happens when the joint of the mechanism coupled together with a heavy load. Thus, if the mechanism moves with a heavy load, it may cause inertia to be initiated on the mechanism. So inertia from the load can cause the mechanism to jerk and vibrate. The load in our mechanism is from the weight of the surgical light [5]. Moreover, sudden shock also influences the mechanical movement. Sudden shock occurs when frequency tracking where the position and the speed of certain target differ in unpredictably so it can't sense the actual input signal. Then the transition from stationary to any moving at a rapidly cause sudden shock [6].

Therefore a good controller like linear controller can compensate this type of problem and allows the mechanism to move smoothly.

1.4 Objective

The objective of this project are;

1. To analyze the open loop performance of movable platform for surgical illumination
2. To design a controller to improve closed-loop performance for movable platform of surgical illumination
3. To compare and analyze the controller performance of the movable platform.

1.5 Scope

The scope of this project are;

I. Using two degrees of freedom pan-tilt mechanism model as linkage bound between the surgical lamp and motor for mechanical modelling.

II. Angular position will be analyzed within (25 -155) in 2 significant figures using Monte-Carlo simulation

1.6 Report Outline

This report consists of 5 main chapters. Firstly, the title of the project was confirmed at the initial stage. This report starts with the first chapter that is the introduction. The first chapter discussed the overview of the project background, problem statement, objective, scope, and the expected outcome of the project. It is explained in detail about the motive of this project. Then this report is continued with the second chapter literature review. Chapter 2 discussed literature review that is related to this project based articles, journal, books, and internet.in this particular chapter it is discussed briefly about the fact, technique and results about from the previous studies. Next is the methodology chapter where it described the planning, methods going to use, procedures of experiment going to be done throughout the project and tools such as Matlab Simulink. Chapter 4 discussed the results and analysis. The results obtained from the project will be analyzed well in this chapter. Finally, the last chapter is conclusion where discussed the project achievement and future recommendation.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this particular section, several studies have been done regarding "control of movable platform for surgical illumination system". This part covers the previous study that is related to this project. The existing surgical light head is able to move in pitch and yaw direction which is already mounted with the ceiling of the operation room. So an automated development in this system needs to move in that particular direction. So based research done the existing pan-tilt mechanism which mostly used in surveillance camera able to move in pitch and yaw direction. Thus, the concept pan-tilt mechanism is inherent in this automated surgical illumination system. Moreover, the type automated system used to move the surgical light also discuss.

2.1.1 Overview Of Pan-Tilt Mechanism

Basically, a pan-tilt mechanism is mostly used in a surveillance camera system. However, in this project, the pan-tilt mechanism has been used as a model to control the movement of the surgical lamp automatically. The pan-tilt platform has two shifting joints. The pan-tilt platform is a mechanism that makes a camera or an object to point in the desired direction when it is mounted with it. The pan-tilt is a degree of freedom mechanism that has a rotatable pan and rotatable tilt with a supporting base to move the mechanism in the desired direction. The pan mechanism and tilt mechanism is perpendicular to each other axis. Furthermore, pan-tilt platform has a gear at the shaft of the motor, which transfers torque to the mechanism which allows it to moves [7].

The pan-tilt device consists of two motor, encoder, motor drivers. It communicates with the processing center through the serial port. The two degree of freedom can be turned and pitched separately. In a surveillance camera, the target is tracked by updating motor specification in real time through the motor driver where it uses programmed velocity mode to track the target. In a vertical direction, the pitch angle is from -90 to 90 degree. But space of rotating angle is -170 to 170 degree. The maximum acceleration of the pan-tilt mechanism is about 167 degree per second. Finally, the pan-tilt mechanism consists of several Hall Effect, which limits the maximum rotation angle [8].

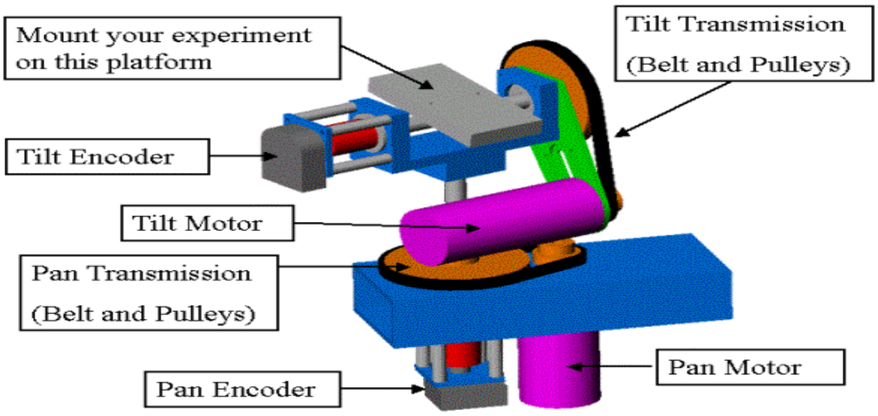


Figure 2.1: Pan-Tilt Mechanism [7]

Thus, due to the size and position limitation of pan-tilt mechanism, the concept of the pan-tilt mechanism is inherent in this project rather than mounting it directly with the surgical lamp.

2.1.2 Automated Voice Controlled Surgical light

System regarding voice controlled surgical equipment is used to perform a surgical procedure in the operating room. Typically, a voice-controlled system able to control the movement of the surgical light and surgical table. The system consists of a speech recognition device that recognizes the voice command from the surgeons. The voice-controlled system is very much responsive to the voice command from the surgeons and produces the output signal based on the recognition which will be generated by the processing unit. Then the feedback from the processing unit which controls the movement of the surgical light.so the surgical light head is connected with a voice recognition system that enables it to move in the desired direction based on voice command. Generally, the surgical light is supported with a mechanical rotary hub member that is attached to the ceiling. This allows the mechanism to move in any direction freely without any mechanical binding [9].

This particular system has more efficient and easier to use in the medical equipment. Furthermore, it also reduces the risk of miscommunication of command during the operation from surgeon's to the other staff to move the surgical light to the required direction. Thus, reduces the number of surgeon's or nurse required for the surgical purpose.one of the main advantage of the system is increasing the safety features where it is included with a first delay reset step. The first delay step is activated when a valid command is given to the system, then it acts to the command and takes a 10-second delay for the next command to be executed. The voice control system is controlled by using word recognition technique. Besides that, the voice-controlled system able to control the on/off action of the light, the brightness of the light intensity and movement of surgical light in tilt, flex, back and stop motion. However, this particular system has a limitation, where it is a semi-automated system, which needs direct commands from the humans to control the movement of the surgical light.

2.1.3 Remotely Operated Surgical Light

The system operates based on a control panel box that is mounted on the wall of the operating room. Basically, a motor is coupled together with the surgical light to provide movement to the mechanism. The control panel box is included with the features of up, down, rotate, left and right movement.as the surgeons initiate a movement on the control panel box, the motor also act according to the movement from the control box.so the surgical light also moves according to it when it is coupled together with the motor. In addition, the remotely operated surgical light has a special feature where it is able to control the light intensity of the surgical light. High light intensity may produce heat radiation and increase the energy requirement, most importantly produces glare in the operation room. This may distract the concentration of the surgeons.to overcome this problem, the incoming voltage to the control panel box is converted to a lower voltage, so the light intensity produce based on this system is lesser compared to the previous surgical light without the control panel box. But this system also a semi-automated system where it required monitoring from a person to enables the movement of the surgical light [10].

2.2 Related Project

The path of studies done from the type of mechanism used, type of actuator, type of method and technique used to control the position of the surgical illumination. Several studies were done to find out the best method to approach the position control of the mechanism.

2.2.1 Method Of Angular Positioning In A System

The angular positioning of the permanent magnet Dc motor (PMDC) motor was controlled using a PID controller. Particularly, these PID controllers operate while the motor angular position signal acquired from the servo potentiometer is above or below the setpoint value. Therefore the motor rotates in the preferred direction and it stays at the position when the valve function signal will become same to the analog set value signal. Thus, the type of input vector given to this system was voltage and angle.In previous work, the mechanism is designed in a way where it is able to move 3 direction heave, pitch and roll directions in which sway, surge, and yaw are repressed by mechanical addictions. This movement is achieved by the positioning the actuators [11]. The figure 2.2 shows the permanent magnet dc motor block diagram. The position control of PMDC motor also is achieved utilizing the Matlab and data acquisition system. The angular position of the motor is calibrated by Matlab based on PID controller where the output voltage produce has to pass through the data acquisition system [12].

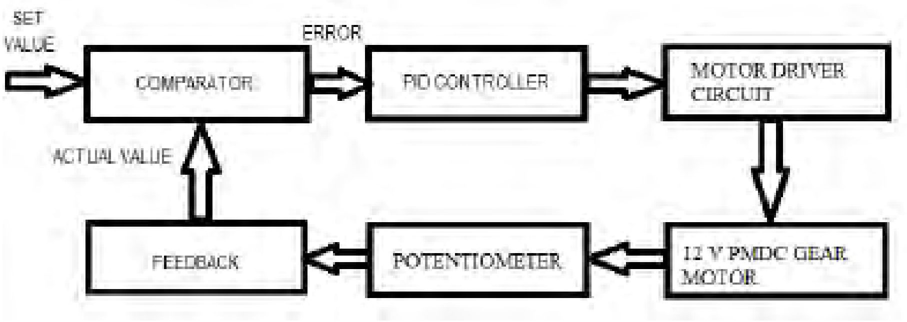


Figure 2.2: Permanent Magnet Dc Motor Control System Block Diagram [12]

Error based self-regulating of the PID controller was designed to control the position of the PMDC motor. In this particular system, the steady state error produces based on the implementation of PID controller is zero. The error may differ, because of two reason that is sudden changes in the parameter and load changes [13].

Besides that, a sliding mode controller (SMC) was developed to deal with nonlinearities changes in vertical position and angular position. So an SMC and PID controller was compared to know the efficiency of the SMC. It is said that a fuzzy logic controller is not appropriate for this system because it needs more detailed about the system. Fuzzy based controller has no custom tuning method. In this project, Ziegler-Nichols methods are used to tune to get the controller gains. The gains were provided from Matlab optimization toolbox. SMC shows high frequency, however, it is robust [14].

Moreover, fuzzy based PID controller was developed to provide better results in controlling the angular position of the system. In the previous study, 3 parallel fuzzy self-adaptive PID Controllers are used to track the desired path and angular position of the autonomous surface of the system that is along the surge, swag and yaw ways. So this hardware construction can be considered into the movable platform of surgical illumination. A fuzzy-based PID controller able to perform faster in tracking and minimize the overshoot. So a Fuzzy PID does not need complex mathematical modeling and it can be used in all working environment. Thus, reduces the error and responds faster than traditional one [15].

The stability of the angular position of an unmanned aerial vehicle was controlled using a PID controller. The stability of the angular position that is the pitch and roll and yaw speed was control within the predetermined value. The controller was tuned by using the technique of Saturation Constraints and Performance Technique (SCPT) and root locus. It produces a good result in term of stability and it does need required complex control technique. As shown in figure 2.3 the speed of the unmanned aerial vehicle was measured along the fixed frame of the roll, yaw, and pitch.

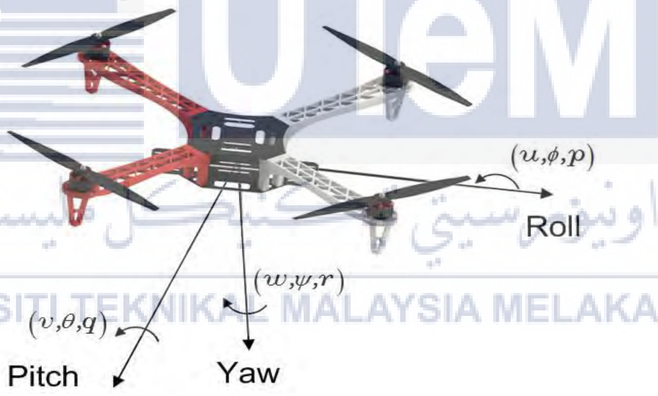


Figure 2.3: Position Of Angular Axis [16]

Basically, the error produced by the system is reduced by the proportional control, eliminate by the integral action and accelerated by the derivative controller. The desired set point was gathered by tuning the controller gain. Saturation from the actuator can limit the efficiency of the controller. Even though the system is tuned by SCPT technique, still there are possibilities of having steady state error in the system. This error can be removed by tuning the integral controller. So the gain of the system can be obtained from the root locus based on the desired value needed [16].

Thus, PID controller also is used for controlling the angular position control of the plate that has nonlinear characteristics. It is required to control a system with a controller that can assure that the system is stable where it does not has an overshoot. This system has a high nonlinear characteristic and sensitive to disturbance. A potentiometer is used to provide feedback on the position motor. PID controller is a simple, operational and relevant technique that can boost the performance of the fan and plate system. PID controller also has a simple structure and good robustness [17].

However, neural network controller was used to developing an intelligent DC Servomotor Neural model position control scheme and it is defined with a mathematical model that can be utilized during offline mode. The important parameter that can affect the angular position control of the dc servo is saturation, dead zone, and load changes. Therefore, the saturation in a system limit the output position of the motor and distract it from reaching its reference position as the set, further increase the overshoot of the system that causes the system to be unstable. Thus, dead zone arises due to the fixed friction which limits the input of the system from the previous one to a smaller input which leads to the system unable to reach its maximum output of the system. Moreover, the backlash may happen due to gear connection do not fit well with motors mechanical system. For instead, now gears slave not mesh exactly leaving some areas in the tooth that causes a loose connection and, hence, a defective impact on the system performance. Load changes in a system cause increase in overshoot in the system which leads to instability. Figure 2.4 shows the block diagram of the servo motor which includes the load, armature and back emf. The traditional controller such as PID control might not provide the best performance to the system due to dynamic factors and nonlinearities of the system. So a neural network controller was used in the system to overcome nonlinearities and dynamic factor. The offline simulation of the system is performed using Matlab Simulink tool [18].

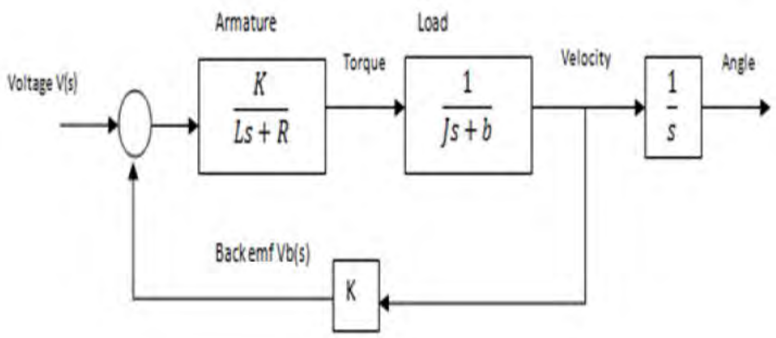


Figure 2.4: Servomotor System Block Diagram [18]

Figure 2.5 shows the servo motor Simulink block diagram that includes the transfer function, integrator, dead zone, saturation and so on. The transfer function of the dc servomotor is obtained from an electrical and mechanical part of the system. The neural network controller is broken up into two types that are Forward Neural Network (FFNN) and Back-propagation Training Method. The FFFN network is a controller that allows the data to move in a single forward direction from the input to the hidden layer than to the output. Back-propagation is upgraded training method where the set input data or the output data are to train the network. Both of this method helps to minimize the error in the desired value.

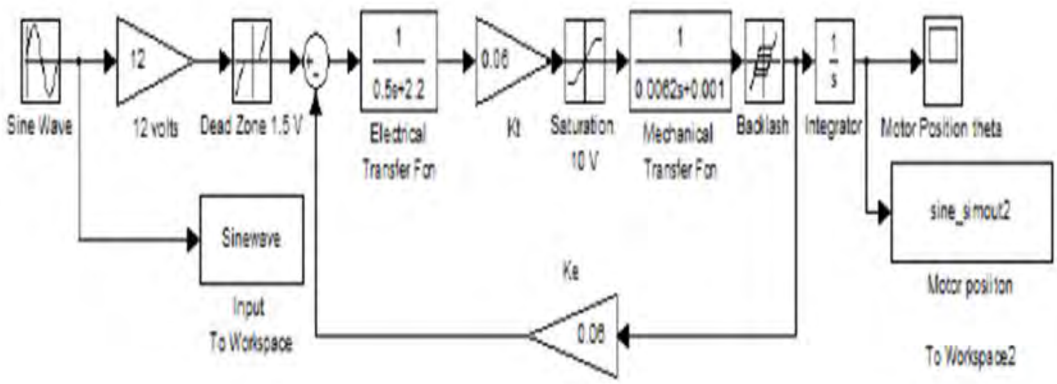


Figure 2.5: Servomotor Simulink Model System [18]

The input data were obtained from the test signal and the output data received from the model, then it was used to train the network to have the same function as the servomotor. As a conclusion the neural network controller able to produce a better performance than the conventional PID controller. The neural network controller able to remove the nonlinear effect on the system [18].

Nevertheless, Fuzzy-Based PID controller has used to the controller the brushless dc motor which is connected vertically to the one DOF Robot Arm. The position of the servo is drive with brushless dc motor. Figure 2.6 shows the robotic arm servo drive block diagram. The load torque of an arm differs from the gravity that acts on it .so it requires a robust feedback controller. A fuzzy-based PID controller provides a better dynamic response than the conventional PID controller. Fuzzy PID controller also provides a better error reduction. The simulation of the system is carried through Matlab Simulink tool [19].

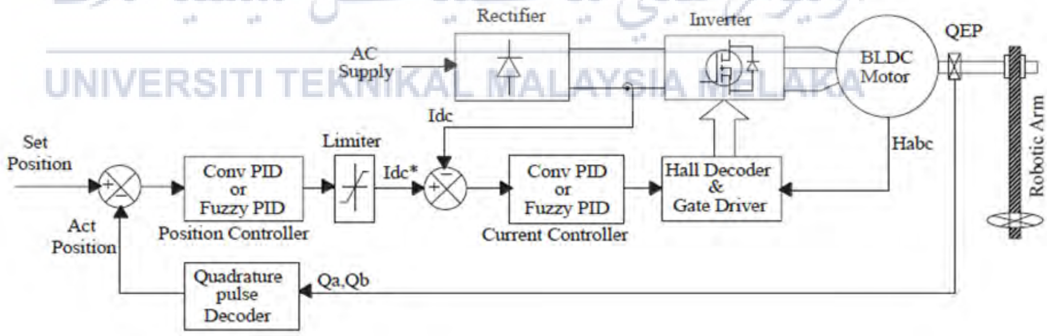


Figure 2.6: Robotic Arm Servo Drive Block Diagram [19]

In this particular system, it requires two feedback from the closed loop which is inner loop current controller that minimizes the current that flows in, as it prevents the motor from damage. Another loop is the position controller outer loop that sustains the arm to move to the desired position. The motor made to move in all four position of the one DOF arm robot. From the experiment done and simulation the fuzzy-based PID able to minimize the settling time and maintain the same time interval between the all four position [19].

The position control of a pneumatic actuator system was controlled using the self–regulation nonlinear PID controller. However, it is challenging to achieve an accurate position control using pneumatic actuator in a nonlinear system. As shown figure 2.7 the controller was designed to compensate the delay time and the error produces from the system. Using self- regulation nonlinear PID, the position error can be compensated by reducing the delay time in the system. The instability caused by the friction from mechanism also can be compensated by tuning the integral controller. The simulation of the mathematical modeling of the system was carried out using Matlab Simulink tool. This particular method able to show the variation of the results between real-time and analysis in different load changes [20].

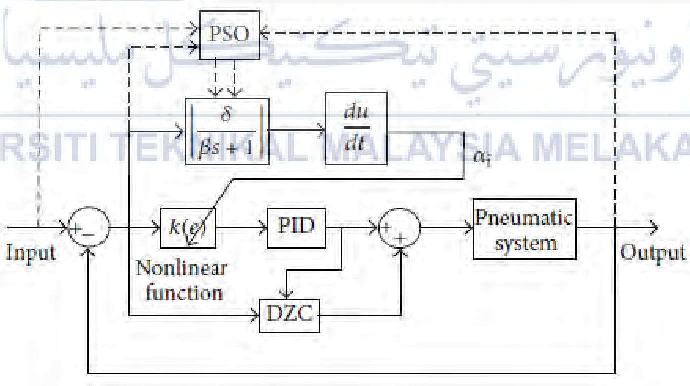


Figure 2.7: self –regulation PID system block diagram [20]

The transfer function of the system is provided from the system identification tool. The input and output results for the open loop system was collected within a range of sampling time. This controller able to reach the displacement of the actuator fast and precisely without significant overshoot. It is robust and more efficient in improving the step response of the positioning on the pneumatic system [20].

Furthermore, two types of the controller which PD-Fuzzy and PID controller is compared to produce the balance control on double link of a two-wheeled mobile robot (TWMR). Figure 2.8 shows the block diagram of the first link using PID controller and Figure 2.9 shows the block diagram of the second link using a PD-fuzzy controller. The controller was used in both links. IMU sensor was used to provide the angular position from the first link, whereas in the second link KALMAN filter theorem was used to reduce the present disturbance. A controller is very much needed in both links because the difference in the angular position in the second link and its linear motion will affect the stability and balancing of the first link [21].

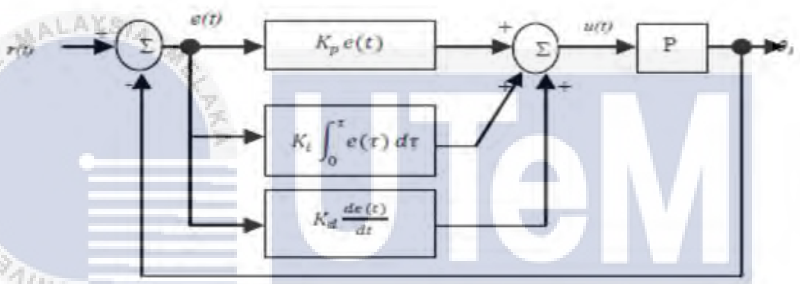


Figure 2.8: 1st Link Controller Block Diagram [21]

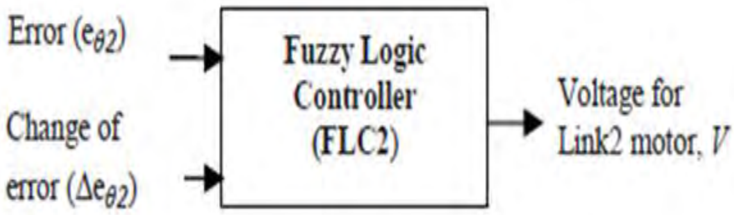


Figure 2.9: 2nd Link Controller Block Diagram [21]

The fuzzy logic controller was designed by using PD-type, where the inputs given to the system were error and change of error, whereas the output provided from the system is the voltage that been supplied to both motor left and right. The system was tested with several input reference. So both of this controller able to provide a balance controlling between both links. The system provides an output faster and has a minimal amount of position error which shows the robustness of the controllers [21].

A proportional controller cascaded with improve fuzzy proportional and integral controller (P-PIFLC) is used to reserve the displacement according to its reference point. Generally, the friction produces from the servo actuator, angular transmission error, and variable transmission behaviour from the gear cause the system performance decline. Matlab Simulink tool was used to provide the simulation result of the system. Figure 2.10 shows the design of the block diagram for the proportional controller cascaded.

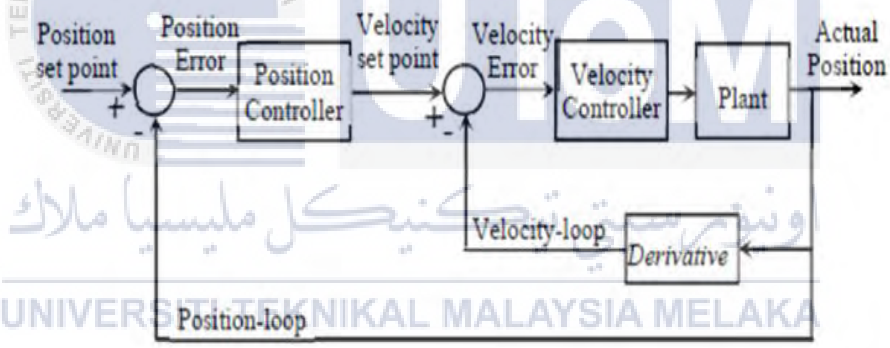


Figure 2.10: proportional controller cascaded system block diagram [22]

Cascade control system able to produce a better performance than the single loop control system. This is system the cascade control system comprises of a proportional controller that controls the position and proportional plus integral controller which control the velocity. As per result to produce standardize velocity error and change in velocity error, the input of the PIFLC was tuned manually based on the block diagram design assumptions. So the PIFLC has improved the positioning of the harmonic drive of the mechanism [22].

2.3 Overview Of Method Used To Control The Angular Positioning Of The System

Most of this method discuss about the angular positioning of a system in pitch, yaw, roll, heave and swag and etc. Several controller and technique were used to achieve the best outcome from the system. This technique could be considered in the movable surgical system where it has two link joints that have to move in yaw and roll direction.

2.4 Summary Of Method Used To Control The Angular Positioning Of A System

Table 2.4: Summary Of Method Used To Control The Angular Positioning Of A System

Author	Type of actuators	Controller	Range of input test and percentage of error	Hardware implementation	Tuning Technique	Sensor
Supachai Prawanta, Sorada Khaengkarn, Jiraphon Srisertpol (2016)[11]	Permanent magnet dc motor	Proportional integral derivative controller (PID)	Range: 135 to 45 degree, the ideal eccentric angle is -135 degree. The rotary encoder was fixed at 0.144 degrees per step. The angular position of the actuator is tested with ± 90 degrees. Error: ±0.15 degree	design based three points of the eccentric cam actuator	Real-time rapid control prototyping platform(RAPCON)	displacement sensor, inclined sensor

Mandakinee Bandyopadhyay, Nirupama Mandal, Subrata Chattopadhyay (2016)[12]	Permanent magnet dc motor (PMDC).	PID controller	Range: output signal 0-5 v, angular position is between 0-270 degrees. The experimental test is 0-20, 20-60 and 90-100 degree. Error: 0-20 degree is ± 1.7 .for 20-60 degree is ±1.0.then for 90 -100 degree is ±2.	A pc based position control system PMDC motor	Data Acquisition system	-
Bahador Rashidi, Milad Esmaeilpoor (2014)[13]	PMDC motor	PID controller and error-based self-regulating PID controller (SPRID)	The shaft encoder is fixed with 20000 pulse/rev.kp and Ki set at maximum 125 and minimum 0. For Kd, the maximum range is 2 and minimum are 0. Error: 0.002 radians	-	Ziegler-Nichols and Chien-Hrones	-

Lindokuhle J. Mpanza, Jimoh O. Pedro (2015)[14]	Servo motor	PID controller and sliding mode controller(SMC)	Range: zd=0.5 sin (0.05t) and od=0.3 sin (0.05t). Error: vertical tracking is below 100mm. angular positioning is 1×10-2 rad.by using PID: displacement 2mm. the angular position error is 5.518 ×10-3rad.by using smc; 8mm, angular position error 4.67×10-3rad	-	Ziegler-Nichols methods matlab optimization toolbox	-
M. H. A. Majid, M. R. Arshad (2015)[15]	Twin electric motor	PID controller fuzzy self-adaptive PID	Range: kd set at 0.3,0.3), (-0.3,0.3), (-0.06, 0.06). Error:	-	-	-
M. F. Silva, A. C. Ribeiro, M. J.	Brushless electric motor	PID controller	Range:-	Unmanned aerial vehicle (UAV) based on a	Saturation constraints and performance	-

Carmo, L. M. Honório, (2016)[16]			Error: overshoot where it has 2.31% of error	quadcopter design type.	technique (SCPT) and Root Locus.	
Emre Dincel, Yaprak Yalçın, Salman Kurtulan (2014)[17]	Asynchronous motor	PID controller	Range: 0-53 degree. Error:-	-		-
Fernando Rios-Gutierrez, Yahia F.Makableh (2011)[18]	Dc servo motor	Intelligent neural network controller(NN)	Error: 0.0005 rad	-		-
R.Manikandan, M.E, (Ph.D.), Dr.R.Arulmozhiyal, M.E, Ph.D., (2015)[19]	Dc brushless motor	PID controller and fuzzy based PID controller	Range: 360 degrees forward and reverse rotation. Error: using PID, -6.66 .using a fuzzy based PID controller error obtain is +2.22.	Fuzzy-Based BLDC Fed Vertically Rotating One DOF Robot Arm position Control System.	-	-

Syed Najib Syed Salim, Mohd Fua'ad Rahmat (2014)[20]	Pneumatic	Self-Regulation Nonlinear PID	Range: displacement between 200 to -200 mm. Error: the variation of error is 2	-	-	-

2.5 Type Of Actuator

The actuator is one of the main criteria in an automatic system. So, choosing the right type of actuator is the most concern thing in this system. Mostly, the common actuator that can be installed in this type of prototype is a servo motor, stepper motor, and dc motor.

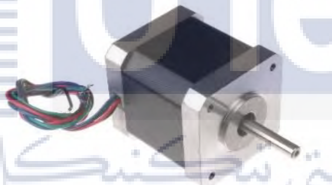
Pneumatic actuators are broadly implemented in numerous industrial applications such as manufacturing, robot manipulator, pick and place motion and rivet machine. The pneumatic actuator is reliable, fast, easy installation and less maintenance. It also does not get overheated fast due to changes of load. However, the actuator shows high nonlinear characteristics due to friction forces, the air compressibility and dead band in the valve movement. These nonlinearities can cause difficulties to the actuator to achieve the desired position control [20].

Dc servo motor is considered as the main element in industrial application and automatic system. They are used in many application such as robotic arms, automatic doors, CNC machine and many other applications [17].A servo motor is normally fixed with four major parts that a dc motor, gearing set, position sensor and control circuit. They consist of 3 main wire that is power, ground, and control. Servo motor able to provide a precise position controlled. Pulse width modulation (PWM) control the signal of the servo motor. Servo motor also able to produce high torque and its fast responding. But it requires a closed loop feedback signal.

Stepper motor has multiple toothed electromagnets that are assembled around the gear in order to provide the position. Stepper motor requires a controller to energize the electromagnet, so the motor will be able to move. But stepper motor does not require any feedback signal. Stepper motor can provide high torque but it is slow. It has a precise position control [23]. Stepper motor is cheaper compared to the servo motor.

Thus, the desire position can't be obtained at the specific time due to the speed of the stepper motor. DC motor has two wire that is power and ground. The speed of the dc motor is controlled by pulse width modulation (PWM). Dc motor produces high torque and it's fast. So it is suitable for the automatic process where it can move to the desired position in quick a section. Furthermore, it has a simple connection. However, the servo motor and Dc motor is suitable to be used in this project, to solve the positioning problem of the surgical lamp. Servo motor provides an accurate positioning and speed control of the system. Table 2.5 shows the comparison between the actuators and the reason for selecting this actuator. [24].

Table 2.5: Comparison Of The Actuators

Servo motor	Stepper motor	Dc motor
 Figure 2.11: servo motor	 Figure 2.12: stepper motor	 Figure 2.13: Dc motor with encoder
High torque and fast	High torque and slow	High torque and fast
Precise positioning	Most precise positioning	Precise positioning
Requires feedback	Does not required feedback	Requires feedback
Position Controlled by pulse width modulation	Controlled by step size	Speed Controlled by pulse width modulation
Moderate	Cheap	Expensive
Quiet	Noisy	Less noise

2.6 PID Controller

The PID controller algorithm consists of three main parameters which are, the proportional, the integral and the derivative. The proportional values refer to the feedback of the present error, the integral values refer to the feedback based on the sum of recent errors and the derivative values refers to feedback based on the rate of the error that has been changing. The sum of these three parameters is used to adjust the process by the control element [25].

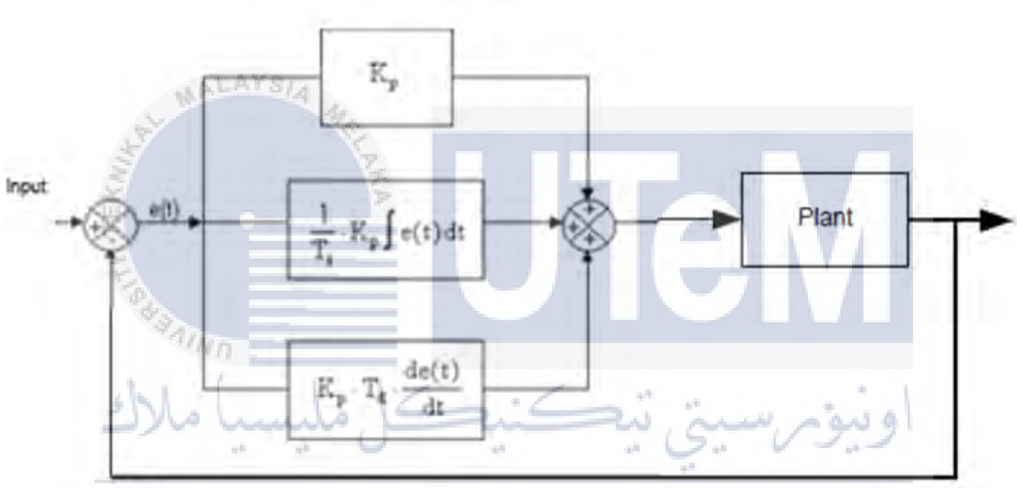


Figure 2.14: PID System Plant [24]

From tuning those three parameters in the PID controller algorithm the controller able to perform certain control action for a specific requirement process. PID controller has a very good response to various parameters. The PID controller can be implemented easily into a system compared to other controllers because of the simple structure of the controller, another controller has a complex structure compared to PID controller. The PID controller able to improve the position error of the system faster and its suitable for the angular positioning system. The most usual PID controller that has been implemented in a system is a conventional PID controller. There are many types of PID controller such as fuzzy based PID controller, error-based self-regulating PID controller (SPRID), and Multi-Loop PID controller. The PID controller able to improve the transient response of a system, particularly the positioning of a system. The transient response of a system is mean by the reducing the overshoot, peak time, rise time and steady-state error of a system. The error produces in the transient response are reduced by tuning the three parameters in the PID controller that is proportional, integral and derivative. PID controller is a simple, effective and applicable technique that can boost the performance. PID controller also has a good robustness that able to cope with noise and external disturbance that produce by the mechanical part of the system by minimizing the positioning error of the motor. So a high precision and accurate positioning able to be produced by implementing PID controller [25].

2.6.1 PID Tuning

A PID controller is a control that depends on the feedback. The output of a system or process is measured and compared with the setpoint. The difference between both ranges is measured and the correction is calculated and applied to the process. The previous step is repeated again, if any changes occurred in the measurement .there are 3 methods of tuning a PID that is manually tuning, tuning of heuristics and auto-tuning. The manual tuning of a PID is done by setting all the gains value to zero. Then, the proportional gain is increased until a steady oscillation responds to the disturbance is formed. Next, increase the derivative gain until the oscillation has been removed away. Both previous steps are repeated again if the oscillation is not removed away. Proportional and derivative values a set at the stable values. Thus, increase the integral gain until the desired setpoint is achieved [26]. For the tuning of heuristics or also known as Ziegler Nichols method where to produce good values of the PID parameters, which are the proportional gain (kp), integral gain (ti), and derivative gain (td).This values can be determined based on its transient response. There are 2 types of the method based on Ziegler Nichols which are step response method and self-oscillation method. The first type method step response is done by applying step response to the system by an integrators or dominant complex-conjugate poles, which unit step response resemble an S-shaped curve with no overshoot. S-shaped curve is known as reaction curve. Self-oscillation method is done by increasing the proportional gain until ultimate gain and an ultimate period is achieved [27]. Furthermore, the next method is the auto-tuning method. The auto-tuning method provides a system where it automatically tunes the parameters and controls the process to its best limits.

2.7 Fuzzy Logic Controller

A fuzzy logic controller is a controller based on fuzzy logic. It's a mathematical system that uses analog inputs has variable between the values of 0 and 1 which differs to the digital logic, which is 1 and 0, which operates in discrete values of either 1 or 0. The fuzzy logic controller is based logical system which is similar to humankind of thinking. A fuzzy logic controller is a more robust controller in a nonlinear system compared to the PID controller. A fuzzy logic controller does not require complex mathematical modelling. The fuzzy logic controller performs faster in tracking and minimizes the overshoot. Figure 2.15 shows the basic design of the fuzzy logic controller. Furthermore, the fuzzy logic controller is can be easily modified and has multiple inputs and outputs sources [28].

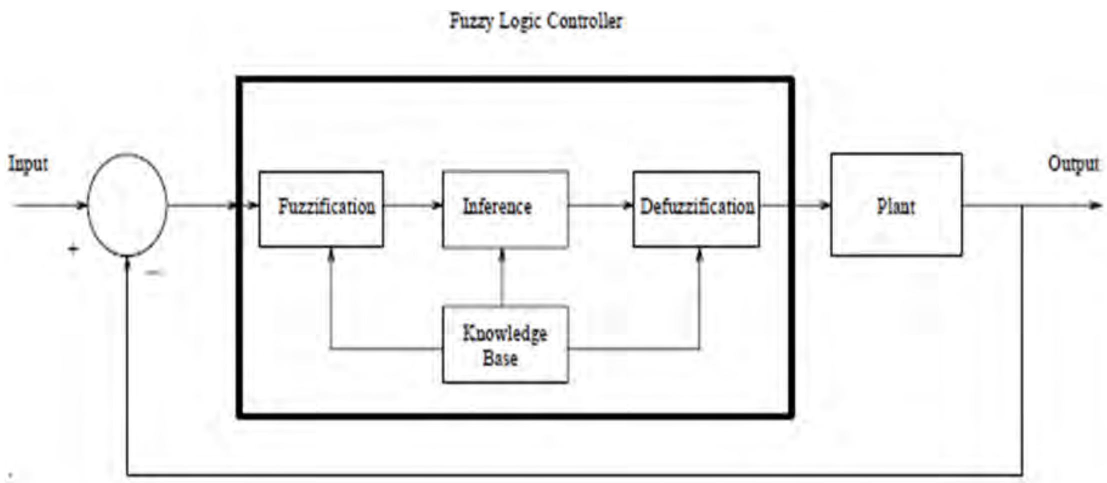


Figure 2.15: The Block Diagram Of The Fuzzy Logic Controller [28]

The Fuzzy Logic Controller (FLC) have more advantages compare to conventional PID controller. The fuzzy logic controller is more robust than the PID controller because it can operate better in the non-linear system. However, the fuzzy logic controller has a complex design compare to the PID controller [28].

2.8 Artificial Neural network controller

The most usual neural network architecture is the multilayer perceptron. The multilayer perceptron is formed using basic components. System identification and control design are the steps involved in the control system using neural network controller. So in system identification, the neural network plant is developed as we desired to control. Whereas, in the control design the neural network plant is used to train the controller. In figure 2.16, training data generation for ANN controller in MATLAB is shown. To train the controller, firstly the artificial neural network should be blocked, so the user could insert their desired input as they wish before the controller start to train. The initial step to train the controller using data generation. As the data generation process proceeds, the plant will respond to the reference model, which is necessary to discover whether the training data set is valid or not. If the training data set is not valid the data set will be regenerated. Then, the data set is valid the controller will go through 'train collector' option. The training is done according to the given parameters. The artificial neural network may take a lot of time to train depending on the given parameters and processing speed. All the validation of the training is transferred into the Matlab Simulink model. The controller consists of neural network model and optimization of the model [29]. Figure 2.17 shows the execution of ANN control for Robot Arm (DC motor position control) through the available model in our MATLAB analysis.

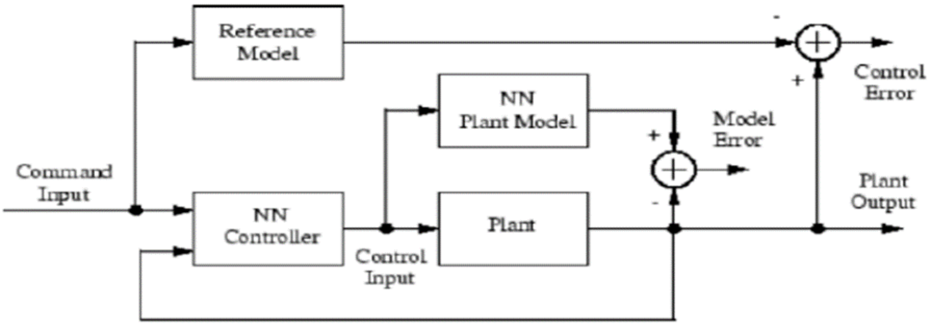


Figure 2.16: Artificial Neural Network Controller Block Diagram [29]

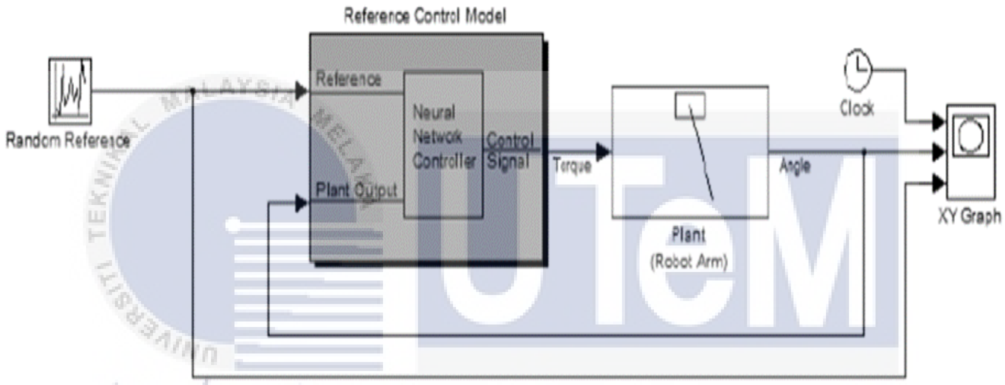


Figure 2.17: ANN controller block diagram for robot arm (dc motor position control) in Matlab Simulink [29]

The neural network controls the input according to the training data given. The difference between the reference input and plant output is the error, whereas the plant output and control error provide the model output. Since the output of the plant is fed back to NN controller's input, it works on back-propagation model of neural networks. Back-propagation neural network is a multilayer feed forward network with back-propagation of an error function. Neural network controller has a high robustness in the non-linear system and performs well in a non-linear system. However neural network controller is complex to design compared to other controllers [29].

2.9 Summary

The model of the movable for surgical illumination system used was a 2 degree of freedom pan –tilt joint, where allows the movement of the surgical light to move in yaw and roll direction. The statistical linear controller was chosen to control the angular positioning of the actuators on both joints, despite there was other better controller such as the PID controller, fuzzy logic controller, and artificial neural network in term of robustness. This controller will reduce the offset produce in the system by providing a best-fit equation from the data collected from the experiment carried out. Moreover, servo motor was chosen as the actuator for both joints of the system. Servo motors are chosen in this project due to high torque, fast responding to the input signal and good precise positioning. Even though, stepper motor able to provide a better positioning than servo motor, but its nature of slow responding has given the advantage to the servo motor. Thus, fast responding to the input signal able to reduce the delay to track input reference. Finally, the performance of the actuator with the compensation of the statistical linear controller will be compared in the following chapter.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, the control of movable platform for surgical illumination system is by using the linear controller for 2 degrees of freedom pan-tilt mechanism. This system consists of 2 joints that the pan mechanism which allows the movement of yaw and tilt mechanism that allows the movement of a roll. Arduino Uno was used as the controller to control the movement of the actuator.

Therefore the actuator used in this system is the servo motor. Servo motor has better performance than other actuators that have discussed in the literature review. The linear controller was developed to control the angular positioning of the motor so that any changes of the position motor based on detection of the surgical tools, transient response, and the error produce will be reduced on the system. The developed linear controller will be added to the movable platform for surgical illumination. Then, the angular position, time response, and transient response will be analyzed.

The linear controller was developed based on the outcome produce from the experiment done from this project. The linear controller helps to control the actual output to the desired output. Several software and methods used to achieve the desired outcome from this project.

3.2 Flow Chart

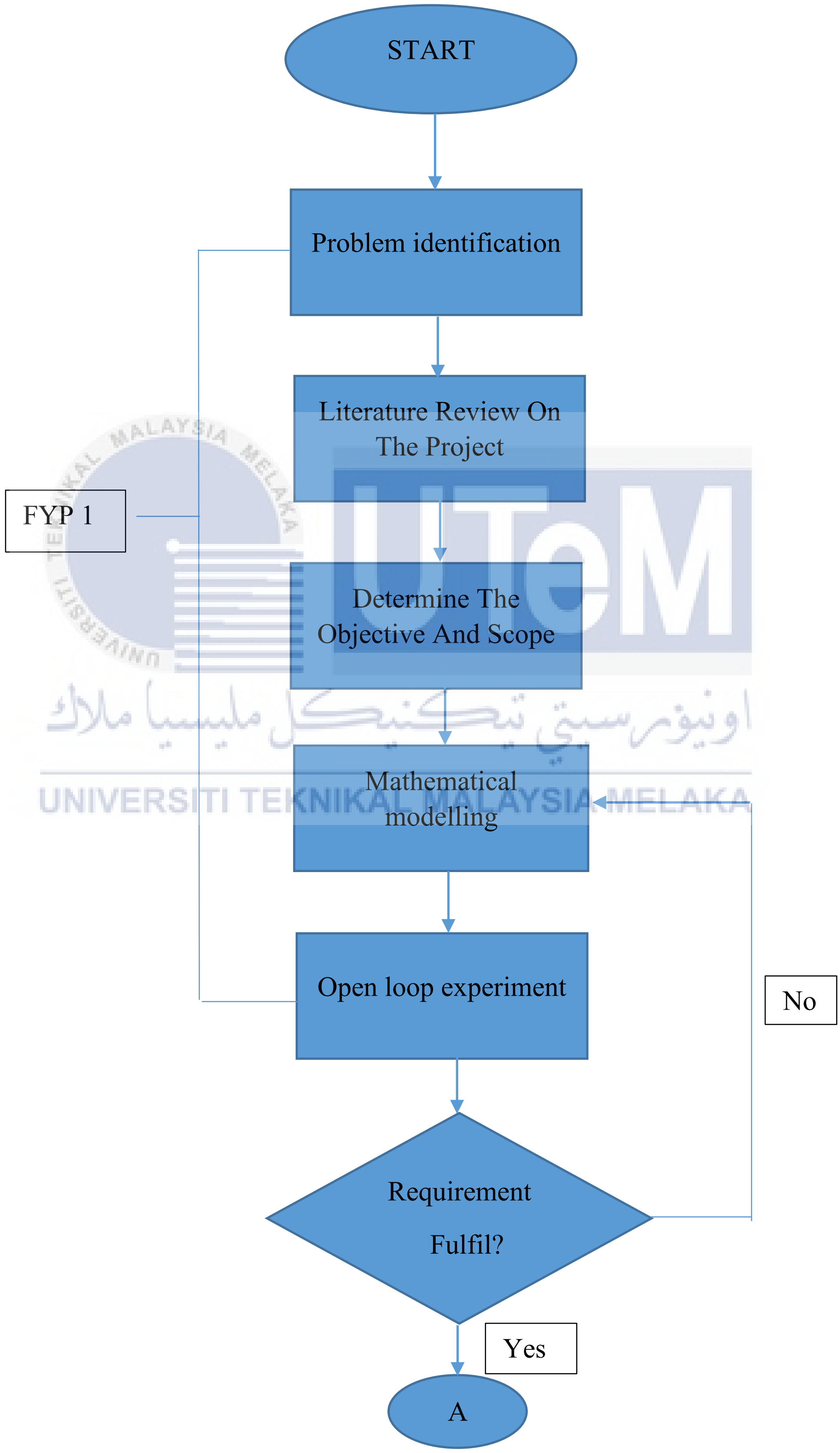
In this part, the steps and methods included in this project are explained briefly in the form of a flowchart. The overall planning flow chart will briefly show the process of the whole final year project system.

3.2.1 Flow Chart of Final Year Project

The Figure 3.1 shows the planning process of the designing a controller for the movable platform, in the form of a flowchart for Final Year Project 1 and Final Year Project 2. The first step of the project, identify the problem. After identifying problem statement of the project, then search or collect some resources such as in articles and journals. Based on the resources gathered the objective and the project scope will be determined. According to the objectives and project scope, the methodology of the project was prepared, where the conceptual design of this project was prepared. The suitable design for this project was selected. After that, the component selection for the project will be done. Table 3.1 shows the Gantt chart of FYP 1.

In FYP 2, the progress of the FYP was continued by fabricating the test rig. The design drawn in SolidWorks was 3d printed. All the part was mounted together with the frame and servo motor. Once the test rig was fabricated, programming was developed to test the performance of the test rig. Arduino was used as the controller to carry out the experiment in the project. Several experiments were carried out, based on that analysis was done in this project. Finally, the final progress is to do the final report after the final analysis has succeeded. Table 3.2 shows the Gantt chart of FYP 2.

3.2 FYP Flowchart



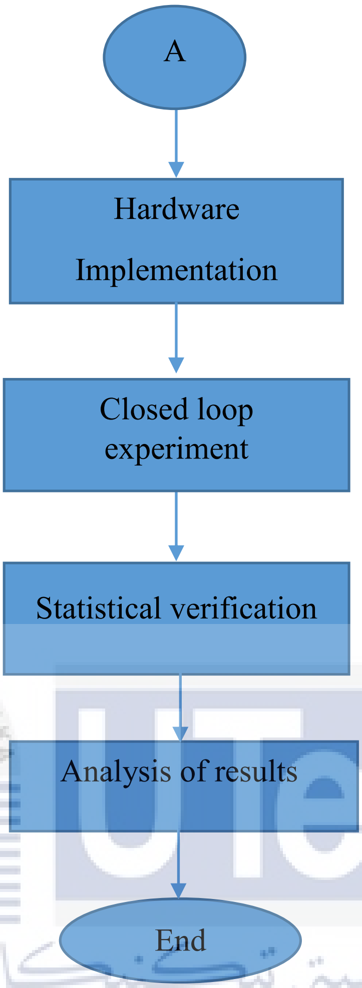


Figure 3.1: Overall Flowchart For FYP 1 and FYP 2

3.3 FYP GANTT CHART

Table 3.1: Gantt Chart For FYP 1

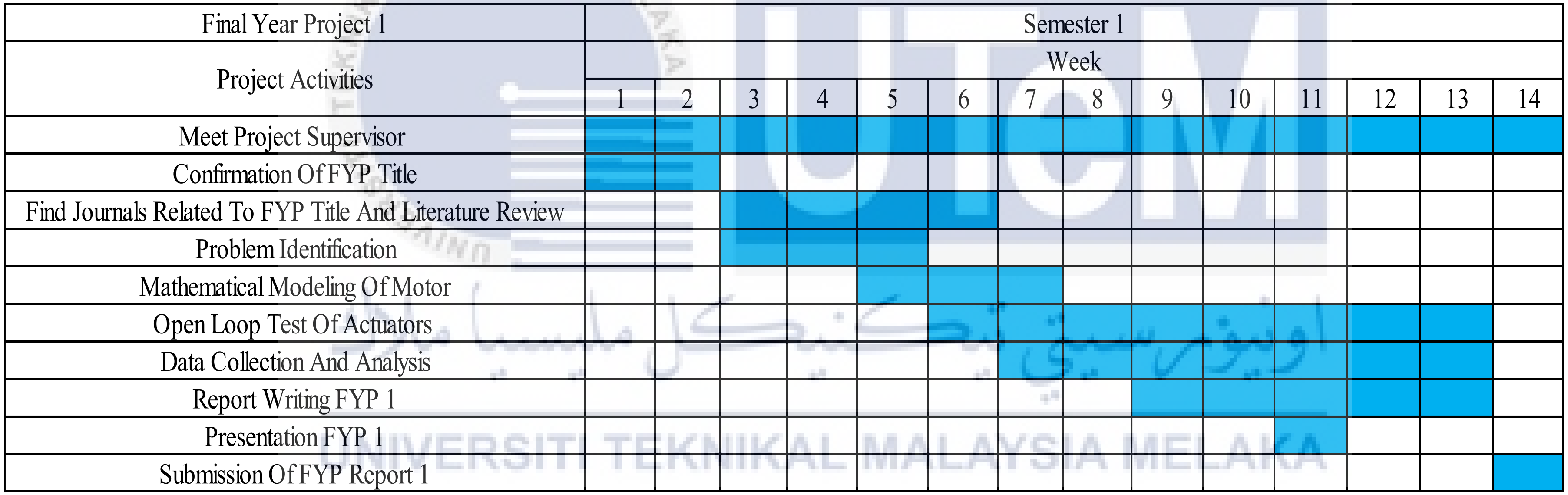


Table 3.2: Gantt Chart For FYP 2

Final Year Project 2	Semester 2													
	Week													
Project Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Meet Project Supervisor	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Literature Review	■	■												
Fabrication Of Test Rig	■	■	■	■	■	■	■							
Develop A Controller For Movable Platfrom			■	■	■	■	■							
Closed Loop Test Of Actuators			■	■	■	■	■	■						
Data Collection And Analysis				■	■	■	■	■	■	■	■	■		
Improvement On The Controller						■	■	■	■	■	■			
Report Writing FYP 2			■	■	■	■	■	■	■	■	■	■	■	
Presentation FYP 2														■
Submission Of FYP Report 2														■

3.4 Mathematical Modelling

As shown in figure 3.2, the total torque required to rotate the lamp along with the beam is equal to the reaction of the torque that produced by the mass of beam 1, the mass of beam 2 and mass of lamp. So the torque of the rotating lamp along with the beam is equal to the motor torque minus the reaction torque that produced by the mass of beam 1, the mass of beam 2 and mass of lamp. Figure 3.3 shows the free body diagram with dimension.

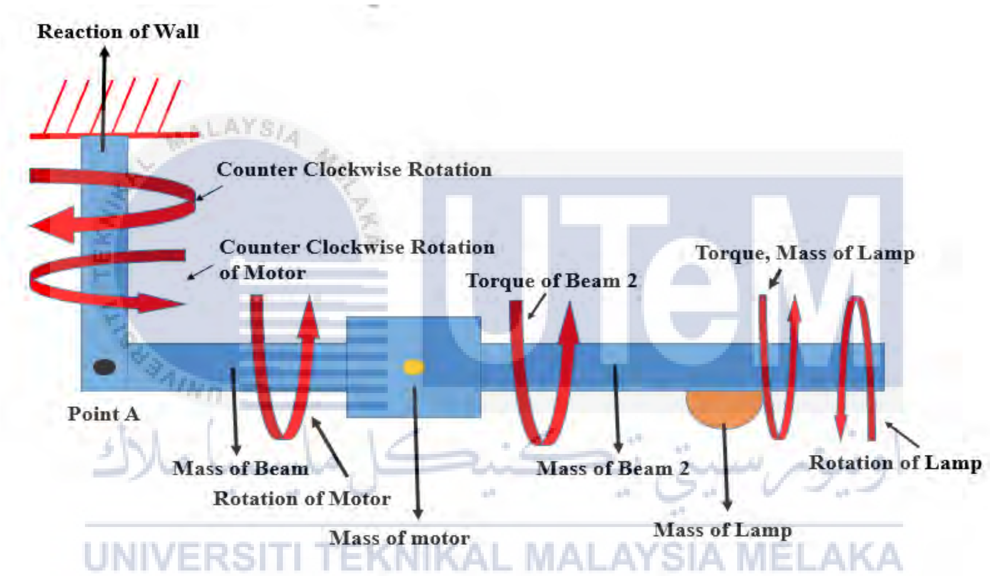


Figure 3.2: Free Body Diagram Of The System

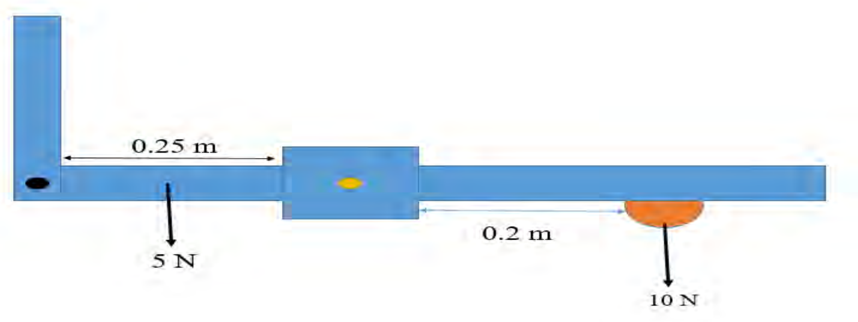


Figure 3.3: Free body Diagram With Dimension.

The torque developed from the motor is developed from the electromagnet force that applied on rotor windings.

$$T_m(s) = (J_m s^2 + D_m s)\theta_m(s) \qquad (3.4.1)$$

The electromagnetic force is proportional to the current flowing through an armature, hence the summarize variable and parameters in a motor is;

Ra = armature winding resistance

La =armature windings inductance

Ia= armature current

Tm = torque develop by the motor

Jm = equivalent inertia at the armature

Dm = equivalent viscous damping

Kt = motor torque constant

Kb = back emf constant

Thus the torque develop by the motor is proportional to the armature current,

Tm(s) = KtIa(s)

Figure 3.4 shows the specification of the motor .The selected servo motor provides the voltage of 6v (ea), stall torque is 1.667 N-m. The inertia formed from the motor is assumed very small, with the value of 0.001. As the for the tilt joint, it has additional inertia that will be contributed the mechanism from the weight of the lamp. The weight of the lamp is approximately 6.48 N. Most importantly the inertia produce from the air friction (Dm) was neglected.

Speed @ 6V:	0.14 sec/60°
Stall torque @ 6V:	17 kg·cm
Speed @ 4.8V:	0.16 sec/60°
Stall torque @ 4.8V:	15.5 kg·cm
Lead length:	10 in

Figure 3.4: Datasheet of the motor

The inertia contributed to the system from the weight surgical lamp (J_L) was calculated using the formula of:

$$I_{end} = \frac{mL^2}{3} \tag{3.4.2}$$

$= \frac{(6.48)(0.3^2)}{3}$

= 0.1944

The gear ratio is assumed as 1 at the initial state. Thus the equivalent inertia Jm was obtained the equation;

$$J_m = Ja + J_L \left(\frac{N1}{N2}\right)^2 \tag{3.4.3}$$

$= (0.001) + (0.1944)\ (1)^2$

$= 0.1954$

$$\frac{Kt}{Ra} = \frac{Tstall}{ea} \tag{3.4.4}$$

$= \dfrac{1.667}{6}$

$= 0.2778$

$$\theta m(s) = Kt \,/\, (\,RaJm) \tag{3.4.5}$$

$= (0.2779)\ (1/\ 0.1944)$

$= 1.429$

$$T_m(s) = (J_m s^2 + D_m s)\theta_m(s)$$

$= (0.1944 + 0)\ (1.429)$

$= 0.\ 2778$ N.m

The transfer function of the system was determined from the equation:

$$\frac{\theta m(s)}{Ea(s)} \equiv \frac{Kt/(RaJm)}{s\left[s + \frac{1}{Jm}\left(Dm + \frac{KtKb}{Ra}\right)\right]} \tag{3.4.6}$$

$$= \frac{(0.2778)(1/0.1944)}{s\left[s + 1/0.1944(0 + (0.2778 \times 0.4091)\right]}$$

$$= \frac{1.429}{s(s + 0.5846)}$$

3.5 Selection Of Simulation Tools

3.5.1 Matlab 2017

Matlab is an engineering design and control software that produce by Mathworks Company the language of technical computing. It is mainly used as a programming environment for developing new algorithm, analyse data, visualization analysis and also for computing complex numerals. Simulink is part of Matlab that is used in a graphical environment for simulation purposes and also to design multi domain dynamic and embedded system via model based design. Mathwork product is also fundamental teaching and research tools in the world's universities and learning institutions. This particular tool includes a lot of analysis research such as model analysis, model reduction, controller tuning, robust tuning, validating results and etc. the important tool used in the Matlab was the Simulink. Simulink is used as a tool for simulation and also to build model based design environment for complicated embedded system. It also can be used for dynamic modelling system as well. Simulink is more of a programming language based on graphical modelling. It uses same data flow as programming but for modelling, simulation and also for analysing multi domain dynamic systems. Simulink comes as a graphical block diagram that has customizable block libraries to change the details as needed for your desires. This tool allows you integrate algorithms from Matlab into models. The results form Simulink models can be exported into Matlab as well for further analysis.

3.5.2 Monte Carlo Simulation

Monte- Carlo is a computational algorithm that is dependent on the random variable. Monte- Carlo simulation provides a better solution for the factor of uncertainties and risk analysis. Monte Carlo produces those users with an outcome of workable results and the probabilities that will happen for any decision about an activity. Monte Carlo simulation performs its analysis by creating a model of probable results by the replacing a range of values into it, such as the probability distribution. The results from the values placed in will be calculated, again and again, so each time a new set of random values of the answer will be produced. The subject to the number of uncertainties and the ranges specified, a Monte Carlo simulation could be include numbers of recalculations before it is complete. Monte Carlo methods draw samples to estimate the desired quantity. Sampling provides the simplest way to estimate the sums and integrals at a reduced cost. The advantages of using Monte Carlo simulation is provided graphical results, where the data that produce from the Monte Carlo simulation is simpler to create a graph of different outcomes and their chances of existence. Thus, it easy to analyse the results, where it shows which input as the biggest effect.

3.6 Actuator Selection

Servo motors (HD1501-MG) is selected to be used in this project. One controls the movement of the pan joint (yaw). The second motor is used to control the movement of tilt joint (roll). Servo motor is chosen because of its ability to move in required angle and can be controlled using the PWM. Figure 3.7 shows the servo motor.

Figure 3.5: HD1501-MG Servo Motor

3.7 Proposed Hardware Implementation

Figure 3.6 hardware design of the surgical illumination system. The hardware implementation process covers the movement of pan joint and tilt joint according to the detection of the surgical tool. The angle of the tilt servo motor (vertically) plays an important role where the surgical lamp is actually attached together with it. The movement of the lamp is based on the movement of the tilt dc motor. The pan motor actually helps the mechanism to move in a horizontal direction. So the pan –tilt servo motors allow the surgical lamp to move in yaw and roll. Thus, the raspberry pi camera is placed together with the surgical lamp. Once the raspberry pi camera has detected the surgical tool, it will send information to the controller where it sends the signal to the servo motors which enable the surgical lamp to move the desired direction based on camera detection.

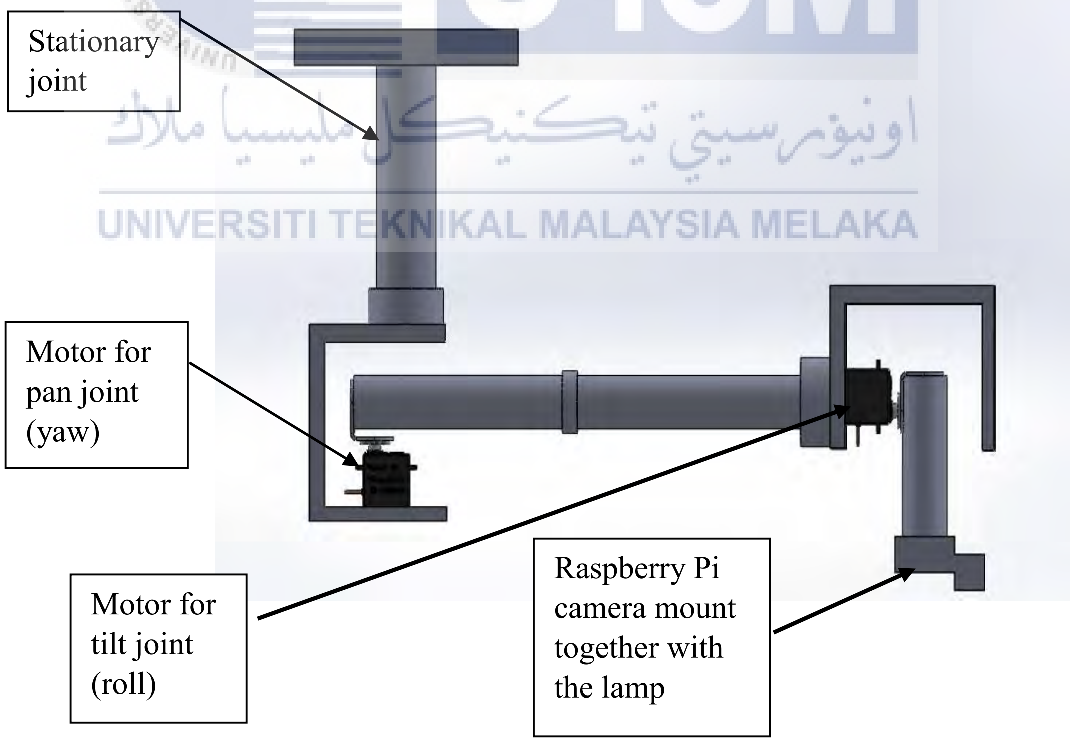


Figure 3.6: Hardware Design Of The Surgical Illumination System

3.8 Development Of Open Loop System

Open loop test is a system where feedback is not given to the system. An open loop system is a system where input reference is directly given to the system and the output is produced from there.so the error produces from the system won't be reduced or eliminated from the system due to there is no feedback from the system.

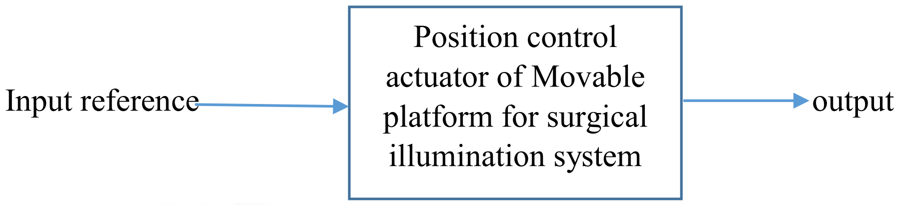


Figure 3.7: Open Loop System Block Diagram

3.9 Development Of Closed Loop System

For a closed-loop test, a system was developed to produce a feedback to the system where the input and the output can be compared. The feedback will be sent to a controller, where the controller will reduce the error between the desired input and actual output. A linear controller was designed based on the output given. Figure 3.5 shows the closed loop system of the project.

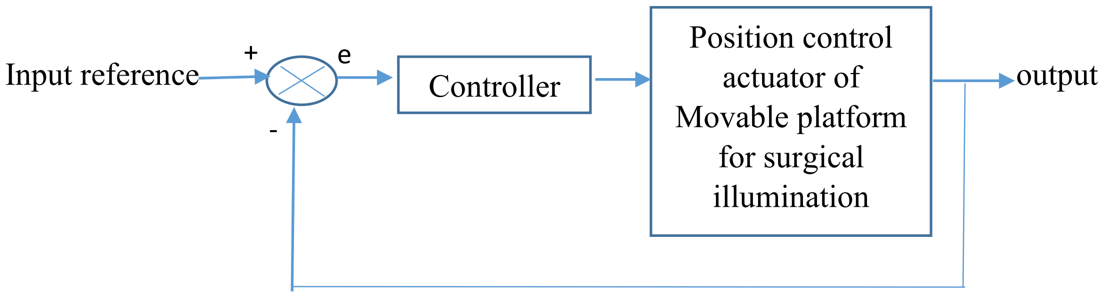


Figure 3.8: Closed System Block Diagram

3.10 Statistical Verification

Each of the test done on this project has been repeated few times to produce the best results. One of the best way to prove accuracy and reliability of the results by using 1-way analysis of the variance. This method can show that whether the results produce is significantly different or not. An ANOVA with repeated measures is used to examine 3 or more group approach in which the participants are identical in each group. The results of the repeated measures values from the experiment is analysed using SPSS Statistics. ANOVA examines the null hypothesis for a sample which is brought together with similar traits or values. To verify this, assumptions are made from the populace of variance. Those estimations depend on numerous assumptions. The ANOVA produces a statistic that is the proportion of the variance which is calculated from several means to the variance of the sample given.

3.11 Experiment Setup

3.11.1 Experiment On Motor Rotation

The goal of the experiment to verify the accuracy and error obtained from the angle of rotation of the motor. The experiment was carried out by coupling the servo motor with a protractor. A sample angle was tested with the motor. The input voltage and signal to the motor was given by Arduino. The test was conducted on both axis yaw and roll. Each angle was tested with repeatability of five times of data collection.

Procedure

1. The servo motor was connected to the Arduino Uno and then the Arduino Uno board was connected to the laptop using the USB cable.
2. The Arduino algorithm for the test was developed and uploaded to the Arduino Uno board.
3. The angle of rotation was set in the Arduino by using pulse width modulation.
4. Then the motor was mound with the protractor and a base.
5. The angle of rotation was set from 30, 60, 90, 120 and 180 and the measured reading from the protractor was recorded.

3.11.2 Experiment on accuracy and precision of the pan-tilt manipulator

The experiment was carried out to find the accuracy and precision of the mechanism went it moves from one point to another desired point. The first objective of this project are achieved from this experiment. Once the fabrication of this mechanism is done, this experiment was conduct to verify whether the mechanism is operating in the required dimensions. The input voltage and signal to the servo motor was given by the arduino. This test will verify the accuracy and precision obtained from the angle of rotation of the mechanism. This test also shows the error obtained from mechanism to reach its desired position. The test was conducted on both axis pan and tilt. Each angle was tested with repeatability of five times of data collection.

.

Procedure

1. The servo motor was connected to the Arduino Uno and then the Arduino Uno board was connected to the laptop using the USB cable.
2. The Arduino algorithm for the test was developed and uploaded to the Arduino Uno board.
3. The desired angle of rotation for the mechanism to move was set in the Arduino.
4. Then the mechanism was mound with the needle facing a protractor at the base.
5. The desired angle of rotation for pan axis was set from 25, 35, 45, 55,60,65,75,80,90,100,110,120,130,135,145 and 155 degrees.
6. Then the measured reading from the protractor was recorded.
7. This step was repeated for the tilt axis with the desired angle of 60,70,80,90,100, and 120 degrees.

3.11.3 Experiment on accuracy and precision with various speed of the pan-tilt manipulator

The experiment was done to study the relationship of speed affecting the movement of the manipulator. The primary aim of this experiment is to reduce the jerk and vibration cause by the mechanism went reaching its desired point. The second objective of this project are achieved from this experiment. So the path to reach its desired point is divided into three ranges. The initial and middle path of the movement is set at speed of 30. Whereas the end part of the movement is slower down with speed of 10.The input voltage and signal to the servo motor was given by the arduino. The test was conducted on both axis pan and tilt. Each angle was tested with repeatability of three times of data collection.

Procedure

1. A rotary encoder was mounted together with servo motor for the both pan and tilt axis.
2. The servo motor was connected to the Arduino Uno and then the Arduino Uno board was connected to the laptop using the USB cable.
3. The Arduino algorithm for the test was developed and uploaded to the Arduino Uno board.
4. The desired angle of rotation for pan axis was set from 65, 110 and 155 degrees.
5. Each desired angle of rotation is divided into three segments.
6. The measured data from the rotary encoder will be displayed on the laptop, and the measured data was recorded.
7. The time taken for the manipulator to reach each segment was collected by using a stopwatch.
8. This step was repeated for the tilt axis with the desired angle of 60 and 100 degrees.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter will explain briefly the result and data obtained from the experiment that has been conducted before this. From the experiment, several data has been collected and tabulated into tables and graphs. The experiments are very important to measure a system's performance and precision. Every data of the experiment is analyzed by plotting a graph. Some experimental results were analysed using the SPSS software to verify the reliability and also the repeatability of the servo motor rotation measurement.

4.2 Experiment Of Motor Rotation

After the design of the system is done, the system was tested. Testing is one of the important part in a system because its shows how well the system is working. The outcome can prove whether the system is able to function well within the requirement. For this project, some tests have been conducted to find the outcome of this system. The. It's just a trial session for the actuator to check whether it works well within certain conditions. Figure 4.1 shows the connection from the Arduino Uno to the servo motor.

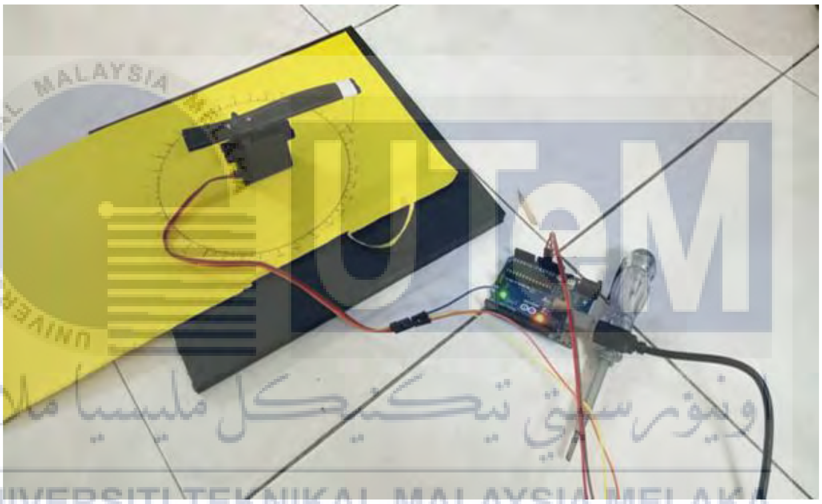


Figure 4.1: Experiment Setup Of The Servo Motor Rotation

So the servo motor needs to move according to the parameters set in the Arduino. Thus, the set angle from the Arduino to the motor was compared with the measured value from the protractor that is mound below the servo motor. For each angle, repetition was done for 5 times. The objective conduct this experiment is to identify the capability of the motor the rotate in different angle without error. As shown in table 4.1, 4.2, 4.3 and 4.4 this experiment was conducted on two separate days for each joint, to find the variance different from the experiment result. However, the results were analysed using t-test statistics to prove the reliability of the motor rotation.

Table 4.1: Data collected from the experiment for pan joint for day 1

Angle (º)	Repeatability Test For Pan Joint Angle (º)						
	1	2	3	4	5	Average	Variance
30	30	30	30	30	30	30	0
60	60	60	58	58	58	58.8	1.2
90	89	88	88	90	89	88.2	1.2
120	120	118	118	118	118	118.4	0.8
150	149	148	148	148	149	148.4	0.3
180	180	180	180	180	180	180	0

Table 4.2: Data collected from the experiment for pan joint for day 2

Angle (º)	Repeatability Test For Pan Joint Angle (º)						
	1	2	3	4	5	Average	Variance
30	30	30	30	30	30	30	0
60	60	58	57	58	58	58.2	1.2
90	89	89	88	90	89	88.8	0.7
120	118	118	117	117	117	117.4	0.3
150	148	148	148	147	149	148	0.5
180	180	180	180	180	180	180	0

Table 4.3: Data collected from the experiment for tilt joint for day 1

Angle (°)	Repeatability Test For Tilt Joint Angle (°)						
	1	2	3	4	5	Average	Variance
15	15	15	15	15	15	15	0
30	30	30	30	30	30	30	0
45	45	45	45	45	45	45	0
60	57	58	58	60	60	58.2	1.2
90	89	89	89	88	89	88.8	0.2
135	135	135	135	135	135	135	0
150	148	148	148	149	148	148.2	0.2
180	180	180	180	180	180	180	0

Table 4.4: Data collected from the experiment for tilt joint for day 2

Angle (º)	Repeatability Test For Tilt Joint Angle (º)						
	1	2	3	4	5	Average	Variance
15	15	15	15	15	15	15	0
30	30	30	30	30	30	30	0
45	45	45	45	45	45	45	0
60	58	58	58	57	58	57.8	0.2
90	89	89	89	90	90	88.8	0.2
135	135	135	135	135	135	135	0
150	149	149	148	149	148	148.6	0.3
180	180	180	180	180	180	180	0

By using SPSS software, 2 different types was carried out to compare day 1 and day 2 measurement and determine the reliability and also the repeatability of the servo motor rotation measurement.

Hypothesis Test was carried out to calculate the reliability and repeatability of measurement for each day. This test also used to identify whether test results are acceptable or not. Then, paired samples test was carried out to compare the significance value and the validity of both data. Two hypothesis test and paired samples test will be carried out which is for the pan axis and tilt axis.

Table 4.5 shows test summary for pan axis for the angle of 30, 60, 90,120,150 and 180 degrees. For the angle 30 and 180, the test samples for each day can't be computed because it does have variation measured values between each trial. Whereas, hypothesis test summary for angle 60, 90,120, 150 indicates that's the results data for day 1 and day 2 are normally distributed where the significant value is greater than 0.05, so it is proceed with the paired samples test.

Table 4.6 shows the summary of paired samples for the pan joint. For rotation angles of 30, and 180 degrees, there were no variation from the expected values. Thus, the data obtained were uniformly distributed (not normal) which violates the paired statistics computational requirements. Further repetitions or better equipment's must be employed to obtain normally distributed data and therefore the paired test statistics. The highest significant value for the paired sample test was obtained from angle 90 degree, which is 0.374 with the mean and standard deviation of paired sample data of 2 days is -0.2000 and 0.44721. The paired difference for angle 90 degrees was not statistically significant at t (4) = -1.000, p=0.338. This shows the statistical for angle 90 degrees are similar in both days. The lowest significant value for the paired sample test for 2 days was obtained from angle 150 degree, which is 0.178 with the mean and standard deviation are 0.4000 and 0.54772. The significance value showed for angle 60, 90, and 150 paired test is more than the set alpha value 0.05, so there is no significant difference between the measurement done on day 1 and day 2. Therefore, the measurement is reliable and repeatable over the duration tested whereas, for 120 degrees pan angle, the paired difference is statistically significant at t (4) =3.162, p=0.034. Statistical significance is set at alpha=0.05. This shows that statistically with the open loop control, the attainment of angular position at 120 degrees is different in both days. This warrant further improvement in control strategy to achieve the expected positioning.

Besides that, table 4.7 shows test summary for tilt joint for the angle of 15, 30, 45, 60, 90,135,150 and 180 degrees. For the angle 15, 30, 45, 60, 135 and 180 the test samples for each day can't be computed because it does have variation measured values between each trial. Whereas, hypothesis test summary for angle 60, 90 and 150 indicates that's the results data for day 1 and day 2 are normally distributed where the statistical significant value is greater than 0.05, so it to proceed with the paired samples test.

Table 4.8 shows the summary of paired samples for the tilt joint. For rotation angles of 15, 30, 45, 135, and 180 degrees, there were no variation from the expected values. Thus, the data obtained were not normally distributed and the paired statistics cannot be computed. Further repetitions or better equipment's must be employed to obtain normally distributed data and therefore the paired test statistics.

The highest significant value for the paired sample test is obtained from angle 60 degree, which is 0.338 with the mean and standard deviation of paired sample data of 2 days is 0.8000 and 1.64317. For 60 degrees roll, the paired difference is not statistically significant at t (4) =1.089, p=0.338. Statistical significance is set at alpha=0.05. This shows that statistically with the open loop control, the attainment of angular position at 60 degrees is similar. The lowest significant value for the paired sample test for 2 days is obtained from angle 150 degree, which is 0.178 with the mean and standard deviation are -0.4000 and 0.54772. For 150 degree rotation, the paired difference is not statistically different at t (4) = -1.633, p=0.178. Thus, it shows the angular position at 150 degree are similar. The significance value showed for angle 60, 90 and 150 degrees paired test is more than the set alpha value 0.05, so there is no significant difference between the measurement done on day 1 and day 2. Therefore, the measurement is reliable and repeatable over the duration tested.

Table 4.5: Test hypothesis of each day for pan joint (yaw)

Angle		Null Hypothesis	Test	Sig.	Decision
Angle 30 º		Day 1 and day 2 mean=30 unable to compute the null hypothesis Standard deviation =0			
Angle 60 º	1	The distribution of day1 is normal with mean 58.80 and standard deviation 1.10.	One-Sample Kolmogorov-Smirnov Test	.510	Retain the null hypothesis.
	2	The distribution of day2 is normal with mean 58.20 and standard deviation 1.10.	One-Sample Kolmogorov-Smirnov Test	.492	Retain the null hypothesis.
Angle 90 º	1	The distribution of day1 is normal with mean 88.60 and standard deviation 0.89.	One-Sample Kolmogorov-Smirnov Test	.577	Retain the null hypothesis.
	2	The distribution of day2 is normal with mean 89.00 and standard deviation 0.71.	One-Sample Kolmogorov-Smirnov Test	.759	Retain the null hypothesis.
Angle 120 º	1	The distribution of day1 is normal with mean 118.40 and standard deviation 0.89.	One-Sample Kolmogorov-Smirnov Test	.214	Retain the null hypothesis.
	2	The distribution of day2 is normal with mean 117.40 and standard deviation 0.55.	One-Sample Kolmogorov-Smirnov Test	.510	Retain the null hypothesis.
Angle 150 º	1	The distribution of day1 is normal with mean 148.40 and standard deviation 0.55.	One-Sample Kolmogorov-Smirnov Test	.510	Retain the null hypothesis.
	2	The distribution of day2 is normal with mean 148.00 and standard deviation 0.71.	One-Sample Kolmogorov-Smirnov Test	.759	Retain the null hypothesis.
Angle 180 º		Day 1 and day 2 mean=30 unable to compute the null hypothesis Standard deviation =0			

Table 4.6: Paired sample test for pan joint

Angle 30 º

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	day1	30.0000^a	5	.00000	.00000
	day2	30.0000^a	5	.00000	.00000

a. The correlation and t cannot be computed because the standard error of the difference is 0.

Angle 60 º

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	day1 - day2	.60000	.89443	.40000	-.51058	1.71058	1.500	4	.208

Angle 90 º

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	day1 - day2	-.20000	.44721	.20000	-.75529	.35529	-1.000	4	.374

Angle 120 º

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	day1 - day2	1.00000	.70711	.31623	.12201	1.87799	3.162	4	.034

Angle 150 °

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	day1 - day2	.40000	.54772	.24495	-.28009	1.08009	1.633	4	.178

Angle 180 °

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	day1	180.0000[a]	5	.00000	.00000
	day2	180.0000[a]	5	.00000	.00000

a. The correlation and t cannot be computed because the standard error of the difference is 0.

Table 4.7: Test hypothesis of each day for tilt joint (roll)

<table>
<tr><td>Angle 15 °</td><td>Day 1 and day 2 mean=15 unable to compute the null hypothesis
Standard deviation =0</td></tr>
<tr><td>Angle 30 °</td><td>Day 1 and day 2 mean=30 unable to compute the null hypothesis
Standard deviation =0</td></tr>
<tr><td>Angle 45 °</td><td>Day 1 and day 2 mean=45 unable to compute the null hypothesis
Standard deviation =0</td></tr>
<tr><td>Angle 60 °</td><td>Hypothesis Test Summary
<table>
<tr><th></th><th>Null Hypothesis</th><th>Test</th><th>Sig.</th><th>Decision</th></tr>
<tr><td>1</td><td>The distribution of day1 is normal with mean 58.60 and standard deviation 1.34.</td><td>One-Sample Kolmogorov-Smirnov Test</td><td>.851</td><td>Retain the null hypothesis.</td></tr>
<tr><td>2</td><td>The distribution of day2 is normal with mean 57.80 and standard deviation 0.45.</td><td>One-Sample Kolmogorov-Smirnov Test</td><td>.214</td><td>Retain the null hypothesis.</td></tr>
</table></td></tr>
<tr><td>Angle 90 °</td><td>
<table>
<tr><th></th><th>Null Hypothesis</th><th>Test</th><th>Sig.</th><th>Decision</th></tr>
<tr><td>1</td><td>The distribution of day1 is normal with mean 88.80 and standard deviation 0.45.</td><td>One-Sample Kolmogorov-Smirnov Test</td><td>.214</td><td>Retain the null hypothesis.</td></tr>
<tr><td>2</td><td>The distribution of day2 is normal with mean 89.40 and standard deviation 0.55.</td><td>One-Sample Kolmogorov-Smirnov Test</td><td>.510</td><td>Retain the null hypothesis.</td></tr>
</table></td></tr>
<tr><td>Angle 135 °</td><td>Day 1 and day 2 mean=135 unable to compute the null hypothesis
Standard deviation =0</td></tr>
<tr><td>Angle 150 °</td><td>
<table>
<tr><th></th><th>Null Hypothesis</th><th>Test</th><th>Sig.</th><th>Decision</th></tr>
<tr><td>1</td><td>The distribution of day1 is normal with mean 148.20 and standard deviation 0.45.</td><td>One-Sample Kolmogorov-Smirnov Test</td><td>.214</td><td>Retain the null hypothesis.</td></tr>
<tr><td>2</td><td>The distribution of day2 is normal with mean 148.60 and standard deviation 0.55.</td><td>One-Sample Kolmogorov-Smirnov Test</td><td>.510</td><td>Retain the null hypothesis.</td></tr>
</table></td></tr>
<tr><td>Angle 180 °</td><td>Day 1 and day 2 mean=135 unable to compute the null hypothesis
Standard deviation =0</td></tr>
</table>

Table 4.8: Paired sample test for tilt joint

Angle 15 º

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	day1	15.0000[a]	5	.00000	.00000
	day2	15.0000[a]	5	.00000	.00000

a. The correlation and t cannot be computed because the standard error of the difference is 0.

Angle 30 º

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	day1	30.0000[a]	5	.00000	.00000
	day2	30.0000[a]	5	.00000	.00000

a. The correlation and t cannot be computed because the standard error of the difference is 0.

Angle 45 º

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	day1	45.0000[a]	5	.00000	.00000
	day2	45.0000[a]	5	.00000	.00000

a. The correlation and t cannot be computed because the standard error of the difference is 0.

Angle 60 º

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	day1 - day2	.80000	1.64317	.73485	-1.24026	2.84026	1.089	4	.338

Angle 90 º

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	day1 - day2	-.60000	.89443	.40000	-1.71058	.51058	-1.500	4	.208

Angle 135 º

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	day1	135.0000[a]	5	.00000	.00000
	day2	135.0000[a]	5	.00000	.00000

a. The correlation and t cannot be computed because the standard error of the difference is 0.

Angle 150 º

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	day1 - day2	-.40000	.54772	.24495	-1.08009	.28009	-1.633	4	.178

Angle 180 °

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	day1	180.0000[a]	5	.00000	.00000
	day2	180.0000[a]	5	.00000	.00000

a. The correlation and t cannot be computed because the standard error of the difference is 0.

4.3 Experiment on determining the accuracy and precision of the pan-tilt Manipulator

Once the fabrication of the project was completed, the project was tested whether it is able to move to the desired position accurately and precisely. Accuracy and precision are one of important criteria to prove the system is moving the desired position correctly over a time period. Several tests were done to shows the accuracy and precision of the system. The results of the test show the accuracy and precision of the system. The servo motors from the manipulators were connected with Arduino. The servo motor rotates according to the values set in the Arduino. The set angle from the Arduino to the motor was compared with the measured value from the protractor that is mound below the manipulator. For each angle, repetition was done for 5 times. The objective conduct this experiment is to show the accuracy and precision of the manipulator to move to several different desired angle with minimum position error. This experiment was conducted for both pan and tilt axis. Figure 4.2 and 4.3 shows the experimental setup of the accuracy and precision test.

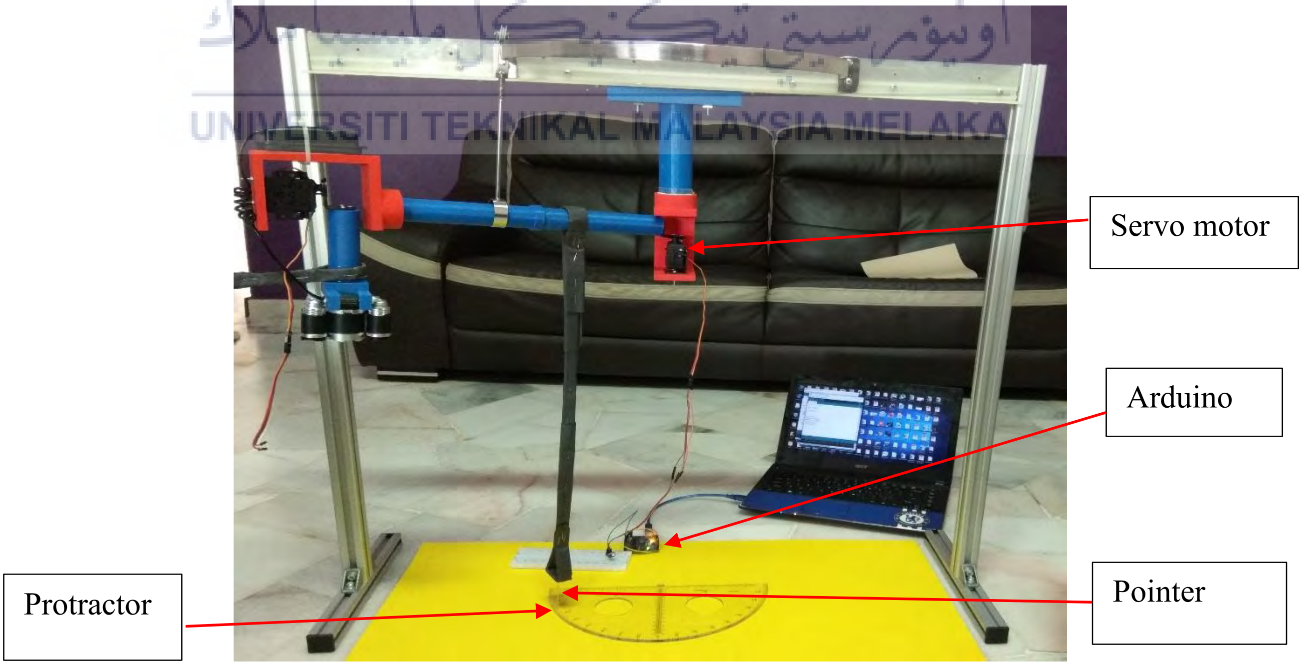


Figure 4.2: Experimental Setup Of The Accuracy And Precision Test For Pan Axis

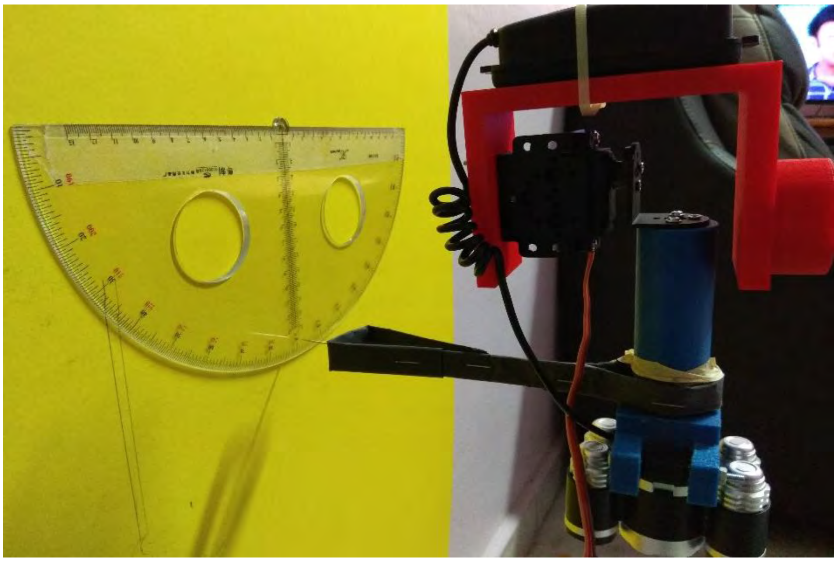


Figure 4.3: Experimental Setup Of The Accuracy And Precision Test For Tilt Axis

The range of the pan axis degree rotation varies from 25 degrees up to 155 degrees. The minimum degree rotation for the pan axis is 25 degrees and the maximum rotation for the manipulator in pan axis 155 degrees. The angle of rotation of the manipulator was set randomly. The average and standard deviation from the measured angle for each angle shows the accuracy and precision of the movement of the manipulator to the desired angle rotation. Table 4.9 shows the data collected for several measured angles of rotation for the pan axis of the manipulator.

Table 4.9: Data collected for the measured angle from the experiment for pan axis

Angle (°)	Repeatability (°)						
	1	2	3	4	5	Average	Standard deviation
25	25	25	26.5	26	26.5	25.8	0.7583
35	35	34	34.5	34	34.5	34.4	0.4183
45	45	45	45	44	45	44.8	0.4472
55	55	53.5	54	54	54	54.1	0.5477
60	58.5	59.5	60	59	58.5	59.1	0.7071
65	62.5	63	62.5	61	62.5	62.3	0.6782
75	74	73.5	73.5	74	74	73.8	0.2739
80	79	78.5	79	79.5	80.5	79.3	0.7583
90	90	90	88	88.5	90	89.3	0.9747
100	100	101.5	100	101.5	101	100.8	0.7583
110	110.5	110	109	109	108.5	109.4	0.8216
120	118.5	117	118.5	118.5	118	118.1	0.5831
130	130	129	129.5	129.5	130	129.6	0.4183
135	135	135	135	134.5	135	134.9	0.2236
145	145	144.5	144.5	145	145	144.8	0.2739
155	152	153.5	151	153.5	154	152.8	1.2550

As shown in table 4.9, the manipulator able to move in pan axis to most of the desired angle of rotation point with a close margin of the average of the set point. The best accuracy and precision for the pan axis rotation is produced at 45 degrees with the average of 44.8 degrees and standard deviation of 0.4472 over the five times reading of repeatability. But in some angle rotation of manipulator in pan axis such as 65,120 and 155 degrees, the results from the test has not produced the accurate reading to the desired rotation angle. It has produced an average result more than 1 degree of rotation from its desired angle of rotation. This is due to the jitter cause from the servo motor of the mechanism. Jitter can be caused by several aspects. Jitter means slight irregular movement, variation, or unsteadiness, especially in an electrical signal which causes the motor to vibrate. This vibration actually affects the transient response of the system that will also affect the movement of the mechanism to reach its desired point. One of aspect that caused jitter is insufficient of the current receive to the servo motor. The motor has to receive a certain amount current in order it function well. The mass of load from the mechanism is also a factor of the motor jitter. The jumper wire connection between the Arduino and servo motor caused the motor to jitter. To reduce the measured angle different that varies from its desired angle of rotation point set, the best fit graph was plotted. An equation also produced from this best fit graph. Figure 4.4 shows the best fit graph of measured angle vs desired angle of the pan axis rotation of the manipulator.

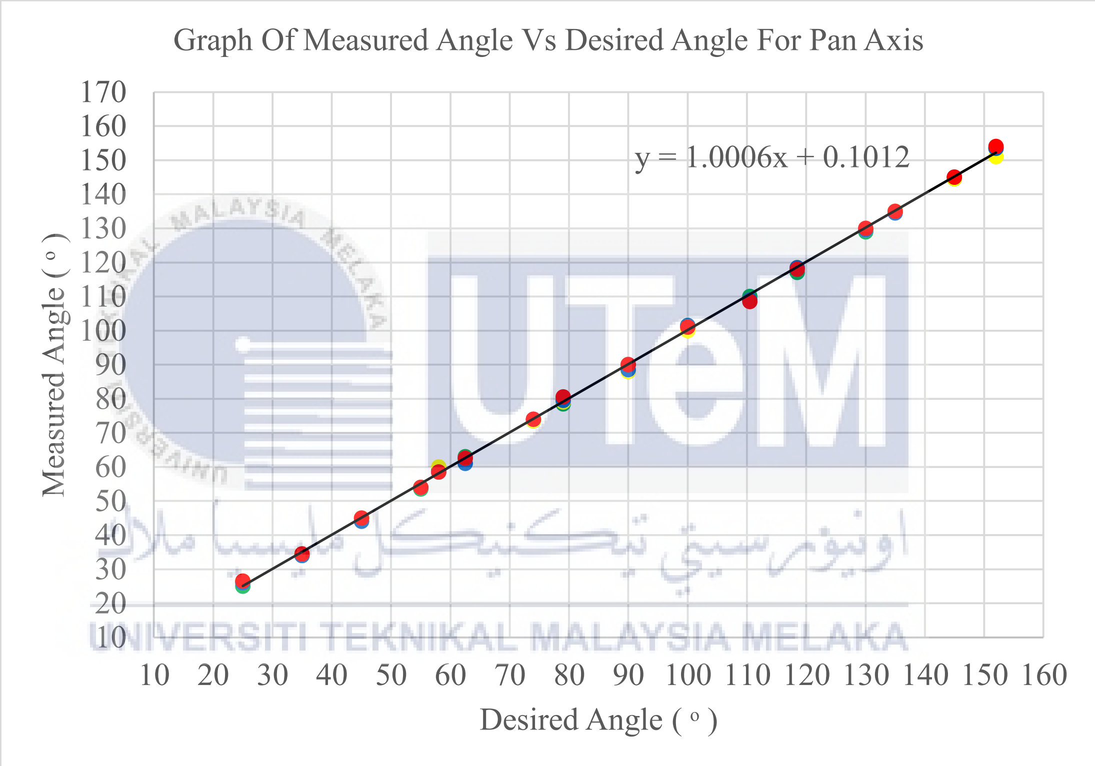


Figure 4.4: Graph of measured angle vs desired angle on the pan axis rotation of the manipulator.

The equation from the best fit graph represents as the linear controller of the system. The gain, K gave to the system is 1.0006, which is shown in the equation. The desired angle was key in into the equation, and the angle produce from the equation is set as the desired angle in Arduino. Then it was compared with the measured angle to test whether it has produced differently in the angle with previous reading. But it does produce much different from the previous reading. This step was continued with the tilt axis. Table 4.10 indicates the data collected for several measured angles of rotation for the tilt axis of the manipulator.

Table 4.10: Data collected for the measured angle from the experiment for pan axis

Angle (°)	Repeatability (°)						
	1	2	3	4	5	Average	Standard deviation
60	60	62.5	61	62.5	61	61.4	1.0840
70	71	70.5	70.5	71	71	70.8	0.2739
80	78.5	77	81.5	78	81	79.2	1.9558
90	90	89.5	89.5	89	89	89.4	0.4183
100	98.5	98	98.5	98.5	98	98.3	0.2739
120	120	119.5	120	118.5	118.5	119.3	0.7583

As shown in table 4.10 the highest accuracy and precision produce in the tilt axis movement at 90 degrees, with average 89.4 and standard deviation of 0.4183. At certain angles such as 60 and 100 degrees, the results of the measured angle are not accurate to its desired point, with having more than 1 degree different from its desired angle of rotation. A best-fit graph was also plotted for the tilt axis rotation. Figure 4.5 shows the best graph of the measured rotation value vs desired rotation value.

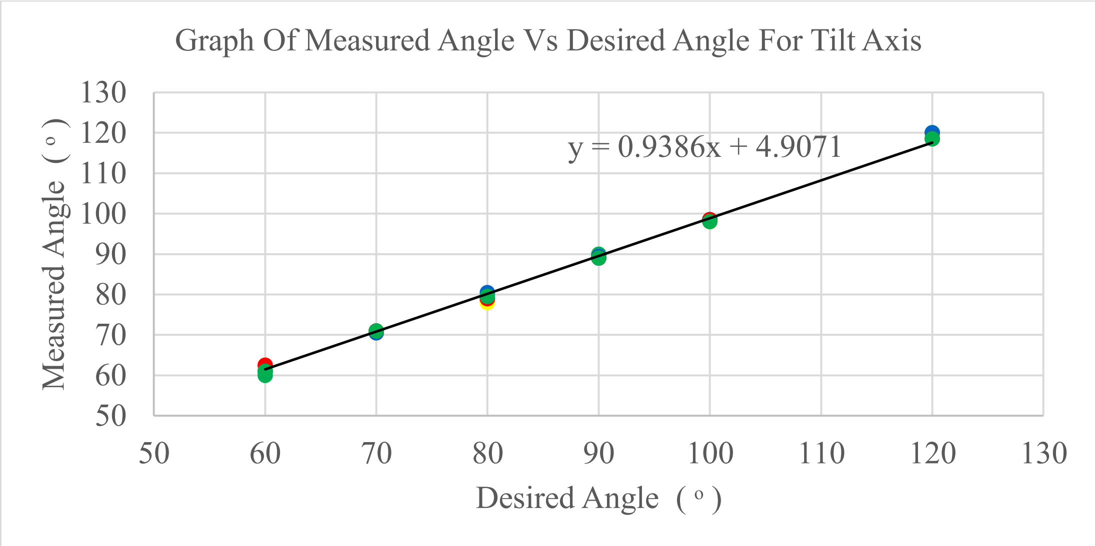


Figure 4.5: Graph of measured angle vs desired angle of the tilt axis rotation of the manipulator.

The gain, K for the tilt axis is 0.9386, which is from in the equation. Again the desired angle was set into the equation, and the value produced by the equation was set as the desired angle in Arduino. The desired value was compared with the measured value. Still, the linear controller has produced the similar outcome as the previous. In the initial stage, PID controller was suggested to be used as the controller in this system in order to control the movement of both pan and tilt axis to reach its desired position with minimal error. However, PID controller could not be implemented in this system. This is because, a PID controller is tuned by varying its input voltage to the motor, also known as the gain of the system. But in servo motor, the input voltage can't vary because it has a fixed voltage which 4.8v or 6.0v. Thus servo motor also does not need a feedback loop to test closed loop of the system, because servo motor has feedback as itself.

4.4 Root mean square error (RMSE)

The term root mean square error (RMSE) is the square root of mean squared error (MSE). RMSE measures the differences between values of the desired actual values and the observed values. RMSE is an unexplained variance that is caused by the system. The error value caused by the system is unpredictable. Also known as measures the quality of the fit between the actual data and the predicted model. RMSE is one of the most frequent methods used measures of the best of fit of generalized regression models. RMSE was done for both measured data pan axis and tilt axis. The equation 4.1 shows the formula to calculate the RMSE value. The RMSE value calculated for the pan axis is 3.09 degrees and for tilt axis is 3.32 degrees. The RMSE value will not affect the whole performance of the system. These values represented the unexplained variation of the measurements of the system (random error). Since the system is intended for gross movement, the 3 degrees variation for both pan and tilt movements are acceptable.

$$\text{RMSE} = \frac{\sqrt{(\textit{difference between each measured value})\,\hat{}\,2}}{\textit{total data size}} \qquad (4.1)$$

The pan axis RMSE value

$$= \sqrt{\frac{(3.5)\hat{}2+(2.5)\hat{}2+(2)\hat{}2+(2)\hat{}2+(3.5)\hat{}2+(4)\hat{}2+(1)\hat{}2+(2.5)\hat{}2+(4)\hat{}2+(4)\hat{}2+(2)\hat{}2+(3.5)\hat{}2+(2)\hat{}2+(1)\hat{}2+(1)\hat{}2+(7)\hat{}2}{16}}$$

= 3.09

The tilt axis RMSE value

$$= \sqrt{\frac{(7)\hat{}2+(2)\hat{}2+(5)\hat{}2+(1)\hat{}2+(1.5)\hat{}2+(2.5)\hat{}2+(2)\hat{}2}{6}}$$

= 3.32

4.5 Trajectory Generation

Trajectory generation is defined as one of motion planning method of a manipulator to move from one point to its desired position. In the previous sections, experiments were conducted to measure how accurate the end points attainment was for the proposed range of movements. However, those experiments were conducted regardless of the dynamics of the system. Therefore, it is the intention of this chapter to try to minimize the abrupt acceleration changes during the movement of the mechanism. During a motion planning, there several constraints to be faced such as jerk limits, torque limit and acceleration and velocity limit. To reduce this constraints trajectory generation method was used. The trajectory generation method was applied to the specific desired point which is more than 1 degree of the average angle different from its desired point. The method was applied to both pan and tilt axis. Trajectory generation allows the manipulator to reach its target point as it's desirable.

An experiment was done to prove the trajectory generation term. This experiment was carried out with three times of repeatability. Firstly, a rotary encoder was attached together with the motor of both pan and tilt manipulator. The measured angle from the rotary encoder and the desired angle was compared. The key element in this experiment is the speed of the movement of the motor to reach the desired point. The speed of the motor can be varied from 1-255 value. The maximum speed is 255, while the minimum speed is 1. The speed for each angle degree test was divided into three ranges. The initial and middle path of the movement is set with 30, and the end the path of the movement is set with 10. The speed of the motor is divided into three ranges, where at the beginning it is fast and the end path it is slow. Therefore, the jerk can from the mechanism could be reduced. Basically, the manipulator reaches its desired position at a fast speed will cause the manipulator to jerk and vibrate. Table 4.11 shows the data collected from the rotary encoder for the pan axis.

Table 4.11: Data collected from the rotary encoder for pan axis

Angle (°)		Time taken for the manipulator to reach its point (s)	Repeatability (°)		
			1	2	3
65	25-45	2.3	48	44	44
	45-60	1.9	60	56	60
	60-65	1.3	68	64	68
110	25-60	4.1	60	60	60
	60-90	3.6	96	92	92
	90-110	2.6	108	112	112
155	25-90	7.3	96	96	96
	90-135	5.2	132	132	132
	135-155	4.9	156	156	156

As shown in table 4.12 the data collected in three ranges of angle for each desired angle. The desired angle for pan axis is 65, 110 and 155 degrees. The reading collected from the rotary encoder has mostly similar kind of reading for three times of repeatability. A graph was plotted from the data collected. Figure 4.6, 4.7 and 4.8 shows the graph for 65, 110 and 155 degrees rotation of pan axis. Figure 4.9 shows the comparison rotary encoder data vs desired angle from the range of 65 to 155 degrees for pan axis.

.

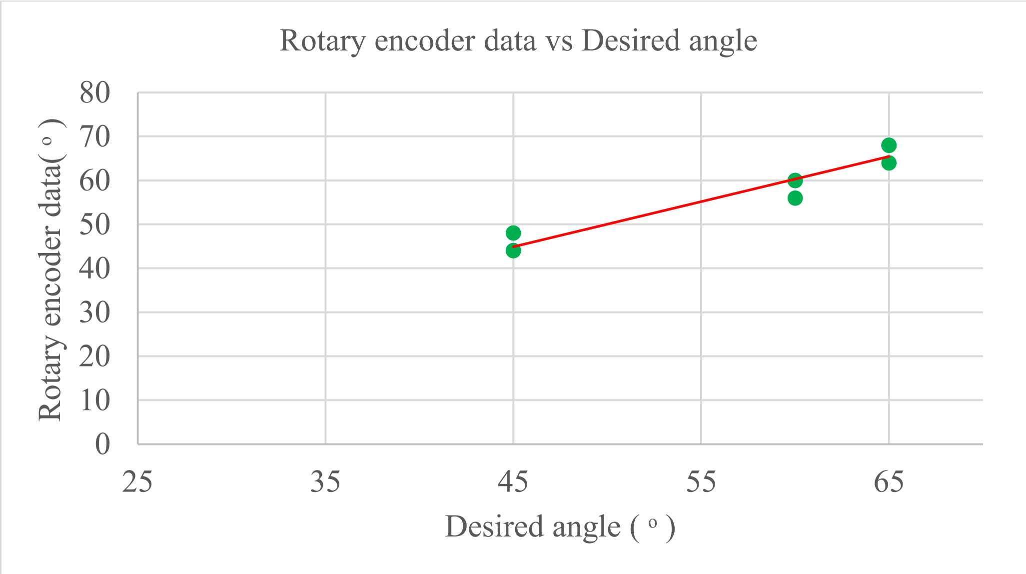


Figure 4.6: Graph of rotary encoder data vs desired angle up to range of 65 degrees for pan axis

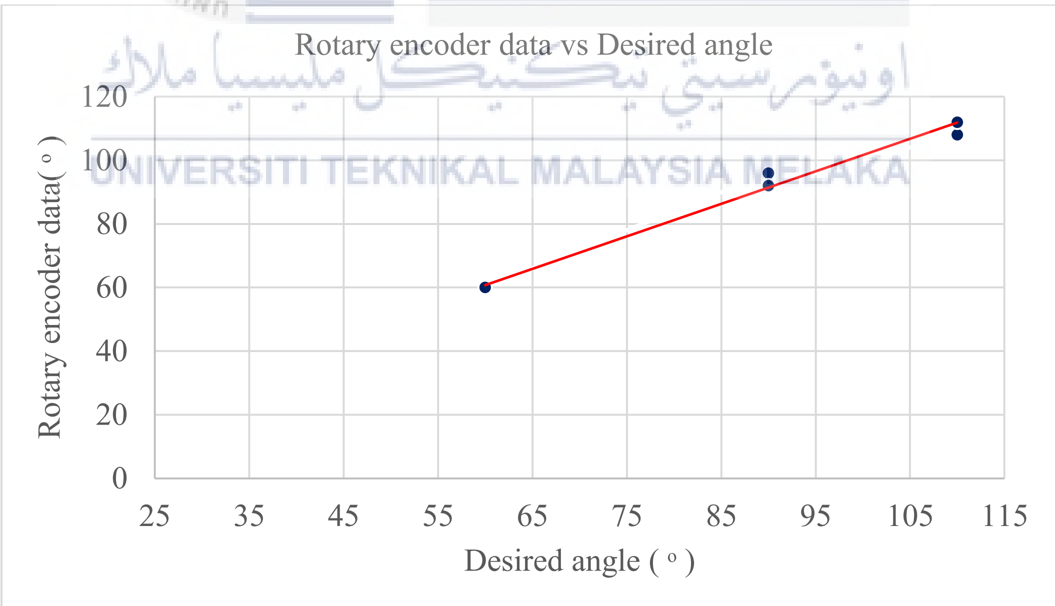


Figure 4.7: Graph of rotary encoder data vs desired angle up to range of 110 degrees for pan axis

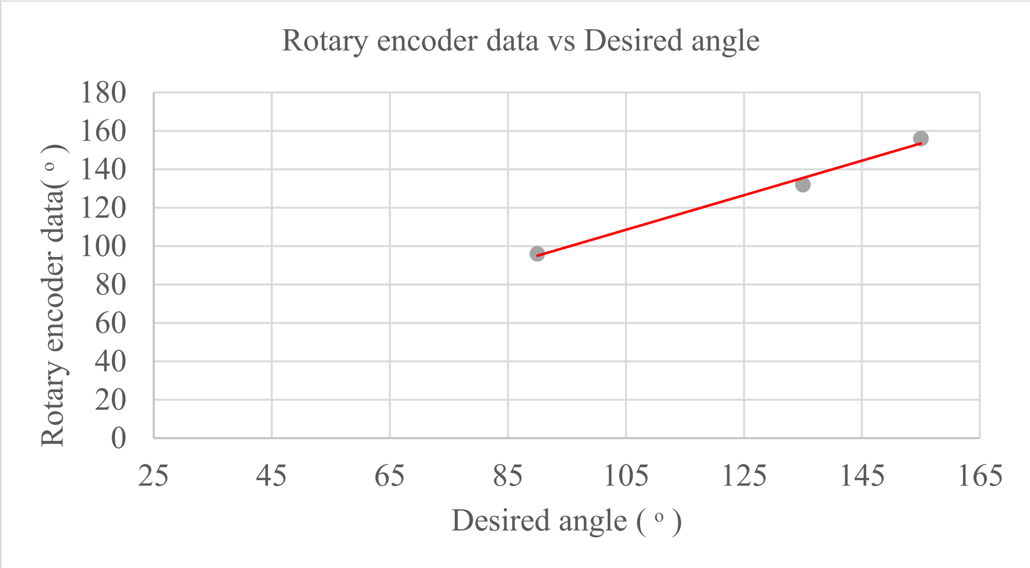


Figure 4.8: Graph of rotary encoder data vs desired angle up to range of 155 degrees for pan axis

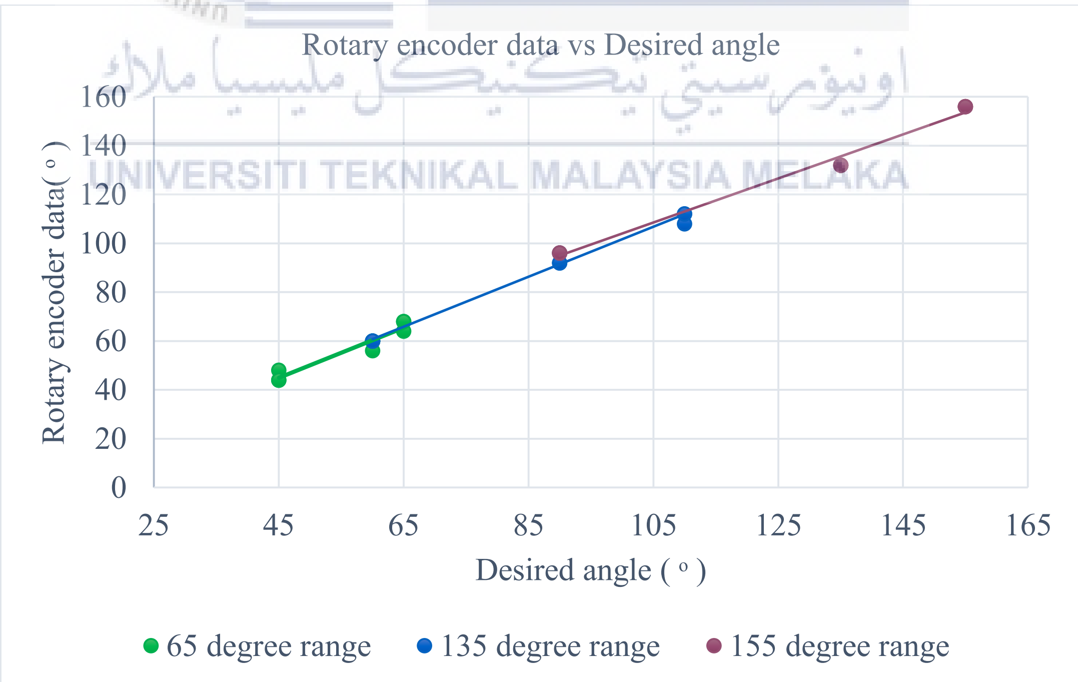


Figure 4.9: Graph of comparison rotary encoder data vs desired angle from the range of 65 to 155 degrees for pan axis

Based on Figure 4.9, the most accurate reading from the rotary encoder is from 90 to 155 degrees of rotation ranges. The data collected from the rotary encoder from the 90 to 155 degree of rotation are similar for each repeatability for each stage of path movement. Particularly, the reading produced by the rotary encoder during 132 degrees is similar for all three repeatability's. This step was repeated for tilt axis. Table 4.12 shows the data collected from the rotary encoder reading for the tilt axis.

Table 4.12: Data collected from the rotary encoder for tilt axis

Angle (°)		Time taken for the manipulator to reach its point (s)	Repeatability (°)		
			1	2	3
60	90-80	1.2	78	78	78
	80-70	1.2	66	66	66
	70-60	1.8	54	54	54
100	70-80	1.2	82	82	82
	80-90	1.2	94	94	94
	90-100	1.8	106	106	106

As shown from table 4.12 the desired angle for the tilt axis is 60 and 100 degrees. The variation produce from each repeatability is similar. So the measured angle from the rotary encoder for this both degrees are precise. A best-fit graph was plotted for both angles. Figure 4.10 and 4.11 shows the graph of measured rotary angle vs desired angle for the angle 60 and 100 degrees of the tilt axis.

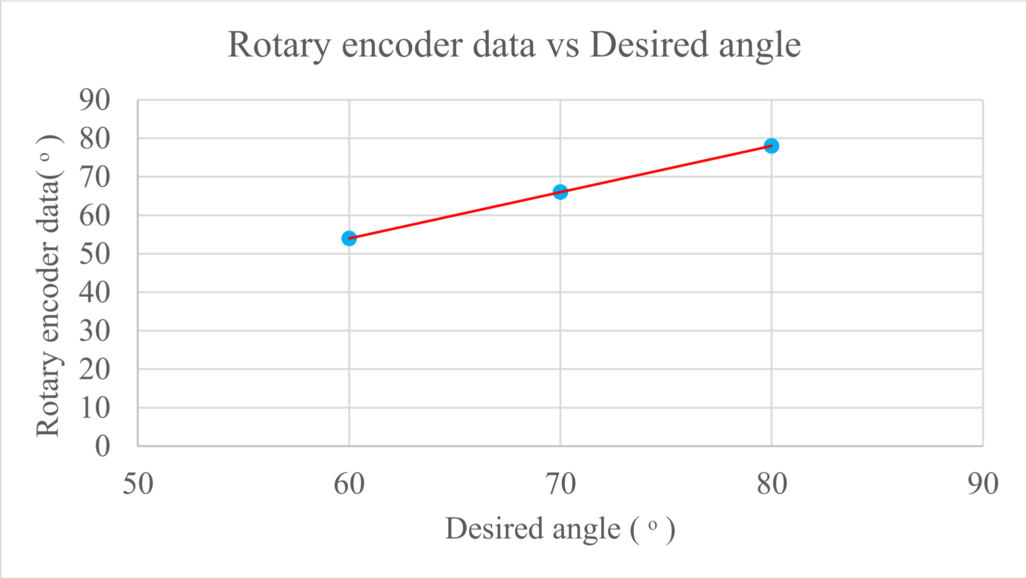


Figure 4.10: Graph of rotary encoder data vs desired angle up to range of 60 degrees for tilt axis

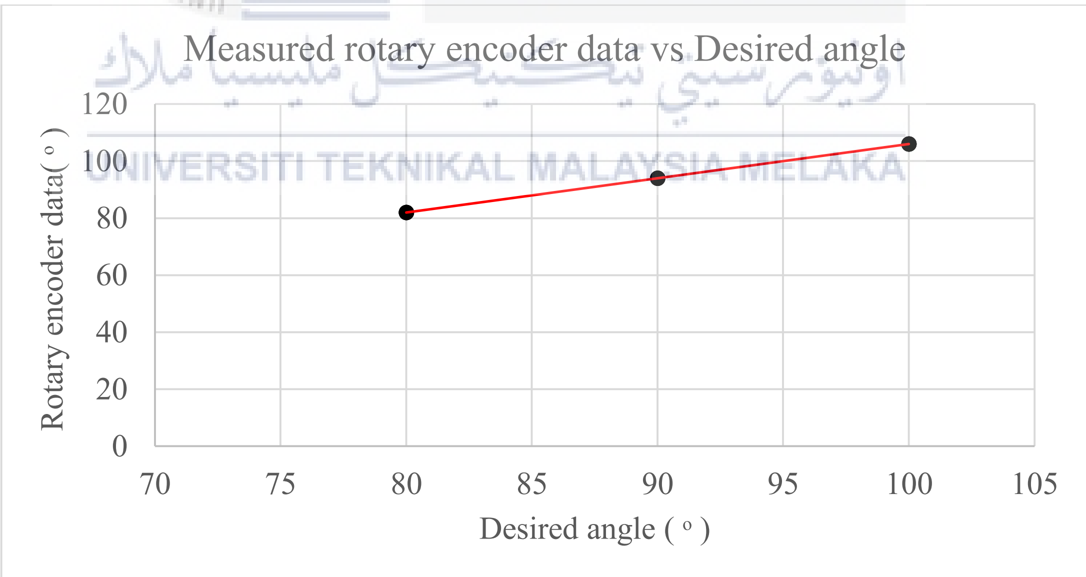


Figure 4.11: Graph of rotary encoder data vs desired angle up to range of 100 degrees for tilt axis

4.6 Comparison between linear movement path and trajectory generation movement path

Based on the data collected and a graph plotted from the accuracy and precision experiment, the manipulator able to move to some desired angle accurately. However, it has a lot of variation between the repeatability of its measured data for each angle. Most of the measured angle is bigger than its desired angle. This is due to the overshoot that occurs in the system during movement the manipulator to reach its desired point. The overshoot happens because vibration and jerk that cause from its mechanism. Generally, the jerky movement usually occurs when a sudden stop happens especially when the previous trajectory was executed with a high speed. At some position, the average measurement reading for both pan and tilt axis is way much different from its desired position. To ensure a smoother movement, a trapezoidal shaped trajectory was explored. The method produces a linear movement with various speed.

The aim of this method is to increase the speed of the movement faster without any overshoot. If the system move in gradual slow speed it going affect the transient response of the system, such as the rise time of the system will be slower. In order to compensate this situation, the speed of the initial stage of the path movement is fast and remains with same speed till the middle path of the movement. At the end path of the movement, the speed is slowing down, to reduce the jerk and vibration caused to the system. So the measured data produced from the trajectory generation is better than linear path movement. For example, the reading produced from the rotary encoder for the desired angle 155 degrees for pan axis is 156 degrees, which are much more accurate than the measured angle from the linear controller with the average measured angle of 152.8 degrees. The measured data from the trajectory measured has less variation over its repeatability for each desired point.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, the control of movable platform for surgical illumination system is an automated system that moves according to the detection of the raspberry pi camera with the support of two rotating link joint that is pan and tilt. Several experiments were done to test the capabilities and performance of the actuators. The major concerns in this system are to achieve the most accurate and precise movement from one point to another point. In order to achieve that the mechanism needs to cope with several constraints such as jerk, vibration, and other dynamic factors. This constraint is caused due to the mass of load, insufficient current supply to the motor and loose connection between the jumper wires. This constraint will affect the transient response of the system and distract the movement of the link in order to achieve its desired position. So a controller is very much needed to compensate this type of constraints. Initially, PID controller was planned to be implemented in this system, but due to some factors, PID controller can't be implemented in this system. So a linear controller was design based on the outcome of the experiment done. The mechanism able to move to several positions accurately in both pan and tilt axis. However, to produce the similar outcome over repeatable times is the main weakness. The results have a lot of variation over repeatable time. The equation produce for pan axis is $y = 1.0006x + 0.1012$ and for tilt axis is $y = 0.9386x + 4.9071$. The gain K for the pan axis is 1.0006, whereas for the tilt axis is 0.9386. The trajectory generation method had shown the jerk produce on the mechanism when moving some position can be reduced.

Comparisons are made between both experiment results. Besides that, the objectives of this project are achieved. Therefore, the mechanism is able to be driven within the joint space with acceptable precision and accuracy.

5.2 Recommendation

This current implementation has the weakness where it can't move to some desired position and the current prototype implementation was not robust. The selection of the motor plays the major part of this project. In this case, servo motor is easy and gives a good outcome in a position controlled scheme. But it can't be tuned because the input voltage given to the motor is fixed. So the implementation of other controllers in the system is difficult. Further study on the torque requirement for the mechanism and the suitability for servo motor should be investigated. Study on relationship between the mass of the load and actuators performance should be made. Change in the motor is very much recommended in this project. The motor that is highly recommended is the dc motor with encoder. By using this motor, PID controller could be implemented in this project. Thus, the weakness faced in this current implementation could be compensated.

LIST OF REFERENCE

1. D. G. Choi, B. J. Yi, and W. K. Kim, “Automation of surgical illumination system using robot and ultrasonic sensor,” Proceedings 2007 IEEE International Conference Mechatronics and Automation. ICMA 2007, no. 2, pp. 1062–1066, 2007.

2. LT, K., MS, D. and JM, C. (2000). To Err is Human: Building a Safer Health System - PubMed - NCBI. [online] US National Library of Medicine National Institutes of Health. Available at: https://www.ncbi.nlm.nih.gov/pubmed/25077248 [Accessed Dec. 2017].

3. A.Bstract, “Electrically Focused Surgical Light,” IEEE Transactions on Robotics and Automation., vol. 8, no. 2, pp. 298–308, 2002

4. S. Ghate, “Design and Development of Soft Actuator for Surgical Application .,” pp. 132–137, 2017.

5. Sanem Evren, Firat Yavuz, and Mustafa Unel "High Precision Stabilization of Pan-Tilt Systems Using Reliable Angular Acceleration Feedback from a Master-Slave Kalman Filter, 11 March 2017

6. Y. C. Chang and J. Shaw, "Low-frequency vibration control of a pan/tilt platform with vision feedback," J. Sound Vibration., no. 4–5, pp. 716–727, 2007.

7. B. B. Bederson, R. S. Wallace, and E. L. Schwartz, “A Miniature Pan-Tilt Actuator: The Spherical Pointing Motor,” IEEE Transactions on Robotics and Automation., vol. 10, no. 3, pp. 298–308, 1994

8. H. Chen, X. Zhao, and M. Tan, “A Novel Pan-Tilt Camera Control Approach for Visual Tracking,” 2014.

9. G. A. Towle, “Voice Controlled Surgical Suite,” no. 12, pp. 0–3, 2013.

10. V. Barrocas, “Illumination Lighting Apparatus And Method Of Controlling Illumination,” 1980.

11. S. Prawanta, S. Khaengkarn, and J. Srisertpol, “Motion control of a 3-DOF girder system using eccentric circular cam,” Proceedings 2016 Asia-Pacific Conference Intellingent Robot System. ACIRS 2016, pp. 132–136, 2016.

12. M. Bandyopadhyay, S. Chattopadhyay, and N. Mandal, "Position control system of a PMDC motor," International Conference On Electric, Electronic and Optimization Technique. ICEEOT 2016, pp. 752–754, 2016.

13. B. Rashidi, M. Esmaeilpoor, M. R. Homaeinezhad, and M. Zoghi, “Error based self-regulating PID angle control of variable structure redundant brushed DC motors,” 2014 2nd RSI/ISM International Conference on Robotics and Mechatronics, ICRoM 2014.

14. L. J. Mpanza and J. O. Pedro, “Sliding mode control of a 2-DOF hydraulic servo system,” Proceedings of the 2015 16th International Carpathian Control Conference, ICCC 2015.

15. M. H. A. Majid and M. R. Arshad, “A fuzzy self-adaptive PID tracking control of autonomous surface vehicle,” 2015 IEEE International Conference on Control System, Computing and Engineering (ICCSCE).

16. M. F. Silva et al., “Design of angular PID controllers for quadcopters built with low cost equipment,” 2016 20th International Conference on System Theory, Control and Computing, ICSTCC 2016 - Joint Conference of SINTES 20, SACCS 16, SIMSIS 20 – Proceedings.

17. E. Dincel, Y. Yalcin, and S. Kurtulan, “A new approach on angular position control of fan and plate system,” Proceedings - 2014 International Conference on Control, Decision and Information Technologies, CoDIT 2014.

18. F. Rios-Gutierrez and Y. F. Makableh, “Efficient position control of DC Servomotor using backpropagation Neural Network,” 2011 Seventh International Conference on Natural Computation pp. 653–657, 2011.

19. R. Manikandan and R. Arulmozhiyal, “Modeling and simulation of fuzzy based BLDC fed vertically rotating one DOF robot arm position control system,” Proceedings of the 10th International Conference on Intelligent Systems and Control, ISCO 2016.

20. S. N. Syed Salim, M. F. A. Rahmat, A. A. Mohd Faudzi, Z. H. Ismail, and N. Sunar, “Position control of pneumatic actuator using self-regulation nonlinear PID,” Mathematical Problems in Engineering, 2014.

21. M. T. A. Rahman and S. Ahmad, “Performance comparison between PD-fuzzy and PID controller towards the stability of the extendable double-link two-wheeled mobile robot,” 2015 10th Asian Control Conference: Emerging Control Techniques for a Sustainable World, ASCC 2015.

22. S. Abdelraheem, “Optimized P-PI Fuzzy Logic Controller of a Positioning Mechanism with Strain Wave Gearing,” 2016.

23. S. Ramasamy, R. Karthikesh, P. Manikandan, and P. Thiagarajan, “Development of stepper motor based two DOF robotic arm transferring liquid using peristaltic pump,” International Journal of Engineering and Technology,

pp. 52–57, 2013.

24. A.Swami and P. Gaur, "ISTF-PID Based D. C. Servo Motor Control," pp. 4–8, 2016.

25. Ade kortiko and Ali Husein, " Design And Implementation Of An Object Tracking System Control Using PID And Movement Prediction" Department Of Electronic Engineering, Polytechnique Campus Subaraya State Electronic PENS – ITS Sukolilo, Subaraya, 2012

26. Han, J.; Wang, P.; Yang, X. Tuning of PID controller based on fruit fly optimization algorithm. In Proceedings of the International Conference on Mechatronics and Automation (ICMA), Chengdu, China, 5–8 August 2012; pp. 409–413.

27. Meshram, P.M.; Kanojiya, R.G. Tuning of PID Controller using Ziegler-Nichols Method for Speed Control of DC Motor. In Proceedings of the IEEE International Conference on Advances in Engineering, Science and Management (ICAESM), Nagapattinam, India, 30–31 March 2012; pp. 117–122.

28. G. R. Yu, K. Y. Bai, and M. C. Chen, “Applications of Taguchi method to fuzzy control for path tracking of a wheeled mobile robot,” in Proceedings of the 17th National Conference on Fuzzy Theory and Its Applications, pp. 857–862, Kaohsiung, Taiwan, 2009

29. M. Aamir, “On replacing PID controller with ANN controller for DC motor position control,” International Journal of Research Studies in Computing, pp. 21–29, 2013.

APPENDIX

Arduino coding

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

Servo servo_test;       //initialize a servo object for the connected servo

int angle = 0;

void setup()
{
  servo_test.attach(9);      // attach the signal pin of servo to pin9 of arduino
}

void loop()
{

    servo_test.write(0);
    delay(5500);

    servo_test.write(15);
    delay(5500);

    servo_test.write(30);
    delay(5500);
```

```
servo_test.write(45);          //command to rotate the servo to the specified angle
delay(5500);

 servo_test.write(60);
delay(5500);

 servo_test.write(90);
delay(5500);

servo_test.write(120);
delay(5500);

 servo_test.write(135);
delay(5500);

 servo_test.write(150);
delay(5500);

servo_test.write(180);
delay(5500);



}
```

```
#include <Servo.h>;

Servo Myservo;

void setup () {

}

void loop () {
Myservo.attach (9);
Myservo.write (25);
delay (2000);
Myservo.detach ();
delay (2000);
Myservo.attach (9);
Myservo.write (35);
delay (2000);
Myservo.detach ();
delay (2000);
Myservo.attach (9);
Myservo.write (45);
delay (2000);
Myservo.detach ();
```

```
delay (2000);
Myservo.attach (9);
Myservo.write (55);
delay (2000);
Myservo.detach ();
delay (2000);
Myservo.attach (9);
Myservo.write (60);
delay (2000);
Myservo.detach ();
delay (2000);
Myservo.attach (9);
Myservo.write (65);
delay (2000);
Myservo.detach ();
delay (2000);
Myservo.attach (9);
Myservo.write (70);
delay (2000);
Myservo.detach ();
delay (2000);
Myservo.attach (9);
Myservo.write (80);
```

```
delay (2000);
Myservo.detach ();
delay (2000);
Myservo.attach (9);
Myservo.write (90);
delay (2000);
Myservo.detach ();
delay (2000);
Myservo.attach (9);
Myservo.write (100);
delay (2000);
Myservo.detach ();
delay (2000);
Myservo.attach (9);
Myservo.write (110);
delay (2000);
Myservo.detach ();
delay (2000);
Myservo.attach (9);
Myservo.write (120);
delay (2000);
Myservo.detach ();
delay (2000);
```

```
Myservo.attach (9);
Myservo.write (135);
delay (2000);
Myservo.detach ();
delay (2000);
Myservo.attach (9);
Myservo.write (145);
delay (2000);
Myservo.detach ();
delay (2000);
Myservo.attach (9);
Myservo.write (155);
delay (2000);
Myservo.detach ();
delay (2000);

}
```

```
#include <VarSpeedServo.h>

VarSpeedServo myservo;    // create servo object to control a servo

void setup() {
  myservo.attach(9);  // attaches the servo on pin 9 to the servo object
}

void loop() {
  myservo.write(25, 30, true);
myservo.write(45, 30, true);
myservo.write(65, 10, true);

}
void loop() {
  myservo.write(25, 30, true);
myservo.write(90, 30, true);
myservo.write(110, 10, true);
}
void loop() {
  myservo.write(90, 30, true);
myservo.write(135, 30, true);
myservo.write(155, 10, true);
```

```
}
#include <Bounce2.h>


#define encoder0PinA  2
#define encoder0PinB  4
#define STEP_SIZE 12


byte encoder0Pos = 0;


Bounce debouncerA = Bounce();
Bounce debouncerB = Bounce();


void setup()
{
   debouncerA.attach(encoder0PinA, INPUT_PULLUP);
   debouncerA.interval(5); // interval in ms
   debouncerB.attach(encoder0PinB, INPUT_PULLUP);
   debouncerB.interval(5); // interval in ms


   Serial.begin (9600);
   Serial.println("start");              // a personal quirk


}
```

```
void loop()
{
  // Read the status of the inputs
  debouncerA.update();
  debouncerB.update();


  int8_t EncVariation = 0;


  if (debouncerA.rose())
  { // if input A changed from low to high, it was CW if B is high too
    EncVariation = (debouncerB.read()) ? 1 : -1;
  }
  else if (debouncerA.fell())
  { // if input A changed from high to low, it was CW if B is low too
    EncVariation = (debouncerB.read()) ? -1 : 1;
  }
  else if (debouncerB.rose())
  { // if input B changed from low to high, it was CCW if A is high too
    EncVariation = (debouncerA.read()) ? -1 : 1;
  }
  else if (debouncerB.fell())
  { // if input B changed from high to low, it was CCW if B is low too
    EncVariation = (debouncerA.read()) ? 1 : -1;
```

```
    }

    {
      encoder0Pos = (encoder0Pos + EncVariation * STEP_SIZE) % 360;

      Serial.println (encoder0Pos, DEC);
    }
}
```