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Faculty of Electrical Engineering

COMPARATIVE STUDY BETWEEN LINEAR AND INTELLIGENT CONTROLLERS FOR ANTI-SWAY GANTRY CRANE SYSTEM

FEDA’AADEEN YAHYA MOHAMMED ALKHASHI

Bachelor of Electrical Engineering (Control, Instrumentation and Automation) with Honor

2017

APPROVAL

I hereby declare that I have read through this report entitled “COMPARATIVE STUDY BETWEEN LINEAR AND INTELLIGENT CONTROLLERS FOR ANTI-SWAY GANTRY CRANE SYSTEM” and found that it has compiled the partial fulfilment for awarding the degree of Bachelor of Electrical Engineering (Control, Instrumentation and Automation).

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COMPARATIVE STUDY BETWEEN LINEAR AND INTELLIGENT CONTROLLERS FOR ANTI-SWAY GANTRY CRANE SYSTEM.

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A report submitted in partial fulfilment of the requirement for the degree of Electrical Engineering (Control, Instrumentation and Automation)

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2017

DECLERATION

I (Feda’aadeen Yahya Alkhashi) declare that this report entitles “COMPARATIVE STUDY BETWEEN LINEAR AND INTELLIGENT CONTROLLERS FOR ANTI-SWAY GANTRY CRANE SYSTEM” is the result of my 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.

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Name: Feda’aadeen Yahya Alkhashi

DEDICATION

To my beloved mother, father and family

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ABSTRACT

Gantry crane is a transporting machine system used to transport heavy loads and dangerous materials in industries, factories, high building constructors and shipyards. Therefore, controlling such system is very crucial in the working environment that generally caused the safety issues. There are many controllers have been applied to control the system, so selecting the suitable and functional controller has been a critical matter. In this project, the methods or techniques of controlling the gantry crane system is discussed and compared together. Advantages, disadvantages and performance of each controller are studied and introduced as a comparative study. To be more specific, two type of controllers are being chosen for this project as there are widely used in practical life. Linear and intelligent controllers are the ones to be studied in this project. Proportional-integral-derivative controller (PID) and linear-quadratic-regulator controller (LQR) will represent the linear controllers. Fuzzy logic controller and fuzzy-PID controller will represent the intelligent controllers. The findings show that, from the comparative study between linear and intelligent controllers, Fuzzy and Fuzzy-PID show better performance as compared to PID and LQR controllers. The performance in terms of design complexity, transient response (OS%, Ts, Tp and T_r), steady state error (e_{ss}), root-mean-square error (RMSE) and maximum amplitude of oscillation of trolley position and sway have been evaluated for several point-to-point tracking controls. As conclusion, intelligent controllers are suitable to be utilized in gantry crane system.

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ABSTRAKT

Gantri kren adalah sistem mesin pengangkutan yang digunakan untuk mengangkut beban berat dan bahan-bahan berbahaya dalam industri, kilang, pengeluar bangunan tinggi dan limbungan. Oleh itu, pengawalan sistem tersebut adalah sangat penting dalam persekitaran kerja yang biasanya menyebabkan isu-isu keselamatan. Terdapat banyak pengawal telah digunakan untuk mengawal sistem, jadi memilih pengawal sesuai dan berfungsi adalah menjadi perkara kritikal. Dalam projek ini, kaedah atau teknik untuk mengawal sistem kren gantri dibincangkan dan dibandingkan bersama. Kelebihan, kelemahan dan prestasi setiap pengawal dikaji dan diperkenalkan sebagai kajian perbandingan. Untuk lebih spesifik, dua jenis pengawal sedang dipilih untuk projek ini kerana ada digunakan secara meluas dalam kehidupan praktikal. Pengawal linear dan pintar adalah orang-orang yang akan dikaji dalam projek ini. Pengawal kadaran-kamiran-derivatif (PID) dan pengawal linear-kuadratik-pengatur (LQR) akan mewakili pengawal linear. Kawalan logik Fuzzy dan kawalan Fuzzy-PID akan mewakili pengawal bijak. Dapatan kajian menunjukkan bahawa, dari kajian perbandingan antara linear dan pengawal pintar, Fuzzy dan Fuzzy-PID menunjukkan prestasi yang lebih baik berbanding dengan pengawal PID dan LQR. Prestasi dari segi reka bentuk, sambutan fana (OS%, Ts, Tp dan Tr), ralat keadaan mantap (ESS), punca min persegi ralat (RMSE) dan amplitud maksimum ayunan kedudukan troli dan bergoyang telah dinilai untuk beberapa kawalan pengesanan titik-ke-titik. Kesimpulannya, pengawal pintar sesuai untuk digunakan dalam sistem kren gantri.

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CHAPTER 1

1. INTRODUCTION

1.1 MOTIVATION

Transportation becomes one of the most vitally important needs in our life. People, animal and goods are required to move from one place to another in order to fulfill their necessity. Things can be transported through many ways such air, road, rail, water, cable, pipelines and space. Nowadays, all of the factories, ports and plants require systems to transport goods and equipment within their working area. Besides, safety is the most concerning and crucial aspect most of the factories and other infrastructures care about. One of the machines that is worldwide used to transport heavy loads and dangerous materials in industries, factories, high building constructors and shipyards is crane system. There are two main types of crane which are rotary crane and gantry crane.

Rotary crane differs from the gantry crane where its load-line attachment point undergoes rotation. It has two types, boom crane which is used in shipyards and the point moves vertically for this type as shown in Figure 1.1. The other type is tower crane which is mostly used in construction as illustrated in Figure 1.2. Besides these motions, the cable can be controlled either to get lowered or raised. Like a spherical pendulum with two-degree-of-freedom sway, the load and cable can be treated.

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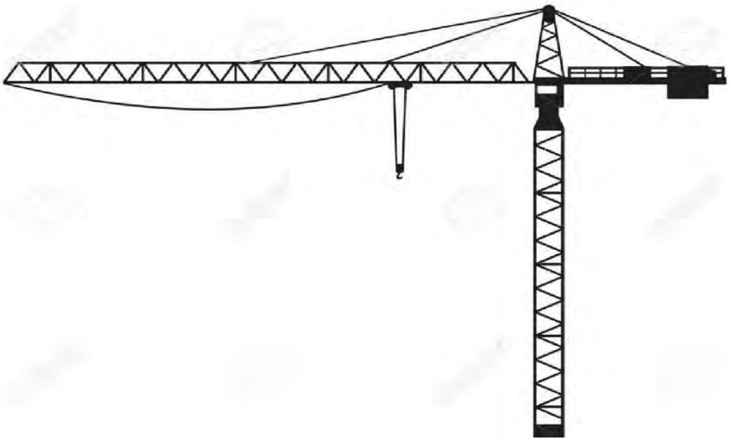

Figure 1.1: Boom Crane

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Figure 1.2: Tower Crane

Gantry crane as illustrated in Figure 1.3 is the other type of cranes that highly utilized in heavy engineering machinery. It mainly consists of three parts which are trolley, cable and payload. The trolley moves horizontally while the payload is attached by the rope whose length can be changed by lifting techniques. The cable attached together with the load is considered as one-dimensional pendulum with one-degree-of-freedom. There is another kind of these type of cranes, which also can move horizontally but in two perpendicular directions. The analysis is almost the same for all of them due to that the two-direction movements can be divided into two uncoupled one-direction motions.

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Figure 1.3: Gantry Crane

However, there are many hazards and dangers in crane system might occur. Injuries, deaths and other disastrous consequences could happen by crane-related accidents as cranes need to be dealt with carefully. Around 323 construction and factories worker deaths was recorded during the period from 1992 to 2006 in the United States of America, an average of 22 deaths per year as shown in Figure 1.4 and tabulated in Table 1.1 [1] . Despite the fact that operator failure has been distinguished as a major cause to crane-related problems, lifting tasks could be done efficiently and safely by providing some practical tools which are available and effectively functioning. Therefore, the design of the crane system must be safe, intelligent and functional.

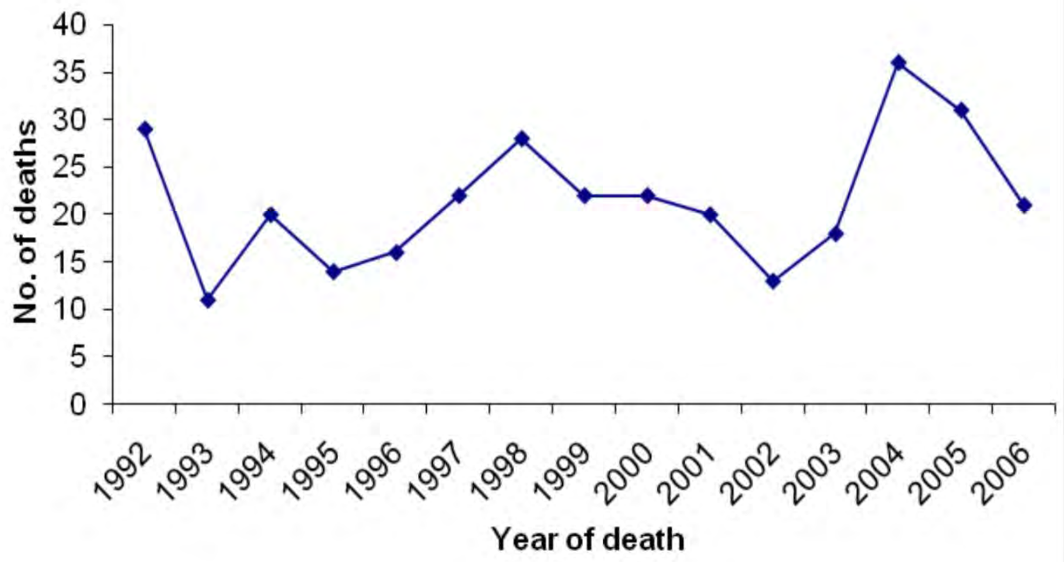

Figure 1.4:Crane-Related Deaths in Construction by Year, 1992-2006

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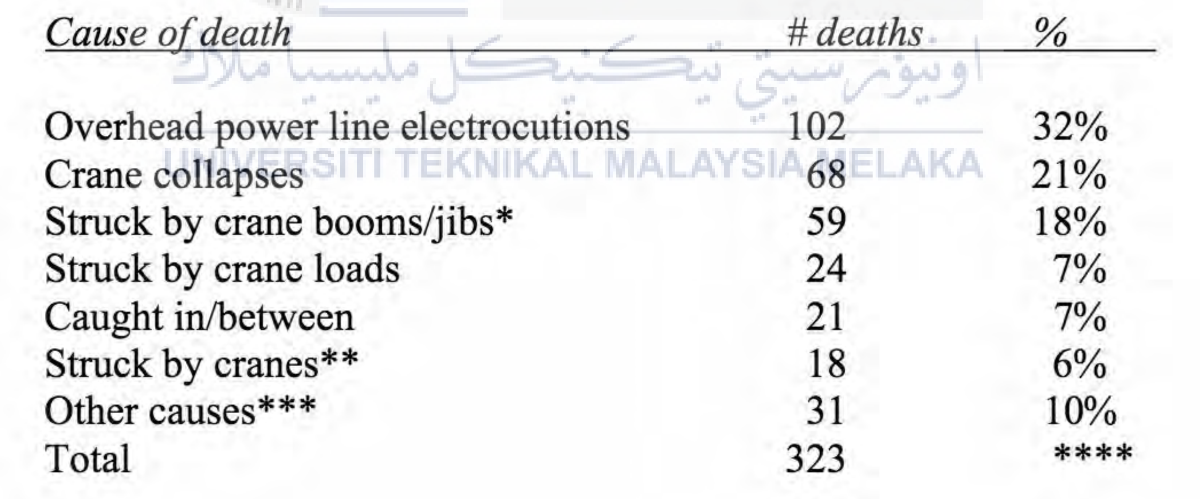
Table 1.1: Reasons of deaths which are related to crane, 1992-2006



Cause of death	*# deaths*	*%*
Overhead power line electrocutions	102	32%
Crane collapses	68	21%
Struck by crane booms/jibs*	59	18%
Struck by crane loads	24	7%
Caught in/between	21	7%
Struck by cranes**	18	6%
Other causes***	31	10%
Total	323	****

1.2 Problem Statement

Despite the fact that there are many ways to improve the operation and functionality of the cranes, there are also major problems associated with the improving processes. One of the most crucial and challenging problems is the load sway in the crane during movement. Oscillation and swaying of a heavy load may cause dangerous and serious bad consequences. Property's damaging and human injuries and deaths are the probable result of such problem. The conventional solution will be based on the feeling, experience and observation of the operator. Very high expertise and proficiency are required for the workers to be qualified controlling the sway and oscillation of the crane's load.

Anti-sway controller means can solve and reduce the incidents and damages caused by the swaying. Speed and reliability of the crane will also better and get improved. There will be less effort and tension required to control and operate the crane with the help of the algorithm of the anti-sway controlling. Moreover, with simple and basic knowledge and qualification the worker can deal well with the crane and manage to control the oscillation perfectly. However, there is no much work on comparative studies about the controller of the gantry crane system. Hereby, this project will apply a comparison between four controllers so the selection process will be easier and clearer.

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1.3 Objective

This project will aim to achieve the following objectives:

i) To establish the mathematical modeling of one degree of freedom gantry crane system.
ii) To design linear and intelligent controllers that capable to track the desired tracking trajectory while reduce the payload oscillation.
iii) To evaluate the performance of linear and intelligent controllers in term of time response, steady state error and maximum oscillation.

1.4 Scope of Work

The scope of this project will focus on the following points:

i) The gantry crane system only considered 1-DOF that consist of payload connected using fixed rope length and driven by trolley.
ii) PID and LQR will be implemented as linear controller
iii) Fuzzy and Fuzzy-PID will be implemented as intelligent controller
iv) The performance will be evaluated in terms of design complexity, transient response performance (OS%, T_s, T_p), steady state error (e_{ss}), root-mean-square error (RMSE) and maximum amplitude of oscillation.

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CHAPTER 2

2. LITERATURE REVIEW

2.1 Gantry Crane System

When it comes to applying the gantry crane to the field of work, the efficiency of production will get affect badly by the load oscillation and might cause hazardous accidents. Moreover, beside the high-efficiency and productivity need, the solution of anti-sway for the crane to get over the difficulty that delayed the goods from positioning and transferring professionally is considered to be something vitally important and urgent. Therefore, the anti-sway measures study for the the crane swinging utensils appears to be more important and essential than ever [2].

In terms of the anti-sway means, there are two general categories for the gantry crane: the mechanical and the electronic. The electronic becomes the primary measure and research focus in the field of the oscillation proof, and takes on a great deal of unparalleled superiority over its mechanical counterpart [2].

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The first method used for anti-swaying was introduced in 1930 by Lueg [3]. As a way to cancel noise vibration, the researcher used the active control technique. Controlling an active sway angle of gantry crane contains artificially generating sources which works on absorbing the energy resulted from the undesired rope’s sway angle to eliminate or decrease the impact on the whole system.

2.2 Control Techniques in Gantry Crane System

The main purpose of controlling gantry crane is to move an object form point to another as quick as possible without causing any excessive swing at the final destination and, at the same time, with keeping the swing small while moving [4]. There are many techniques used for controlling gantry crane systems based on closed loop and open loop systems.

2.3 Linear Controllers

2.3.1 PID Controller

Proportional-Integral-Derivative (PID) controller is considered to be one of the feedback controller and as stated in [5], due to its simplicity PID controller has been commonly used in feedback control system design. Its output depends on the difference between the set point of the system and the measured process variable. Every part of the PID controller has to do a certain action taken on the error. Then, the error is used to modify some of the process input in order to get its defined set point.

However, the PID method is not suitable for controlling a system with large amount of lag, parameter variations and uncertainty in models. Thus, PID control method cannot accurately control position in a hydraulic system. To improved PID control performance, many researchers have integrated fuzzy Logic Control technique to tune the PID parameter.

In [6], proportional-integral-derivative (PID) controller is utilized with high convenience and ordinary usage for user. As a result, it has been widely and extensively used in actual and real industries. PID controller has been designed for crane automatic position and anti-sway in order to consider nonlinear elements of an Air Traffic Control (ATC). An automatic change in varying conditions must happen to the PID parameters, as transfer crane has many dynamic characteristics. Nevertheless, PID controller has low robustness against the system environment compared to other controllers.

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2.3.2 Linear Quadratic Regulator

Linear Quadratic Regulator (LQR) controllers have been proposed as a solution to some of the PID controller problems in [7]. Applying LQR controller to a system will result in a good and suitable performance and outcomes related to a given performance measure. This measure of performance is considered to be a quadratic function consist of two factors which are control input and state vector.

Pole positioning method theory is well carried out by LQR. There are two functions that the LQR algorithm can define the pole positioning theory based on. First stating the optimal performance index and second solving the algebraic Riccati equation. Iteration method should be the way to define the cost function of the gain as there’s no specific solution LQR can provide to define it.

Obtaining the optimal input signal u(t) from state feedback is considered to be the main advantage of the LQR controllers. However, the difficulty in finding the analytical and systematic solution to the Riccati equation in most cases but simple one is the main weakness of the controller.

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2.4 Intelligent Controllers

2.4.1 Fuzzy Logic Controller

In[2], fuzzy logic controller has been one of the techniques that have been proposed by many studies and researchers. Fuzzy logic controller was fully able to realize the horizontal positioning control precisely. The experimental results indicated that this system is capable of both the precise positioning and angle attenuation within a less time period and with less disturbance ability.

Moreover, in [8] the proposed fuzzy logic controllers consist of two main parts which are position controllers and anti-swing controllers. The information of the professional operators was the base of the fuzzy logic control's design. The intelligent controller's performance is experimentally evaluated and calculated on a lab-scale of gantry crane. Compared to a gantry crane system operated with classical PID controller, the gantry crane controlled by fuzzy logic controller showed a better performance in the experimental result.

Nevertheless, the weakness of fuzzy logic controller is that it is hard and requiring much time to heuristically find the proper principles function of membership, the parameter of fuzzification and also the deffuzification parameter [4].

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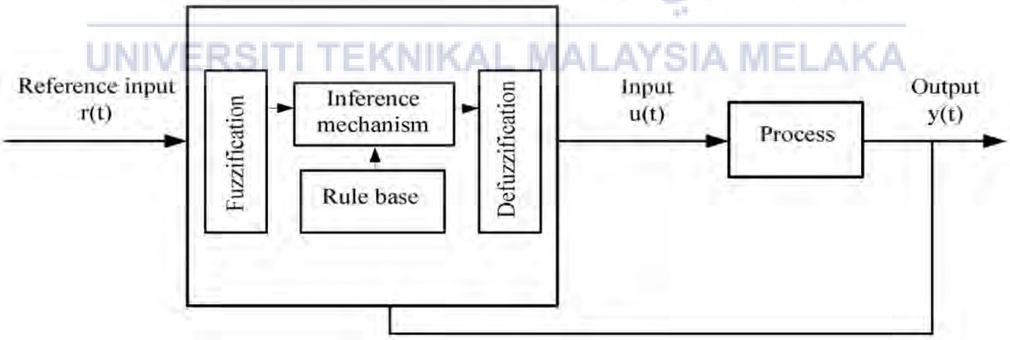

Figure 2.1: Fuzzy Controller Structure

2.4.2 Neural Networks

According to [9] and [20], Neural networks have been adopted for the dynamical system's control and used in divers fields and spaces like prediction, recognition and classification. Neural-network-based, self-tuning controllers has been proposed for overhead cranes. Moreover, a novel method for overhead cranes' trajectory planning was introduced in order to alleviate the oscillation and sway motion after moving to the last destination. To generate the trolley position's optimal trajectory, radial basis function networks have been utilized. Lately, an algorithm called particle swarm optimization (POS) has been used to learn and evaluate the neural network's parameters. POS is an evolutionary computation technique. It's been adopted to train the radial basis function network. By moving the trolley along the generated track, the reduction of sway angle can be achieved smoothly; that is, the proposed control scheme does not require sensors to measure the undesired oscillation as it's an open loop control. Figure 2.2 indicates the schematic of the neural network.

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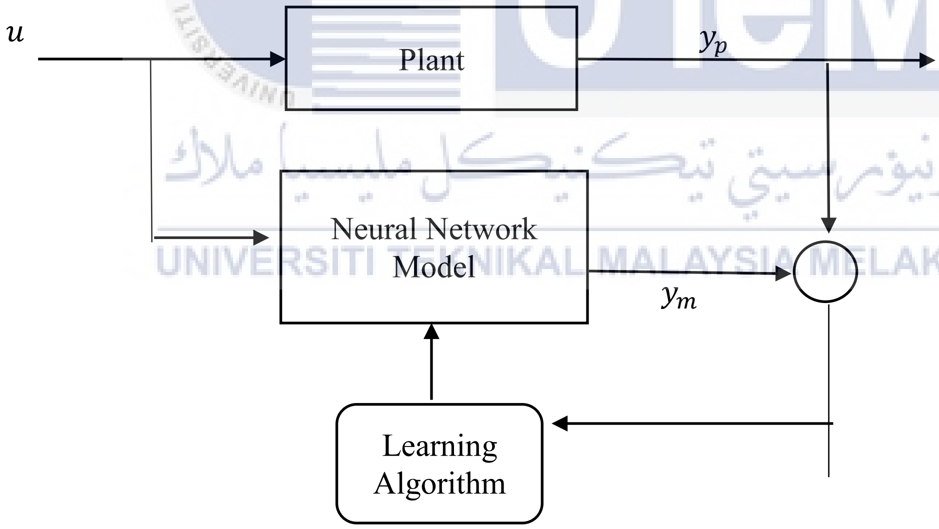

Figure 2.2: Neural Network Block Diagram

2.5 Robust Controllers

2.5.1 H_∞ Controller

The H_∞ technique is introduced in [10] as one of the control technique which has been used for closed loop system. This technique has been applied for the purpose of controlling the positioning of gantry crane payload without or with minimum sway. It has a suitable performance in dealing with many kinds of control purposes like the stabilization of robust for unclear systems, disturbance elimination, input tracking ability or open-loop response shaping. However, handling with closed loop pole location and transient response behaviour instead of frequency aspects is considered as the disadvantage or the weakness of the controller.

It is known that in closed-loop system moving the poles to the left-side plane will give specifications with a good time response and under-actuated crane system's closed-loop damping. Furthermore, it's been showed that H_∞ synthesis can be expressed as a convex optimization problem. The formulation can be done by involving linear matrix inequalities (LMI). The normal Riccati equation with inequality condition has been used in this case. Wide span of flexibility will be produced by such behaviour in combining various restrictions on the closed loop system. H_∞ controller with pole placement constraints can be handled by using this flexible nature of LMI schemes. Regional pole placement in this study will be the reference that the pole placement limitations will refer straight to. The difference to the pointwise is slight. Based on specific wanted time response specifications, the poles are allocated at specific locations in the complex plane. In such case, the crane system's closed- loop poles are enclosed in a good area of the complex plane. This area contains wide range of beneficial bunch of regions such as half-planes, sectors, disks, vertical/horizontal strips, and any intersection thereof. In H_∞ controller, when LMI approach is used there are three main points should be guaranteed by the regional pole placement identified as LMI region merged with design objective. The three point are precise payload locating, fast input tracking proficiency and very minimum oscillation or sway motion.

2.5.2 Sliding Mode Controller

The sliding mode controller technique has been implemented in [11], which has been involved in constraining the motion of the system along various of decreased dimensionality in the state space, is a unique discontinuous control technique which could be applied to a broad diversity of practical systems. Sliding mode controllers have been proposed and used for the crane system. To reduce the swing angle oscillation, a switching function that couples the load dynamics with the trolley motion is applied in. The switching function of the whole system and the stability of each subsystem are proved by a hierarchical sliding-mode control. However, the convergence speed of the switching function of each subsystem is not guaranteed. Anyway, there are still some problems of reaching phase (problems during the transient period until the controlled system reaches the sliding surface from the initial state). The controlled system may be sensitive to parameter disturbances and variations during this transient period due to that the sliding-mode is not realized. Finally, the switching gain of SMC needs to be high for robustness when the model uncertainties are large. The switching gain should be limited in order to make the sliding mode controller practically realizable which results in reducing the crane control's performances.

There are two main properties of the integral sliding mode design concept: first it has no reaching phase (i.e. an initial period of time in which the system has not yet reached the sliding surface) and second, resulting from the first one, it ensures insensitivity of the desired trajectory with respect to uncertainties from the initial time instant. The basic idea of integral sliding mode control is to include an integral term in the sliding surface such that the system trajectories start on the sliding surface from the initial time instant. Furthermore, the under-actuated crane behaviour also results in a very hard problem in reaching good planning of trajectory. Some trajectory planning structure's impact have been described [10].

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2.6 Feedforward Controllers

2.6.1 Open Loop Optimal Strategy

In [12], it has been stated that for almost 50 years the closed-loop and open-loop strategies are used to deal with the time-optimal control design for real-life systems. Closed-loop approaches such bang-bang control laws and open-loop means like the input shaper. Mostly due to the hard computation process of costate trajectory, implementing the current feedback loops are not as simple as implementing the practical derivation of the switches' number.

However, the time- optimal control problem of the gantry crane can be redesigned according to the recent study in, where instead of deriving the analytic trajectory of the costate vector, computing the required quantities can be done with a geometric approach. Moreover, it is shown that, for the bridge crane considered herein as second-order systems, the boundaries between regions of constant control and the switching curve can be changed into assembling of logarithmic spirals. By only implementing such diagrams, the number of switches and the switching times can be determined geometrically. This method will be done in a simulation environment, where the bridge crane will show good nominal performance. Unfortunately, the above time-optimal approach is very sensitive to the system parameters and could not compensate for the effect of wind disturbance [10].

Also, its performance is highly related to the accuracy of the model. This fact may cause a problem as the length of the rope, the weight of the load and especially the damping coefficients may vary a lot along different operating conditions. [12]

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2.6.2 Input Shaping Technique

In [13], the input shaping was proposed as it has been used to alleviate undesirable swaying in cranes. It is a common filtering method used to mitigate motion swaying. Input shaper is considered to be a sequence of pulses which by convolving it the input shaping is implemented, with a baseline command. The product of convolution is then issued to the system in place of the main standard command. Linear system will produce minimal swaying in response to the adjusted command for standard commands which achieve a steady-state value and for well-designed input shapers. Allocating zeros near the locations of the oscillatory system's flexible poles is one the effect that the process acquires. In the input shaper, solving the set of constraints is used to determine the impulses' amplitudes and time locations. Maximizing speed in order to minimize the system sway and reach a well positional accuracy in a minimum time is what most of crane control systems are mainly designed to.

The system's characteristic parameters for design and evaluation of the input shaping control techniques is determined by an unshaped square pulse current input. Based on the system's properties for anti-sway control the input shapers are then designed. The response of crane to the shaped inputs' simulation results are presented in time and frequency domains. The shapers performances are tested in terms of time response specifications and swing angle alleviation. However, input shaping has been shown to be effective and functional for controlling oscillation of gantry cranes only when the load does not undergo hoisting [3].

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2.7 Summary

It can be summarized that the linear controllers have high convenience and feasibility to be implemented. Design of the gain is based on the system parameters and if the parameters aren’t known the gain can be designed based on the tracking error of the system. However, linear controller has low robustness against the system environment compared to other controllers.

For the intelligent controllers, there are two main advantages their simplicity and interpretability, and they don’t require many data to train. Nevertheless, the weakness of fuzzy logic controller is that the design need to struggle in finding the palatable principles membership function, fuzzification and deffuzification parameter heuristically.

Robust controllers have a suitable performance in dealing with many kinds of control purposes and they produce a well-controlled result. Yet, complexity represents the weakness of the system and the under-actuated behaviour gives a very challenging problem in achieving good trajectory planning.

For the feedforward controllers, they are considered to be one of the old and suitable technique of controlling systems. However, their performance is highly related to the accuracy of the model so it is hard to be designed if the model has some problems.

However, in this project only two types of controllers are being discussed and evaluated which are PID and LQR implemented as linear controllers, Fuzzy and Fuzzy-PID implemented as intelligent controllers

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CHAPTER 3

3. METHODOLOGY

3.1 Introduction

It is known that gantry crane system is very important to be applied to its fields. Then, controller drives must be implemented to the crane. The selection of controller also crucial to the practitioner or gantry crane system. From the literature, it is found that linear and intelligent controllers are the most widely used and utilized due to their simplicity, convenience, feasibility, interpretability and that intelligent controllers do not require much data to train.

In this project PID and LQR will be used as linear controller while Fuzzy and Fuzzy-PID (F-PID) will be implemented as intelligent controller. Finally, the performance of these controllers will be evaluated in in terms of design complexity, transient response performance (OS%, T_s, T_p), steady state error (e_{ss}), root-mean-square error (RMSE) and maximum amplitude of oscillation.

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3.2 Project Methodology

At the first stage the modelling of gantry crane will be discussed. Then, there will be evaluation of open-loop without controller. Developing and designing the linear controllers which are PID and LQR will be the next step. After that, comparison between PID and LQR will be reviewed. Then, intelligent controllers will be developed and designed. Two types of the intelligent controllers which are fuzzy and fuzzy-PID controllers will be compared together next. Lastly, a general comparison between the linear and intelligent controllers will be applied and the performances will be verified. The whole flowchart of the process is shown clearly in Figure 3.1.

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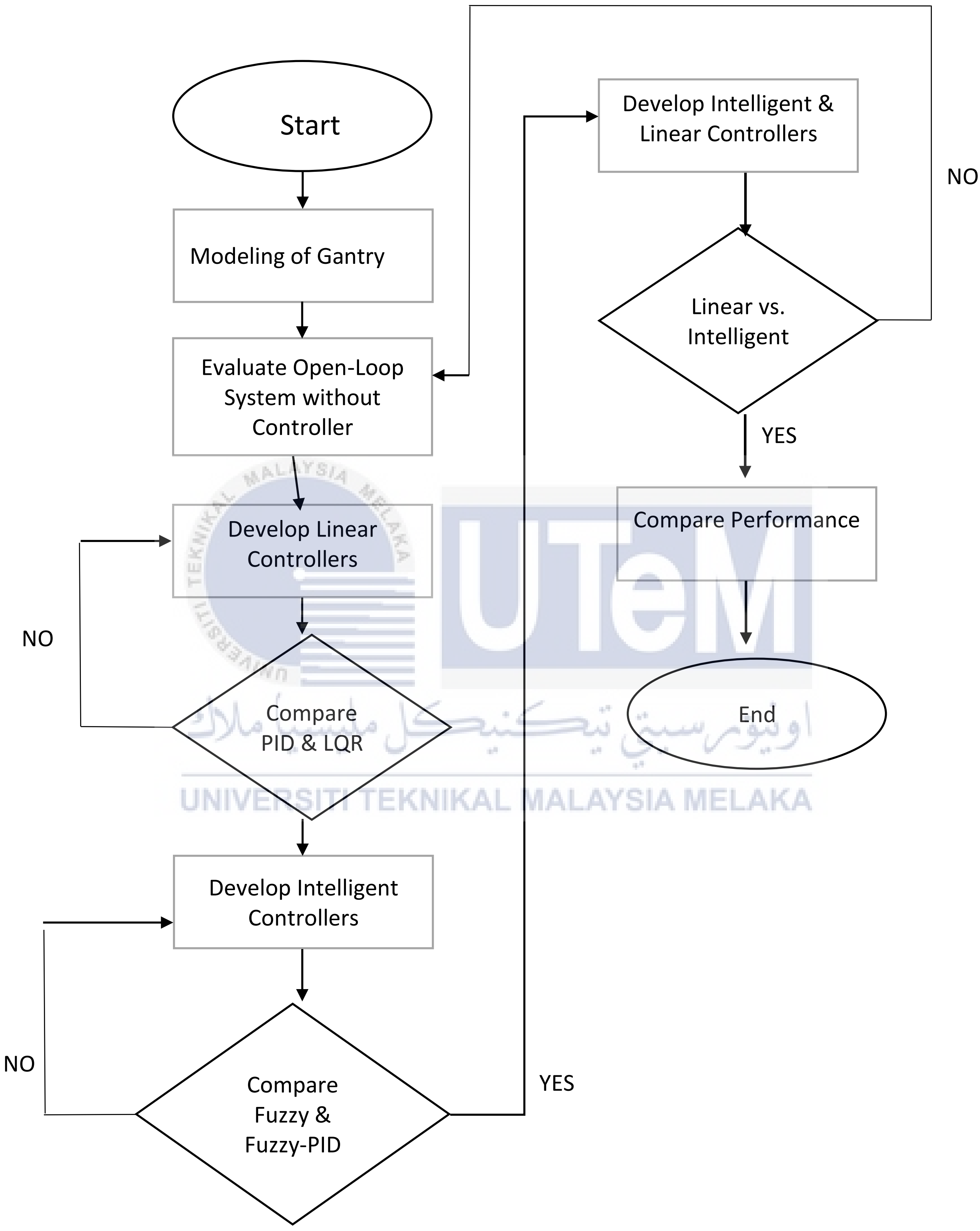

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Figure 3.1: Flowchart Diagram of The Project

3.3 Modelling of Gantry Crane System

Figure 3.2 shows the gantry crane model which is going to be used and discussed in this project. It's shown that the cart is movable along axis x_1 and the applied force to the cart is u. It is seen that the load is hanged to the rigid terminal of the bar. m_c represents the mass of the cart, m_l represents the mass of the load, θ stands for the sway angle of the angle between both the vertical axis and the bar, and l stands for the length of the bar. In Figure 3.3 the physical model is shown.

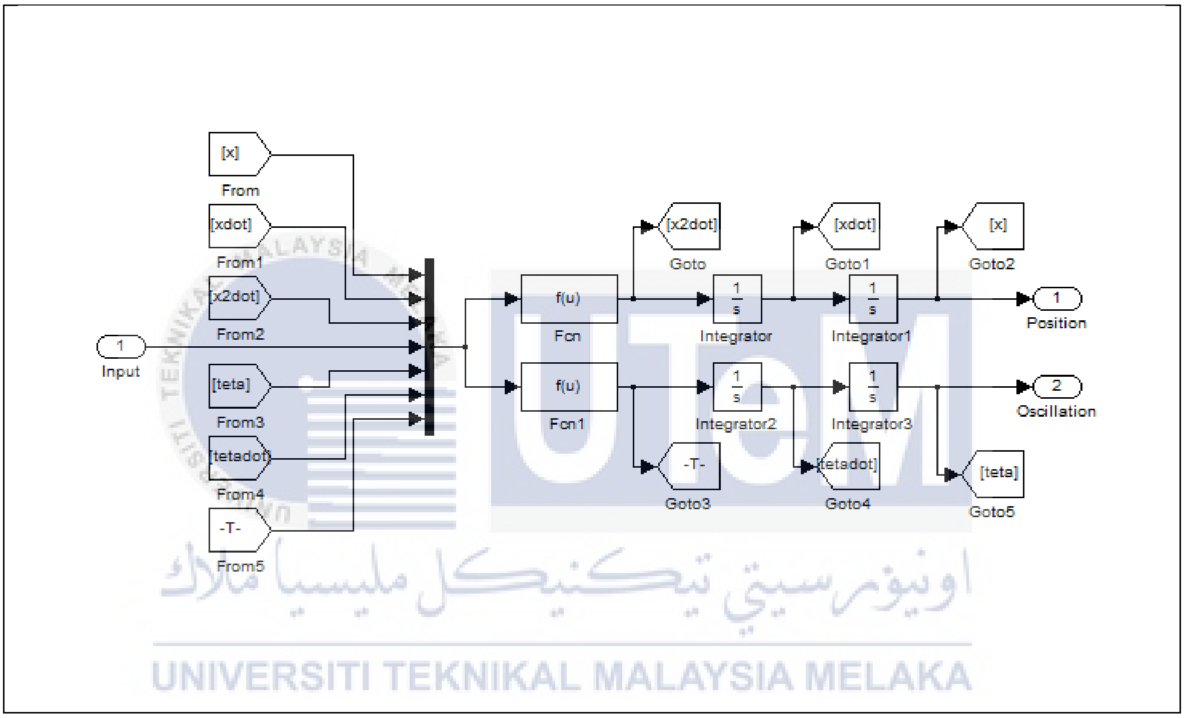

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Figure 3.2: Gantry Crane Simulation Model

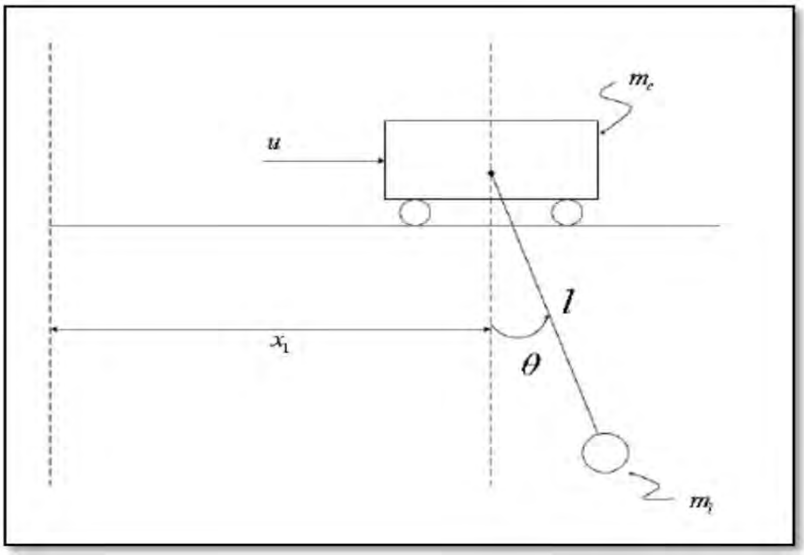

Figure 3.3: Gantry crane physical model

The gantry crane system is modelled by linearizing the nonlinear equation of motion that obtained using Euler-Lagrange formula. The state space model used in the system is shown in Figure 3.4 and its matrix equation is given as

$$\begin{bmatrix} \dot{x_1} \\ \dot{x_2} \\ \dot{x_3} \\ \dot{x_4} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & -\dfrac{m_L}{m_C}g & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & -\dfrac{m_L+m_C}{lm_C}g & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} 0 \\ \dfrac{1}{m_C} \\ 0 \\ -\dfrac{1}{lm_C} \end{bmatrix} u \tag{3.1}$$

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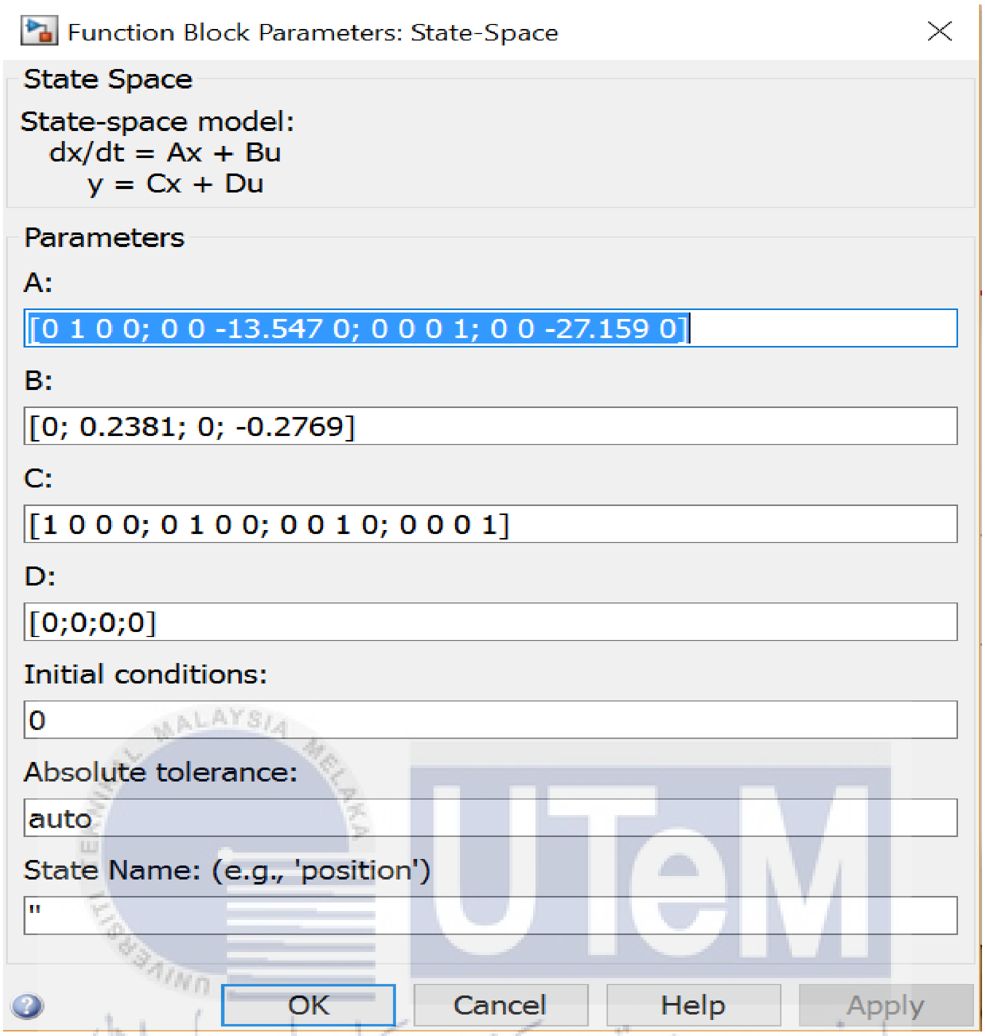

State-space model:
dx/dt = Ax + Bu
y = Cx + Du

A:
[0 1 0 0; 0 0 -13.547 0; 0 0 0 1; 0 0 -27.159 0]

B:
[0; 0.2381; 0; -0.2769]

C:
[1 0 0 0; 0 1 0 0; 0 0 1 0; 0 0 0 1]

D:
[0;0;0;0]

Initial conditions:
0

Absolute tolerance:
auto

State Name: (e.g., 'position')
''

Figure 3.4: Gantry Crane State Space Model

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The model has been applied to MATLAB Simulink by putting the function we got previously. Figure 3.5 shows the open-loop Simulink setup for the gantry crane system. It can be noticed that there are two scopes one to show the cart displacement and the other one to show the load oscillation. Initial setting of gantry crane parameter variable is illustrated in Figure 3.6.

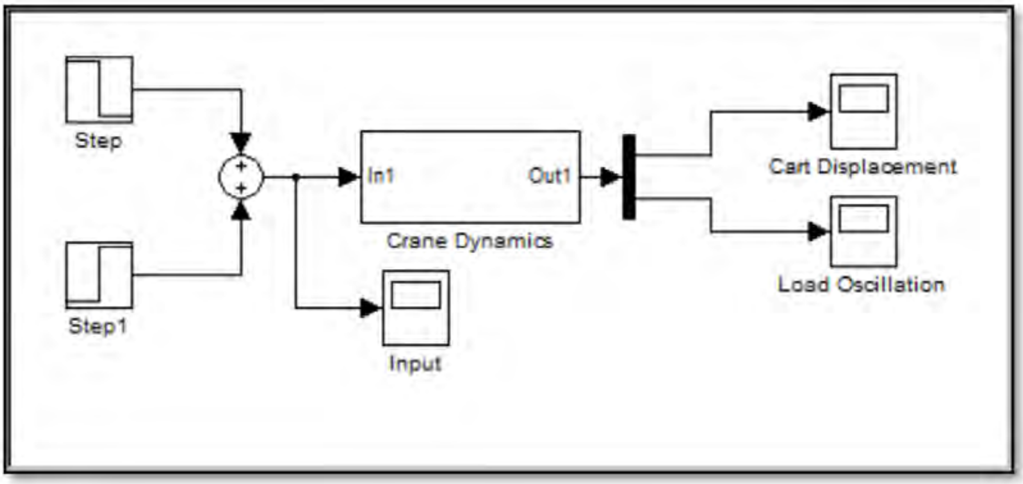
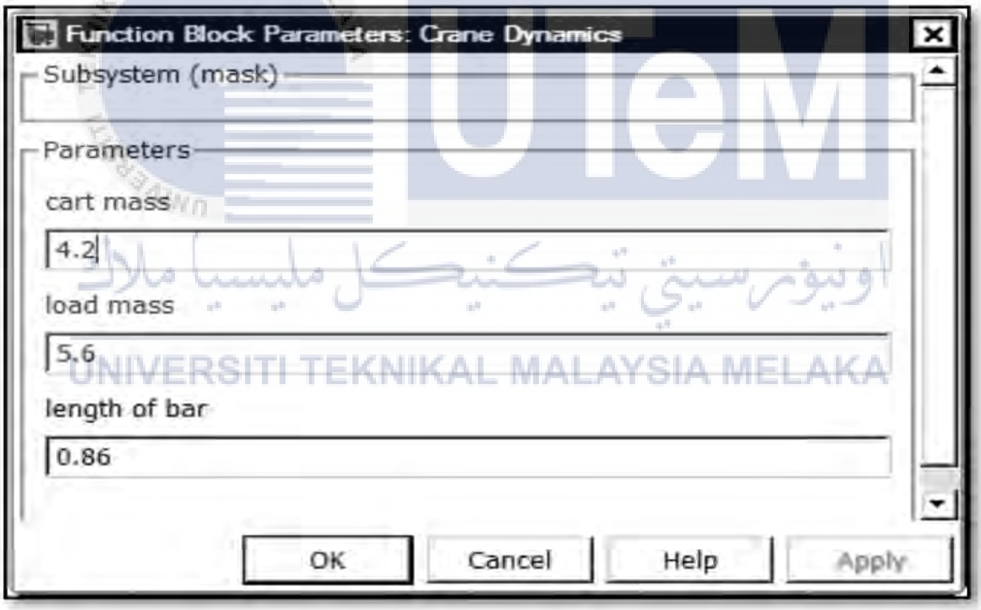


Figure 3.5: Simulink Setup of Gantry Crane



cart mass

4.2

load mass

5.6

length of bar

0.86

Figure 3.6: Parameter Variable Setting

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3.4 PID Controller

The schematic or the design of the PID controller is shown in Figure 3.7. There are three main parameters that must be designed in PID controller. The transfer function of the controller is stated below;

$$G_{pid} = K_p + \frac{K_i}{s} + K_{d.s} \tag{3.2}$$

where K_p stands for the gain of the controller, K_i stands for the integral time and K_d for the derivative time. Determining suitable parameters is crucial to gain system performance and stability.

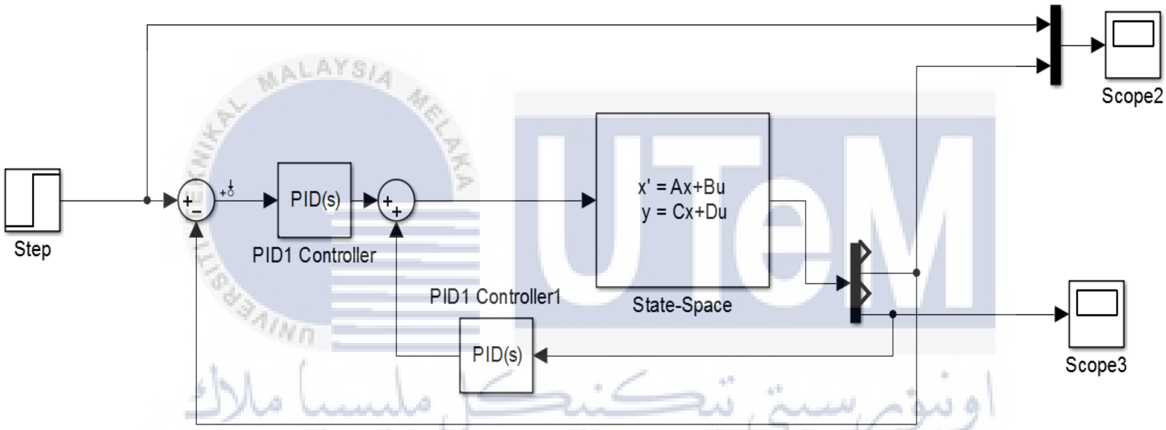
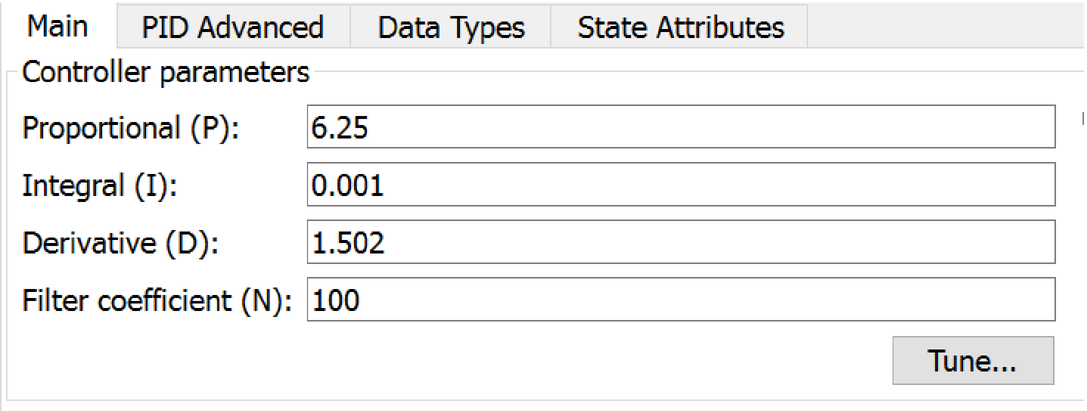


Figure 3.7: PID controller block diagram

As stated in this diagram Figure 3.6, the step input signal is sent to the system. The PID controller then will control the plant which is here the gantry crane. As a closed loop system, there is a feedback signal sent back to the summing junction and there are two scope to show the result of position and sway responses. The parameters of the system have the following values: the payload mass $m_l = 1\ kg$, the trolley mass $m_c = 5\ kg$ and the length of the rope $l = 0.75\ m$. The parameters which are the proportional, integral and derivative of the controller for both positioning and anti-swaying are shown respectively in Figure 3.8 and Figure 3.9. The system response before applying the controller looks like what is shown in Figure 3.10.



Controller parameters

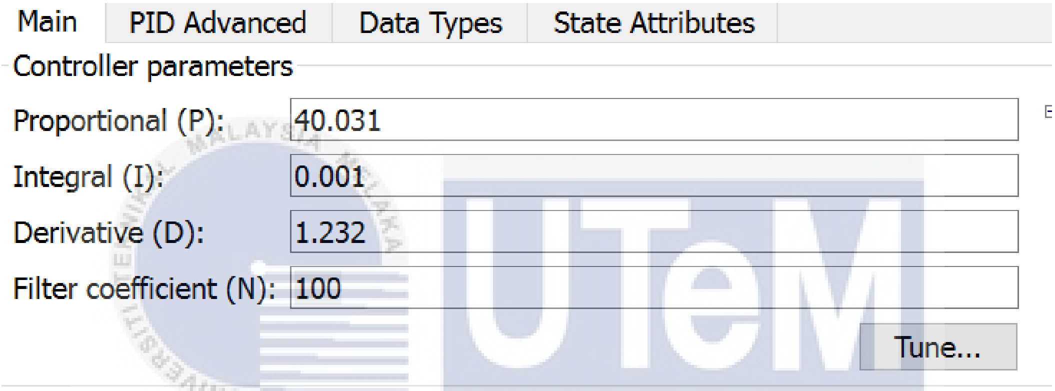
Proportional (P): 6.25

Integral (I): 0.001

Derivative (D): 1.502

Filter coefficient (N): 100

Figure 3.8: PID Controller Position Parameters



Controller parameters

Proportional (P): 40.031

Integral (I): 0.001

Derivative (D): 1.232

Filter coefficient (N): 100

Figure 3.9: PID Controller Anti-Sway Parameters

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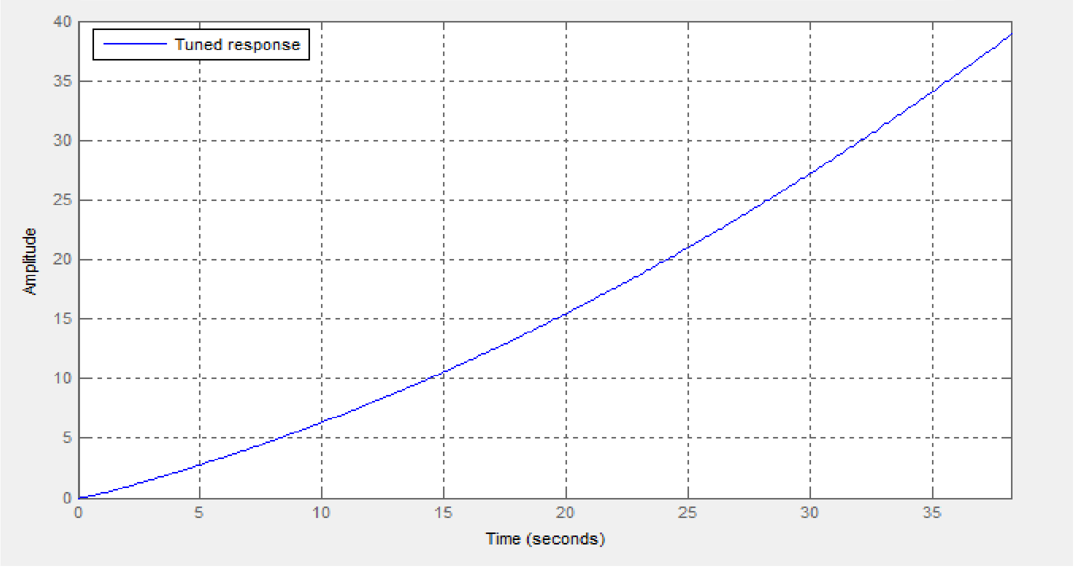

Figure 3.10: Uncompensated Gantry Crane System Response

3.5 LQR Controller

Linear quadratic regulator technique is applied for this gantry crane to define the state-feedback control gain matrix K. There are two parameters (Q and R) the LQR needs to balance the control effort (u)'s relative importance and the error in the cost function J. Figure 3.11 and Figure 3.12 show the block diagram and the Simulink model of LQR controllers respectively. After the establishment of the weighting matrices Q, R and the values of the controller gain are found, LQR controller design will run for the system. The equation of the controller [14] with step response is stated in

$$\dot{X} = Ax + Bu \tag{3.3}$$

where the cost function stated as

$$J = \int (x^T Qx + u^T Ru)\, dt \tag{3.4}$$

and the feedback equation which will minimize the cost function is

$$u = -Kx \tag{3.5}$$

whereby, the gain $K = R^{-1}B^T P$ (3.6)

In the following Riccati Equation in which P is the steady state solution that yields a unique optimal control to minimize the cost function

$$PA + A^T P - PBR^{-1}B^T P + Q = 0 \tag{3.7}$$

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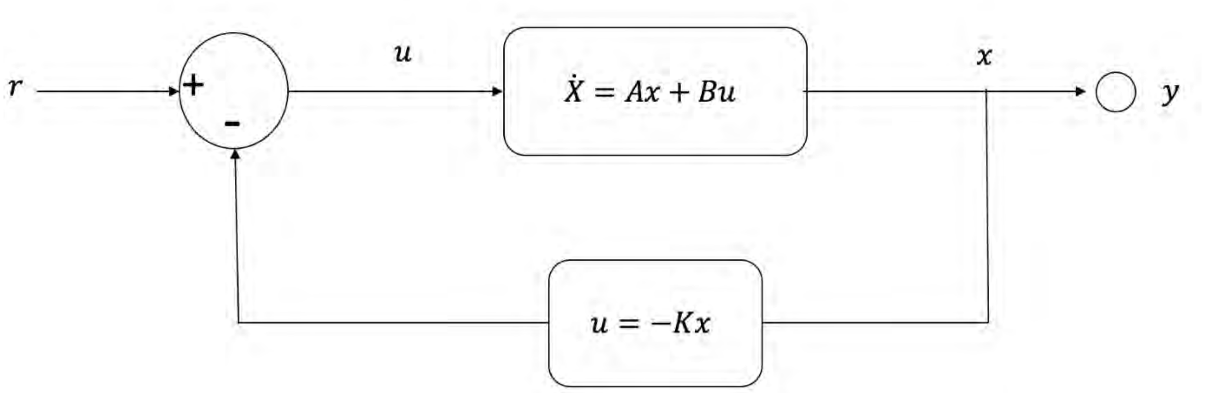

Figure 3.11: LQR Design Block Diagram

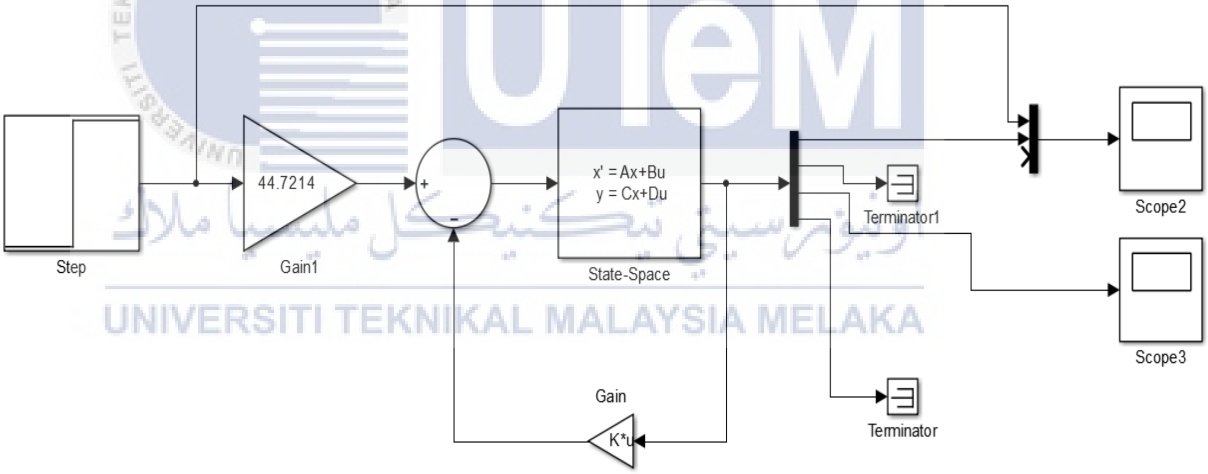

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Figure 3.12: LQR Controller Simulink Model

3.6 Fuzzy Logic Controller

Figure 3.13 shows the block diagram of the fuzzy-based gantry crane system. There are two fuzzy logic controllers applied to the system. One to control the oscillation and the other one to control the position. The purpose of the fuzzy logic controllers is control the position of the payload and to move as fast as possible to the desired destination without any excessive angle sway of the payload.

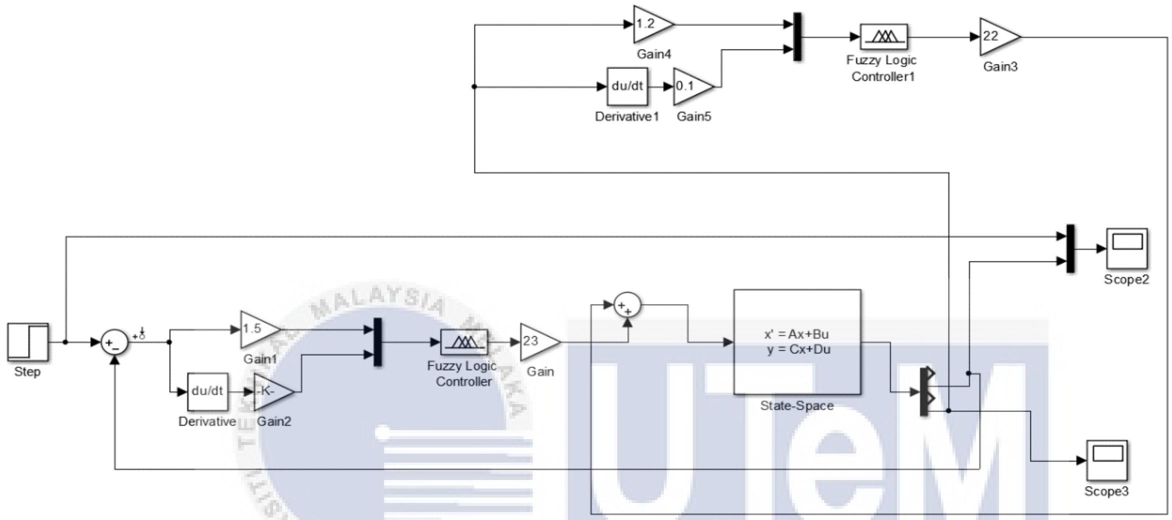

Figure 3.13: Fuzzy Logic Block Diagram

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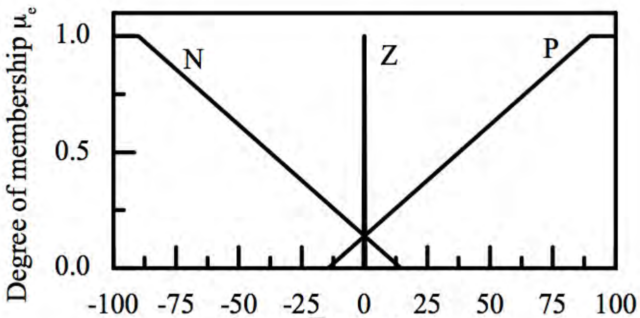
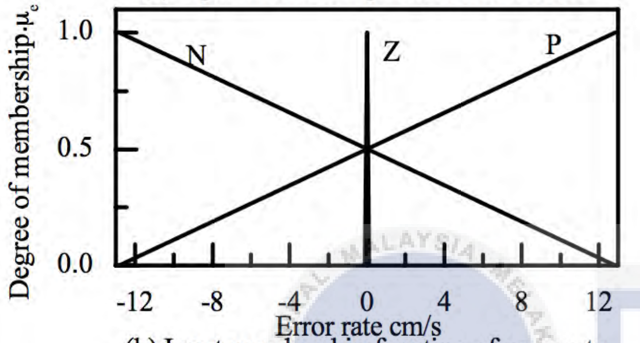
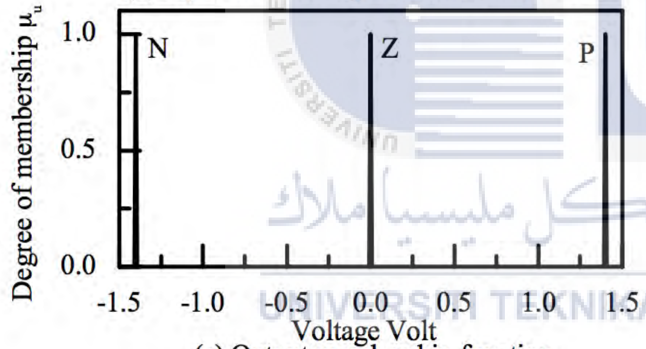
It is known that fuzzy logic controller design is featured with the development and improvement of input and output membership function. The figures below show the membership functions of the position and anti-sway control. For the position control the error, error rate and voltage functions contains Positive (P), Negative (N) and Zero (Z) as shown in Figure 3.15. While for the anti-sway control the error, error rate and voltage functions contains Positive Big (PB), Negative Big (NB), Zero (Z), Positive Small (PS) and Negative Small (NS) as illustrated in Figure 3.14. The position control universe of discourse range is between (-100cm, 100cm) for error, between (-12.85cm/s, 12.85 cm/s) for error rate and between (-1.4, 1.4) for voltage. While, for anti-sway the universes of discourses is between (-1rad,1rad) for error, between(-2.5cm/s, 2.5 cm/s) for error rate and between (-1.4, 1.4) for voltage.



(a) Input membership function of error e

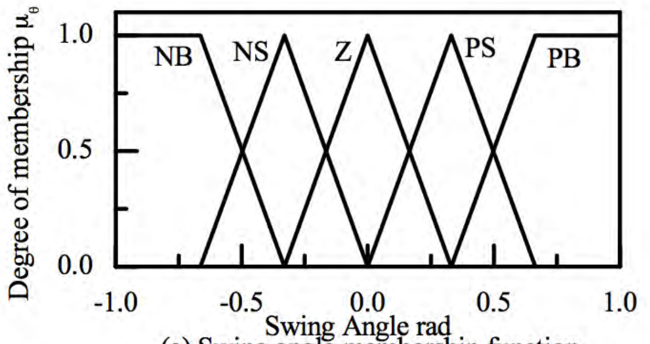


(b) Input membership function of error rate

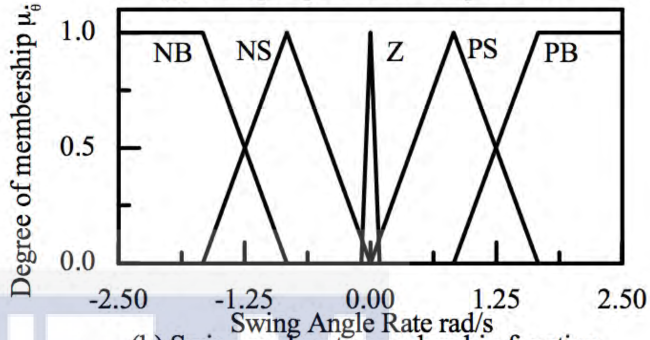


(a) Output membership function

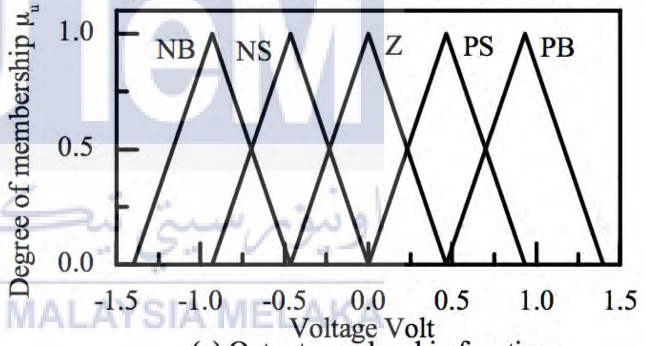
Figure 3.15: Membership Function of Position Control



(a) Swing angle membership function



(b) Swing angle rate membership function



(a) Output membership function

Figure 3.14: Membership Function of Anti-Swing Control

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The roles that have been used for fuzzy position and sway controls are assumed due to the experiences and knowledge of the operator. Rules for the fuzzy position are shown and tabulated in Table 3.1, while the rules of fuzzy sway are illustrated in Table 3.2. Table 3.3 shows the abbreviation of the simples used in the rules and membership functions.

Table 3.1: Fuzzy Rule Base of Position Control

Error Rate/ Error		**Error rate $\dot{e}(t)$**		
		P	**Z**	**N**
Error $e(t)$	**P**	P	P	P
	Z	N	Z	P
	N	N	N	N

Table 3.2: Fuzzy Rule Base of Anti-Swing Control

Swing angle rate $\dot{\theta}(t)$/ Swing angle		**Swing angle rate $\dot{\theta}(t)$**				
		PB	**PS**	**Z**	**NS**	**NB**
Swing angle	**PB**	PB	PB	PB	PB	PB
	PS	PB	PS	PS	PS	PS
	Z	PB	PS	Z	NS	NB
	NS	NS	NS	NS	NS	NB
	NB	NB	NB	NB	NB	NB

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Table 3.3: Rules Base Abbreviation

PB	**PS**	**Z**	**NS**	**NB**
Positive Big	Positive Small	Zero	Negative Small	Negative Big

3.7 Fuzzy-PID Controller

To obtain the best result and to have a more practical PID controller, it can be tuned. Yet, it is stated previously that PID is not robust toward any changes or parameter changes. In this project, the varied parameters are cable length l, and the payload mass m_l. So, any system must use the PID parameters used during tuning process in order to get the best result. That means PID controller must be changed when the parameter is changed in actual world, which result in making it impractical in real life.

In order to overcome this problem, fuzzy logic controller will be used to evaluate the error and error rate in each system and therefor tune the PID gains to alleviate the output and produce the best response. The design of fuzzy-PID controller is shown in Simulink model in Figure 3.16 and the subsystem used is illustrated in Figure 3.17.

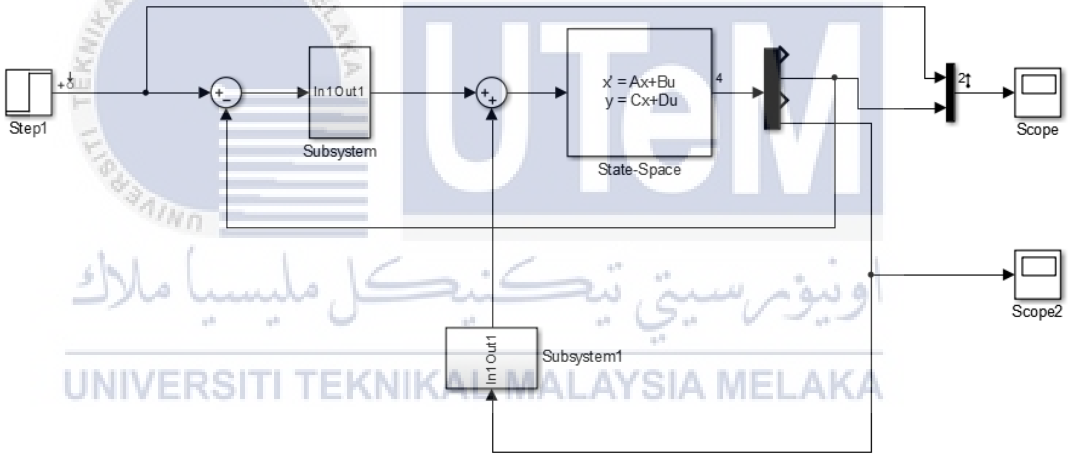

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Figure 3.16: Simulink Model of Fuzzy-PID control

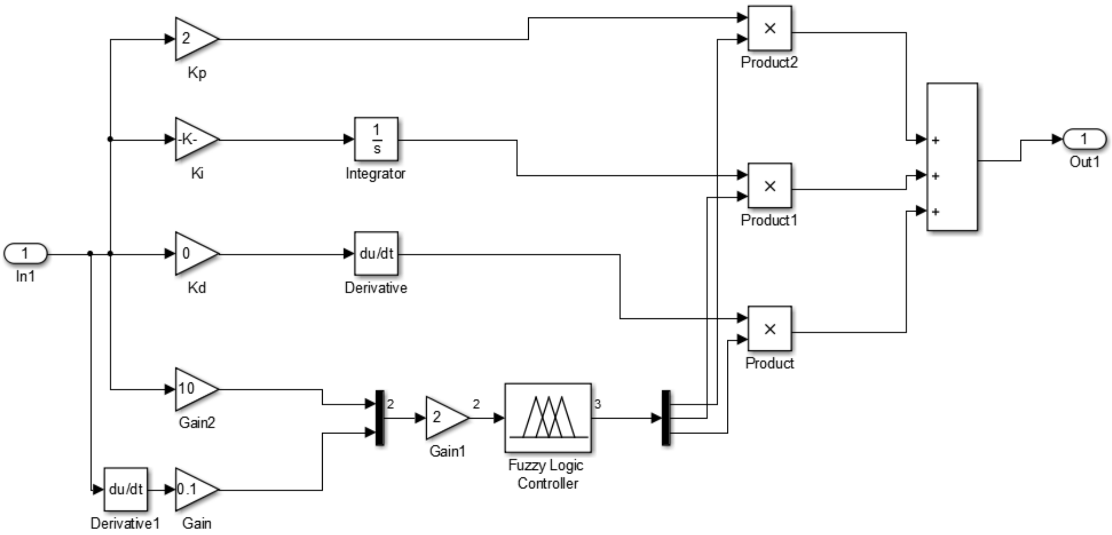

Figure 3.17: Subsystem of Fuzzy-PID Control Scheme

The nominal values of the system parameters should be set first. They have the following values: the payload mass $m_l = 1\ kg$, the trolley mass $m_c = 5\ kg$ and the length of the rope $l = 0.75\ m$. From the stated values the PID gains will be obtained. By comparing the PID and fuzzy-PID controller responses, the evaluation of position and oscillation responses will be gained.

There are three input triangular members for the fuzzy system. Meanwhile, there are three triangular members for k_P output, and two triangular functions for k_D and k_I output. According to determined universe of discourse the membership was chosen and determined. Constant modifications were applied to these values for getting best result.

The universe of discourse of fuzzy input for error is between (-1.087 and 1), while between (-1 and 0.1807) for error rate. Output universe of discourse or range is between (0 and 5) for k_P, between (0 and 0.6) for k_D and between (0 and 2.5) for k_I. The membership function for error and error rate of fuzzy is illustrated in Figures 3.18, 3.19 and 3.20.

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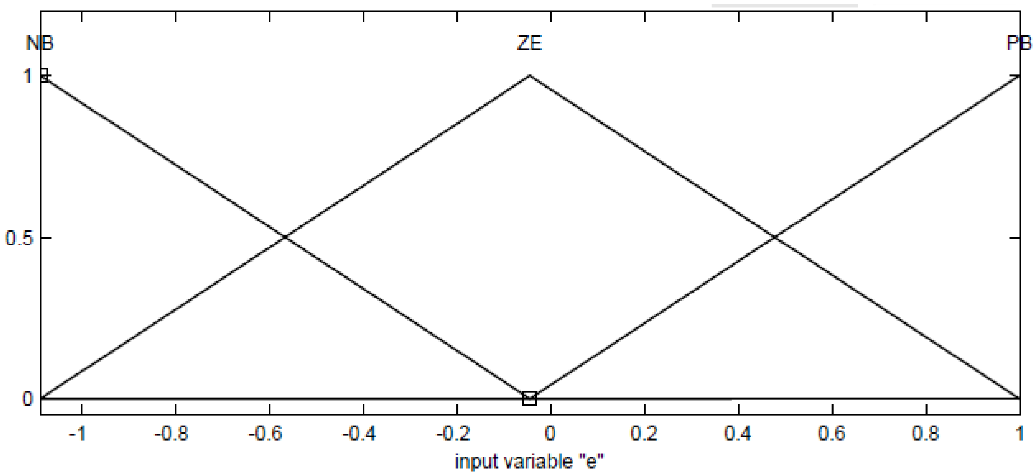

Figure 3.18: Membership Function of Fuzzy Input (Error)

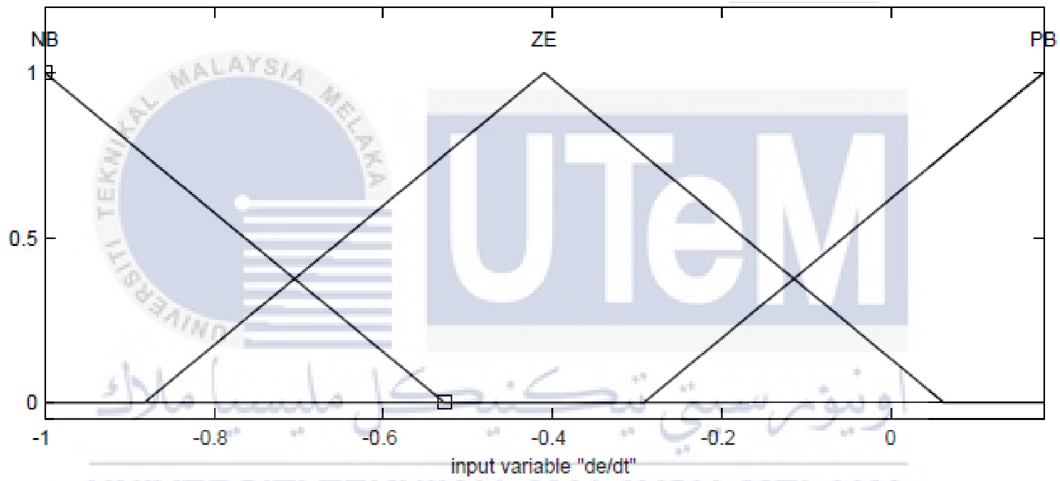

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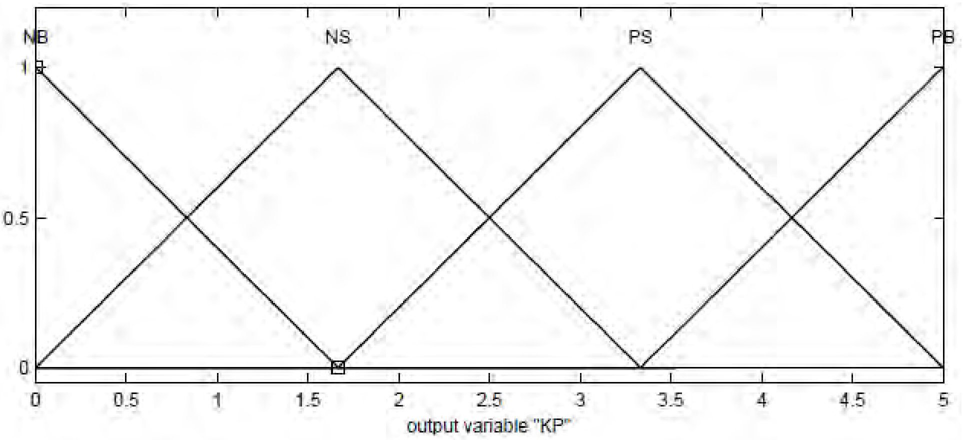
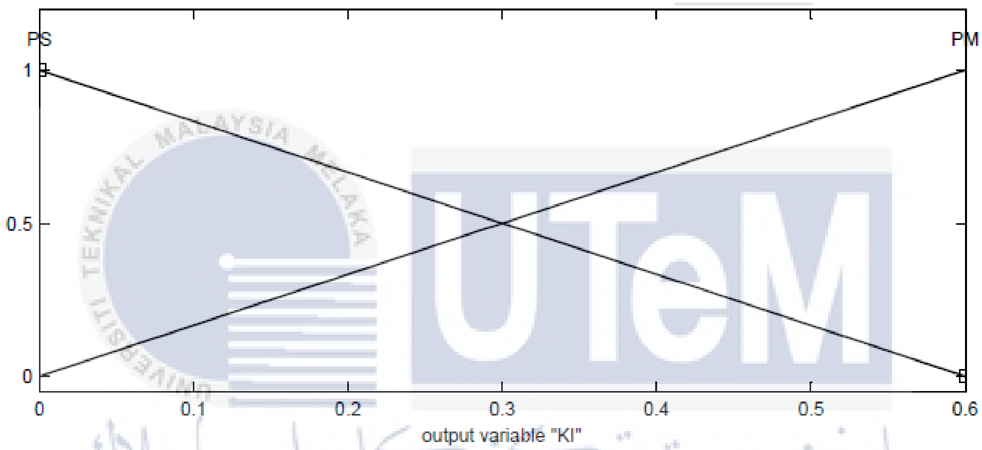
Figure 3.19: Membership Function of Fuzzy Input (Error Rate)



a) k_P Membership Function



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b) k_D Membership Function

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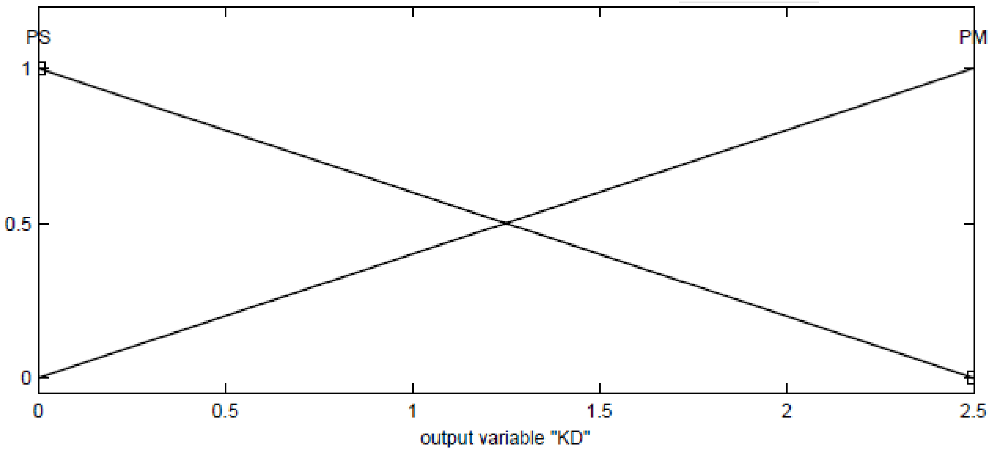

c) k_I Membership Function

Figure 3.20: Membership Function of Fuzzy Output

Table 3.4: Fuzzy Rule Base of Kp

k_P	**Error Rate**			
Error		**NB**	**ZE**	**PB**
	NB	-	NB	-
	ZE	NS	-	PS
	PB	-	PB	-

Table 3.5: Fuzzy Rule Base of Ki

k_I	**Error Rate**			
Error		**NB**	**ZE**	**PB**
	NB	-	PS	-
	ZE	PS	-	PM
	PB	-	PS	-

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Table 3.6: Fuzzy Rule Base of Kd

k_D	**Error Rate**			
Error		**NB**	**ZE**	**PB**
	NB	-	PS	-
	ZE	PM	-	PM
	PB	-	PS	-

Table 3.7: Rules Base Abbreviation

PB	**PS**	**PM**	**ZE**	**NS**	**NB**
Positive Big	Positive Small	Positive Medium	Zero	Negative Small	Negative Big

3.8 Evaluation of Performance

After the design of each technique or controller, there will be an analysis and evaluation of the performances. The evaluation will be in terms of design complexity, transient response performance which are overshoot, settling time, peak time, rise time, steady state error, of oscillation and robustness toward any changes such payload weight, rope length and different trajectories.

Overshoot which can be find using Equation (3.8) is stated as the maximum deviation of the response from its steady state value expressed in percentage of the steady state value and it is defined as the maximum positive deviation of the response from its steady state value. Settling time which is the time required for the system to remain within a specified percentage of the input value and can be calculated using Equation (3.9). Peak time which is the time required for the system to reach the highest value in its performance and Equation (3.10) can be used to find its value. Rise time which is the time required for the system to rise from 10 to 90 percent of the steady state. Steady state error which represent the difference between the input and output of the system and its equation is illustrated in Equation (3.11).

$$OS\% = e^{-\frac{\zeta\pi}{\sqrt{1-\zeta^2}}} \times (100)\ . \tag{3.8}$$

$$t_s = -\frac{1}{\zeta\omega_n}\ln(0.05\sqrt{1-\zeta^2}\ . \tag{3.9}$$

$$t_p = \frac{\pi}{\omega_n\sqrt{1-\zeta^2}}. \tag{3.10}$$

$$e_{ss} = \lim_{s\to\infty} e(t) = \lim_{s\to 0}\{sE(s)\}. \tag{3.11}$$

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CHAPTER 4

4. RESULTS AND DISCUSSION

4.1 Introduction

In this chapter both the positioning and swaying responses of linear and intelligent controllers will be discussed in their simulation results and outcomes. This simulation work is an important procedure for evaluating the capability of the proposed controllers before implementing any of them in the real plant system. The simulation exercises have been done using the MATLAB and Simulink. MATLAB is an abbreviation for MATrix LABoratory which studies matrix manipulation and problem solving related to modelling, simulation and control application. Simulink simulates the dynamic models by creating a graphical block diagram of the system. The positioning responses of linear controllers (PID and LQR) will be compared firstly in terms of overshooting, setting time, peak time, raise time statistic error and root-mean-square. Swaying responses will also be compared in terms of maximum-oscillation, root-mean-square and oscillation time. Then intelligent controllers (Fuzzy and Fuzzy-PID) result will be shown and discussed the same way as linear controllers. Finally, the comparison will be on all the controllers and among them the faster and more stable controller will be chosen or recommended.

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4.2 Linear Controller

4.2.1 PID & LQR Positioning Result

The PID controller is tuned using Ziegler Nichols which is an advanced and easy method for tuning the PID controller parameters. However, fine tuning is added in order to get the best performance of the controller and satisfying result as well. The Gantry Crane system is operated with the assistance of the PID controller using the parameters tuned with the step input reference signal of 1.0 second step time as clearly demonstrated in Figure 4.1 for the position balancing purpose and to suppress the vibration of the system during movement and once the system stopped in the final desired position. The position tracking of the GCS system has a good improvement as shown in the blue color dotted line of Figure 4.1 and as tabulated in Table 4.1. The base of the GCS has raised from 10% until 90% of the final desired destination in 0.874 seconds and has a settling time of 1.764 with an acceptable overshoot of 3.8%. The steady state error can be neglected as it is very small. Based on the transient response analysis it can be said that the PID controller has fast response and is capable to improve the transient response and steady state error of the GCS system.

The LQR controller is optimal and easy to be designed. In this study, the LQR controller is designed for the position balancing and oscillation suppression of the GCS system. The LQR controller have been tuned and the tuning is depending on changing the Q weighing matrix in order to obtain the appropriate feedback gain matrix for the optimal performance. The Q weighing matrix written in Equation (4.1) yields the LQR feedback gain matrix which written in Equation (4.2). This tuning produced satisfied transient response performance of the GCS system especially the settling time, the overshoot and the rise time which are 1.15 second, 1.4% respectively and 0.803 respectively as shown in Table 4.2 and Figure 4.2 with red color solid line.

$$Q = \begin{bmatrix} 1500 & 0 & 0 & 0 \\ 0 & 100 & 0 & 0 \\ 0 & 0 & 6500 & 0 \\ 0 & 0 & 0 & 10 \end{bmatrix} \tag{4.1}$$

$$K = [38.7298 \quad 23.0430 \quad -107.2293 \quad -13.3367] \tag{4.2}$$

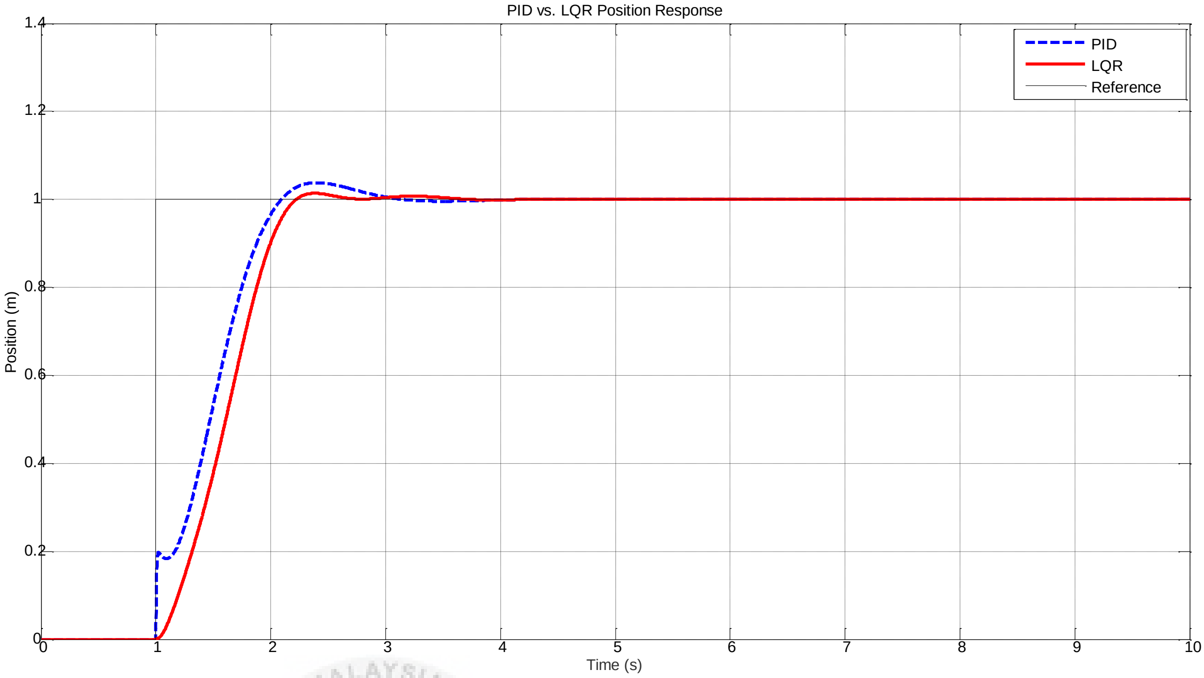

Figure 4.1: Linear Position Response

Table 4.1: Parameter Analysis for Linear Controllers' Positioning

Controller	**OS%**	**T_s(s)**	**T_p(s)**	**T_r (s)**	**e_{ss}**	**RMSE**
PID	3.8	1.764	1.401	0.874	0	7.382×10^{-5}
LQR	1.4	1.15	1.386	0.803	0	2.412×10^{-6}

According to Figure 4.1 and Table 4.2, LQR has better performance than PID controller as it has faster and more stable response with less root-mean-square error. So LQR controller applies better control for the positioning, therefor it's more recommended compared to PID.

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4.2.2 PID and LQR Anti-Swaying Result

During the movement of the load from the start point until it stopped in the final desired position, an oscillation or vibration will occur to the load. These oscillations may have a large deflection and oscillate for long time based on the system response speed or the capability of the controller to reduce its oscillations. Improving the transient response of the GCS system by utilizing the PID controller tuned using the Ziegler Nichols method with fine tuning generated small amplitude oscillations of the load which is the maximum peak is 0.064 Meter and needed about 1.275 seconds to eliminate the oscillations which is considered good time as shown in the blue color dashed line of Figure 4.2 and summarized in Table 4.2.

However, for LQR controller based on the data tabulated in Table 4.2 and shown in the red color solid line of Figure 4.2, the largest deflection of the GCS vibration reached 0.117 Meter. Despite, the deflection amplitude of the vibration is large, the LQR controller managed to totally restrain the vibration in 1.264 second. This case of study is not enough to evaluate the LQR controller performance for the positioning and vibration suppression of the GCS system, so the evaluation will be clearer for utilizing different feedback gain.

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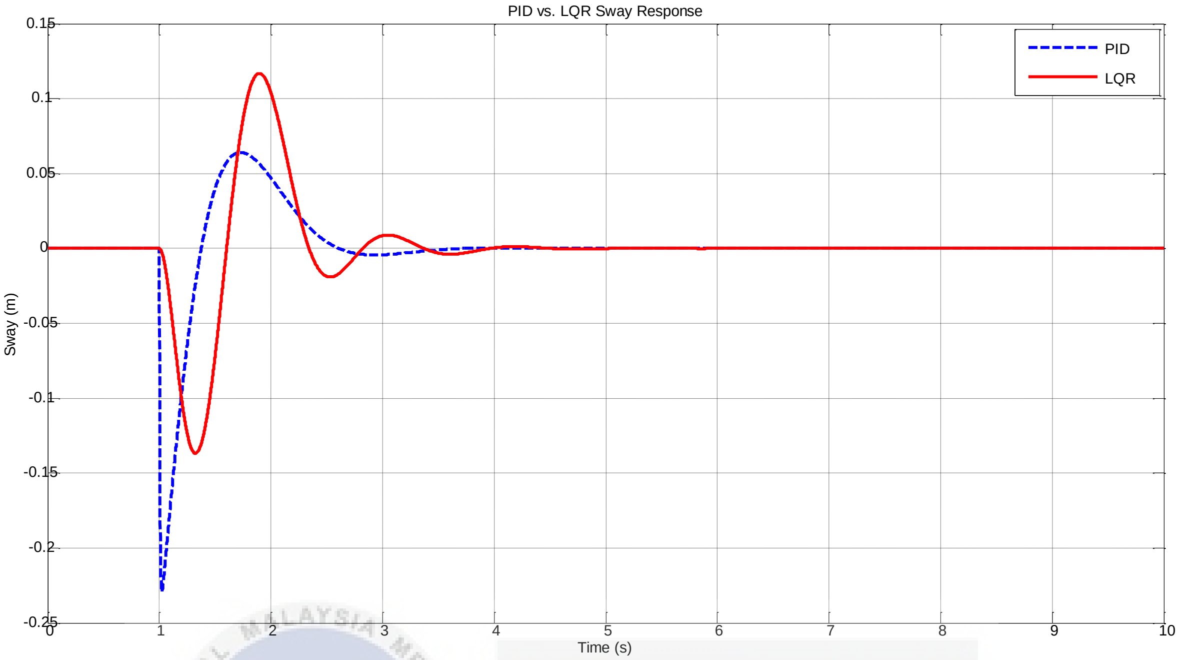

Figure 4.2: Linear Swaying Response

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Table 4.2: Parameter Analysis for Linear Controllers' Swaying

Controller	**Maximum Ocsillation (m)**	**RMSE**	**T_{osc} (s)**
PID	0.064	7.382×10^{-5}	1.275
LQR	0.117	2.412×10^{-6}	1.264

It can be noticed that PID has better performance in controlling the swaying of the Gantry Crane system than LQR. As shown in Figure and Table 4.2 PID has lower maximum amplitude in the oscillation and less root-mean-square error

4.3 Intelligent Controllers

4.3.1 Fuzzy and Fuzzy-PID Positioning Result

Fuzzy logic controller is fully able to realize the horizontal positioning control precisely. Using such controller in the Gantry Crane system might not show a big difference in the transient response but it’s more practical and can deal with changes in the input of the systems once faced. As illustrated in the red colour solid line in Figure 4.3 and Table 4.3, fuzzy logic controller produces a satisfying improvement in GCS response. It requires 0.833 second to rise from 10% until the 90% of the destination and its settling time, peak time and overshoot are 1.41second, 1.449second and 5.6% respectively. Root-mean-square error is 1.306x10^{-7} and for the statistic error it’s very small and can be neglected.

In order to improve the fuzzy logic control, PID controller can be added to produce then a fuzzy-PID controller. Although it has a noticeable overshoot in controlling the positioning of the gantry crane system, it has fast response and less error. The blue color dashed line in Figure 4.3 shows the response graphically and Table 4.3 shows the positioning parameters of the fuzzy-PID controller which is 13.2% for overshoot, 1.336 second for settling time, 1.085 second for peak time and 0.64 for the rise time. Fuzzy-PID controller records the lowest root-mean-square error with only 2.433x10^{-8}.

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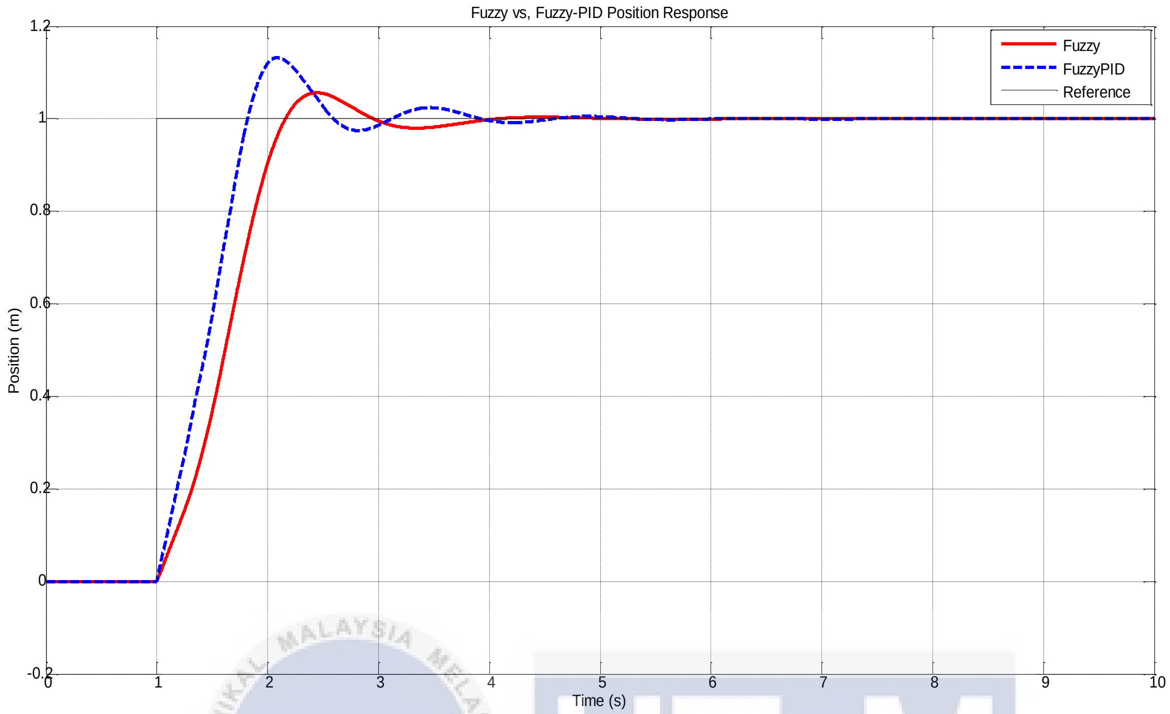

Figure 4.3: Intelligent Positioning Response

Table 4.3: Parameter Analysis for Intelligent Controllers' Positioning

Controller	**OS%**	**T_s(s)**	**T_p(s)**	**T_r(s)**	**e_{ss}**	**RMSE**
Fuzzy	5.6	1.41	1.449	0.833	0	1.306×10^{-7}
Fuzzy-PID	7.2	1.34	1.085	0.64	0	2.433×10^{-8}

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4.3.2 Fuzzy and Fuzzy-PID Anti-Swaying Result

Intelligent controllers apply good control to the swaying and vibration of the gantry crane system. Figure 4.4 and Table 4.4 illustrate the parameters of maximum oscillation and oscillation time of both fuzzy and fuzzy-PID controllers. As stated in Table 4.4 the maximum amplitude fuzzy logic controller reaches are 0.072 meter and requires 1.26 second to reach the stable mode. The fuzzy logic graphical response is shown in the red color solid line Figure 4.4.

The fuzzy-PID controller performance in controlling the swaying of the GCS system is illustrated in the blue color dashed line Figure 4.4 and the parameters are 0.16 meter for the maximum point of vibration and 1.164 second to get out of the oscillation period. The statistic error for both controllers could be neglected as it almost reaches zero.

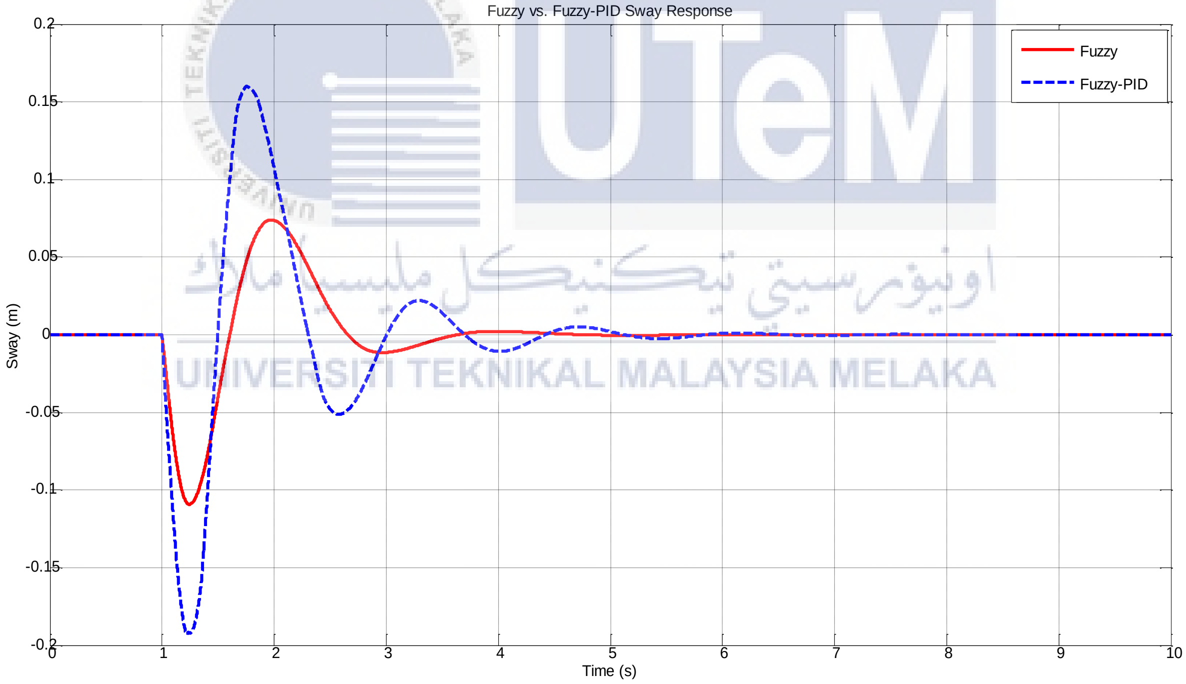

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Figure 4.4: Intelligent Swaying Response

Table 4.4: Parameter Analysis for Intelligent Controllers' Swaying

Controller	Maximum Ocsillation (m)	RMSE	T_{osc}(s)
Fuzzy	0.064	1.306×10^{-7}	1.26
Fuzzy-PID	0.160	2.433×10^{-8}	1.16

Fuzzy-PID controller has better performance in the settling time, peak time, rise time and root-mean-square error that fuzzy logic controller. However, the fuzzy controller has less over shooting than fuzzy-PID. Swaying has well response and reaches the stable period faster when get controlled by fuzzy-PID control. So, it can be concluded that fuzzy-PID in general produces faster and more stable response than fuzzy logic control as experienced with Gantry Crane system.

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4.4 Evaluation on Linear and Intelligent Controller Performance

4.4.1 PID, LQR, Fuzzy and Fuzzy-PID Positioning Response

Putting all the controllers together will illustrate more the comparison and will give a very clear vision to which controller is more accurate and reliable to be applied to a system like Gantry Crane system. Figure 4.5 shows the four controllers position response, blue color solid line represents the fuzzy-PID controller, red color solid line goes for the fuzzy logic controller, dashed green color line represent the PID controller and cyan color dotted line represent the LQR controller. Referring to Table 4.5 among the linear controllers LQR controller seems to be faster and has better overshoot percentage compared to PID controller, however PID result could be improved by using other methods of tuning. The controller which reaches the fastest settling time among all the controllers is LQR controller with a very short time of 1.15 second. The smallest overshoot percentage goes for LQR controller recording 1.4% only. So, for linear controllers LQR is more recommended to be used.

While for intelligent controllers despite the fact that fuzzy-PID has noticeable high overshooting percentage, yet it shows more satisfying result in other parameters (settling time, peak time, rise time and root-mean-square error) to control the gantry crane system than fuzzy logic controller. The controller which records the lowest root-mean-square error among the four controllers is fuzzy-PID controller with $2.433\text{x}10^{-8}$ RMSE. The fastest response which raised from 10% until 90% of the final desired destination is fuzzy-PID controller in almost half second. So, for intelligent controllers fuzzy-PID controller is nominated to have the best response in controlling the positioning of the Gantry Crane system.

Comparing the four controllers according to Figure 4.5 and Table 4.5 controller with settling time of 1.336 sec, peak time 1.085 sec, rise time of 0.64 and root-mean-square error of $2.433\text{x}10^{-8}$ has the best performance and fastest response among the four controllers. Although fuzzy-PID controller might have less or similar result as linear controller in some parameters, it is the most suitable controller as it is more flexible and can deal with variable changes unlike linear controllers.

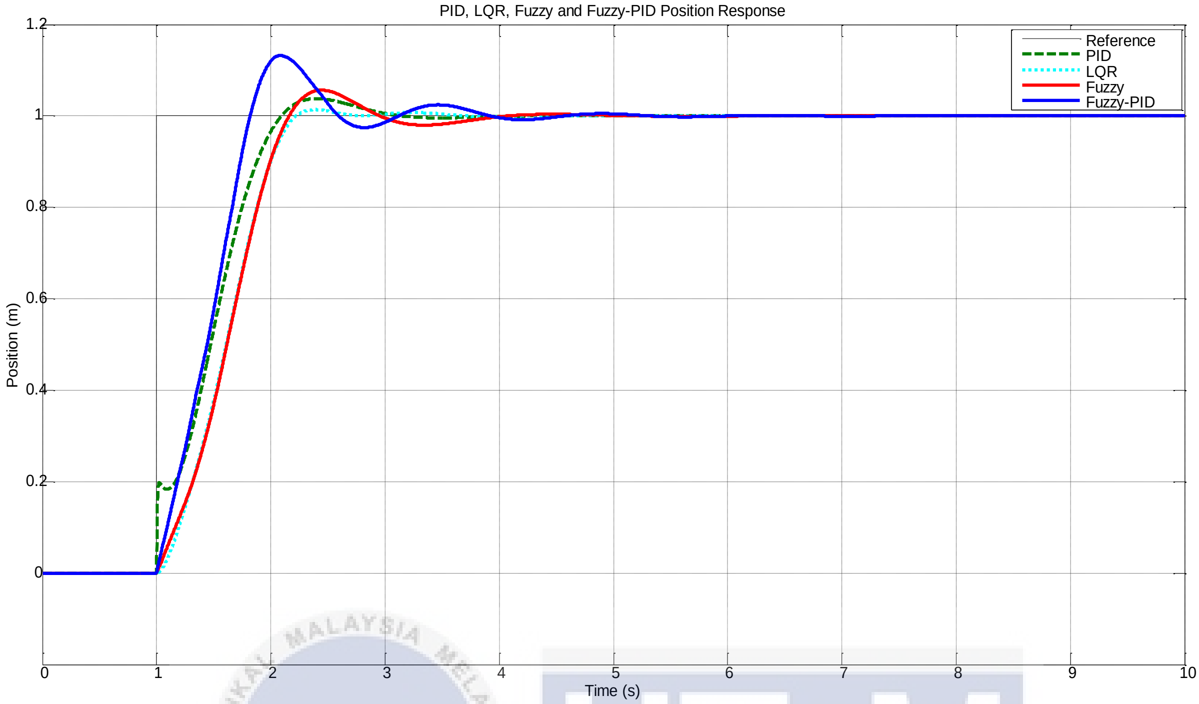

Figure 4.5: Linear & Intelligent Controllers Positioning Response

Table 4.5: Parameter Analysis for Intelligent Controllers' Positioning

Controller	**OS%**	**T_s(s)**	**T_p(s)**	**T_r(s)**	**e_{ss}**	**RMSE**
PID	3.8	1.764	1.401	0.874	0	7.382×10^{-5}
LQR	1.4	1.15	1.386	0.803	0	2.412×10^{-6}
Fuzzy	5.6	1.41	1.449	0.833	0	1.306×10^{-7}
Fuzzy-PID	7.2	1.34	1.085	0.64	0	2.433×10^{-8}

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4.4.2 PID, LQR, Fuzzy and Fuzzy-PID Anti-Swaying Response

Figure 4.6 presents the fuzzy-PID controller in blue color solid line, fuzzy logic controller in red color solid, PID controller in dashed green color and LQR controller in cyan color dotted line. As tabulated in Table 4.6 PID controllers records the lowest maximum oscillation amplitude of 0.064 meters with highest oscillation time of 1.275 seconds. However, fuzzy-PID controller show the opposite performance in controlling the swaying of Gantry Crane system. It records the largest maximum oscillation amplitude of 0.160 meter and reaches the settling period as fast as 1.164 second.

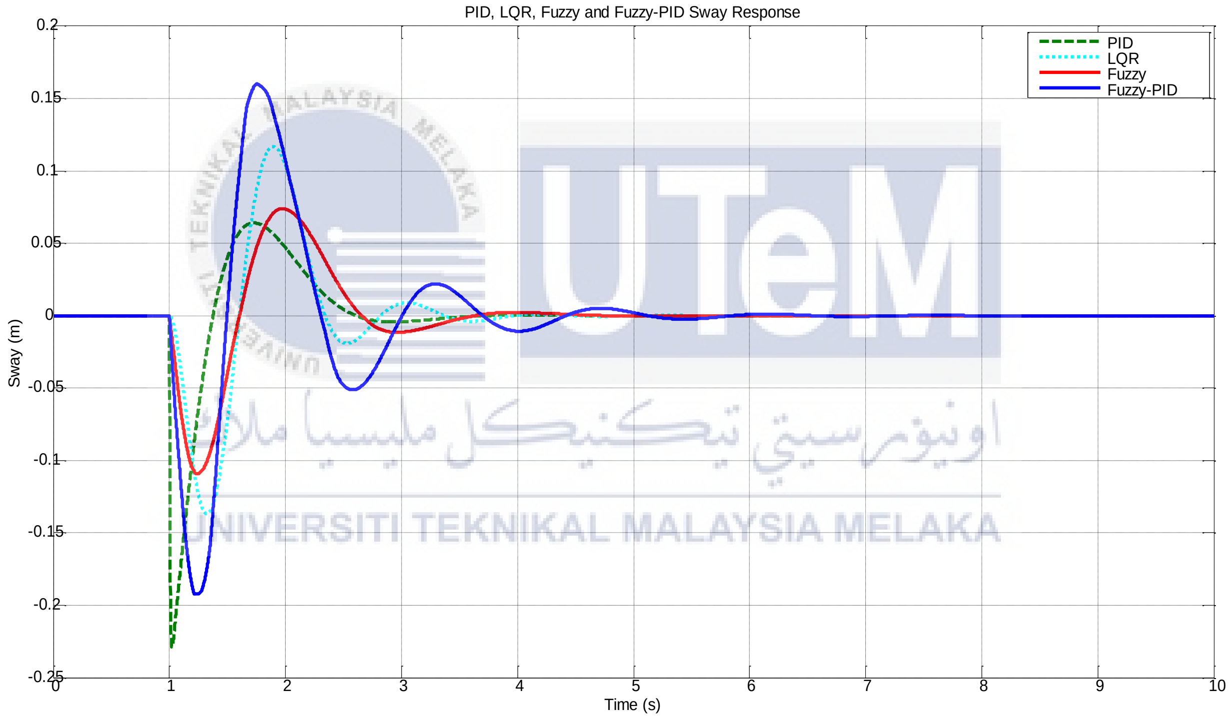

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Figure 4.6: Linear & Intelligent Controllers Sway Response

Table 4.6: Parameter Analysis for Intelligent Controllers' Swaying

Controller	**Maximum Ocsillation (m)**	**RMSE**	**T_{osc}(s)**
PID	0.064	7.382×10^{-5}	1.275
LQR	0.117	2.412×10^{-6}	1.264
Fuzzy	0.064	1.306×10^{-7}	1.26
Fuzzy-PID	0.160	2.433×10^{-8}	1.16

Although there are some limitations in some of its parameters, it can be concluded that fuzzy-PID is the most reliable and suitable controller to be applied to the Gantry Crane System. It is showing the best positioning and swaying control with fast and stable response comparing to other controllers.

Figure 4.7 shows a clear drawing chart for the comparison between the four controllers in term of positioning control, while Figure 4.8 illustrates a chart for the swaying control of the four controllers as well. The PID controller is represented by the blue column, LQR controller appears in the orange column, grey column is for Fuzzy controller and finally the yellow column is for the Fuzzy-PID controller. So, the differences can be noticed easily and the selection of the best controller will be obvious and clear.

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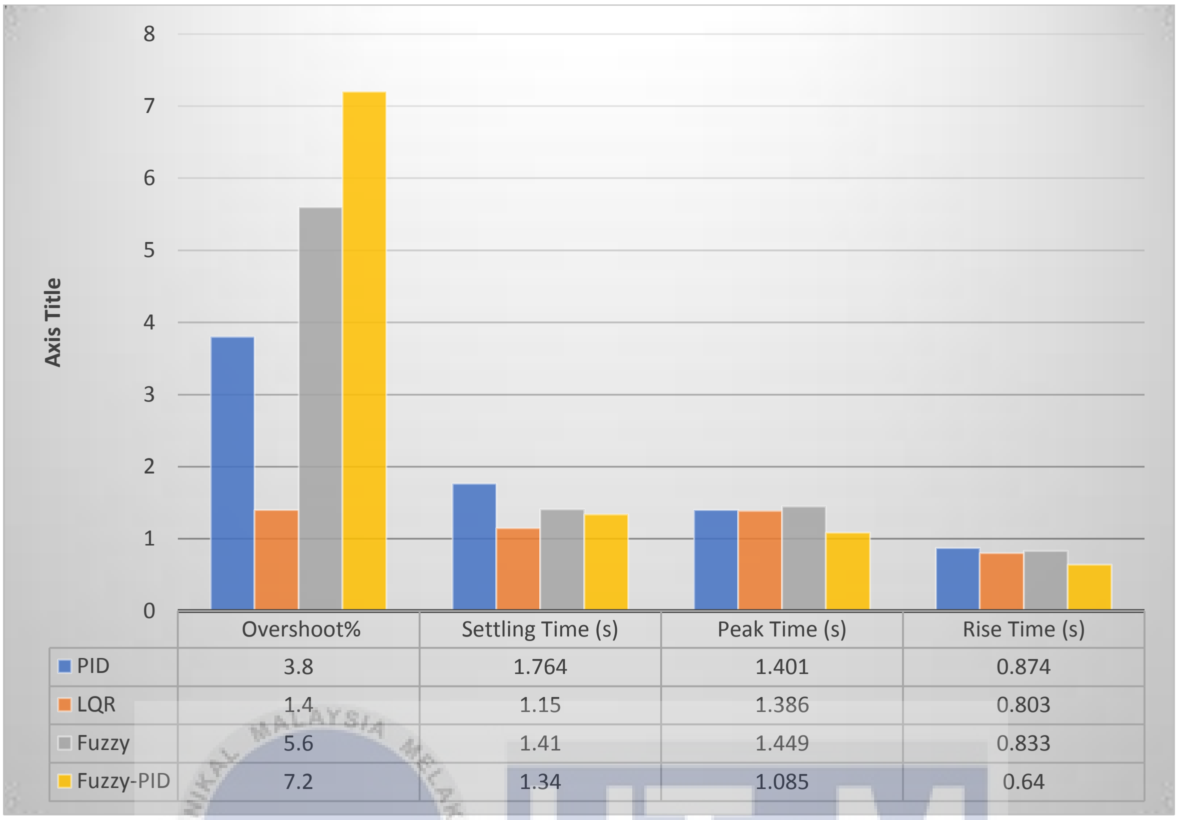

	Overshoot%	Settling Time (s)	Peak Time (s)	Rise Time (s)
🟦 PID	3.8	1.764	1.401	0.874
🟧 LQR	1.4	1.15	1.386	0.803
⬜ Fuzzy	5.6	1.41	1.449	0.833
🟨 Fuzzy-PID	7.2	1.34	1.085	0.64

Figure 4.7: Linear and Intelligent Controllers' Position Performance Chart

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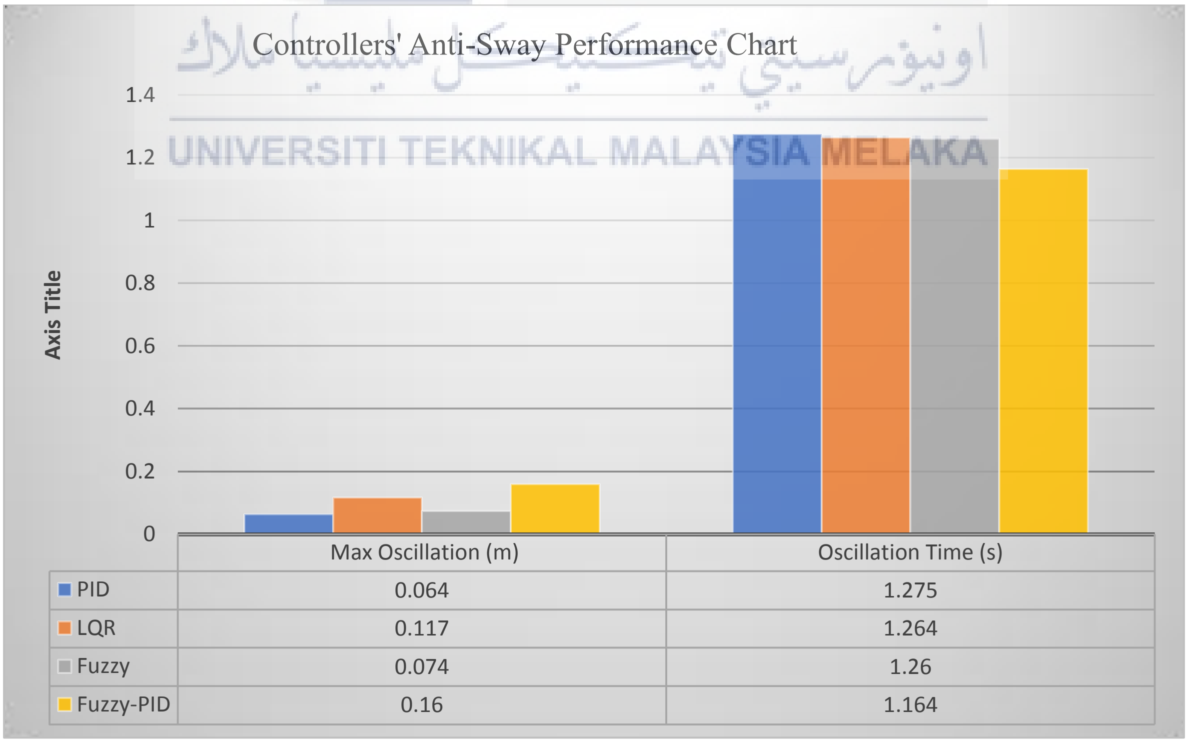

	Max Oscillation (m)	Oscillation Time (s)
🟦 PID	0.064	1.275
🟧 LQR	0.117	1.264
⬜ Fuzzy	0.074	1.26
🟨 Fuzzy-PID	0.16	1.164

Figure 4.8: Linear and Intelligent Controllers' Anti-Sway Performance Chart

CHAPTER 5

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, it can be said that the objectives have been achieved and accomplished. Gantry crane system and the importance of controlling it have been justified and clarified. The advantages and disadvantages of linear, intelligent, robust and forward controllers have been stated clearly. Moreover, the comparison between proportional-integral-derivative (PID), linear-quadratic-regulator (LQR), fuzzy logic and fuzzy-PID controllers have been discussed and explained. So, the selection of gantry crane system's controller will be somehow easier and simpler. Eventually, the result has been evaluated for the closed loop PID controller, LQR controller, fuzzy logic controller and fuzzy-PID controller. A comparison between the controller was discussed then the performance of each of them was clarified.

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5.2 Recommendation for Future Work

Based on the finding of this research, the further development of the research is implementing the proposed controllers into the hardware development. Since this research work is only operated in simulation environment, it cannot be guaranteed that the proposed controllers are able to perform as perfect as in simulation work either for the positioning or the vibration suppression of the GCS system when it is operated to the real time environment as it is well known that the real time environment is totally exposed to the real environment effects, therefore, it is recommended to implement the proposed controllers scheme to the real time GCS system to evaluate the capability of the proposed controllers for the positioning and oscillation suppression of the GCS system compared to their capability in the simulation environment.

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APPENDICS

Appendix A: Gantt Chart for Final Year Project 1

Week Task	1	2	3	4	5	6	7	8	9	11	12	13	14
1. Project Introduction -Motivation -Problem Statement -Objective -Scope	⬛	⬛	⬛										
2. Literature review -Gantry Crane System -Control Techniques -Linear Controllers -Intelligent Controllers -Robust Controllers -Feedforward Controllers			🟦	🟦	🟦	🟦	🟦						
3. Methodology -Modelling of Gantry Crane System. -PID Controllers -LQR Controllers -Fuzzy Controllers -Fuzzy-PID Controllers							🟨	🟨	🟨	🟨			
4. Preliminary Result										🟩	🟩	🟩	
6. Conclusion												🟧	🟧

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Appendix B: Gantt Chart for Final Year Project 2

Week **Task**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**11**	**12**	**13**	**14**
1. LITERATURE REVIEW	⬛	⬛											
2.METHODOLOGY		🟦	🟦	🟦									
3.RESULT -Design PID Controller -Design LQR Controller -Design Fuzzy Controller Design Fuzzy-PID Controller				🟥	🟥	🟥	🟥	🟥	🟥	🟥			
4.Analyses And Discussion									🟩	🟩	🟩	🟩	
5.Conclusion & Recommendation												🟪	🟪
6.Report Submission													🟨

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