3D CRANE CONTROL

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UNIVERSITI TEKNOLOGI PETRONAS
JUNE 2010

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By

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FINAL PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved:

(Assoc. Prof. Dr. Mohd Noh Karsiti)
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

June 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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(Mohd Nor Firdaus Bin Mohd Adnan)

ABSTRACT

In industries nowadays, the used of crane is absolutely important. It is use for industries such as port and factories to carry heavy loads safely. The drawback in a crane is the swing motion of a load. So the objective of this project is to design controller for the 3D crane Model that helps to overcome the swinging of the load during the movement of the crane. This model is a mini model of the real life autonomous gantry crane that being used in the industries. The swing motion of the load happens because the behavior of the crane is similar to pendulum by the movement and friction on the load. It is vital to have a controller that has the ability to reduce or overcome the swing motion that will lead the optimization of productivity, efficiency and most importantly the safety. This project will have two approach of controller which is PID controller and Fuzzy Controller. When those controllers are being applied later on, Fuzzy Logic Controller has better accuracy and precision in reducing the crane's swinging effect compared to PID Controller.

ACKNOWLEDGEMENTS

The greatest pleasure in writing such report is when it comes to acknowledge the efforts of many people whose names may not appear on the cover, but without their hard work, cooperation, support and understanding, producing this report would be impossible.

First of all, I would like to thanks to my supervisor, Assoc. Prof. Dr. Mohd Noh Karsiti for all the support that he gave on the project. Not forgetting to Mr. Azhar and Ms Siti Hawa for providing guidance and technical support on this project.

Last but not least, warmest gratitude to my friends and family who never ending believe in my capability and never stop to give an inspiration and encouragement for me to move forward in completing this project.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

The aim of this project is to reduce the swing effect of 3D crane by designing a controller. In bigger industrial such as loading and unloading loads, port, nuclear waste handling facilities, to have a smooth system of crane is vital. The crane oscillations make it difficult to manipulate the payload quickly and with good positioning accuracy. It is important that the crane must have as minimum oscillation as possible since the crane is moving loads that is heavy and might be dangerous and fragile. In the industries, productivity, efficiency and safety depend on how efficiently the crane is managed and become the important issues

1.2 Problem Statement

The effectiveness of gantry cranes is often limited by both the transient sway and the residual oscillation of the payload. If the crane acts largely like a pendulum, then experienced crane operators can eliminate much of the residual sway by causing a deceleration oscillation that cancels the oscillation induced during acceleration. The success of this approach depends largely on the skill and diligence of the operator [1]. Thus designing an anti swing controller for the crane arise for such matter.

1.3 Objective and Scope of Work

All projects and research have some objective to be achieved so that the project can be completed successfully. This project is focusing on designing anti swing controller to overcome the swinging effect of the payload.

Scope of Study

1. PID Controller
2. Nonlinear System
3. 3D Crane Model
4. MATLAB and SIMULINK
5. Fuzzy Logic

For the first part of this project, the author will focus on PID Controller and the second part will be Fuzzy Logic Controller and later to compare both of it.

CHAPTER 2
LITERATURE REVIEW

2.1 Literature Review

The 3D crane consists of a trolley, driving motors, and the flexible wire. It is often used in the factories and harbours for moving heavy cargoes. The motors drive the trolley and the flexible wire ties the load. Fast, smooth, and precise moving to the goal is the main objective of crane control. Usually, the experienced crane operator moved the load to the destination slowly, drove the trolley back and forth to make the load stationary, and tried to stop the trolley at the destination precisely and smoothly. However, due to the nonlinear load swing motion, smooth transportation and precise load positioning by the crane operator are not easy. In addition, transporting the load rapidly but without swing is an even more difficult objective [2].

Figure 1 The 3D Crane Setup

The 3D Crane is a rather complex object for mathematical description. It contains three control inputs and consists of the cart, moving in the x-y plane and a payload hanging on a rope, which can be shifted up and down. Usually, the analysis of cranes is simplified by the assumption that the angle between the rope and a vertical plane is small enough to avoid trigonometric functions in describing the position of payload, which leads to linear equations. Often, the models presented in literature are two-dimensional [3].

2.1.1 PID Controller

The PID controller calculation (algorithm) involves three separate parameters; the proportional, the integral and derivative values. The *proportional* value determines the reaction to the current error, the *integral* value determines the reaction based on the sum of recent errors, and the *derivative* value determines the reaction based on the rate at which the error has been changing. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve or the power supply of a heating element [4].

By tuning the three constants in the PID controller algorithm, the controller can provide control action designed for specific process requirements. The response of the controller can be described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the set point and the degree of system oscillation. Note that the use of the PID algorithm for control does not guarantee optimal control of the system or system stability [4].

Some applications may require using only one or two modes to provide the appropriate system control. This is achieved by setting the gain of undesired control outputs to zero. A PID controller will be called a PI, PD, P or I controller in the absence of the respective control actions. PI controllers are particularly common, since derivative action is very sensitive to measurement noise, and the absence of an integral value may prevent the system from reaching its target value due to the control action [4].

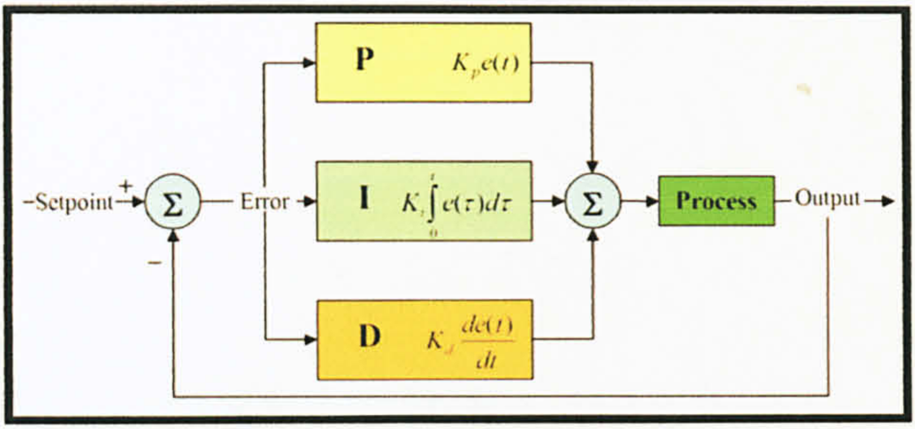


Figure 2 Block Diagram of PID Controller [3]

Table 1 Relationship of PID with Rise Time, Overshoot, Settling Time and Steady State Error

CL RESPONSE	RISE TIME	OVERSHOOT	SETTLING TIME	S-S ERROR
Kp	Decreases	Increases	No Change	Decreases
Ki	Decreases	Increases	Increases	Eliminates
Kd	No Change	Decreases	Decreases	No Change

To design a PID controller, the general rule is to add proportional control to get the desired rise time, add derivative control to get the desired overshoot, and then add integral control (if needed) to eliminate the steady-state error. Readjust the three variables is needed to fine-tune the response to achieve the desired result. Readjust all the three variables are needed to fine-tune the response to achieve the desired result.

2.1.1.1 Tuning Using Ziegler-Nichols Method

Tuning Rule Based on Critical Gain

In order to find all the value for P, PI and PID, Ti is set to infinity and the value for derivative mode which is Td is set to be 0. The ultimate gain and ultimate period is calculated by using only proportional gain. By increasing the gain from 0 until the critical gain value, K_{cr}, at which the output sustained oscillation [5].

Table 2 Ziegler-Nichols Tuning Rule

Controller	Kp	Ti	Td
P	$K_{cr} / 2$	infinity	0
PI	$K_{cr} / 2.2$	$P_{cr} / 1.2$	0
PID	$K_{cr} / 1.7$	$P_{cr} / 2$	$P_{cr} / 8$

2.1.2 Basic Crane System

The behavior of crane is a similar as the pendulum characteristic. The payload will start to oscillate or swing if the cart is start to move or with the external forces like wind. The pendulum is in equilibrium when the mass of the payload is balanced by the tension of the string that attached to the payload. When a pendulum is displaced from its resting equilibrium position, it is subject to a restoring force due to gravity that will accelerate it back toward the equilibrium position. When released, the restoring force will cause it to oscillate about the equilibrium position, swinging back and forth [6].

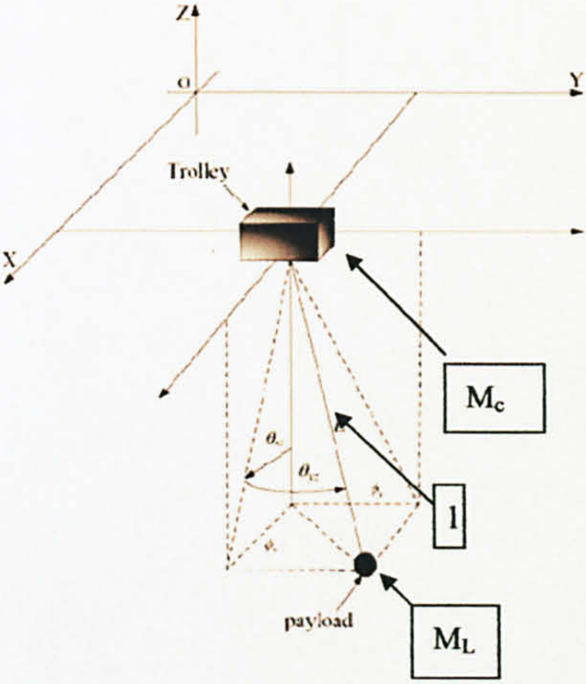


Figure 3 Swing Diagram of 3D Crane

Derive crane control system

$$M_C l\ddot{\theta} - (Mc + M_L)g\theta - u$$

$$M_C\ddot{\theta} = u - M_L g\theta$$

Define the state variable;

$$X_1 = \theta$$

$$X_2 = \dot{\theta}$$

$$X_3 = x$$

$$X_4 = \dot{x}$$

State space representation

$$\dot{x_1} = x_2$$

$$\dot{x_2} = \frac{M_L + M_C}{M_C} g x_1 - \frac{1}{M_C l} u$$

$$\dot{x_3} = x_4$$

$$\dot{x_4} = \frac{M_L}{M_C} g x_1 - \frac{1}{M_C} u$$

$$\dot{x} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ a & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ b & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} 0 \\ c \\ 0 \\ d \end{bmatrix} U$$

$$y = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix}$$

Equation for parameters in matrixes

$$a = \frac{M_C + M_L}{M_C l} g$$

$$b = -\frac{M_L}{M_C} g$$

$$c = -\frac{1}{M_C l}$$

$$d = M_C$$

Table 3 List of Parameters Values

Parameter	Values	Description
M_C	7 kg	Mass of the cart and moving rail
M_L	0.7 kg	Mass of the load
l	0.35 m	Length of cable
g	$9.81\ ms^{-1}$	Gravitational force

2.1.3 Fuzzy Logic Controller

Our perception of the real world is pervaded by concepts which do not have sharply defined boundaries, for example, many, tall, much larger than, young and many more are true only to some degree and they are false to some degrees as well [7]. These concepts can be called fuzzy or gray (vague) concepts. The Fuzzy Logic Controller are configure as the block diagram below.

Figure 4 Fuzzy Logic Controller Stages

2.1.3.1 Fuzzification

Fuzzification is an important concept in the fuzzy logic theory. Fuzzification is the process where the crisp quantities are converted to fuzzy (crisp to fuzzy). By identifying some of the uncertainties present in the crisp values, the fuzzy values are form. The conversion of fuzzy values is represented by the Membership Functions [7]. Membership Functions generalized the indication functions which represent the degree of truth. It is based on the system limitation.

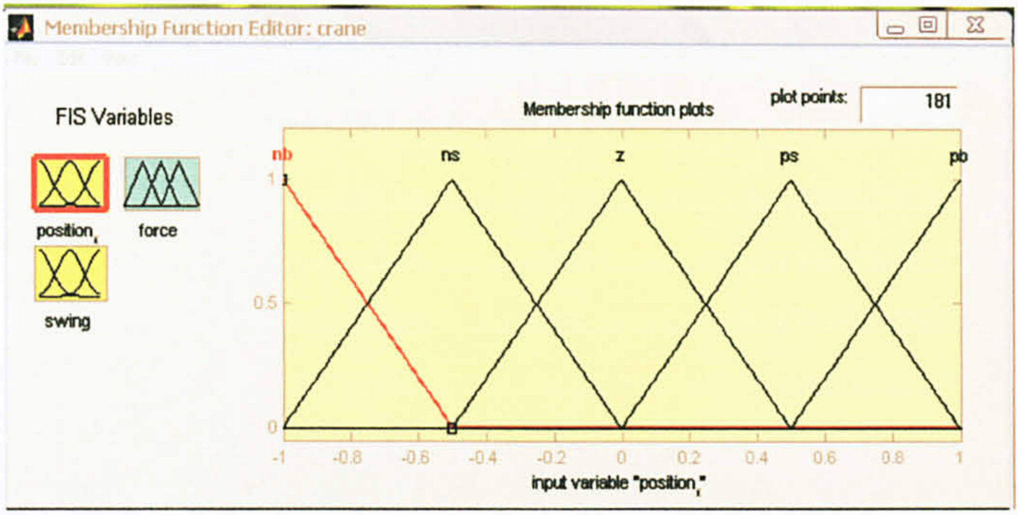


Figure 5 Membership Function

2.1.3.2 *Define Rule Base*

The outputs of the fuzzy logic depend on the rule that have been set. Such method is the rule base that use If-Then rules. It formulates the condition statements by comparing the inputs. For example:

"If *m* is A and *n* is B, then *p* is C"

Where A, B, and C are the fuzzy sets of the universe of discourse M, N and P.

2.1.3.3 *Defuzzification*

Defuzzification means the fuzzy to crisp conversions. The fuzzy results generated cannot be used as such to the applications, hence it is necessary to convert the fuzzy quantities into crisp quantities for further processing [7]. This stage is the connection between the control rule base and the physical system to be controlled. Therefore it acts inversely to fuzzification where this stage converts the data in membership function to a data that compatible with the system.

CHAPTER 3

METHODOLOGY

3.1 Procedure Identification

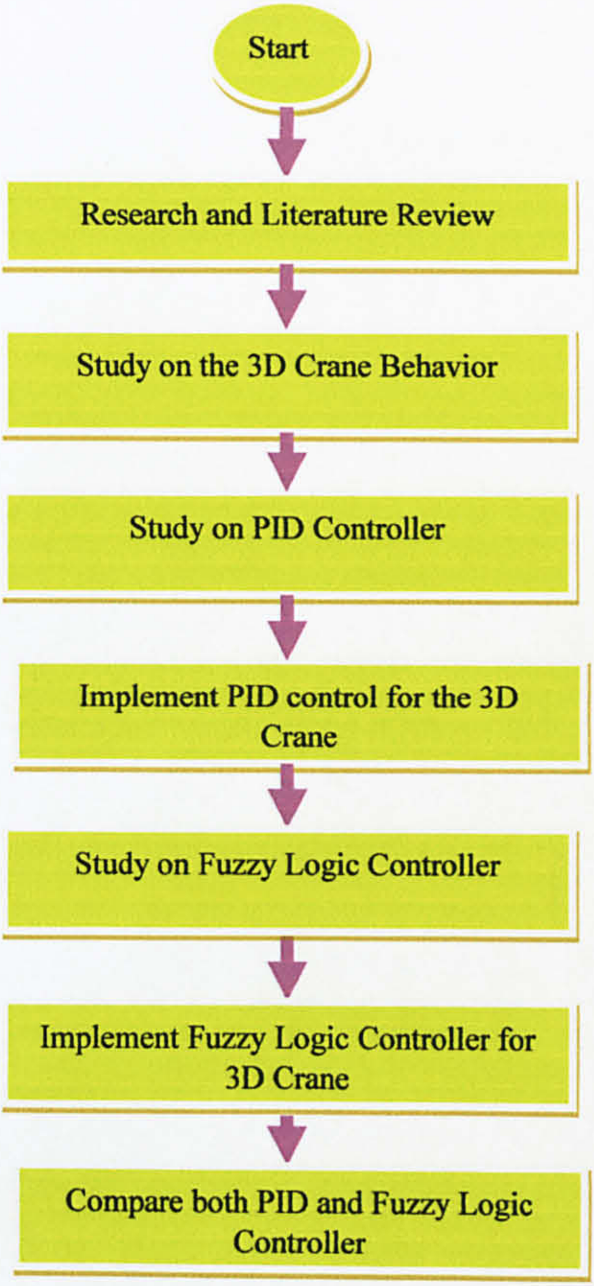


Figure 6 Flow Chart of Work Progress

3.1.1 Research and Literature Review

The flow chart (Figure 2) shows the progress of the project. The author does some research based on journals, books and internet related to the project like PID, Fuzzy Logic, and theory of pendulum.

3.1.2 3D Crane Behaviour

With the help from lab technician, the author learned on how to use the software to control and simulate the 3D Crane. The author exposed to the hardware and makes some basic testing for x-axis, y-axis and z-axis movement. The test covered the movement to the center and back home or original position either each axis separately or simultaneously.

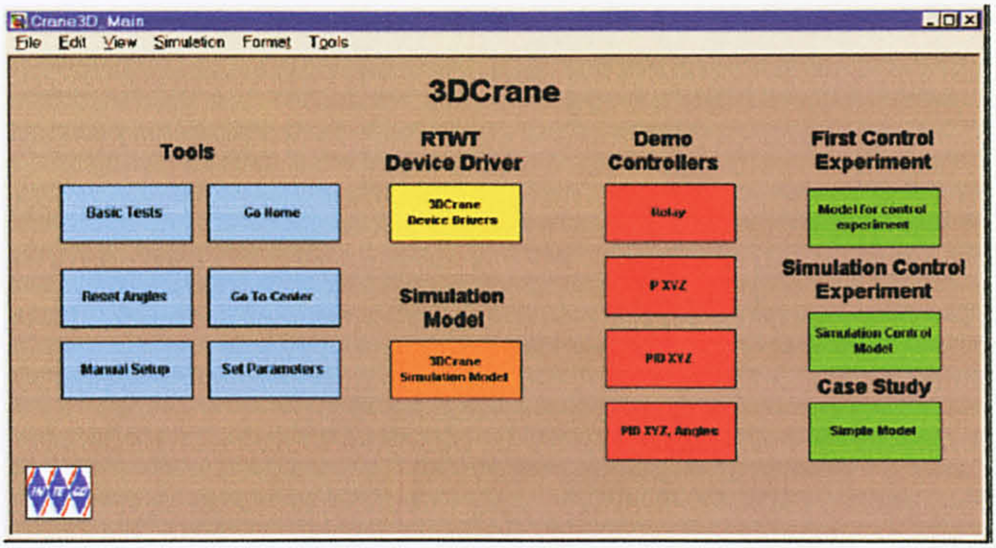


Figure 7 The Main Control Window for 3D Crane System

3.2 Hardware and Software

In this project, it consists of hardware and software. For hardware, the crane model is used to simulate the industrial crane with nonlinear system. This model is a real time model which is controlled by SIMULINK in the MATLAB through Real Time Window Target.

3.2.1 Hardware

This project is using Inteco 3D Crane Model as a model for the real crane used in industry. It consists of payload hanging on a pendulum-like lift-line wound by a motor mounted on a cart. This model is a real time model which is controlled by SIMULINK software in the MATLAB via Real Time Window Target.

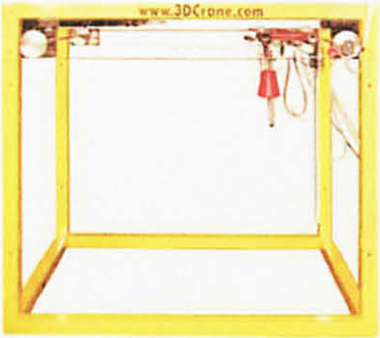


Figure 8 Inteco 3D Crane Model

Components of the system

Hardware:

- mechanical unit: frame, rails, cart with measurement unit, payload,
- motors: DC, 12 V, PWM controlled,
- 5 incremental encoders (position and angle measurements),
- interface and power supply units
- I/O RT-DAC/PCI board

3.2.2 MATLAB/SIMULINK

3DCrane uses MATLAB and SIMULINK to develop and run the controllers. SIMULINK, Real-Time Workshop, and the Real-Time Windows Target generate real-time controllers [2].

CHAPTER 4
RESULT AND DISCUSSION

4.1 PID Controller

The first approach to reduce the swing motion of the payload is by using PID Controller. The first step to determine the value of the PID is to fine the critical gain and the critical period. From the block diagram derived for the system, simulation had been tested using MATLAB/SIMULINK.

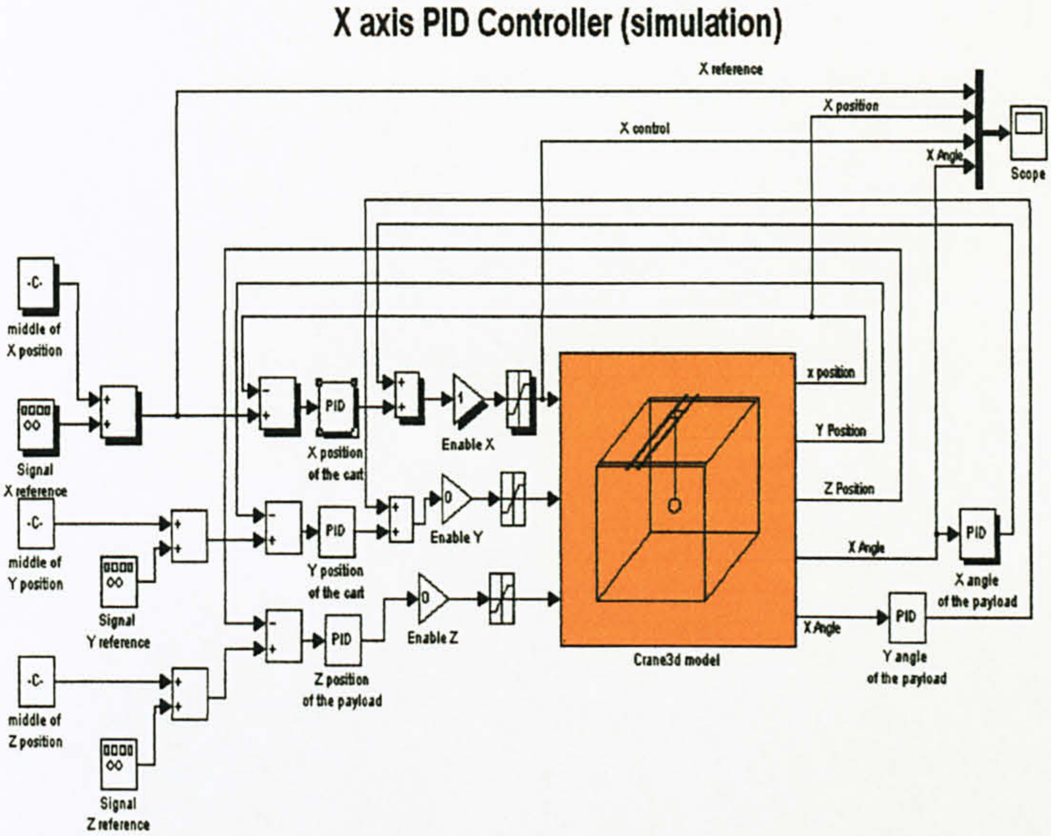


Figure 9 Simulation Model of the Crane

The input signal which represents a force is applied with square wave generated by signal generator. The input and output signal for position x is plot by the scope to find the critical gain, K_{cr} and critical period, P_{cr}.

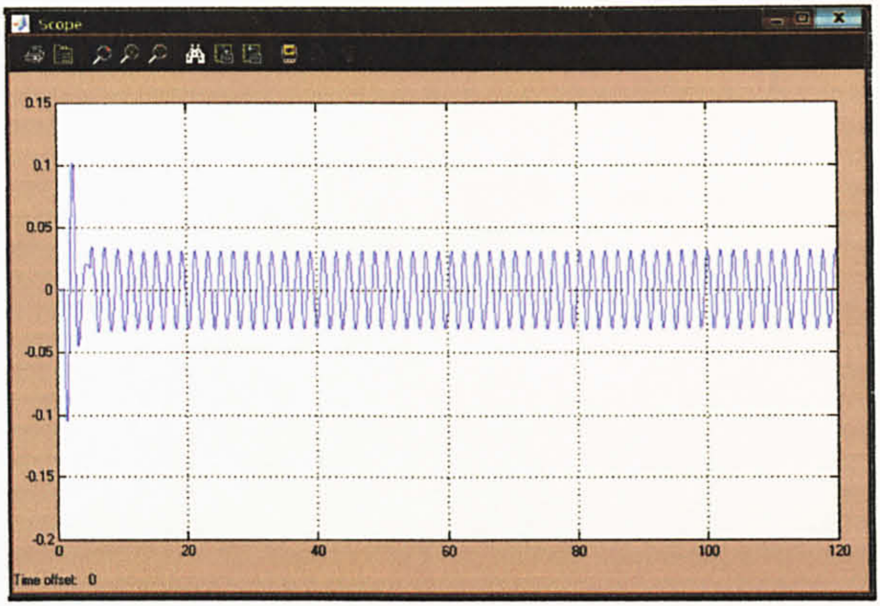


Figure 10 Constant oscillation to find gain and ultimate period

Referring to the Figure 10, the system goes wild after gain only applied to the system. The system sustains constant oscillation when the gain is 2. The critical gain and period obtained as follows:

$$K_{cr} = 2$$

$$P_{cr} = 10s \div 5$$

$$P_{cr} = 2s$$

Then the value of P, PI and PID is calculated base on Table 2. The values then tabulated in Table 4:

Table 4 Controller Values Based on Critical Gain and Period

Controller	Kp	Ti	Td
P	1	∞	0
PI	0.9	1.667	0
PID	1.2	1	0.25

After all the values are obtained, the controller is tuned to achieve smooth output by slightly changing the values of the parameters.

4.2 PID Result

All the values for PID being implemented in the Simulation Model to see the output response which is the sway output signal. The value PID calculated previously is the value only for x-position. *PID* value for angle-x is using the default value in the system. After the simulation is done, the value was tested in the Real Time Window Target which is applying the value to the real crane.

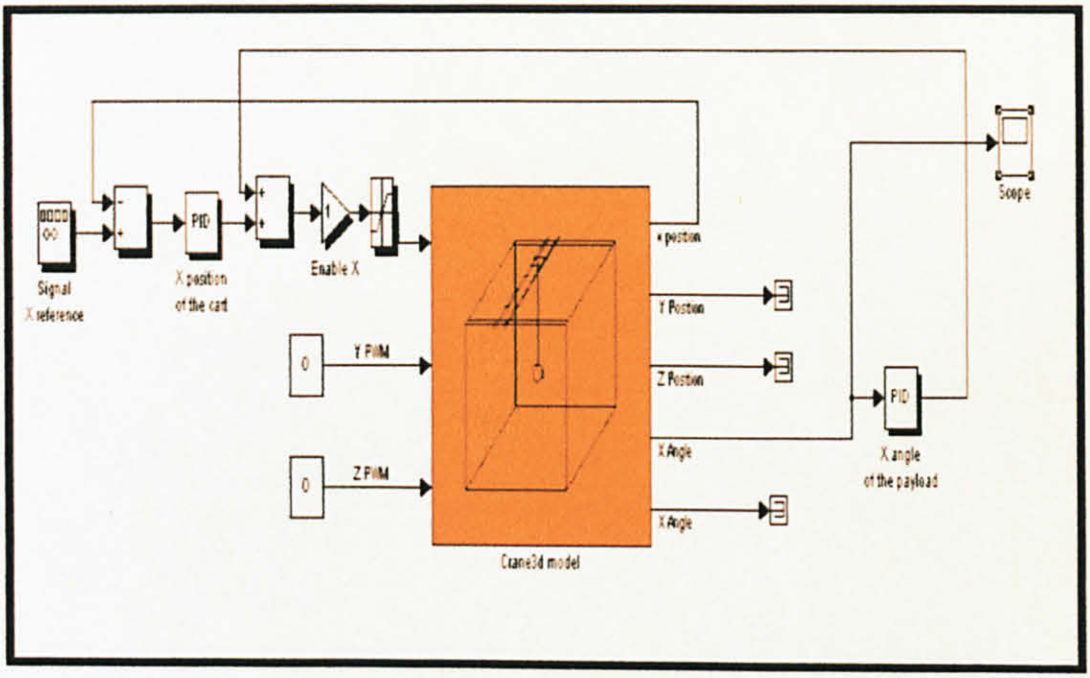


Figure 11 Simulation Model of 3D Crane

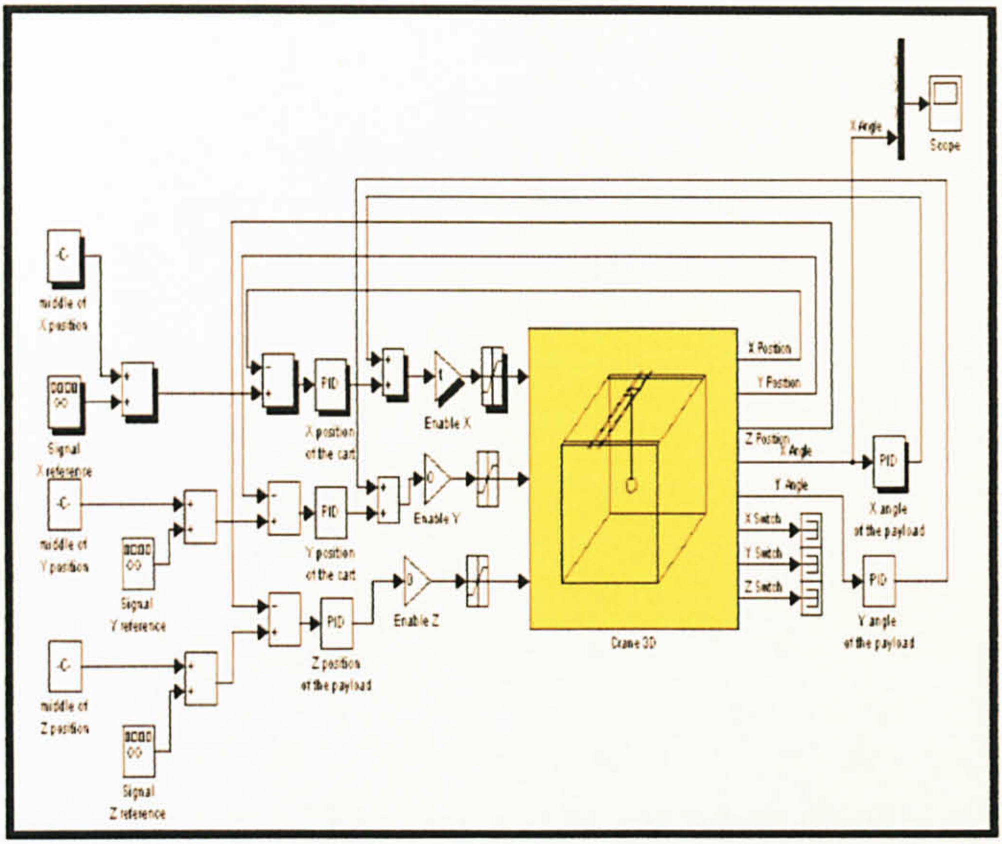


Figure 12 PID controller for Real Time experiment

The scope in the Figure 9 is connected to the output of angle-x to see the sway output signal of the system. The figure above shows that the position affected the sway motion of the crane. There were two PID controller implemented to control the position and angle of x.

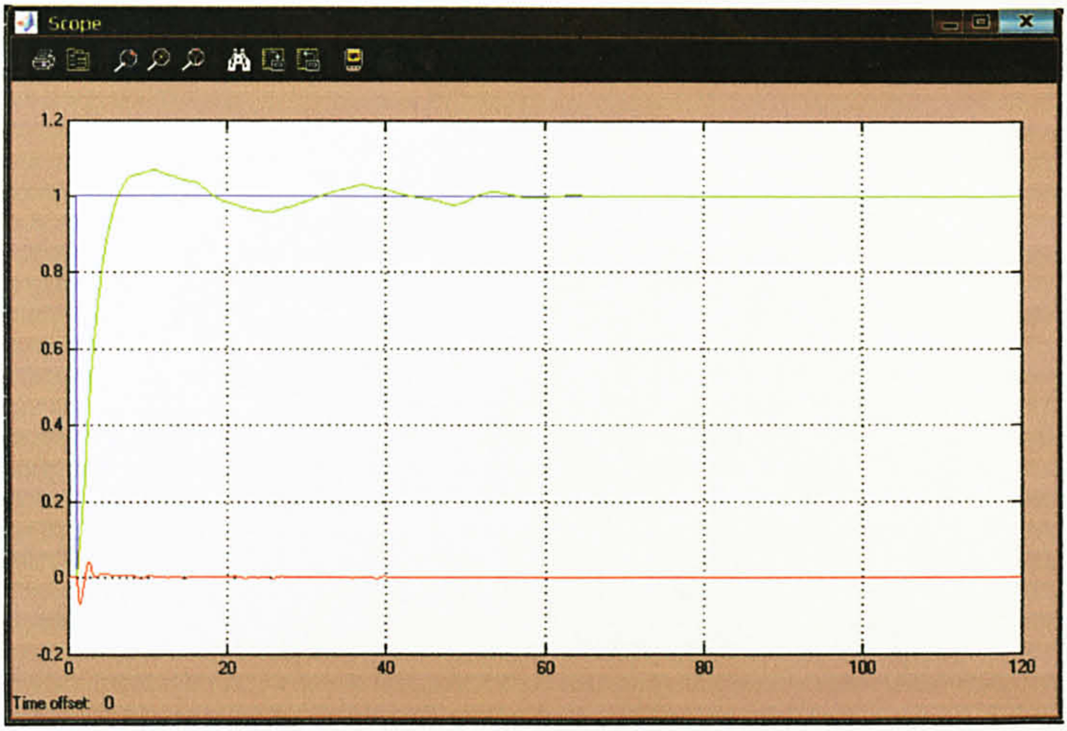


Figure 13 PID Result

Figure 14 Sway Output Signal of the Real Window Target of Crane System

The output shows the system oscillate within the range of approximately -0.04 to 0.04. By using the trigonometric formula, the displacement error of the sway angle can be calculated.

$$l = 0.35\ meter$$

$$\theta = 0.04\ rad\ @\ 2.29^\circ$$

$$displacement\ error, x = l \times sin\theta$$

$$x = 0.014\ meter$$

4.3 Fuzzy Logic

In order to transfer the payload economically and efficiently, the crane operator has to drive the cart to the goal as fast and as smooth as possible. However, the travel of crane always accompanies the undesired load swing. When the cart accelerates, the resulting backward swing of load can be expected, and the deceleration of crane leads to the forward payload swing. These phenomena can be explained by the inertia theorem. Most researches applied Lagrange's equations to derive the mathematical model of a crane and used the nonlinear methods to control the crane. However, these methods, such as the PD and nonlinear coupling controllers are rather complex and difficult. Hence, this study develops a simple and novel fuzzy-based method to control the crane [8].

Fuzzy Logic Controller has a better accuracy in controlling nonlinear system. Compared with PID Controller, Fuzzy can control more than one variable. In this project, the variables to be considered are the position error (x-axis) and sway angle. Hence, the fuzzy membership rule is set to relate between this two variables.

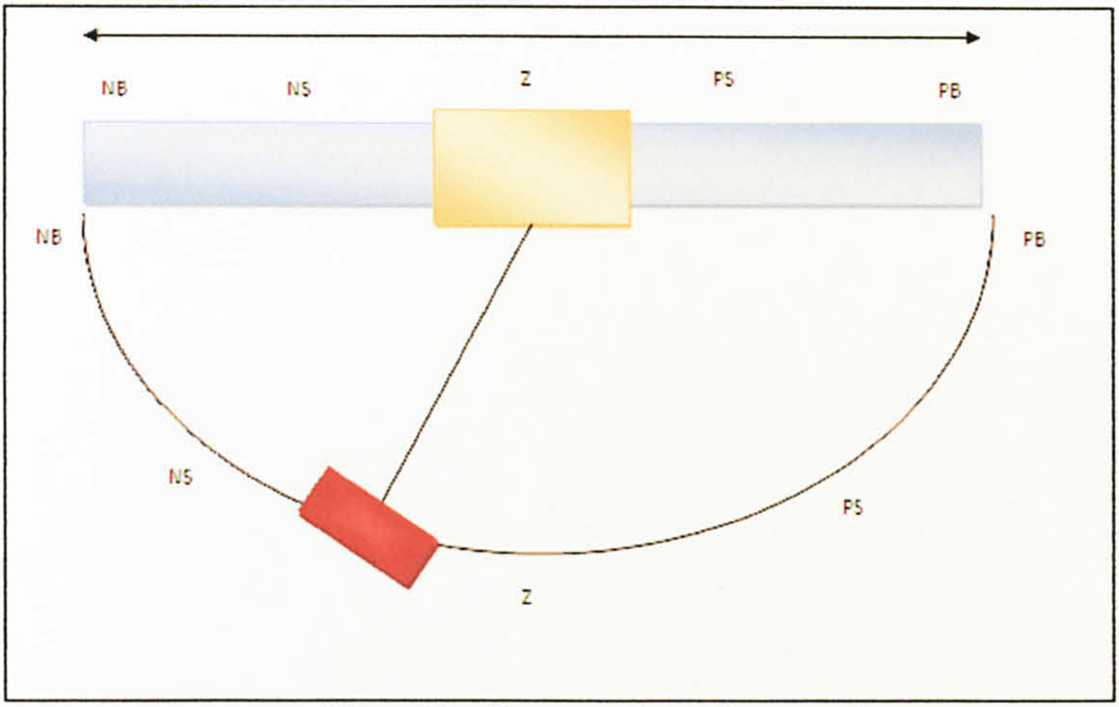
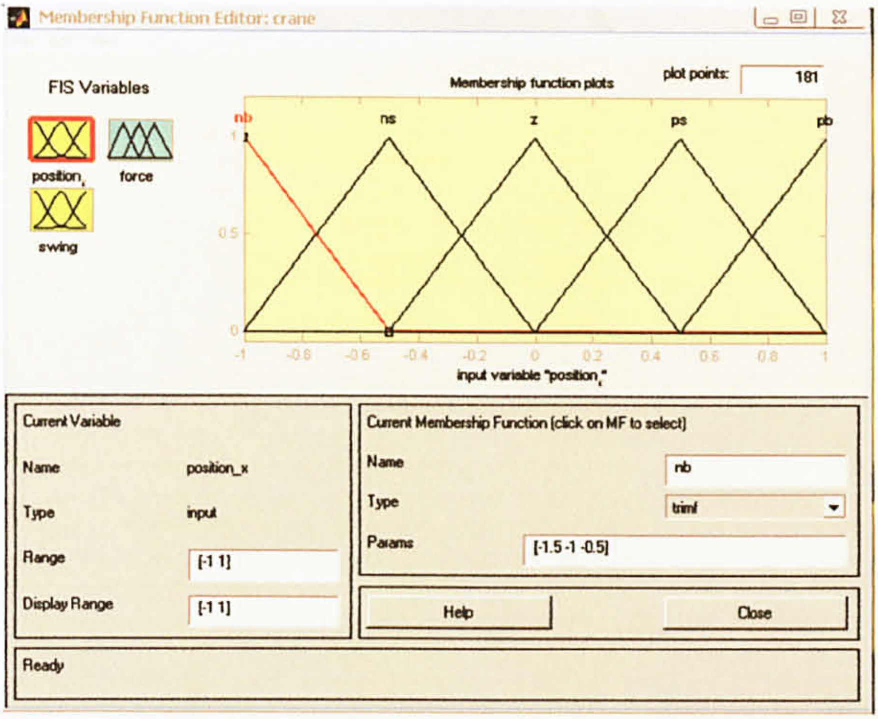


Figure 15 Crane position and sway angle.

In the FIS (Fuzzy Inference System), triangular membership function is chosen and the linguistic variables can be set. The connective rules are formed and based on these rules the fuzzy associative memory table is formed.



plot points: 181

Current Variable

Name position_x

Type input

Range [-1 1]

Display Range [-1 1]

Current Membership Function (click on MF to select)

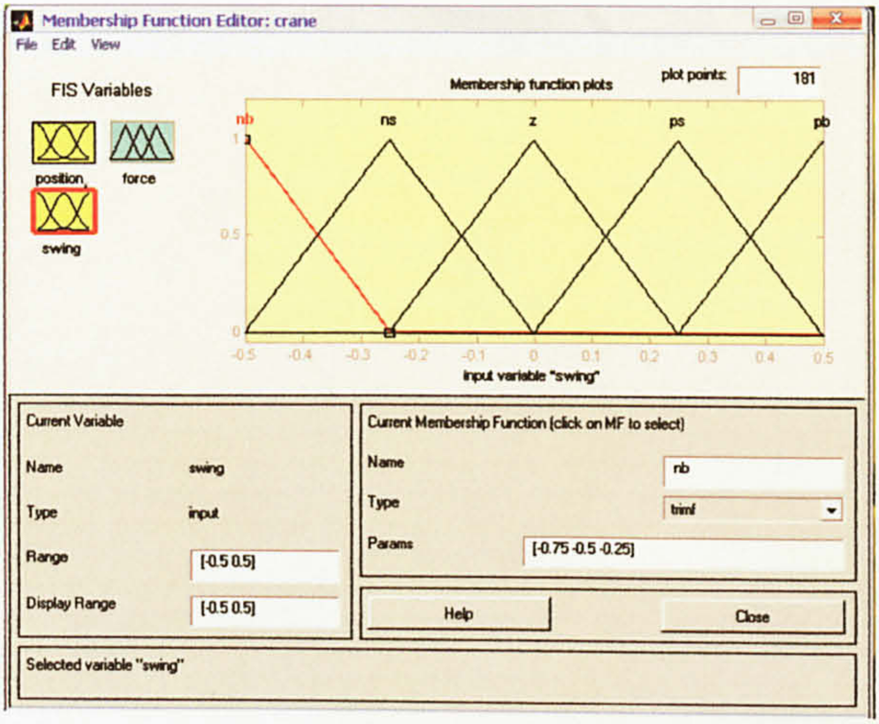
Name nb

Type trimf

Params [-1.5 -1 -0.5]

Ready

Figure 16 Membership Function for position x



plot points: 181

Current Variable

Name swing

Type input

Range [-0.5 0.5]

Display Range [-0.5 0.5]

Current Membership Function (click on MF to select)

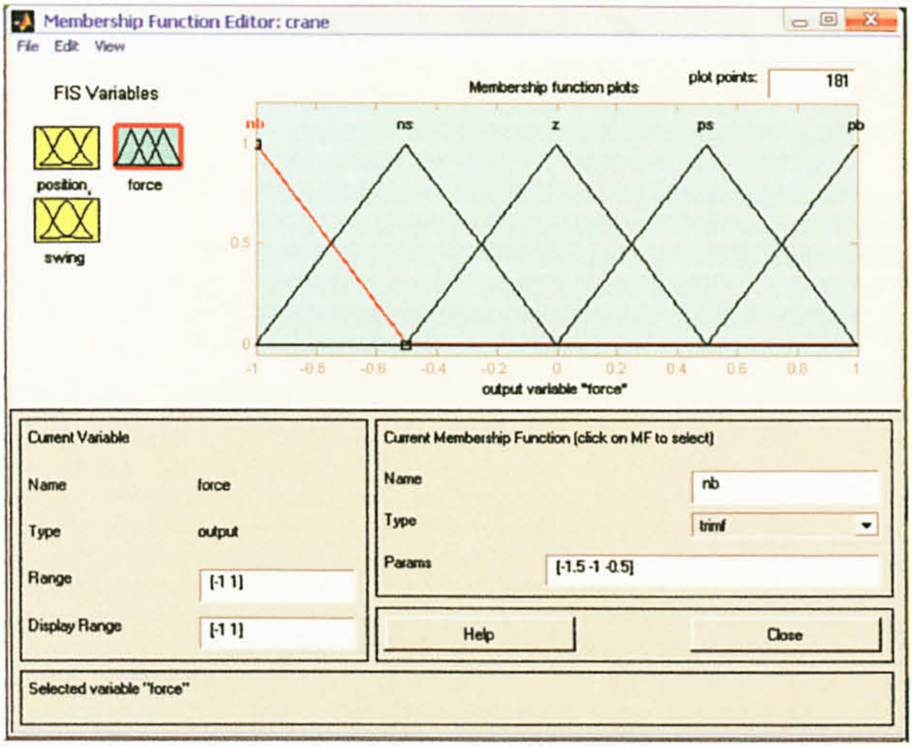
Name nb

Type trimf

Params [-0.75 -0.5 -0.25]

Selected variable "swing"

Figure 17 Membership Function for sway angle



plot points: 181

Current Variable

Name force

Type output

Range [-1 1]

Display Range [-1 1]

Current Membership Function (click on MF to select)

Name nb

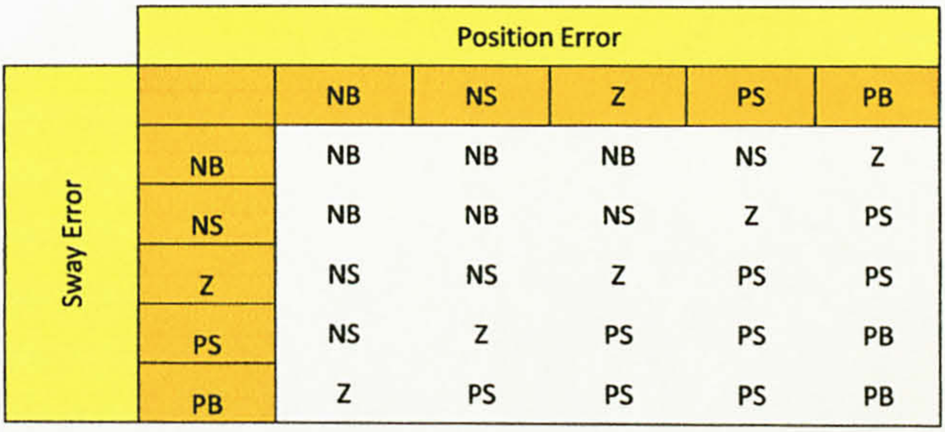
Type trimf

Params [-1.5 -1 -0.5]

Selected variable "force"

Figure 18 Membership Function for output

Table 5 Rule base



		Position Error				
		NB	NS	Z	PS	PB
Sway Error	NB	NB	NB	NB	NS	Z
	NS	NB	NB	NS	Z	PS
	Z	NS	NS	Z	PS	PS
	PS	NS	Z	PS	PS	PB
	PB	Z	PS	PS	PS	PB

Legend

NB – Negative Big

NS – Negative Small

PB – Positive Big

PS – Positive Small

Z – Zero

Rules form the basis for the fuzzy logic to obtain the fuzzy output. The rule based form uses linguistic variables as its antecedents and consequents. The result of this controller is depends on how the rule base is constructed. For example in this project, the relation between the position and the sway angle is to eliminate one and another. If the position error is negative big and the sway error is also negative big, the output force will be negative big.

4.3.1 Result for Fuzzy

The simulation for fuzzy logic is constructed with two input into the fuzzy block which are the position error x and the sway angle. The position error is determined by comparing with the input signal and the output displacement. Real Time Window Target was tested after the simulation was done.

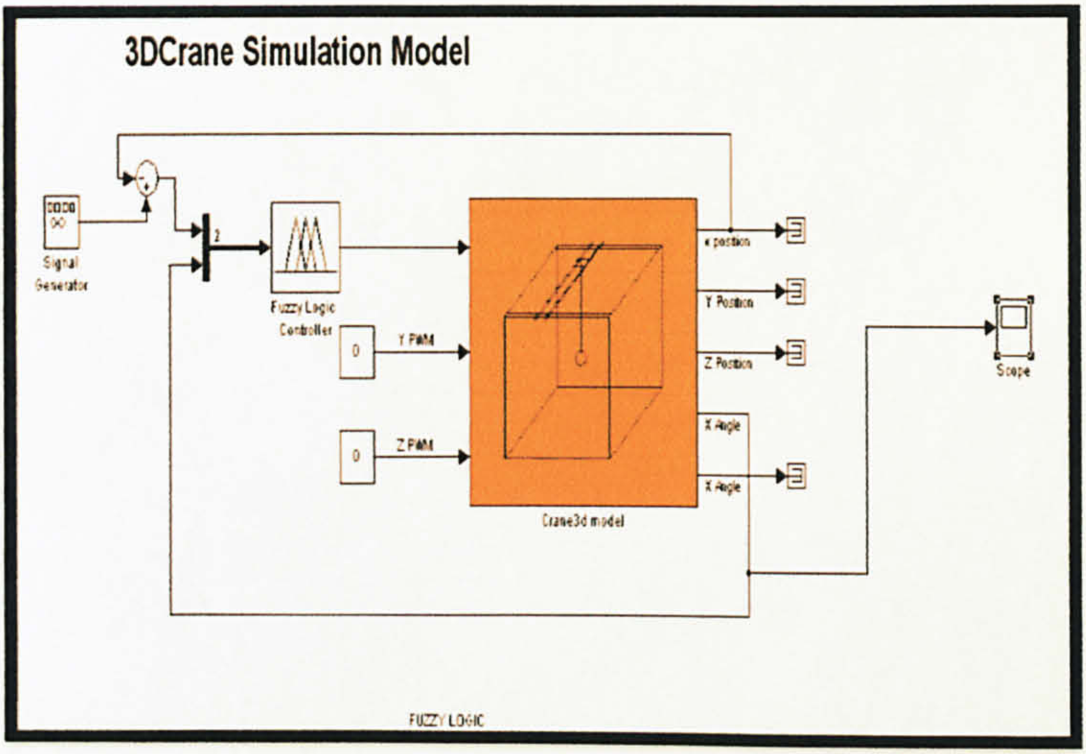


Figure 19 SIMULINK Diagram for Fuzzy Logic

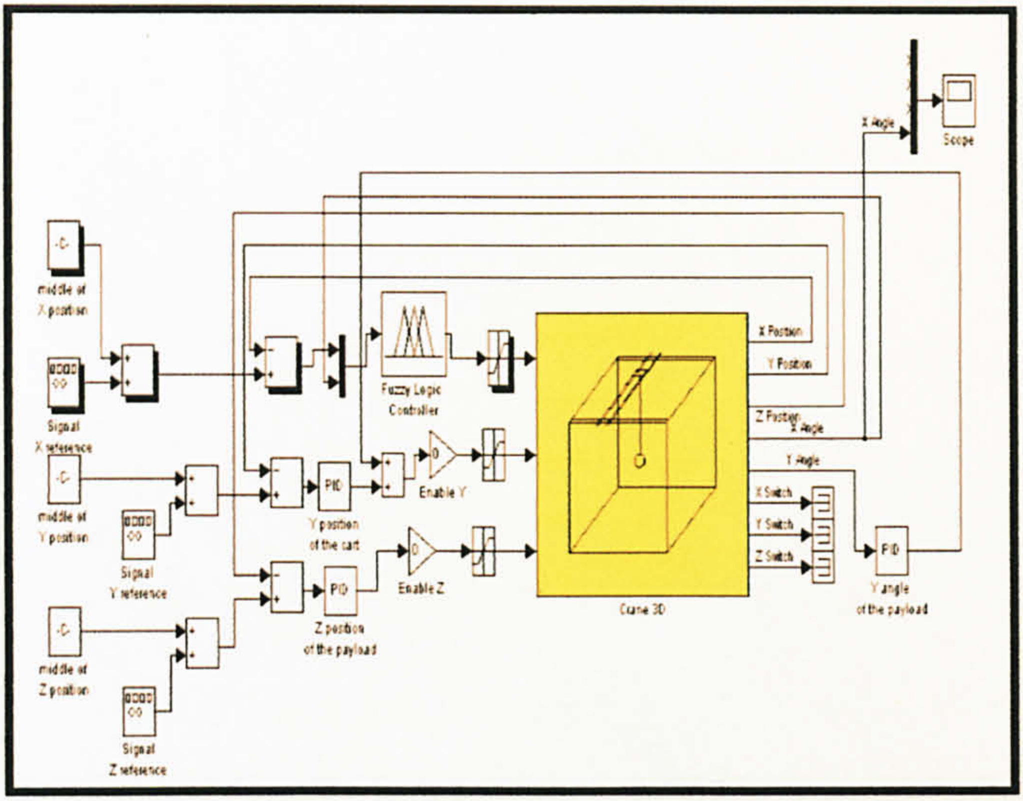


Figure 20 Fuzzy Logic Controller Real Time Diagram

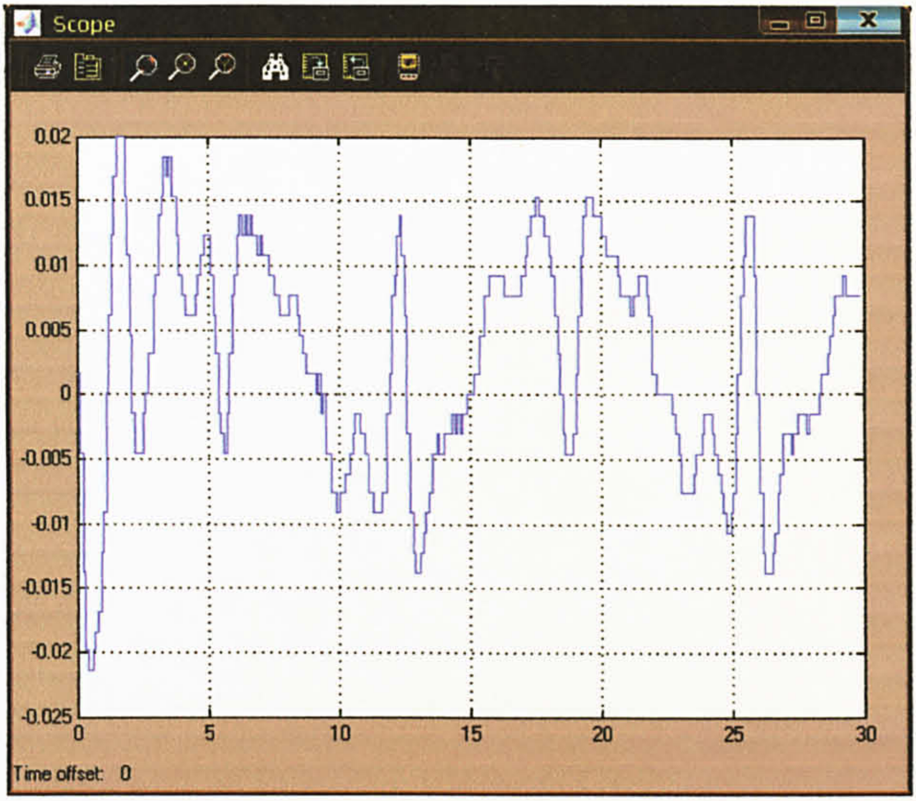


Figure 21 Output sway angle for Fuzzy Logic

The sway output angle is small and at range of between -0.015 and +0.015. The displacement error of the sway angle is calculated by using the trigonometric formula.

$$l = 0.35\ meter$$

$$\theta = 0.015\ rad\ @\ 0.86°$$

$$displacement\ error, x = l \times sin\theta$$

$$x = 0.0053\ meter$$

4.4 Comparison Between PID and Fuzzy Logic

The objective of this project is to compare between PID Controller and Fuzzy Logic Controller to reduce the sway angle of the crane. Comparison is done by comparing the sway angle.

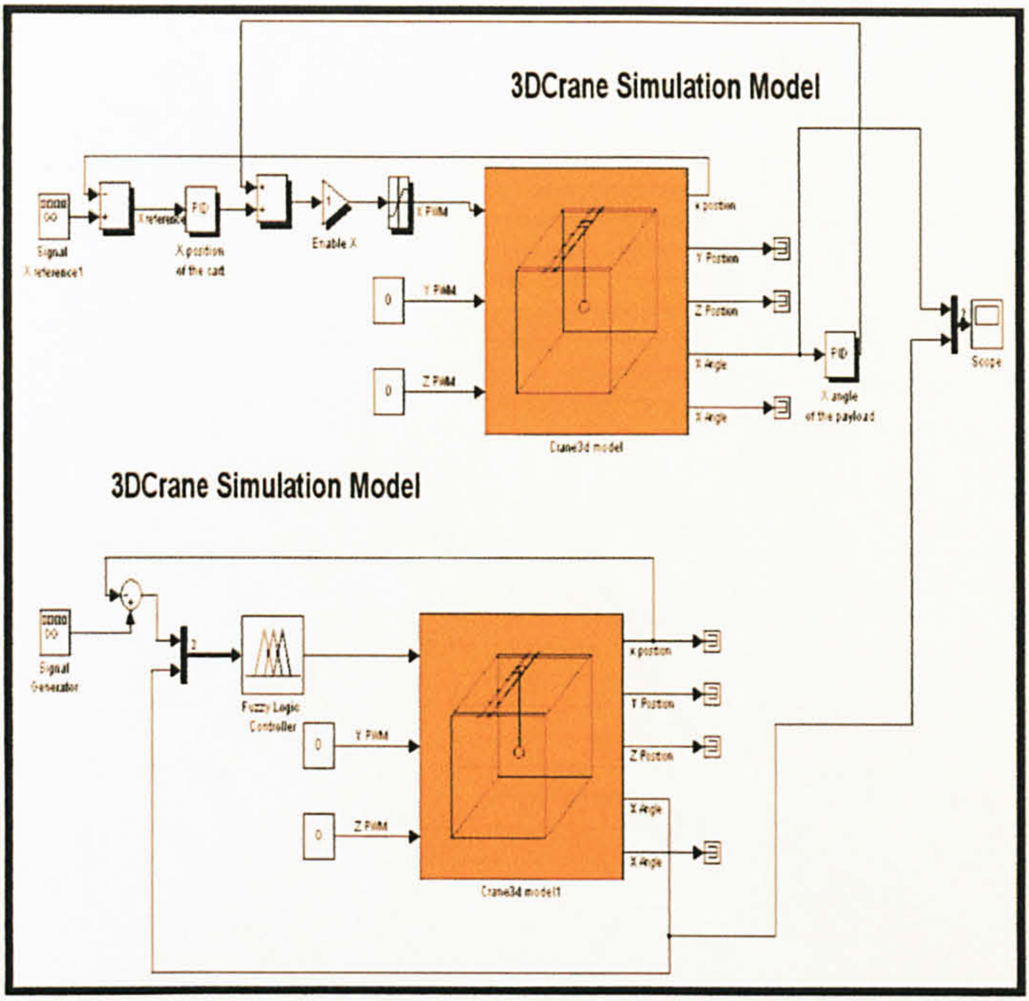


Figure 22 Comparison between PID and Fuzzy Logic

From the result of PID and the Fuzzy Logic, the result is almost reducing the sway angle and Fuzzy shows a slightly better result. The output sway of fuzzy is in range of -0.015 to +0.015 and PID is -0.04 and +0.04. In term of displacement error, the PID is 0.014 meter and Fuzzy Logic is 0.0053 meter. The values show that Fuzzy has small value for displacement error.

4.5 Discussion

In order to achieve the objective of this project which is to reduce the swing motion, deep study on theories and ability to use the software is critical. When deal with the hardware of the 3D Crane, error is commonly occur. Sometime the movement of the cart and the load did not follow the instruction and go wild. This is because the sensor might have some problem. Precaution need to be taken care to avoid damage to the model. Before start the simulation, basic test need to be done first so the error can be avoided. For PID, the controller only control one input and fuzzy logic can control many input. Hence PID needs two controller two controls for the position error and the sway angle of the crane.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The result of the PID controller to reduce the swing effect of the crane is discuses in the previous chapter. PID controller look effective in order to reduce the sway motion but improvement can be made so that the better result can be achieved. With tuning, PID can be as good as Fuzzy Logic. The advantage of using fuzzy logic is that only one controller is needed to control the position error and the sway angle of the crane. To get a better result for Fuzzy Logic, more combination of the rule based can be implemented.

From the experiment and the simulation, it can be conclude that Fuzzy Logic is better than PID to control a non linear systems.

5.2 Recommendation

In order to improve the efficiency of reducing the sway motion of the crane, user need to improvise certain things which are:

1. For PID controller, user need to ensure the value of gain is taken when the system oscillate at the constant oscillation.
2. For Fuzzy Logic Controller, the rule base is a critical part which determines the output of the system. User must clearly define the rule based so that desired output will be achieved.

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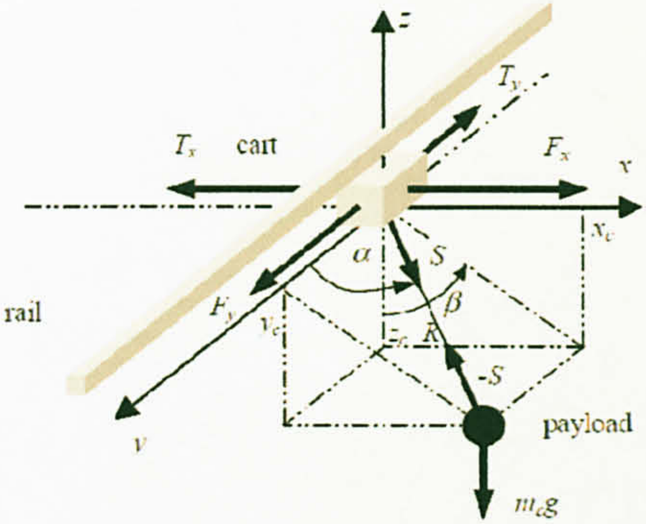
APPENDICES

APPENDIX A

MATHEMATICAL MODEL OF 3D CRANE

Mathematical model of the 3DCrane



There are five measured quantities:

- x_w (not marked in Fig. 8.1) denotes the distance of the rail with the cart from the center of the construction frame;
- y_w (not marked in Fig. 8.1) denotes the distance of the cart from the center of the rail;
- R denotes the length of the lift-line;
- α denotes the angle between the y axis and the lift-line;
- β denotes the angle between the negative direction on the z axis and the projection of the lift-line onto the xz plane.

Denote also:

m_c - mass of the payload
m_w - mass of the cart
m_s - mass of the moving rail
x_c, y_c, z_c - coordinates of the payload
S - reaction force in the lift-line acting on the cart
F_x - force driving the rail with cart
F_y - force driving the cart along the rail
F_R - force controlling the length of the lift-line
T_x, T_y, T_R - friction forces.

APPENDIX B

GANTT CHART

	Semester 1														Semester 2														
Details / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Selection of project title/ supervisor	■		H1N1 HOLIDAY						MIDSEM BREAK													MIDSEM BREAK							
Preliminary research • Study on the 3D crane		■		■																									
Research on PID controller				■	■																								
Submission of Prelim Report				■																									
Study using MATLAB/SIMULINK						■	■																						
Submission of progress report								■																					
Project work →3D Crane experiment →Implement PID controller on the 3D crane								■		■	■	■	■																
Seminar											■																		
Submission of final interim report														■															
Oral Presentation														■															
Redo the PID controller															■														
Research on Fuzzy Logic Controller																■													
Testing Fuzzy Logic Controller																	■	■	■	■	■								
Submission of progress report																					■								
Implement Fuzzy Logic to the Real Time experiment																							■	■	■				
Poster exhibition																										■			
Draft report submission																											■		
Submission of dissertation (Soft bound)																												■	
Final presentation																													■
Submission of dissertation (Hard bound)																													■