Autonomous Crane Control
(Anti-Swing Controller)

By

Mohd Azrul Adha B. Mohd Sohaimi

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)

Universiti Teknologi Petronas
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Autonomous Crane Control
(Anti-Swing Controller)

By

Mohd Azrul Adha B. Mohd Sohaimi

A project dissertation submitted to the
Electrical & Electronics Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfillment of the requirement for the
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

Approved:

Assoc. Prof. Mohd Noh Karsiti
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

June 2007

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.

Mohd Azrul Adha B. Mohd Sohaimi

ABSTRACT

The main objective for this project is to design controller for the 3D Crane Model that helps to overcome the swinging phenomena during the movement of the crane. 3D Crane model is a simulation or a mini model of the real life autonomous gantry crane that industries, such as port and factories, uses to carries heavy loads. Cranes behavior is similar to pendulum where movement and friction on the load will create a swinging effect on it. In these industries, swinging of the load will affected their productivity, efficiency and most importantly the safety. So by having a controller that have the ability to overcome the swinging effect, this will optimize the productivity, efficiency and also the safety. In designing the "anti-swing" controller, a lot of problems encounter especially when dealing with 3 direction non-linear models. To understand the 3D Crane Model's capability and ability also will take a lot of time. This project will require knowledge in all types of controllers since the best controller out of all the controllers are needed to be use. As for the first part of this project, a PID controller is selected. Then a Fuzzy Controller are designed to compare with PID Controller to see which has better accuracy and precision in reducing the crane's swinging effect.

ACKNOWLEDGEMENTS

In the name of Allah, the Gracious, the Merciful, the Author would like to thank Him for giving the strength, skill, knowledge, patience and good health in producing this report and the product. 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. Mohd Noh Karsiti for all the support that he gave on the project. Not forgetting to Ms Noor Hazrin Hany, Ir Idris Ismail, Ms Illani M Nawi and also Mr. Azman Zainuddin for sharing knowledge and providing brilliant advice on the project.

I would also like to thanks to Mr. Azhar, Mr. Megat, Mr. Sanni, and Ms Siti Hawa for providing guidance and technical support on this project. Special thanks for Solihah Mohd Salahuddin, Shahriman MShariff, Syahril Izwan, Shahrul Ridhwan, and everybody who directly or indirectly help me in giving technical support and also encouragement in completing this project.

Last but not least, warmest gratitude to my parent and family who never ending believe in my capability and never stop to give an inspiration and encouragement for me to move forward. Thank you so much for your sincere cooperation and May God Bless you all.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

FLC	-	Fuzzy Logic Controller
PID	-	Proportional, Integral and Derivative
MF	-	Membership Functions
SS	-	Steady State
GUI	-	Graphical User Interface

CHAPTER 1
INTRODUCTION

1.1 Background Study

The main purpose of this project is to design a controller that can reduce and minimize the swinging effect of 3D crane. Cranes are one of the essential equipment in industry. Crane are used in numerous industrial application such as loading and unloading loads, nuclear waste handling facilities, factory automation and many more. In these applications, 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. The oscillation may affect the productivity and also safety of the equipment and the environment which tends to be one of important issues and priority in every company.

1.2 Problem Statement

1.2.1 Problem Identification

In every project there must be problems that needed to be solved before completing the project. As for this project, the following list will summarize the problems:

i. Deriving the System Equation
ii. Understanding and Study on the System Behavior
iii. Choosing the Appropriate Controller
iv. Tuning the Controller
v. Enhancement of the System

1.2.2 Significant of the project

This project will improve the efficiency of the crane by improving the oscillation reduction controller. This controller will reduce the oscillating motion of crane in for safety and productivity purpose.

1.3 Objective and Scope of Work

In every project accomplishments, there will always be some objectives to aim and achieved so that in the end, the project can be completed successfully.

The objectives of this project are:

- Design a controller that reduce the crane swinging and oscillating effect
- Enhance the controller ability by adding features such as obstacle recognition, path planning and also tracking control

Scope of Study

- PID Controller
- Nonlinear System
- 3D Crane Model
- MATLAB and SIMULINK
- Fuzzy Logic

All this research and the design of swinging reduction controller will be completed in the first part of the project. On the second part of the project, the scope of work will be concentrating on some of enhancement and addition futures of the system.

CHAPTER 2
LITERATURE REVIEW AND THEORY

2.1 Literature Review

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. [1]

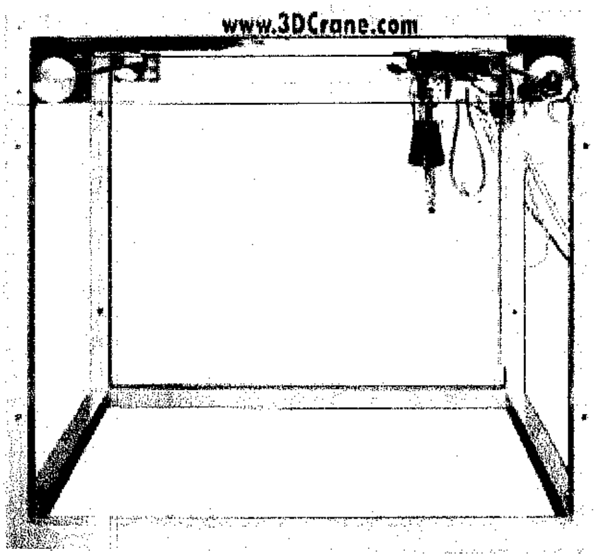


Figure 1 3D Crane Model

The 3DCrane is a laboratory system imitating an industrial gantry crane. The size of the model is customizable and can be as large as 3x3x3 meters long. The crane is controlled via computer and can move independently in three perpendicular directions. The current load deviations from the equilibrium down position are permanently processed by a control algorithm due to the unique 2-D angle measuring unit.

The payload is lifted and lowered in the 'z' direction. Both the rail and the cart are capable of horizontal motion in the 'x' direction. The cart is capable of horizontal motion along the rail in the 'y' direction. Therefore the payload attached to the end of the lift-line can move freely in 3 dimensions. The 3DCrane is driven by three DC motors. [1]

There are five identical encoders measuring five state variables: the cart co-ordinates on the horizontal plane, the lift-line length, and two deviation angles of the payload. These encoders together with the specialized mechanical solution create a unique measurement unit.

The 3DCrane control system is a perfect tool for research and teaching at technical universities in the field of automatic control and mechatronic systems. 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.

2.2 Theory

2.2.1 Basic Crane System

Crane characteristic is similar as a simple pendulum characteristic. With the movement of the crane or a gust of wind on the crane, the payload will start swinging or oscillating. The system is in an equilibrium state when the weight of the mass is balanced by the tension of the spring. If the system is displaced from the equilibrium, there is a net restoring force on the mass, tending to bring it back to equilibrium. However, in moving the mass back to the equilibrium position, it has acquired momentum which keeps it moving beyond that position, establishing a new restoring force, now in the opposite sense and this time due to gravity.

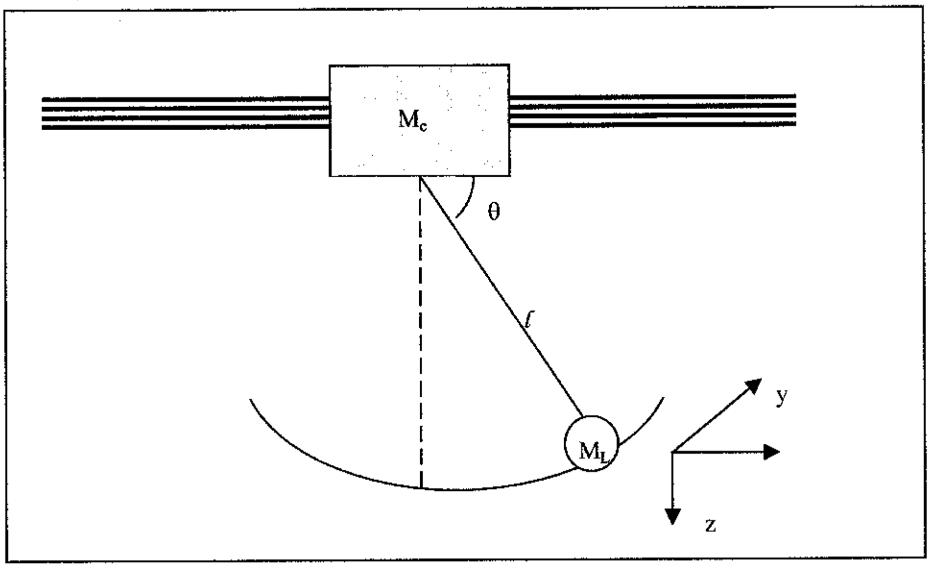


Figure 2 Crane Diagram

Derived Crane Control System

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

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

Define the state variables as;

$X_1 = \theta$

$X_2 = \dot{\theta}$

$X_3 = x$

$X_4 = \dot{x}$

Redefine the state variable with Crane Control System (for state space representation)

$$\dot{x_1} = x_2$$

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

$$\dot{x_3} = x_4$$

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

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

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

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

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

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

$$d = M_C$$

Table 1: List of Parameters Values

Parameter	Values	Description
M_c	7 kg	Mass of the cart and moving rail
M_L	0.5kg	Mass of the load
l	0.35 m	Length of cable
g	$9.81ms^{-1}$	Gravitational force

2.2.2 PID Controller

The Controller compares a measured value from a process with a reference set point value. The difference (or "error" signal) is then used to calculate a new value for a manipulatable input to the process that brings the process' measured value back to its desired set point. Unlike simpler control algorithms, the PID controller can adjust process outputs based on the history and rate of change of the error signal, which gives more accurate and stable control. (It can be shown mathematically that a PID loop will produce accurate, stable control in cases where a simple proportional control would either have a steady-state). PID controllers do not require advanced mathematics to design and can be easily adjusted (or "tuned") to the desired application, unlike more complicated control algorithms based on optimal control theory. [2]

Open loop

Open loop system is a system that does not monitor its output nor correct for disturbance. This method is simple to implement but cannot suppress swing motion caused by external disturbance. The disadvantage of open loop system is mainly because of its sensitivity to disturbances and inability to correct for these disturbances. [3]

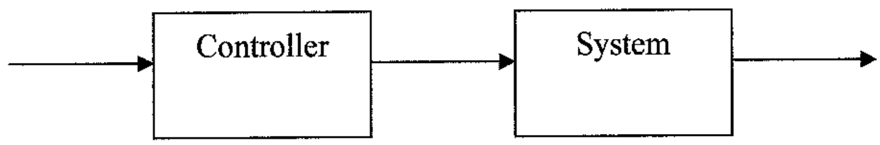


Figure 3 Open Loop System

Closed Loop

Closed loop system is a system that monitors its output and correct for disturbance. It is characterized by feedback paths from output. This system compensated for disturbance by measuring the output response, feeding that measurement back through a feedback path and comparing that response to the input at the summing junction. This will provide the ability to eliminate existing swing motion and rejects disturbances at the cost of extra sensor. [3]

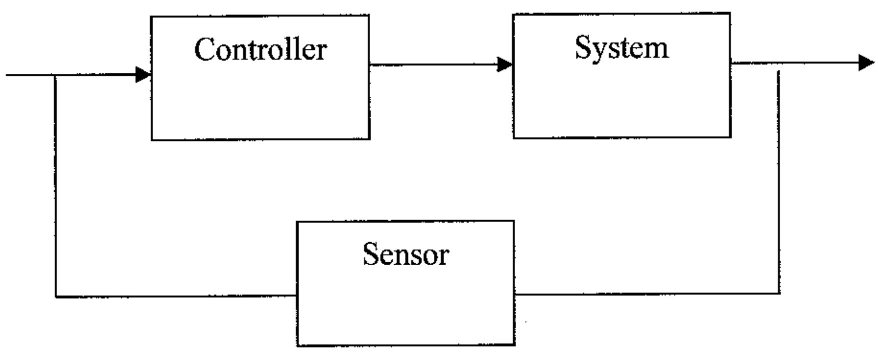


Figure 4 Closed Loop System

Table 2: Relationship of PID with Rise Time, Overshoot, Settling Time and SS Error

Parameter	Rise Time	Overshoot	Settling Time	SS Error
K_p	↓	↑	Small Change	↓
K_i	↓	↑	↑	Eliminated
K_d	Small Change	↓	↓	Small Change

Proportional Control (P)

The desired output of a closed loop system is known as the reference signal or the set point signal. The controller will use the error, or difference between the reference signal and the measured output signal Proportional control is used to make controller action to be proportional to the size of error signal

Integral Control (I)

Integral control is used when the system required the controller action to correct for any steady and continuing offset from desired reference signal. Integral overcomes the shortcoming of proportional control by eliminating offset without the use of excessively large controller gain.

Derivative Control (D)

Derivative control makes the controller use the rate of change of the error signal in the control action.

PID Control

Proportional mode of the integral mode removes the offset and give steady state values same as the input set value. The addition of the derivative mode enables the system to rise more rapidly to steady state value. PID is used when rapid and large disturbance may occur. Derivative mode takes care of rapid changes and I mode the large offset resulting from the large disturbance.

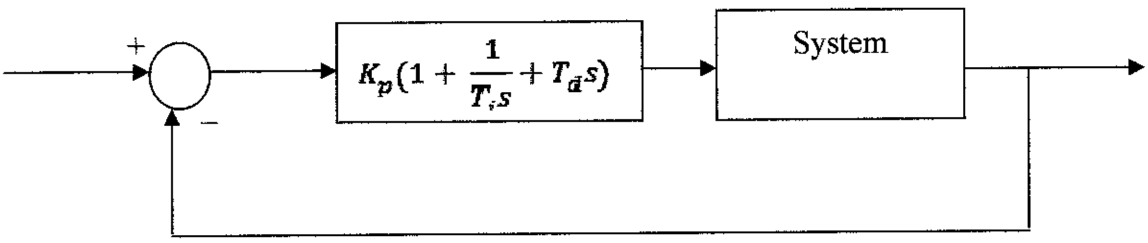


Figure 5 PID Control of the System

2.2.2.1 Tuning Using Ziegler Method

First method

The first method applies if the response to the step input exhibits an S-shaped Curve. Such step-response curve may be generated experimentally from the dynamic simulation of the plant. [11]

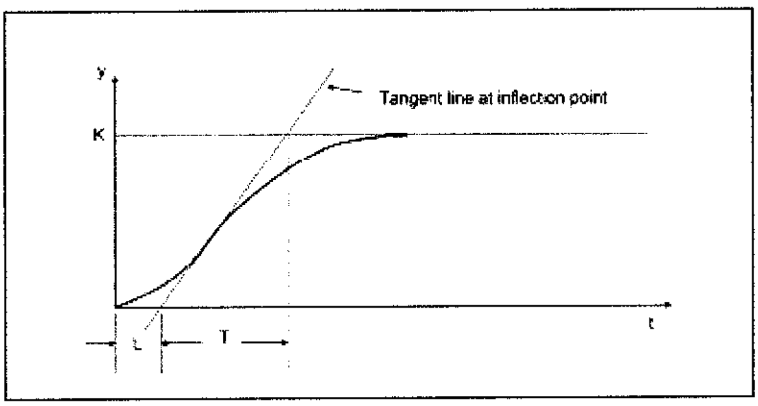


Figure 6 S-Shape Response Curve

Table 3: Ziegler-Nichols Tuning Rule based on Step Response of the Plant

Type of Controller	Kp	Ti	Td
P	T/L	inf	0
PI	0.9 T/L	L/0.3	0
PID	1.2 T/L	2 L	0.5 L

Second method

In the second method, the system is connected as figure 8 where Ti is set to infinity and Td is set to be 0. By only using the proportional gain, the gain is increased from 0 to a critical value, K_{cr}, at which the output exhibits sustained oscillation. [11]

Table 4: Ziegler-Nichols Tuning Rule based on Critical Gain, Kcr, and Critical Period, Pcr

Type of Controller	Kp	Ti	Td
P	$0.5K_{cr}$	inf	0
PI	$0.45K_{cr}$	$P_{cr}/1.2$	0
PID	$0.6K_{cr}$	$0.5P_{cr}$	$0.125P_{cr}$

2.2.3 Fuzzy Logic Controller

The Fuzzy Logic Controller (FLC) are configure as the block diagram below. The FLC consist of 3 stages which is the Fuzzification, Rule Base and Defuzzification.

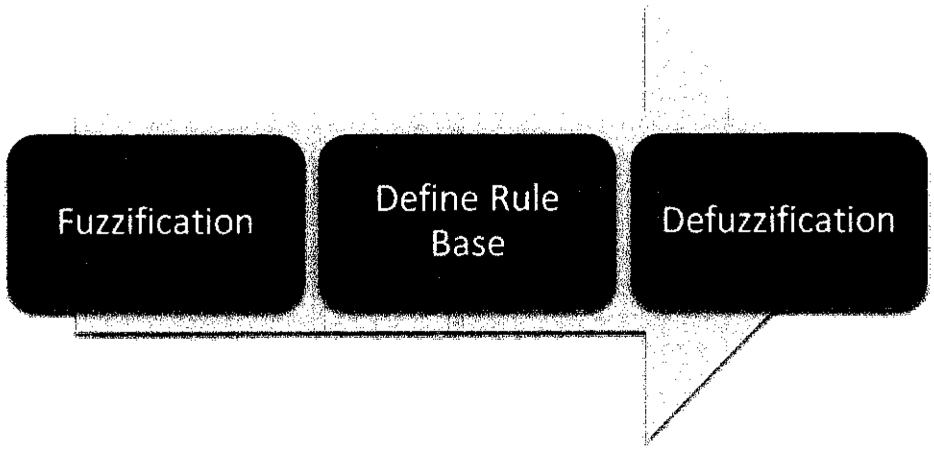


Figure 7 Fuzzy Logic Controller Stages

2.2.3.1 Fuzzification

In the Fuzzification stage, the input data is converted into degrees of Membership Functions for the antecedents (IF) and the consequences (Then). Membership Functions (Figure 4) generalize the indication functions which represent the degree of truth. The degree of truth in the membership function is based on the system limitation.

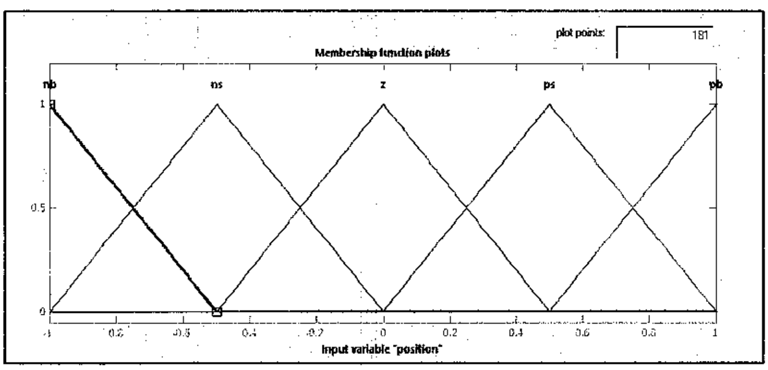


Figure 8 Membership Function

2.2.3.2 Define Rule Base

The Rule Base is where the inputs Membership Function match with all the condition of rules. Rule Base of the FLC usually done in If -Then Rules. If -Then Rule statement are used to formulate the condition statement by comparing the input to get the output.

" If x is A and y is B, then z is C "

Where A, B and C are the fuzzy sets of the universe of discourse X, Y and Z.

2.2.3.3 Defuzzification

The last stage is the Defuzzification where the results of Membership Functions are processed to producing a quantifiable result in fuzzy logic. 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 covert the data in membership function to a data that compatible with the system.

CHAPTER 3
METHODOLOGY

3.1 Procedure Identification

All steps and procedures to be taken in carrying out this project have to be clarified step by step. This methodology section will briefly show the pre-determined track of accomplishing the project. The project flows are as the flow chart below:

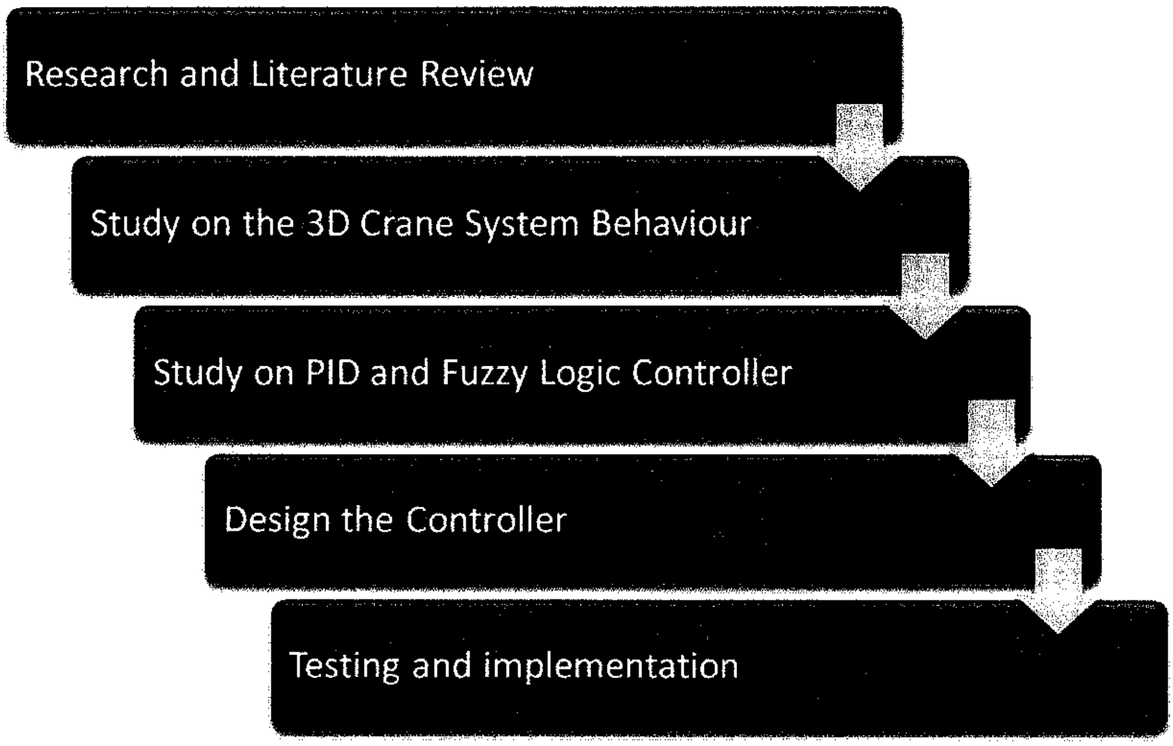


Figure 9 Work Flow Chart

3.1.1 Research and Literature Review

The Work Flow Chart (Figure 9) shows the projects full work flow. The first three block is done in the first part of the project which in the FYP 1. The project started by doing some research on the anti-sway controller. Few related journals and documentations from international seminars and conferences are taken as a reference to get a basic and general idea in starting the project.

3.1.2 3D Crane System Behavior

The project is continued by studying the 3D Crane Model itself. The 3D Crane Model is studied in details by trying the demos to identify and understand how the system works. After that, the basic knowledge of control system is used to design the controller.

After deriving the crane system (Chapter 2), the system is tested by simulating the derive system in SIMULINK software (Figure 10).

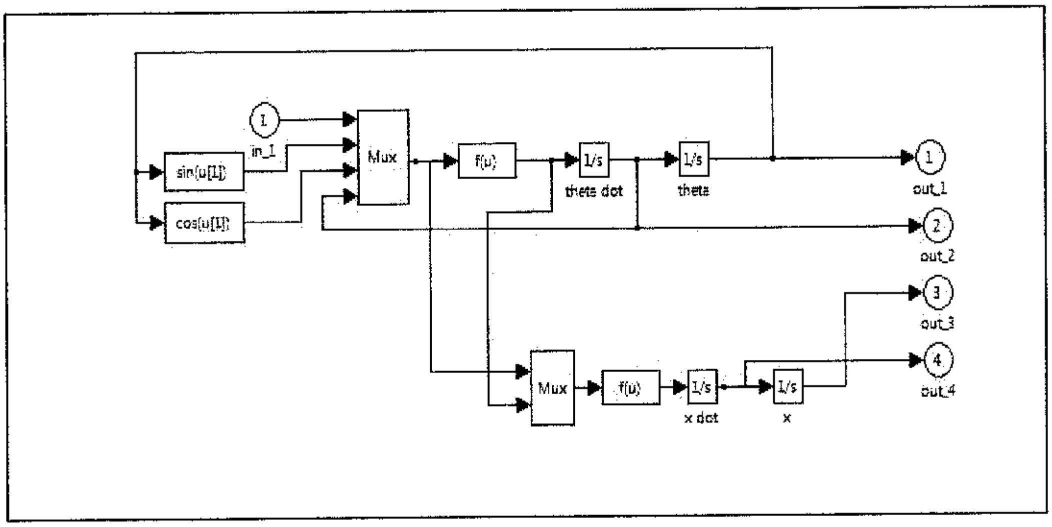


Figure 10 SIMULINK Model of the Crane

A SIMULINK Model is designed referring to the control system derived in chapter 2. The input of the Crane SIMULINK System is force which is represented by square wave generated by a signal generator model. The output of the system is represented by out_1, out_2, out_3 and out_4 which represented sway angle, velocity of the sway angle, position and also velocity of the crane respectively.

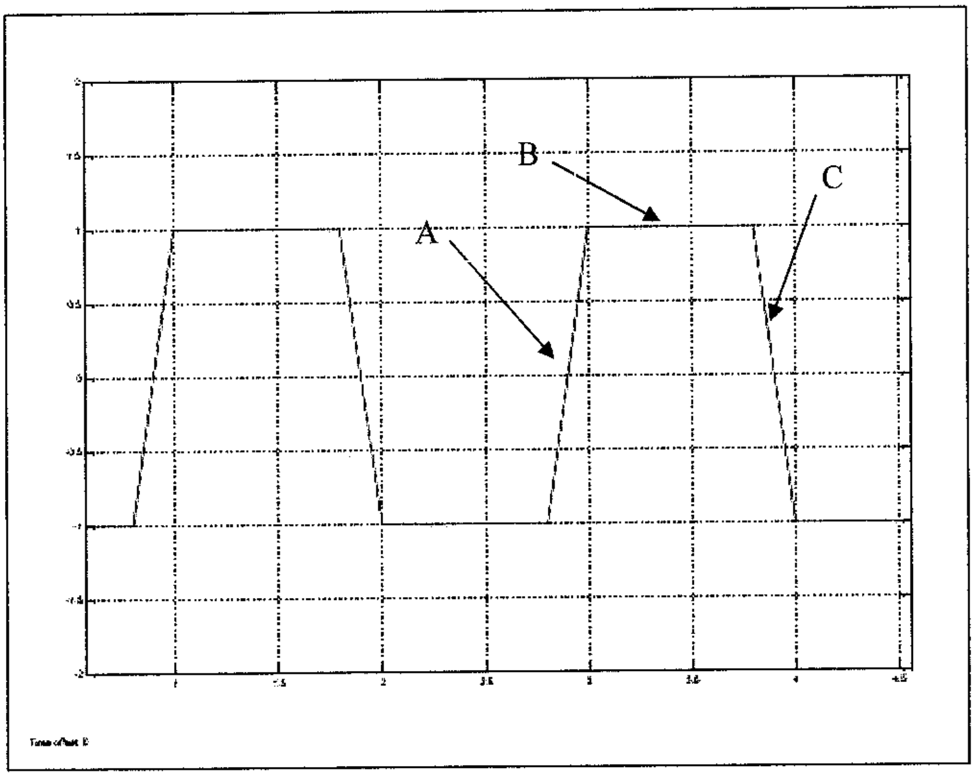


Figure 11 Input Signal from the Signal Generator

Referring to the Input Signal from Figure 11, 'A' is a condition where the crane is starting to accelerate. In condition 'B', the crane stops for few second and in condition 'C' is where the crane accelerate back in the opposite direction. One cycle of the signal will indicate the movement of the along the axis and back to the initial position.

3.1.3 PID Controller

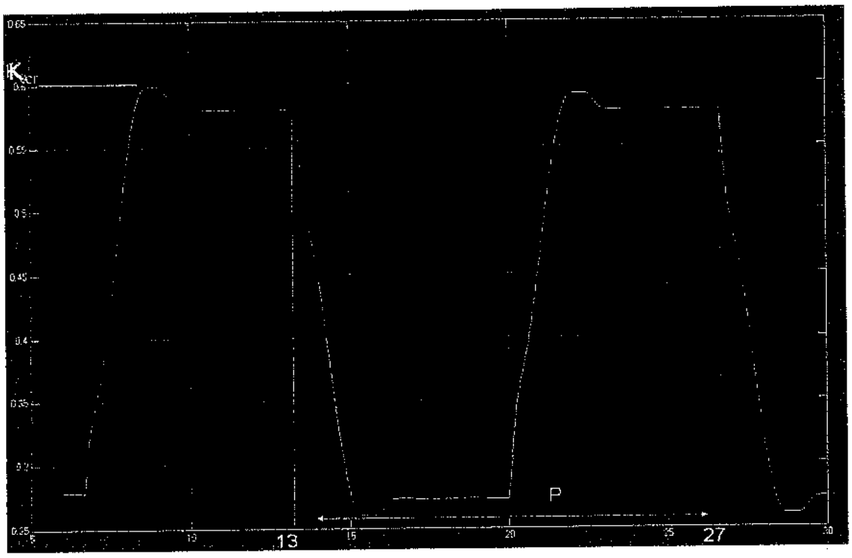


Figure 12 Output Signal (Position)

From the output signal obtained from the system (Figure 12), the value of Critical Gain (K_{cr}) and Period are obtained. Referring to Table 4, the value of Kp, Ti and Td are obtained as follows:

$K_{cr} = 0.6 - 0.28$

$= \underline{0.32}$

$P = 27 - 13$

$= \underline{7}$

$Kp = 0.6\ K_{cr}$

$= 0.6\ (0.32)$

$= \underline{0.2}$

Ti = 0.5 P

= 0.5 (7)

= <u>3.5</u>

Td = 0.125 P

= 0.125 (7)

= <u>0.875</u>

After obtaining the value of all the Proportional, Integral and Derivative parameters, the controller is tuned by slightly changing the values obtained and observe the output signal.

3.1.4 Fuzzy Logic Controller

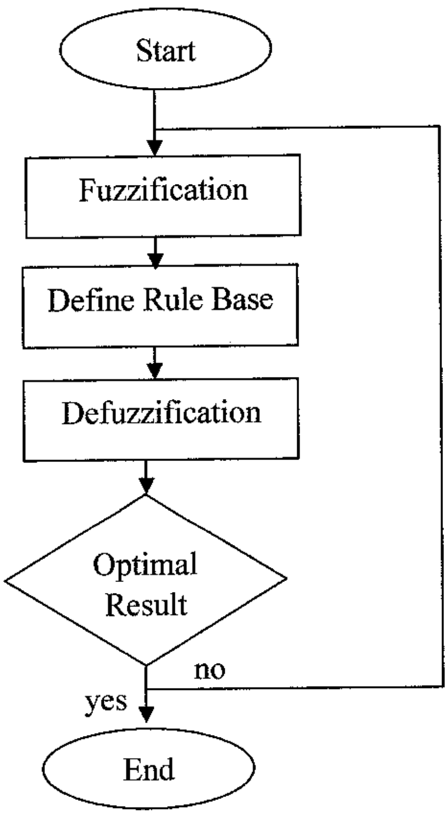


Figure 13 FLC Design Flowchart

The design process is started with defining the inputs and outputs of the controller. For this project, the inputs selected are the displacement (position error) and sway angle. As for the output, force is selected to supply to the input of the crane system which is in term of force.

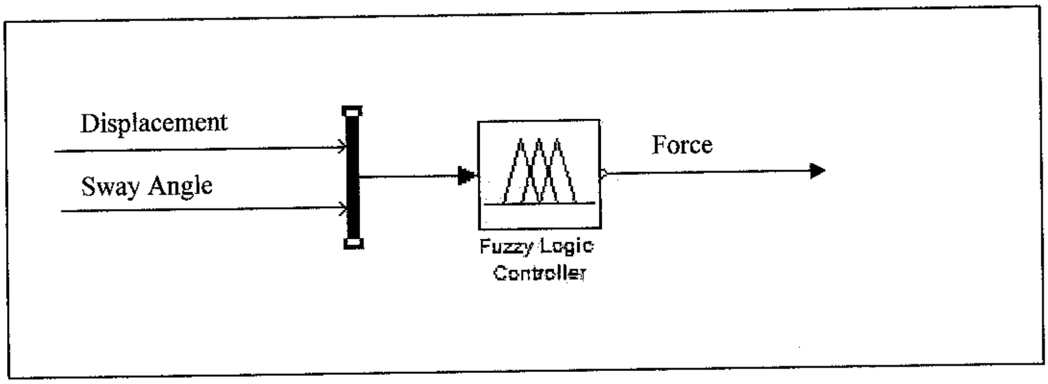


Figure 14 Inputs and Output of FLC

After defining the inputs and output, each inputs and output must be converted into degree of truth of membership functions (Fuzzification). For the displacement, the set point is set to be in range of -1 to 1 while the sway angle is set to be in range of -0.5 to 0.5.

The next step is to define the rule base from the relationship of the two inputs to obtain the desired output. The rule base is in If-Then Rule where if the input A is in condition 1, and input condition is in condition 2 then the output will be in condition 3. The rule is set in the Rule Editor (Figure 15) in MATLAB.

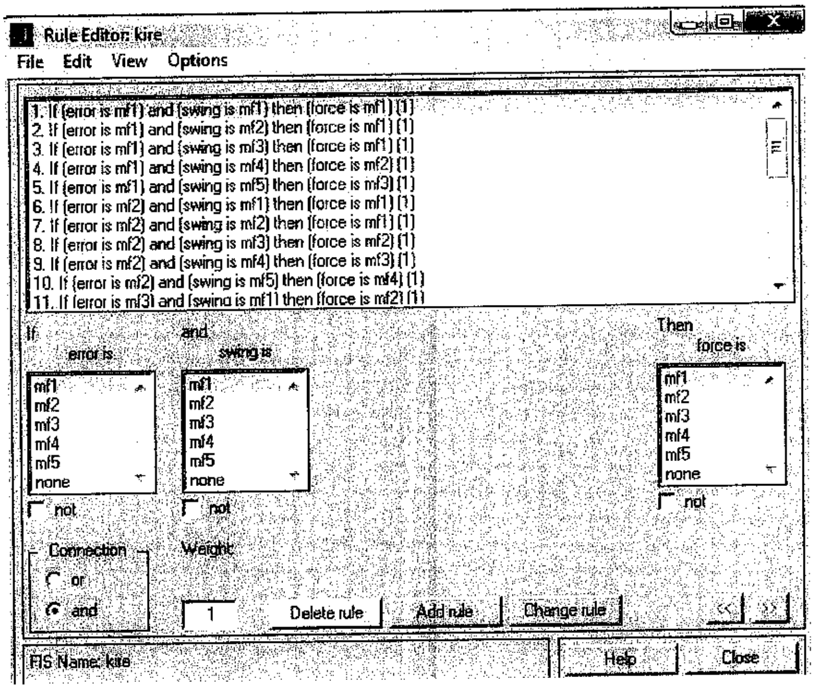


Figure 15 Rule Editor

Then the controller can be tested by observing the output of the system. Tuning and modification process can be done by adjusting the rule base of the controller and also the degree of truth in the membership functions.

3.2 Tools and Software

i. INTECO 3D Crane Model

INTECO 3D Crane is a laboratory model to simulate an industrial crane with nonlinear electromechanical system. This model is a real time model which is controlled by SIMULINK software via Real Time Window Target (RTWT)

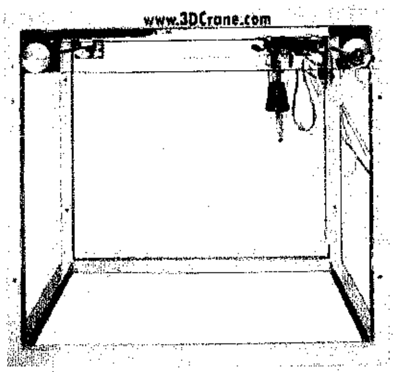


Figure 16 INTECO 3D Crane Model

ii. RT-DAC/PCI Card

The RT-DAC is type of PCI boards which contains A/D, D/A converters and digital I/O lines. All the I/O functions are realizable by hardware due to the on-board programmable logic device. The OMNI board equipped with an EEPROM memory is used to store the ready-to-use or user-defined logic. Once installed in the computer the board suits to a number of applications that require different types and numbers of I/O channels. [1]

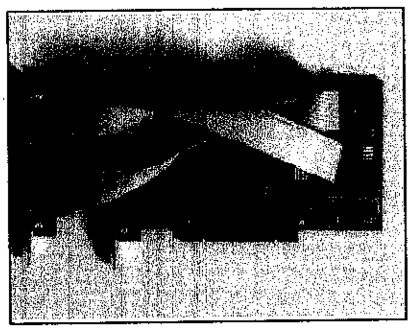


Figure 17 RT-DAC/PCI Card

iii. HEDM 5505/J06 Encoder

This encoder is used as sensors for detection of the crane's and load's motion. It is a high performance, low cost, two and three channel optical incremental encoders. These encoders emphasize high reliability, high resolution, and easy assembly. The encoder contains a lensed LED source, an integrated circuit with detectors and output circuitry, and a code wheel which rotates between the emitter and detector IC. [4]

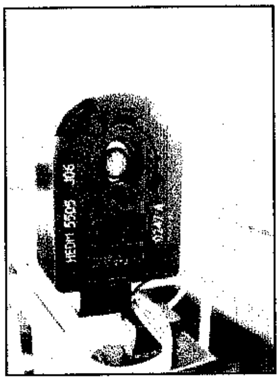
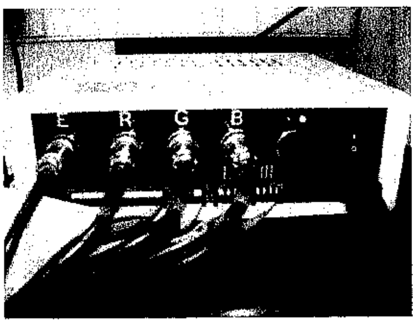


Figure 18 Encoder (Sensor for x, y and z Angle)

iv. Power Interface

Power interface is an interface between the RT-DAC/PCI Card with the 3D Crane Model. It supplies input voltage to the motor on the crane according to specified value that is set from the program.



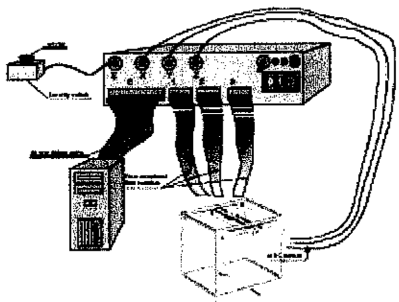


Figure 19 Power Interface

v. MATLAB/SIMULINK

MATLAB is an engineering software that has the ability to do matrix manipulation, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs in other languages. MATLAB/SIMULINK and Real Time Window Target (RTWT) is used to design and generate real time controller. It contains the library of ready to use real time controllers. This software will be used to simulate the controller to reduce the swing motion of the load.

CHAPTER 4
RESULT AND DISCUSSION

4.1 Fuzzy Logic Controller

Fuzzy Controller is said to have a better accuracy and precision in controlling nonlinear system. It also has the advantage to work with 2 subsystems. As for this project, the fuzzy logic is used to consider sway angle with respect to the position error of the system. Unlike conventional PID Controller, the each controller can only control one variable. So the fuzzy membership rule is set as Table 5 to relate the sway angle with the position error.

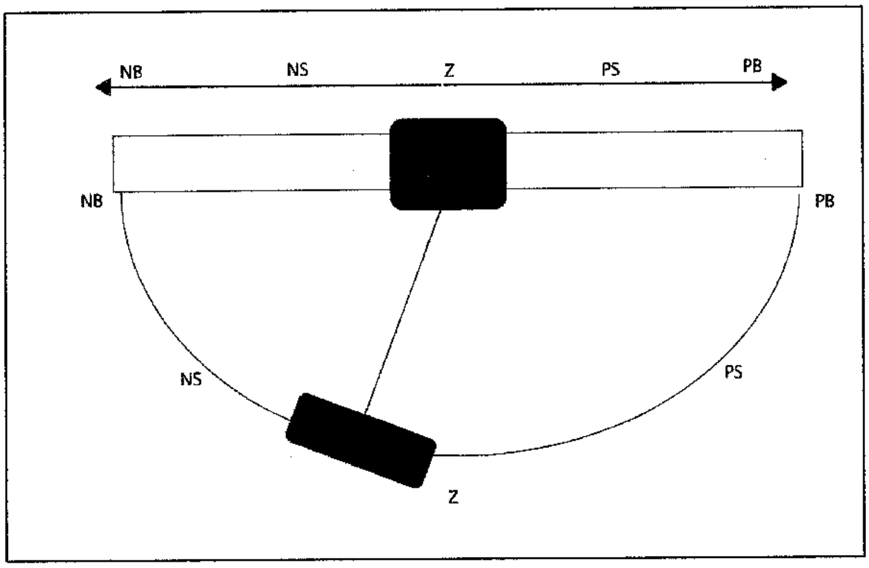


Figure 20 Crane Displacement and Angle Parameter

[14] James B. Dabney, Thomas L. Harman, *Mastering SIMULINK*, Pg 180-192 Prentice Hall, 2004

[15] Gillian Khinah, *Anti Swing Controller of 3D Crane*, Final Year Project Report, June 2006

[16] Hung T. Nguyen, Nadipuram R. Prasad, Carol L. Walker, Elbert A. Walker, *A First Course in FUZZY and NEURAL CONTROL*, Chapman & Hall/CRC, 2003

[17] Tae-Young Lee, Sang-Ryong Lee, *Anti-sway and Position 3D Control of The Nonlinear System using Fuzzy Algorithm*, International Journal of the Korean Society of Precision Engineering Vol 3, No 1, Jan 2002

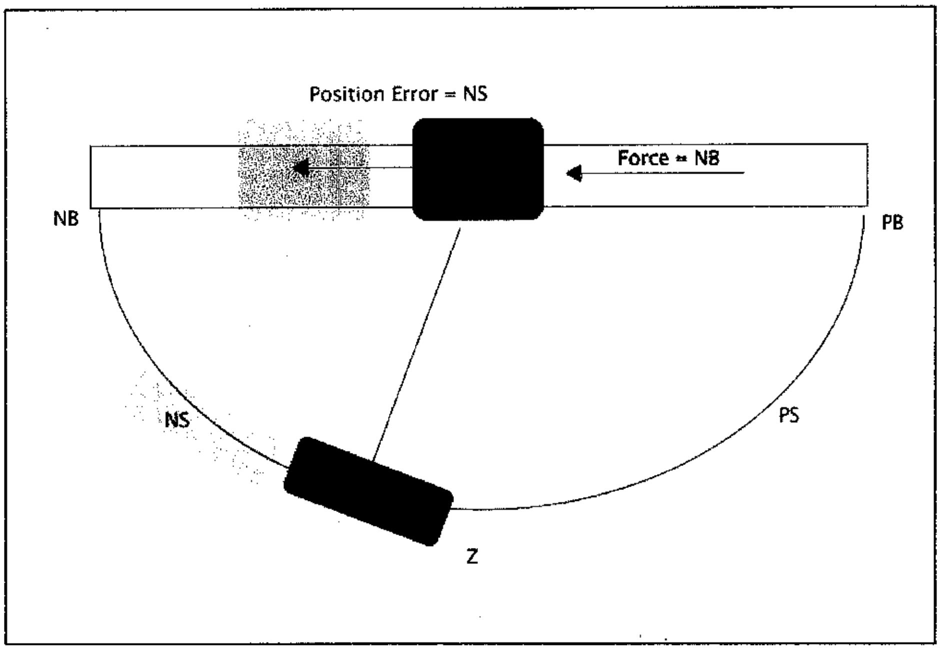


Figure 21 Diagram Representation of the Rule Relationship

4.2 SIMULINK Representation

4.2.1 Fuzzy Logic Controller

The Fuzzy Logic Controller was design in MATLAB using the FIS Editor. Inside this editor, the inputs variable, output variable and the rules are configured. The range of input values and output values is also configured in this FIS Editor under the Membership Functions Editor. The controller for this project is configured as figure below:

Table 5: Relationship between Position Error and Sway Error

		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

NB = Negative Big

NS = Negative Small

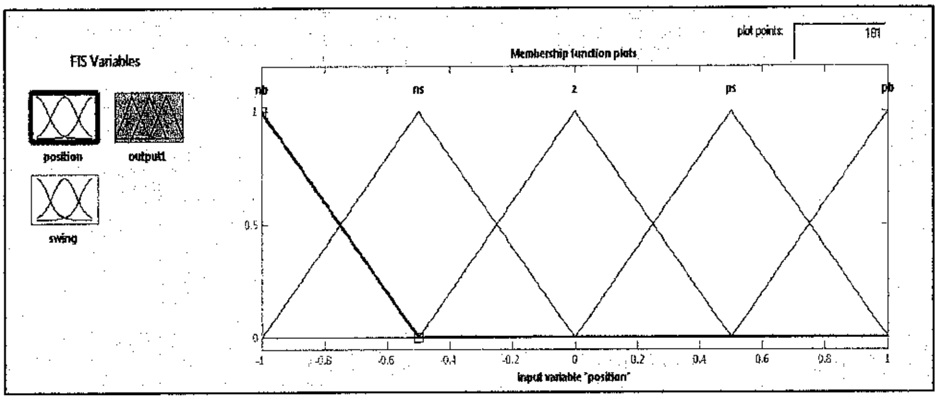
Z = Zero

PS = Positive Small

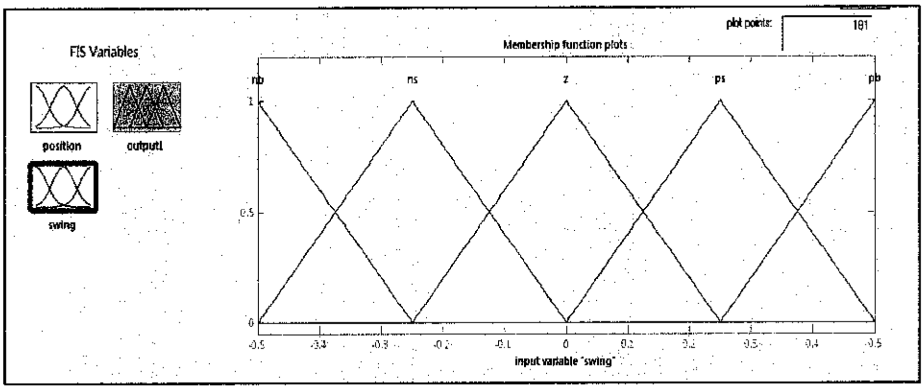
PB = Positive Big

The rule is defined using above linguistic quantification as a rule base. The rule base is the most important part in the controller. The optimization and effectiveness of the controller is depends on how the rule base is construct. For this project, the relationship between Position Error and Sway Error is set to eliminate one another for example:

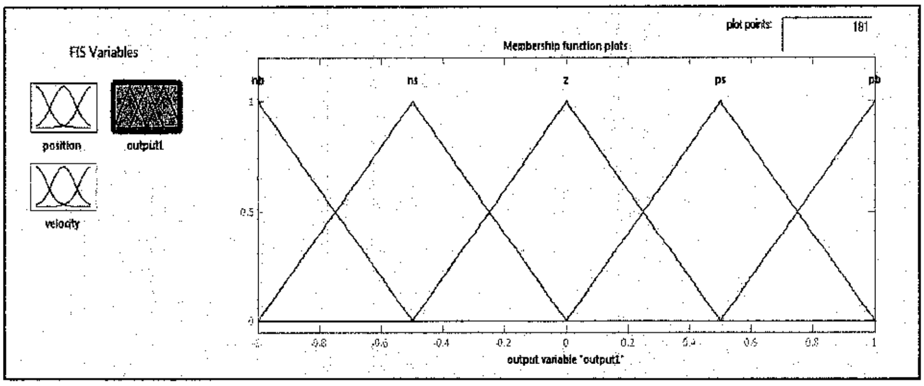
- **If** the error is NS **and** the sway angle is NS, **then** the force has to be applied is in NB so that the sway can be eliminated.



(a)



(b)



(c)

Figure 22 Membership Function

4.2.2 Overall System

From the derived Crane System and the designed Fuzzy Logic Controller, a simulation block is constructed in SIMULINK (MATLAB) to observe the output of the system. The simulation is constructed with 2 feedbacks that come from the output displacement and also the sway angle. The output displacement is compare with the input signal to obtain a position error. Then the position error is related with the output sway angle by using the Fuzzy Logic Controller to obtain value of force which becomes input to the crane system.

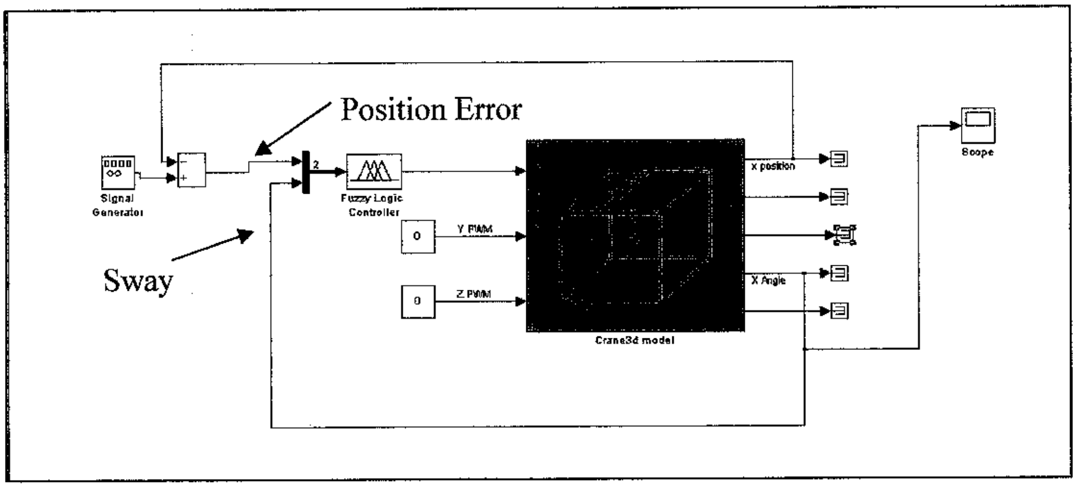


Figure 23 SIMULINK Diagram of the Crane System

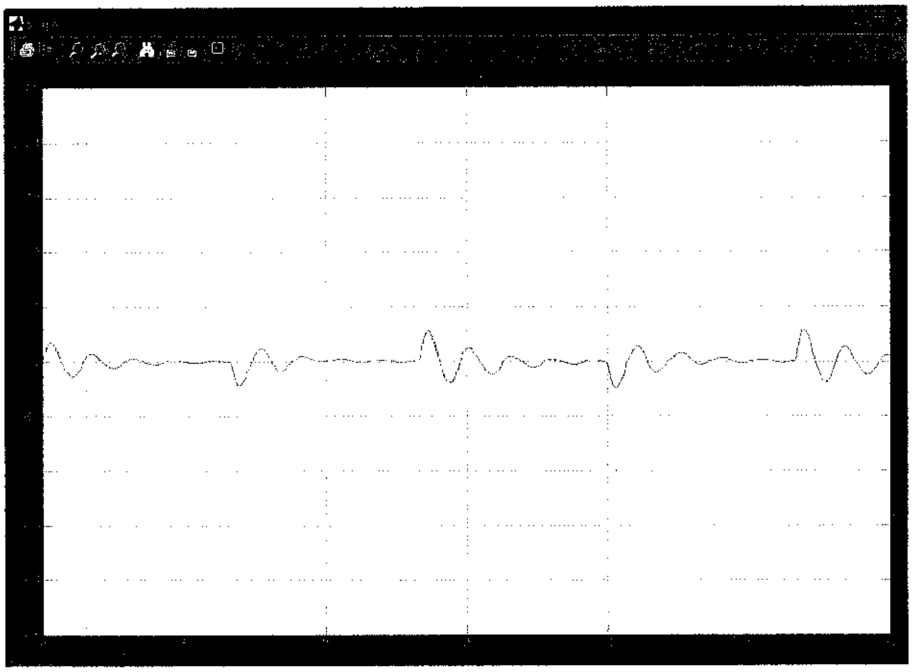


Figure 24 Sway Output Signal of the Crane System

4.3 Comparison between PID Controller and Fuzzy Logic Controller

A comparison is done between PID Controller with Fuzzy Logic Controller in terms of the out put sway angle. The PID calculation is done during the Final Year Project 1 and with result of output sway is compared to the output sway of Fuzzy Logic Controller.

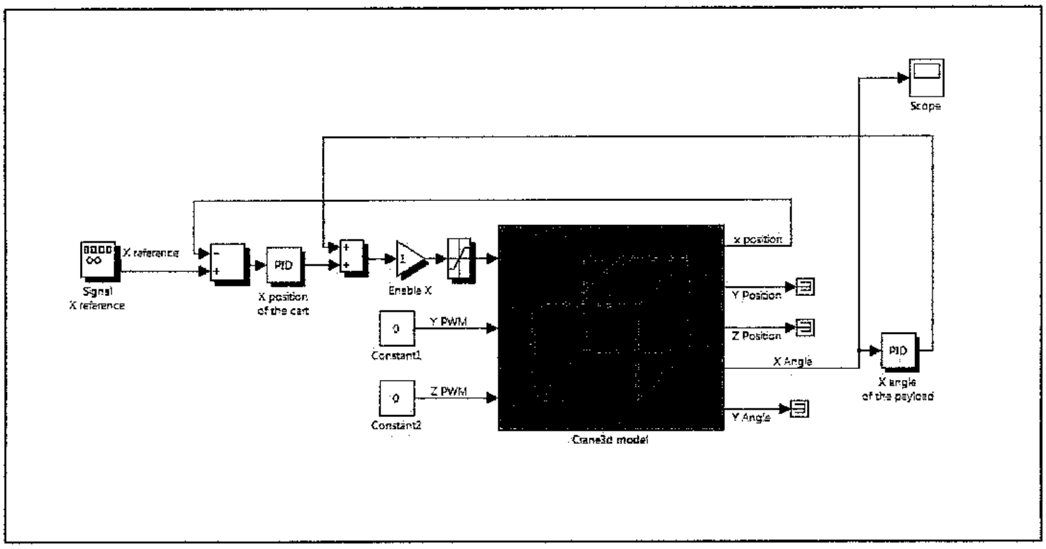


Figure 25 3D Crane system with PID Controller

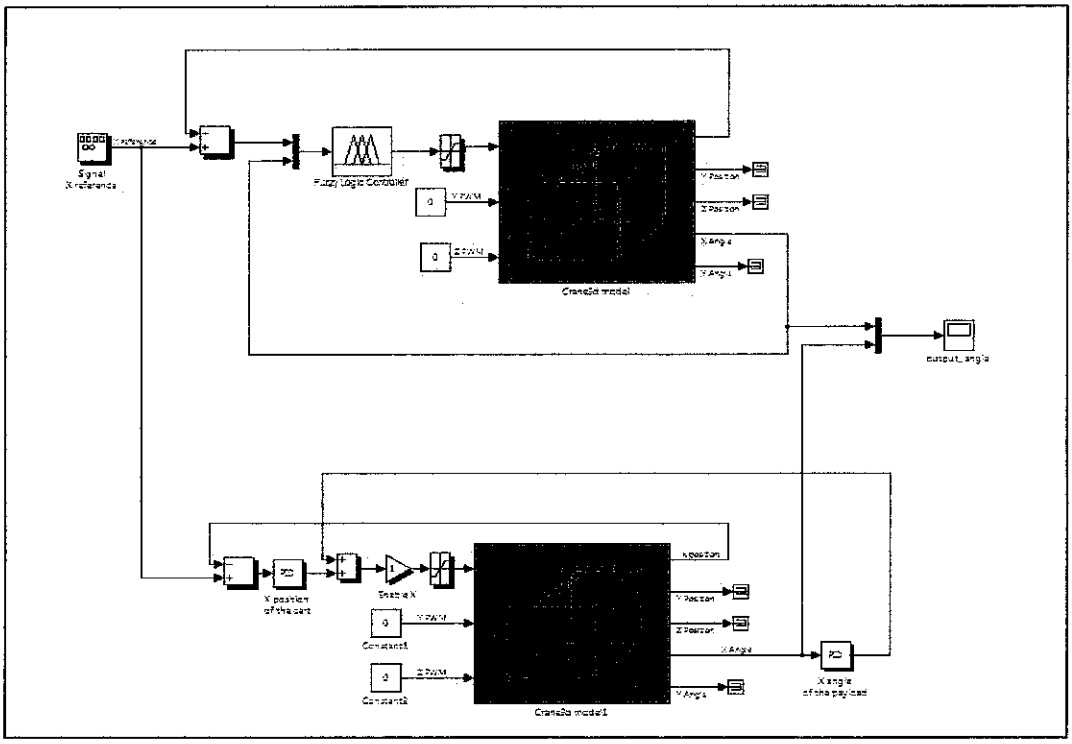


Figure 26 Comparison between PID Controller and Fuzzy Logic Controller

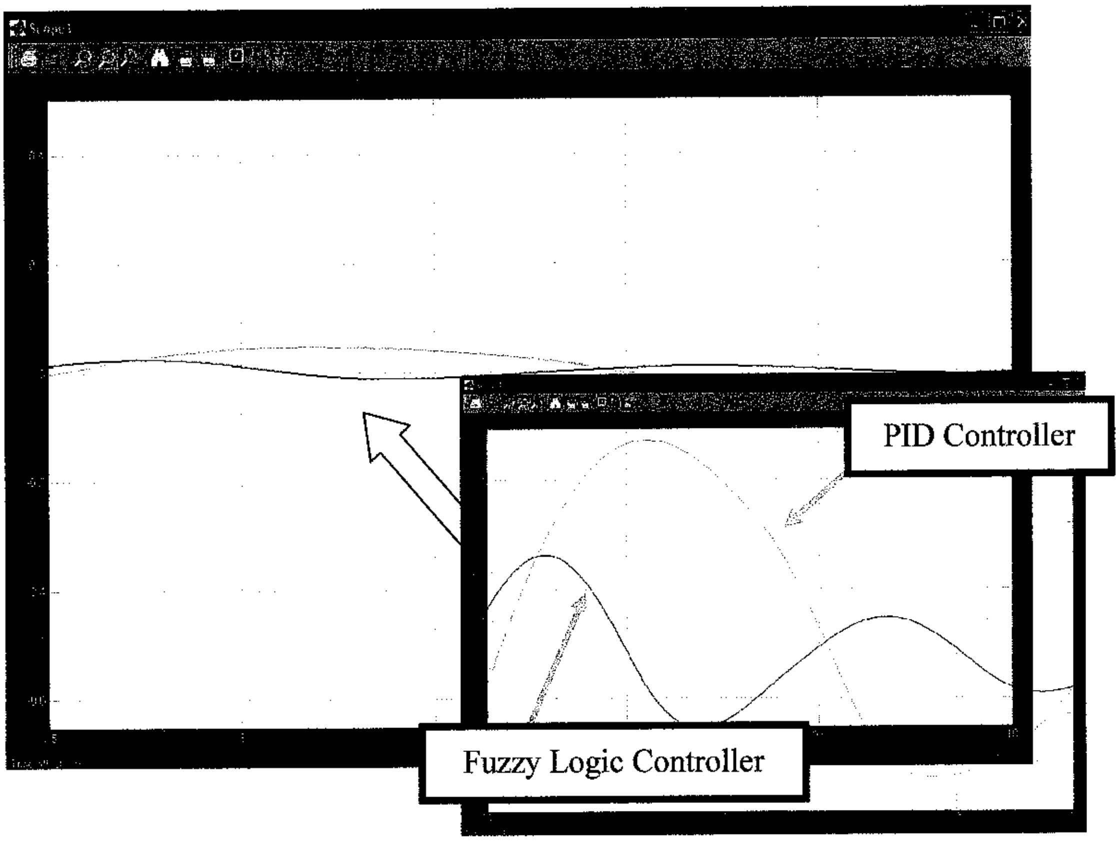


Figure 27 Comparison of PID Controller with Fuzzy Logic Controller (Sway Output Signal)

From the sway output signal, we can see that Fuzzy Logic Controller produce smaller sway angle compared to PID Controller. The outputs shows that the system oscillate within the range of -0.012 to 0.023 on Fuzzy logic Controller and -0.024 to 0.049 on PID Controller.

Furthermore, it required two PID Controller to control the position and angle (one PID controller each). Unlike Fuzzy Logic Controller, it only requires one controller to control the two variables.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

From the result, it is observed that Fuzzy Logic Controller is much better than PID Controller in reducing the swinging effect of the crane system. However, PID can be as good as Fuzzy Logic Controller if the controller is tuned properly. In advantage of using Fuzzy Logic Controller, it only requires one Fuzzy Logic Controller to control the displacement and sway angle compared to PID Controller where it needs two controllers to control the displacement and also sway angle of the crane.

The result can be enhanced by proper adjustment and enhancement of the Membership Functions of the output. This will make the result more accurate compare to lesser Membership Functions in the output. More combination can be tested and compare to obtain much smother output.

All the results are obtained from simulation of the system. Implementation on the system is still on going since there are some technical problems in the model sensor and also programming to connect the model to SIMULINK.

Theoretically and by simulation, it can be concluded that the Fuzzy Logic Controller is better than conventional PID controller in handling nonlinear systems

5.2 Recommendation

To make the project more presentable, a Graphical User Interface (GUI) will be design for the user to key in the desire position. This will prove that the controllers are workable in any position specified by the user.

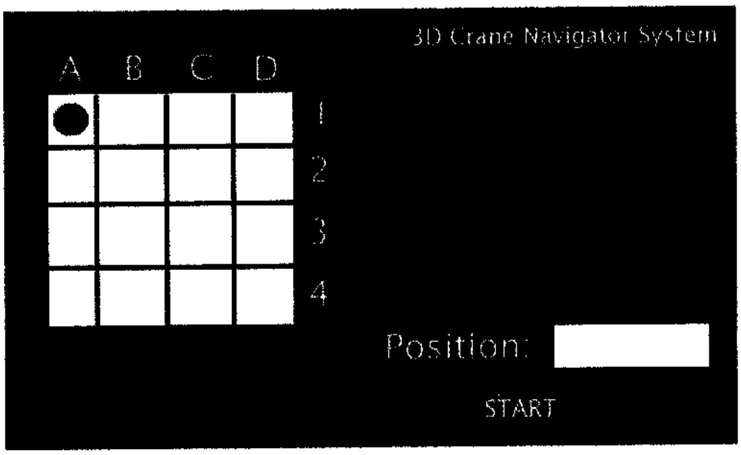
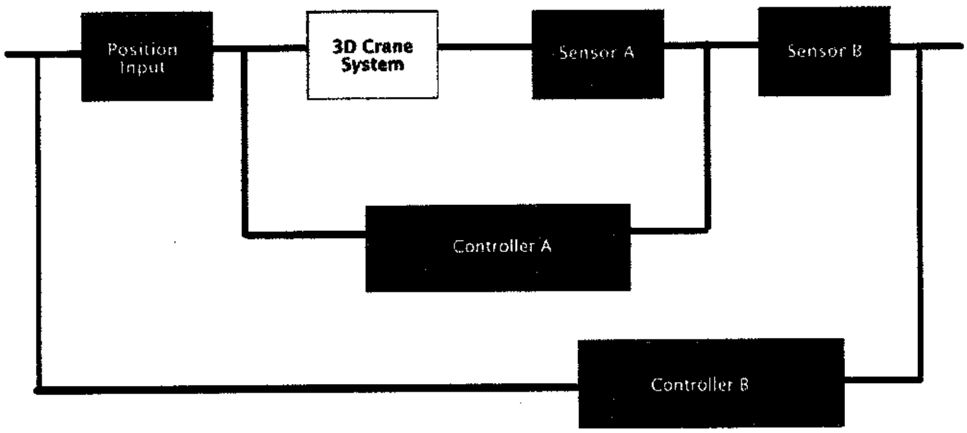


Figure 28 GUI for 3D Crane Navigator system

An enhancement such as Figure 28 can be done to make the project more realistic where the user can key in desired position and view the movement of the crane. In addition to the GUI for Navigator System, the crane also can be connected to another sensor to detect obstacle and find another route to the desired position.



Sensor A = Angle Sensor
Sensor B = Obstacle Sensor
Controller A = Anti-swing Controller
Controller B = Obstacle Avoider Controller

Figure 29 New System Configuration with Obstacle Avoider Controller

REFERENCE

[1] INTECO Ltd.,*3D Crane*, July 2006, http://www.3DCrane.com

[2] http:// www.wikipedia.com, *(control system)*

[3] Norman S. Nise, *Control System Engineering*, United States: Wiley International Edition, 2004

[4] Agilent Technology, *HEDM 5505/J06 Encoder Datasheet*, Jan 17 2002.

[5] F.Omar, F.Karray, F. Basir, L.Yu, *Autonomous Overhead Crane System Using a Fuzzy Logic Controller*, 20 July 2002, Journal of Vibration and Control, Waterloo Canada

[6] Zhenyu Yang, *Reliable Fuzzy Control of a Gantry Crane System*, Spring 2005, Aalborg University Esbjerg.

[7] Matsushita Communication Shizuoka R&D Labs. Co. Ltd, *Anti Swing Control of the Container Crane by Fuzzy Control,* 1993, Setagayuku, Tokyo.

[8] Dr. M. Necip Sahinkaya, "Root Locus Design", Presentation Slide, University of Bath, 1995

[9] M.Mahfouf, I.Ismail, G.Zissis, *Neural-Fuzzy based 3D Anti-Sway Modeling and Control Design for Overhead Cranes*, The 2001 International Conference on Artificial Intelligence, Las Vegas, Nevada, US

[10] Kevin M. Passino, Stephen Yurkovich, *Fuzzy Control*, Addison Wesley Longman Inc.1998

[11] Katsuhiko Ogata, *Modern Control Engineering*, Pg 682-685, Fourth Edition, International Edition, Prentice Hall

[12] Leonid Reznik, *Fuzzy Controllers*, Newnes, 1997

[13] Maizura Ismail, *Optimization of PID Controller For Inverted Pendulum System Using Fuzzy Logic Controller*, Final Year Project Report, Dec 2005

Appendices

Appendix A: Timeline of Final Year Project

	Final Year Project 1						Final Year Project 2					
Month	1	2	3	4	5	6	1	2	3	4	5	6
Research												
Study on 3D Crane System												
Study on Controller												
Designing												
Testing and Implementations												

Research

Researches on the background of the 3D Crane are done in order to define the scope of work and identify problem for this project.

Study on 3D Crane System

This stage is the most crucial stage because in order to use the 3D Crane Model, user need to understand and know how to handle the system, know the capability and limitation of the system.

Study on Controller

During this stage, different types of controller are studied and the suitable controller is chosen. The fundamental and basic knowledge on the controller must be acquired in order to design the controller.

Designing

The selected controllers are design according to the system behavior this stage. For this project, PID Controller and Fuzzy Controller are selected.

Testing and Implementation

After designing the controller, the controllers are tested on the 3D Crane model. During this stage, a lot of problem developed. During the compilation of the controller and system, errors and warnings obtained. Therefore, all the errors and warning should be overcome to complete the project.

Appendix B: Complete Derivation of the System

Kinetic Energy of the Cart

$$T_1 = \frac{1}{2} M_c \dot{x}^2 \quad (4.1.1)$$

Kinetic Energy of Load

$$T_2 = \frac{1}{2} M_L \left(\dot{x} l^2 + \dot{y}^2 \right) \quad (4.1.2)$$

Where;

$$x_1 = x + l \sin\theta \qquad y_1 = l \cos\theta$$

$$\dot{x}_1 = \dot{x} + \left(l\dot{\theta} \right) \cos\theta \qquad \dot{y}_1 = -\left(l\dot{\theta} \right) \sin\theta$$

Moment of inertia

$$T_3 = \frac{1}{2} J_c \frac{\dot{x}^2}{r_c^2} \quad (4.1.3)$$

Where

$$x_1 = r_c \theta$$

Total Kinetic Energy

$T = T_1 + T_2 + T_3$

$$T = \frac{1}{2} M_c \dot{x}^2 + \frac{1}{2} M_L \left(\dot{x} l^2 + \dot{y}^2 \right) + \frac{1}{2} J_c \frac{\dot{x}^2}{r_c^2} \quad (4.1.4)$$

$$T = \frac{1}{2} M_c \dot{x}^2 + \frac{1}{2} M_L \left(\left(\dot{x} + l\dot{\theta}\cos\theta \right)^2 + \left(-l\dot{\theta}\sin\theta \right)^2 \right) + \frac{1}{2} J_c \frac{\dot{x}^2}{r_c^2} \quad (4.1.4)$$

$$T = \frac{1}{2} M_c \dot{x}^2 + \frac{1}{2} M_L \left(\dot{x}^2 + 2\dot{x} l \dot{\theta} \cos\theta + (l\dot{\theta})^2 \cos^2\theta + (l\dot{\theta})^2 \sin^2\theta \right) + \frac{1}{2} J_c \frac{\dot{x}^2}{r_c^2}$$

(4.1.5)

Total Potential Energy

(4.1.6)

$U = -M_L g y = M_L g l \cos\theta$

Lagrangian Equation

L =Total kinetic Energy + Total Potential Energy

$$L = \frac{1}{2}M_c \dot{x}^2 + \frac{1}{2}M_L\left(\dot{x}^2 + 2\dot{x}l\dot{\theta}\cos\theta + (l\dot{\theta})^2\cos^2\theta + (l\dot{\theta})^2\sin^2\theta\right) + \frac{1}{2}J_c\frac{\dot{x}^2}{r_c^2} + \mathrm{M_L gl}\cos\theta \qquad (4.1.7)$$

Only force in x axis which applied by motor is acting on the cart and swing dynamic. The θ coordinate of the system does not have any external force that directly acts upon it.

Applying the Langrangian Equation,

$$\frac{d}{dt}\left[\frac{\partial L}{\partial \dot{x}}\right] - \left[\frac{\partial L}{\partial x}\right] = F \qquad (4.1.8)$$

$$\frac{d}{dt}\left[\frac{\partial L}{\partial \dot{\theta}}\right] - \left[\frac{\partial L}{\partial \theta}\right] = 0 \qquad (4.1.9)$$

Substituting (4.1.7) into (4.1.8)

$$\frac{\partial L}{\partial \dot{x}} = M_c\,\dot{x} + M_L\,\dot{x} + M_L l\dot{\theta}\cos\theta + \frac{\dot{x}}{r_c^2} \qquad (4.1.10)$$

$$\frac{d}{dt}\left[\frac{\partial L}{\partial \dot{x}}\right] = M_c\,\ddot{x} + M_L\,\ddot{x} + M_L l\dot{\theta}\dot{\theta}\sin\theta + M_L l\ddot{\theta}\cos\theta + \frac{\ddot{x}}{r_c^2} \qquad (4.1.10)$$

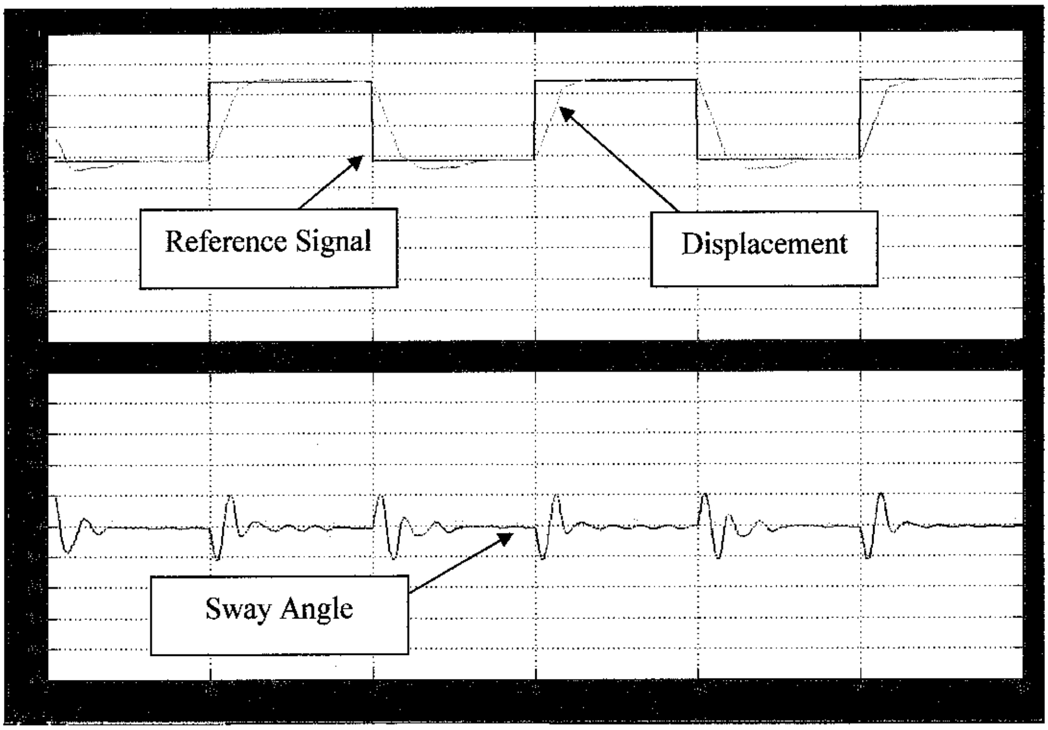
$$\frac{\partial L}{\partial x} = 0 \qquad (4.1.11)$$

$$\mathrm{F} = M_c\ddot{x} + M_L\ddot{x} + M_L l\dot{\theta}\dot{\theta}\sin\theta + M_L l\ddot{\theta}\cos\theta + \frac{\ddot{x}}{r_c^2} \qquad (4.1.12)$$

In order to linearize the equation, assume that sinθ ≈ θ, sinθ² ≈ 0, cosθ ≈0 and θ̇² ≈ 0 (This assumption can be made for small θ).

Appendix C: Output Signal of Displacement vs. Reference and Sway Angle

PID Controller



Fuzzy Logic Controller