3D CRANE

By

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FINAL PROJECT REPORT

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

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CERTIFICATION OF APPROVAL

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Approved:

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

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

May 2013

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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(Nurul Huda Saffry Binti Mohamad Jemuri)

ABSTRACT

Nowadays, the crane systems are used widely. It is important to have a crane especially for heavy industry as it will helps people to carry heavy loads from one place to another place safely. This report is to present the research plan for Feedback Linearization Control of a 3D Crane. The objective of the project is to design and implement feedback linearization for 3D crane motion controller. The 3D crane model operates like the actual crane used in real life. The swing motion of the load in actual crane is the same as the pendulum in 3D crane. The load swing creating by the movement of the load caused the system to become unstable. Feedback Linearization is implementing in the model so that the whole system can become a linear system. Modeling the 3D crane dynamic is important for simulating the model on MATLAB to design a suitable controller. To increase the crane reliability, the standard controller will be implemented including PID and state feedback. Finally, the Feedback Linearization will be added and the performance of the sway angle produced using PID and Feedback Linearization will be observed.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my deepest gratitude to God, for giving me strength and guidance to overcome the challenges and obstacles along finishing this final year project.

Not to forget, to my Supervisor, Assoc. Prof. Dr. Mohd Noh Karsiti for giving me support and encouragement towards the project completion. Besides, special thanks to Mr. Azhar, the technician, for his guidance in the technical work. Without his cooperation, the setup for the hardware might be difficult.

Last but not least, thanks to my fellow friends who are always believed in my strength in completing the whole works. Without their moral support, it would be impossible for me to understand and complete the project.

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LIST OF ABBREVIATIONS

PID – Propotinal-Integral-Derivative

CHAPTER 1
INTRODUCTION

1.1 Background of study

3D crane model is an example of industrial crane system. In real life, the crane can either be operated manually by crane operators or by radio type control. Basically a crane equipped with a hoist ropes, hook, and sheaves. There are various types of cranes used such as tower crane, gantry crane and truck mounted crane. As 3D crane model move in 3 different ways, the behavior of the overhead crane might have similarities with the model.

Mostly, the crane systems are used in factories that required moving a heavy load. The cranes are also often used at the port, and construction site. As the crane involve with the heavy industry, it is important to have a crane that give the shortest path when transferring the load, use minimize energy and minimize sway.

The load in 3D crane system is move not only at x-axis and y-axis. The motion involve with the z-axis resulting load swing to the system. If the payload swing angle of the system is not in an appropriate angle, the crane can get severe damage.

1.2 Problem Statement

3D crane system moves the load in three directional ways which are x, y and z direction. As it involve with different direction, the movement of the load will creating some payload swing affecting from internal energy or outside disturbance. It is known that the system is in a nonlinear system due to the sway motion. When the system is in nonlinear state, it is difficult to design a suitable controller. Most of the controller being implement when the system is in linear state. In order to make the system can be operated in a linear system, some control methodologies need to be taken into account.

As we want to move the load to the desired position with the shortest path when transferring, use minimize energy and minimize sway angle, a better controller need to be implemented to the system.

1.3 Objective

From the problem mentioned above, the main objective of this project is to design and implement feedback linearization control for 3D crane motion controller to reduce the sway angle produce by the crane.

1.4 Scope of study

In this project, the main topic that need further studies are:

1. Feedback Linearization Control
2. Nonlinear System
3. 3D Crane Model
4. MATLAB and Simulink
5. PID Controller

CHAPTER 2
LITERATURE REVIEW

This chapter contains information about crane system and critical analysis of literature review that has been published related to the project title.

2.1 3D Crane

2.1.1 History of crane

Crane system is one of the important systems needed in heavy industries. In order to place the load in a very short time with the limited human power, a crane system is implementing to make the work easier. Basically a crane is equipped wire rope or chain that is used to carry the load.

In the old days, crane system was powered from human strength. The problem arises as when moving the crane manually, a lot of sway motion produced. It also required a lot of energy to carry the load.

Therefore as the time passes, the modern crane system has been created. The electric motor installed in the system make the process of transferring the load become easier. More loads can be transfer when using a modern crane system.

There are some matters need to be taken when designing the crane. A crane must be able to lift the load at certain high with appropriate mass. Many researchers have developed program to control the crane oscillation. Singhose et all [6] mention that the control methods allow human operators to rapidly move the payloads with little residual oscillation.

2.1.2 3D Crane Model

3D crane is one of the models used to portray the actual crane system in the industries. As stated in the 3D Crane Manual [2], the model consists of a payload hanging on a pendulum-like lift-line wound by a motor mounted on a cart. The motor used to move the load after receiving command from system controlled by PC.

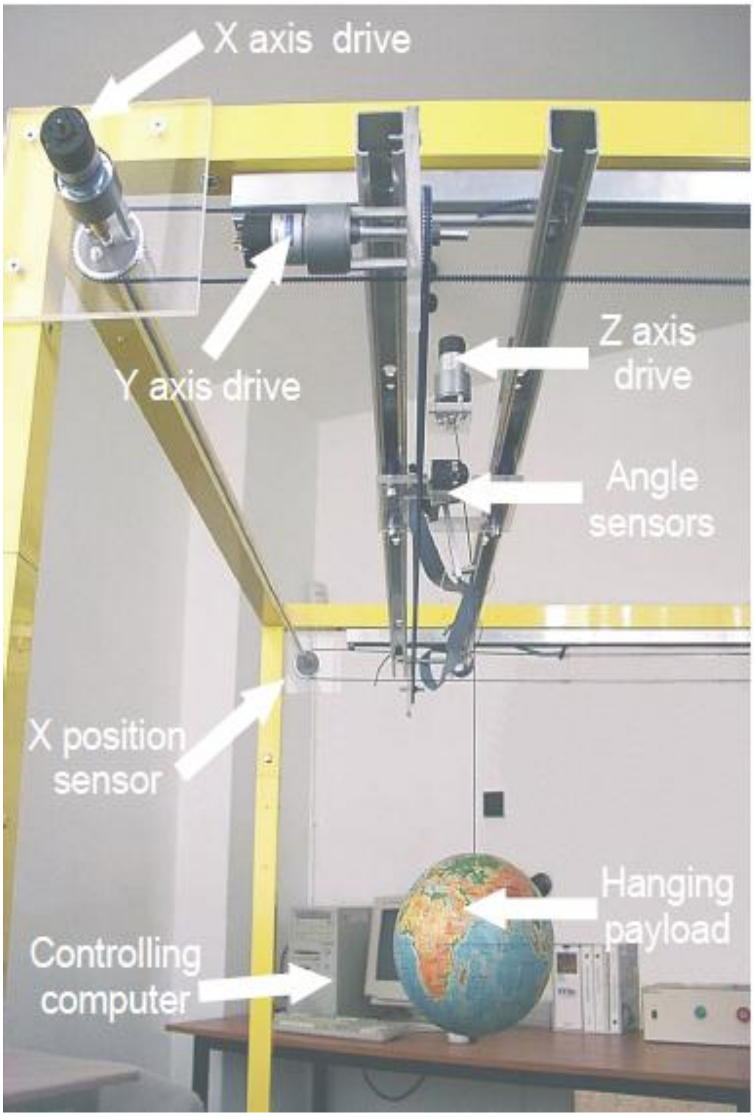

Figure 1 3D Crane Model [2]

There are some basic parts that play the important role in this project. X-axis drive, Y-axis drive and Z-axis drive consist of motor that can support the load and drive the crane to 3 directional ways. The X-axis and Y-axis drive is important to move the load in X and Y direction while Z-drive is useful to lift the load in the Z direction

The crane also consists with X-position sensor, Y-position sensor and Z-position sensor. The X and Y sensor help to measure the x and y position of a main hook while Z sensor helps to measure the long of the rope. The angle sensor is another sensor that can help to measure the degree of angle in x and y direction.

As mentioned before, crane system is used to move the load in a short time with minimize energy and sway. When placing the load at the desirable place, the system expected the load to be at appropriate position. However, due to the nonlinear payload swing motion, the required movement of the load by using crane system will encounter severe problem.

Some of the controllers were design to overcome this problem. For instance, anti sway control is one of the solutions provided. In order to achieve high productivity and having safety precaution with the crane, most of the operators will manually control the movement of the load. However this technique still poses some human error when conducting the controller.

2.2 PID Controller

PID Controller stands for Proportional Integral Derivative Controller. PID Controller is commonly used controller design in the industry. More than 95% of the control loops nowadays are from PID type controller [9]. The time-domain algorithm of the PID controller is shown below.

$$u(t) = K\left(e(t) + \frac{1}{T_i}\int_0^t e(\tau)d\tau + T_d\frac{de(t)}{dt}\right)$$

where *y* is measured process variable, *r* is the reference variable, *u* is the control signal and *e* is the control error. The algorithm for the PID involves with three different term called proportional, integral and derivative denoted by P, I and D. The controller parameters are proportional gain *K*, integral time *Ti* and derivative time *Td*. The three parameters can be interpreted as control actions based on the past, the present and the future [9].

The controller can provide different control action by adjusting the tuning of the parameters in the system. The effectiveness of the controller can be observed from the reaction curve resulted from the tuning in term of the overshoot, the settling time of the system and the responsiveness of the controller to an error.

2.3 Feedback Linearization

There is lot of control methodologies has been implementing to the nonlinear control system in the crane. Various techniques research has been done for stabilization of nonlinear systems. Feedback linearization control is one of a promising technique that can be used for highly nonlinear system such as the 3D crane system. It is an approach to nonlinear control design that can turn nonlinear system to linear system. By selecting the appropriate feedback strategy, the overall system can become a linear system, allowing for the use of the widely available design tool for linear system. This technique has become one of the interested topics to be discussed for future research in recent year [1].

One of the techniques used to control a nonlinear mechanical system is 'Jacobian Linearization' [3]. However this technique can only be used at certain situation involving an operating point. Feedback linearization process is said to be the effective solution for nonlinear system related to the crane system [4]. Many researchers have used feedback linearization in the nonlinear system. H.K. Khalil et al [5] developed a Robust Feedback Linearization using high–gain observer and has been proved through experiment. He reported that the observer can be stabilized by implement feedback linearization followed by a linear control design.

In [7] partial feedback linearization technique has been used in the nonlinear controller design for 3D crane. The simulation result shows the effectiveness of the controller to make the system stabilize. Tuan et al [4] also reported the partial feedback linearization controller can stabilizes the system states in 3D overhead Crane.

Therefore, implementation of feedback linearization to the 3D crane system will help to reduce the sway motion of the load.

2.4 Dynamic Modeling of Crane

Appendix A shows the list of 3D cranes coordinate and forces. The mathematical modeling of 3D crane can be derived using Lagrange's multiplier associated to geometric constrain between generalized coordinates. When modeling the crane system, some assumption is made as follow [7]:

- The mass of the payload and the crane cart is assumed to be connected by a mass-less, rigid link.
- The mass of the payload is assumed to be concentrated at a point and the value of this mass and the overall cart mass are known.
- The hinged joint, where the payload link connects to the crane cart is assumed to be frictionless
- The control input to the system is the mechanical force applied directly to the crane cart.

CHAPTER 3
METHODOLOGY

3.1 Research Methodology

This process takes place when collecting information about the whole project. A lot of reading and research based on the project title is done in order to get the precise information. The sources of information might be from e-journals, books and trusted website from internet.

The research was done based on selected area:

- 3D crane model
- Implementation of feedback linearization
- How to control 3D crane using MATLAB
- PID controller

3.2 Project Activities

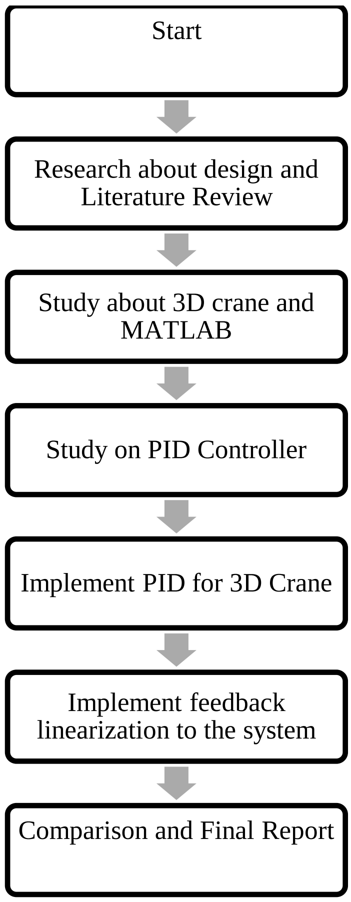

Figure 2 Project FLow

3.2.1 3D Crane Behaviour

In this project, it is important to know how to use MATLAB/Simulink to control the crane. With the assist from the technician and the manual of 3D crane, the author learned how the software being used in controlling the load. As the project dealing with a very sensitive sensor attached to the load, some basic test will be done before further experiment continues related to the motion through x-axis, y-axis and z-axis.

3.3 Project Duration

Details/Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Selection of project title	■	■												
Preliminary research			■	■	■									
Submission of extended proposal						■								
Further study of controller for crane						■	■	■						
VIVA									■					
Testing with PID Controller										■	■	■	■	
Preparation of Interim Draft Report										■	■	■	■	
Submission of Interim Final Report														■

Table 1 Gantt Chart for FYP 1

Details/Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Redo the PID Controller	■	■												
Research on Feedback Controller			■											
Implement the Feedback Linearization				■	■	■	■							
Submission Progress Report							■	■	■					
Compare the performance										■				
Poster Exhibition											■	■		
Final Presentation													■	■
Submission of dissertation														■

Table 2 Gantt Chart for FYP 2

3.4 Key Milestone

At the end of the project, there is some outline need to be completed:

1. Manage to control 3D Crane Model using Matlab/Simulink
2. Understanding about feedback linearization
3. Implementing feedback linearization to 3D Crane Model

3.5 Tools

This project will involve with software and hardware. For the software, the tools needed are MATLAB/Simulink. This software through Real Time Window Target will help to build the program and send command to the motor and the whole 3D crane systems. In short, the software design created using MATLAB will be used and interface it to the 3D crane motion simulator. 3D crane model will act like a real crane used in the industry.

For hardware, the project will use Inteco 3D Crane Model [2]. The components are:

- Mechanical unit
- Motors : DC, 12V, PWM controlled
- 5 incremental encoders
- Interface and power supply units
- I/O RT-DAC/PCI Board

CHAPTER 4
RESULT AND DISCUSSION

The simulation is done with PID Controller first. PID controller is chosen as this is commonly used controller nowadays. Then feedback linearization will be impellent to the system.

4.1 PID Controller

Figure below shows the simulation used using PID Controller. By using different value for K in PID parameter the simulation is run to observe the stability of the system. Figure 4, 5 and 6 shows the system condition when different value of K used. The higher the value of K, the system will be unstable.

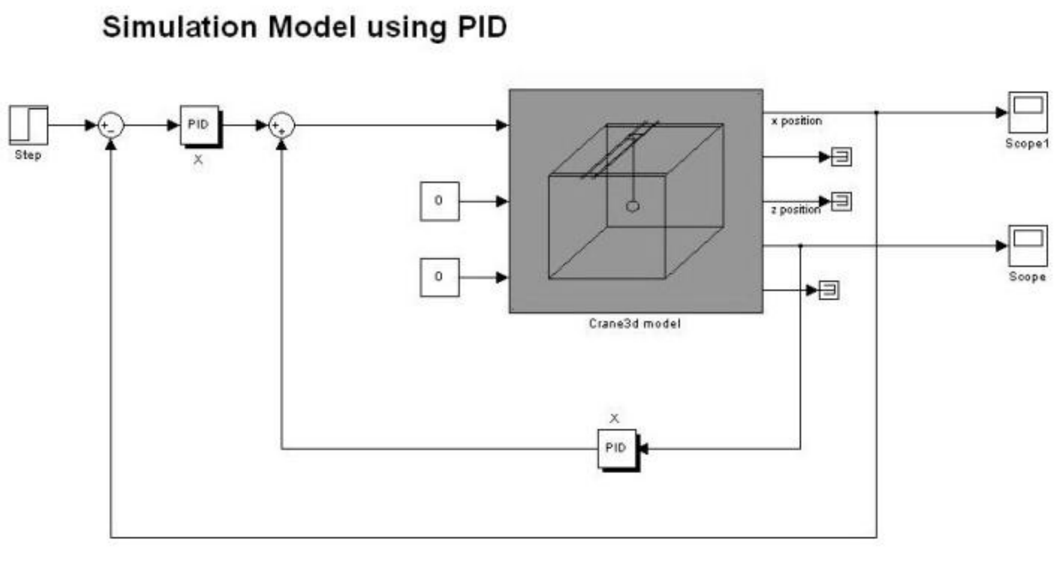

Figure 3 Simulation Model

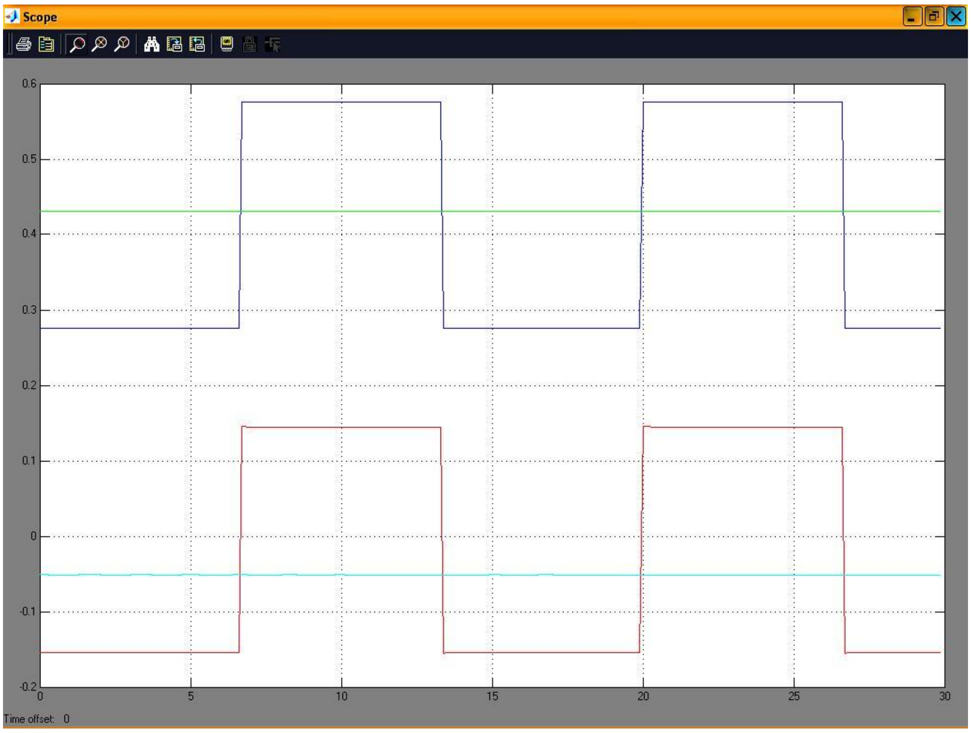

Figure 4 When K = 1

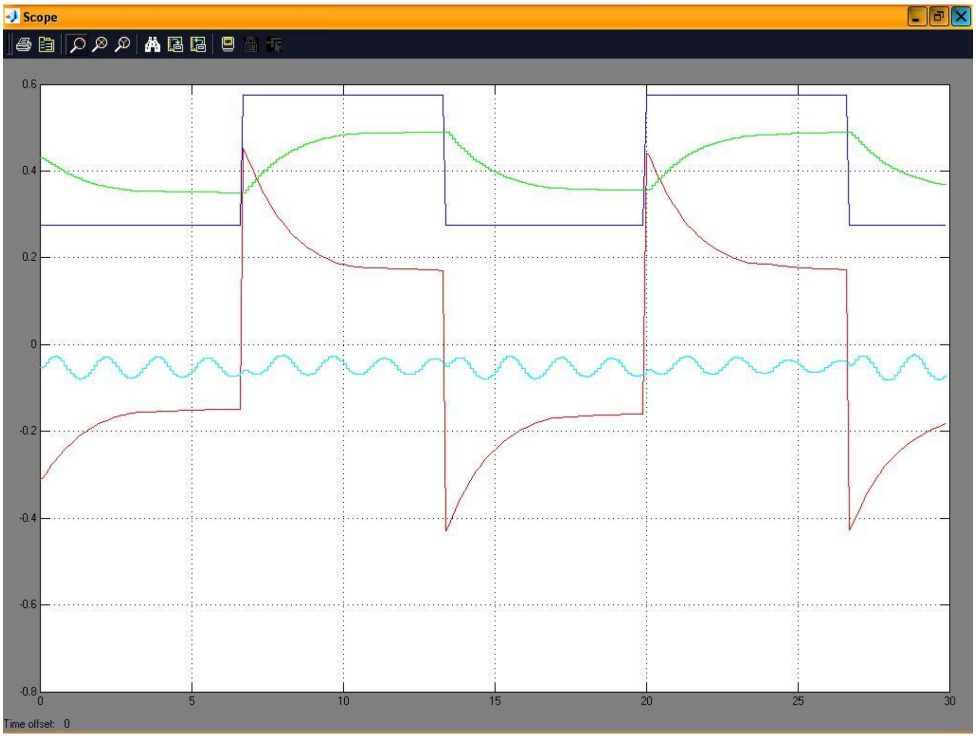

Figure 5 When K = 2

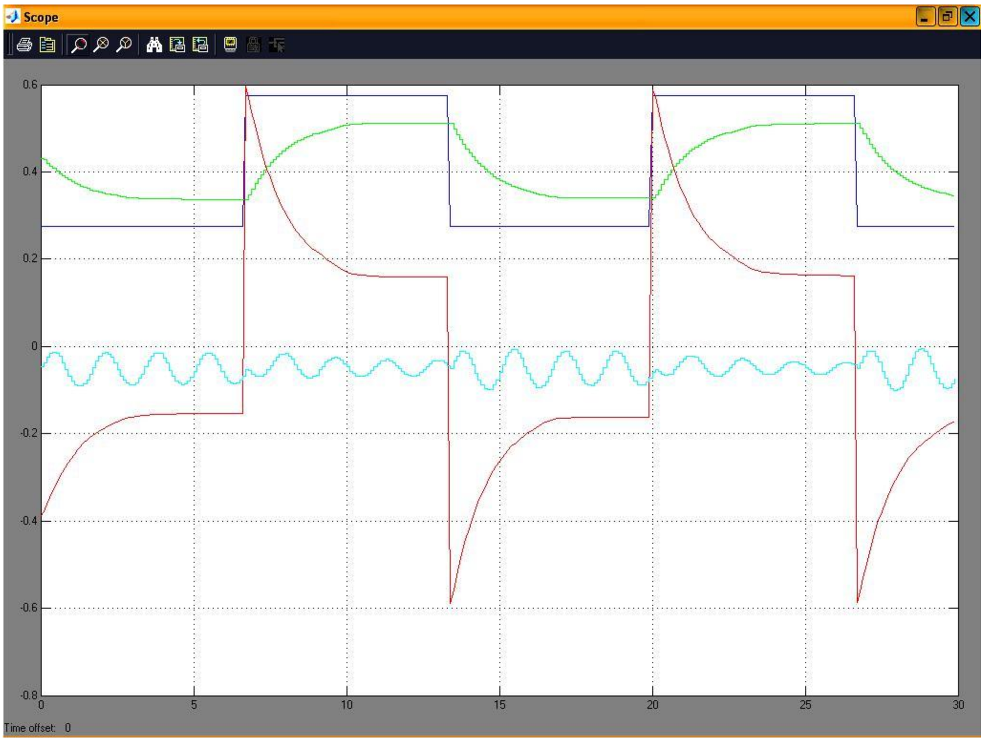

Figure 6 When K = 2.5

Then the value for the PID is determined by finding the ultimate gain and the ultimate period. As shown in Figure 7, the system having constant oscillation when the gain 2.2 is applied. The value of time for 3 oscillations is 5. Therefore ultimate period is equal to 1.67.

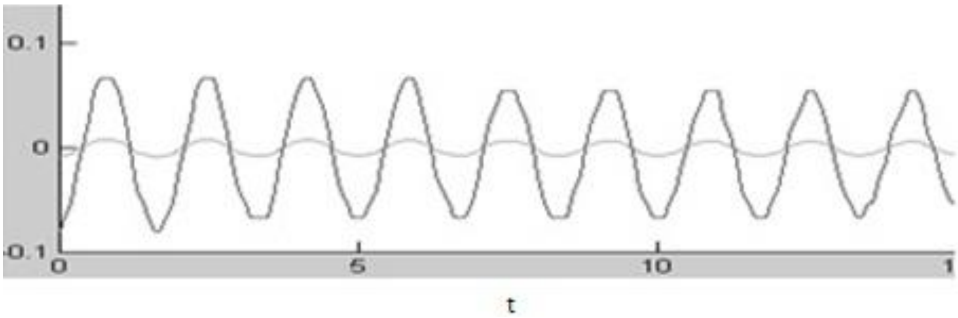

Figure 7 Constant Oscillation to find ultimate gain and ultimate period

After finding the value for ultimate gain and ultimate period, the value for P, PI and PID is calculated using Ziegler-Nichols Closed Loop Correlations. The result is tabulated in the table.

Control Mode	Kc	Ti	Td
P only	1.1	-	-
P + I	0.99	1.39	-
P + I + D	1.32	0.84	0.21

Table 3: Parameter obtained for PID simulation

Then the performance of the PID controller will be observed by using the parameter calculated using Ziegler-Nichols Closed Loop Correlation.

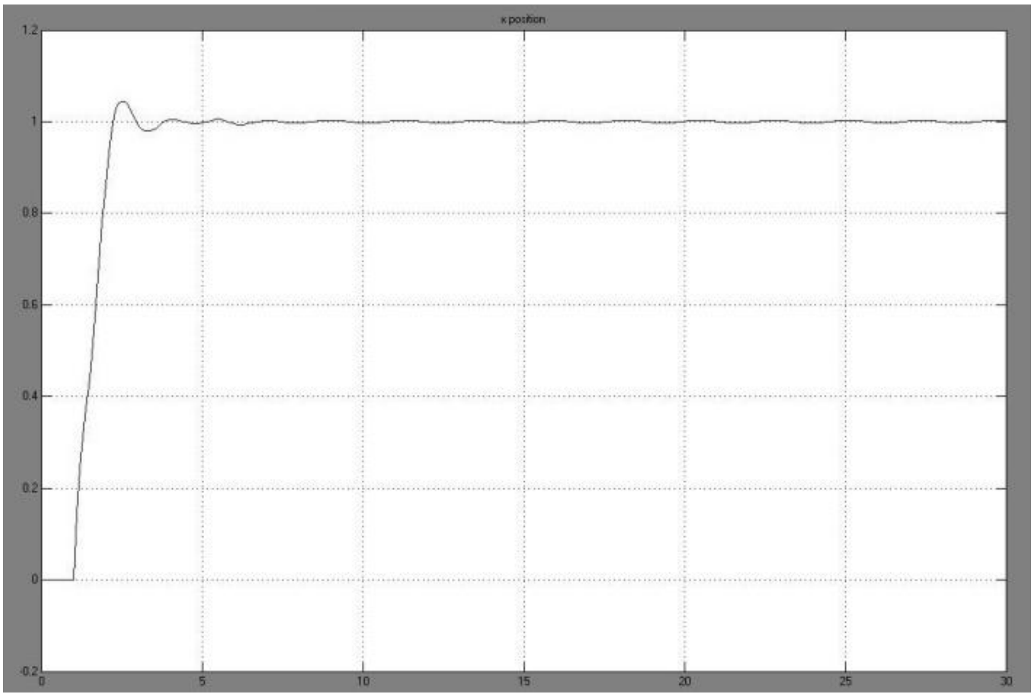

Figure 8 Reaction Curve for PID

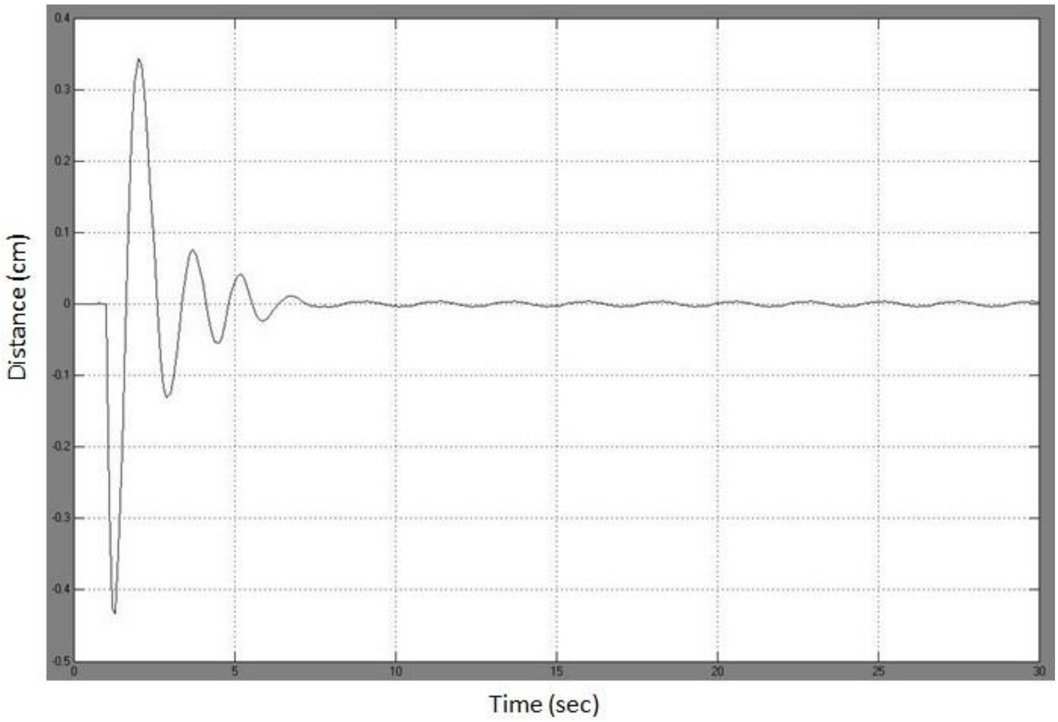

Figure 9 Payload Sway Angle for PID

4.2 Feedback Linearization

When using the crane, we want the payload to be transfer efficiently with less payload swing. However, transferring the load with high speed can lead the payload to create high payload angle. Feedback linearization controller is one of the controller uses to overcome this problem.

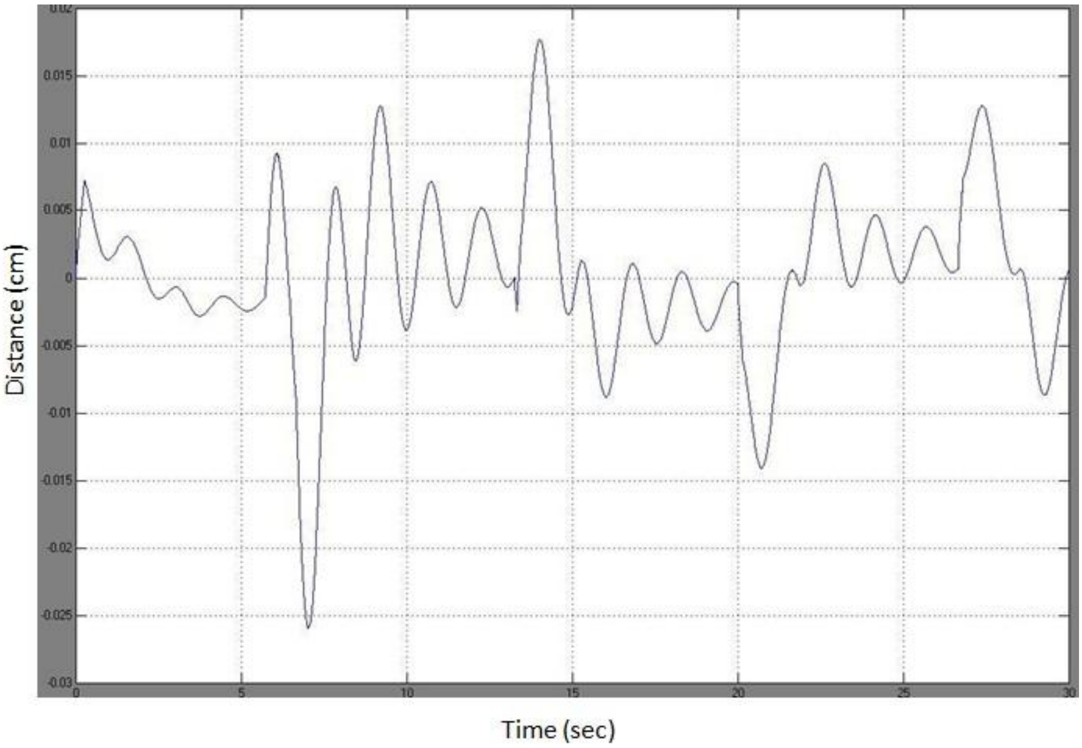

Figure 10 Payload Sway Angle for Feedback Linearization

Figure 9 show the system oscillates between -0.35 and 0.35 while Figure 10 shows the system oscillates between -0.025 and 0.018. This shows that the payload sway angle reduced after feedback is implemented.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

PID controller is one of the method can be used to reduce sway angle. In the experiment, the motion only involve with the x direction. The behavior of the payload seems better when PID controller is applied.

Feedback Linearization is another control methodology than can be used to the nonlinear control system in the crane. It can cancel the nonlinearities in the nonlinear system, so that the closed-loop dynamics is in a linear form. In this project, by having feedback in the system, we can reduce the swing effect of the crane better than PID controller. Further improvement for the feedback linearization performance will be done for future development.

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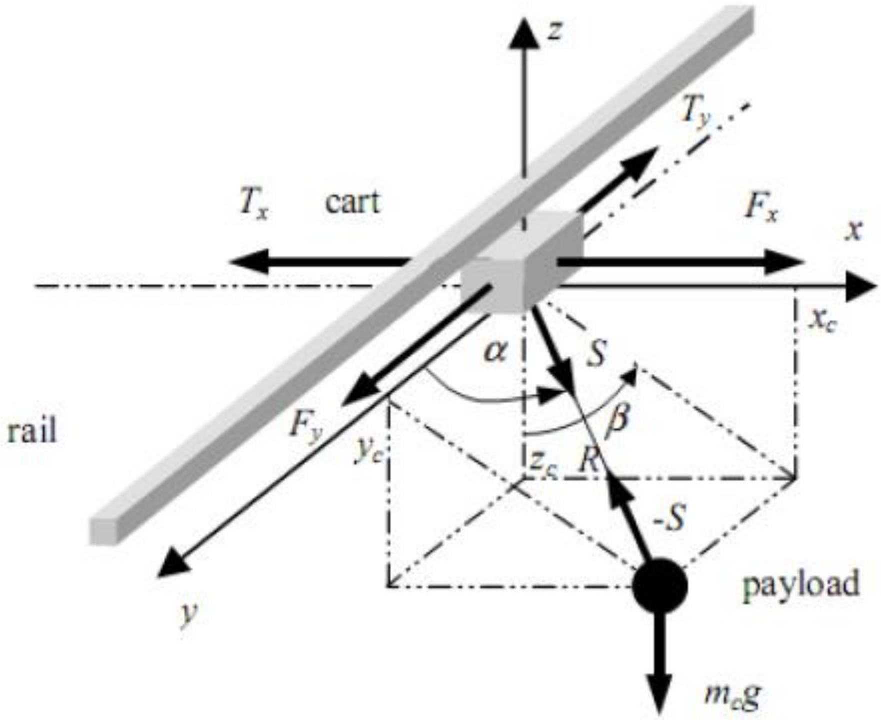
APPENDICES

APPENDIX A
COORDINATE AND FORCES FOR CRANE [8]



mc – mass of the payload

mw – mass of the cart

ms – mass of the moving rail

xc, yc, zc – coordinate of the payload

S – Reaction force in the lift-line acting on the cart

Fx – force driving the rail with cart

Fy – force driving the cart along the rail

Fr – force controlling the length of the lift-line

Tx, Ty, Tr – Frinction force