DEVELOPMENT OF ROTARY CRANE SYSTEM CONTROLLER USING FUZZY LOGIC CONTROLLER: MEMBERSHIP FUNCTION STUDY

MOHD AZRI BIN AKHIAK

A project report submitted in partial
fulfillment of the requirement for the award of the
Degree of Master of Electrical Engineering

Faculty of Electrical and Electronics Engineering
Universiti Tun Hussein Onn Malaysia

JANUARY 2012

ABSTRACT

The rotary crane also known as a tower crane is widely being used in the construction of higher buildings. The crane is consists of a jib that rotates in a horizontal plane around a fixed vertical axis and a trolley that holds the load which can move linearly along the jib. This study only focuses on the linear motion of trolley along the jib. The challenging process in order to control the crane are to make sure the trolley stop at the desired position and to deal with swing phenomenon introduced by the trolley motion. But, for the beginning of this study, the position control issue needs to be considered. Since many controllers can be implemented in this system in order to control the position, thus the implementation of practical controller must be investigated. A practical controller known as a fuzzy logic controller with various types of membership functions is implemented to control the position of the trolley. Since fuzzy logic controller is known as non-model based controller, hence it will be less time consuming to design. The scope of this study is limited only for four types of membership function which are common triangular, gaussian, trapezoidal and generalized bell membership function due to their similarities of symmetry characteristics. The performance of fuzzy logic controller with those membership functions is recorded and compared by using Simulink (MATLAB) simulation.

ABSTRAK

Kren berputar atau juga dikenali sebagai kren menara digunakan secara meluas dalam sektor pembinaan bangunan-bangunan tinggi. Kren ini terdiri daripada lengan yang boleh berputar pada satah melintang dimana ia mengelilingi paksi tegak dan mempunyai troli yang berupaya untuk mengangkat beban dan bergerak secara linear di sepanjang lengan. Namun, kajian ini hanya memfokuskan kepada pergerakan linear troli sepanjang lengan kren tersebut. Proses yang mencabar dalam mengawal kren adalah untuk memastikan troli ini berhenti tepat pada posisi yang dikehendaki dan menangani fenomena ayunan yang dicetuskan oleh pergerakan troli. Sebagai permulaan, isu berkaitan kawalan posisi akan diambilkira terlebih dahulu. Oleh kerana pelbagai pengatur boleh diaplikasikan ke atas sistem ini untuk mengawal posisi, maka perlaksanaan pengatur yang praktikal perlu di siasat. Salah satu pengatur yang praktikal dipanggil pengatur logik kabur dengan fungsi kesertaan yang pelbagai digunakan untuk mengawal posisi troli. Oleh kerana pengatur logik kabur ini juga dikenali dengan pengatur yang tidak bersandarkan kepada model, maka ia menjimatkan masa untuk direkabentuk. Skop kajian ini hanya terhad kepada empat fungsi kesertaan iaitu triangular, gaussian, trapezoidal dan generalized bell disebabkan persamaan ciri simetri mereka. Prestasi pengatur logik kabur bersama fungsi-fungsi kesertaan itu akan direkod dan dibandingkan menggunakan simulasi perisian Simulink (MATLAB).

TABLE OF CONTENTS

	TITLE		**i**
	DECLARATION		**ii**
	DEDICATION		**iii**
	ACKNOWLEDGEMENT		**iv**
	ABSTRACT		**v**
	TABLE OF CONTENTS		**vii**
	LIST OF TABLES		**ix**
	LIST OF FIGURES		**x**
	LIST OF SYMBOLS AND ABBREVIATIONS		**xii**
	LIST OF APPENDICES		**xiv**
CHAPTER 1	**INTRODUCTION**		**1**
	1.1	Project overview	1
	1.2	Problem statement	2
	1.3	Project objective	3
	1.4	Project scope	3
	1.5	Project report layout	4
CHAPTER 2	**LITERATURE REVIEW**		**5**
	2.1	Related work	5
	2.2	Types of crane	6
		2.2.1 Gantry crane	7
		2.2.2. Rotary crane	8
		2.2.3 Boom crane	9
	2.3	Fuzzy logic controller system	10

	2.3.1	Fuzzification	11
	2.3.2	Rule base	14
	2.3.3	Inference engine	15
	2.3.4	Defuzzification	16
CHAPTER 3	**METHODOLOGY**		**18**
	3.1	Introduction	18
	3.2	Proposed plant	18
	3.2.1	Rotary crane system structure	18
	3.2.2	DC motor position modeling	20
	3.3	Proposed controller	24
	3.4	Fuzzy logic controller design	24
	3.4.1	Fuzzification interface	25
	3.4.2	Fuzzy inference mechanism	30
	3.4.3	Fuzzy rules	30
	3.4.4	Defuzzification interface	33
CHAPTER 4	**RESULT AND ANALYSIS**		**34**
	4.1	Introduction	34
	4.2	System performance without controller	35
	4.3	System performance of PID controller and fuzzy logic controller	36
	4.4	System performance of fuzzy logic controller with different types of membership function	40
CHAPTER 5	**CONCLUSION AND RECOMMENDATION**		**45**
	5.1	Conclusion	45
	5.2	Recommendation	46
	REFERENCES		**47**
	APPENDICES		**49**

LIST OF TABLES

2.1	Example of rule base for air conditioner system	15
3.1	Parameter of jib’s DC motor (Faulhaber DC motor)	22
3.2	Fuzzy rules for position control	31
4.1	Performance comparison between PID controller and fuzzy logic controller	40
4.2	Performance comparison between different types of fuzzy logic controller	43

LIST OF FIGURES

2.1	Gantry crane	7
2.2	Rotary crane	8
2.3	Boom crane	9
2.4	Structure of fuzzy logic controller system	10
2.5	Triangular membership function shape	12
2.6	Gaussian membership function shape	12
2.7	Trapezoidal membership function shape	13
2.8	Generalized bell membership function shape	13
2.9	Sigmoidal membership function shape	14
3.1	Main components of rotary crane system (1: base plate, 2: tower, 4: jib, 6: trolley, 7: steel cable, 8: payload)	19
3.2	Components of jib (2: tower, 4: jib, 5: jib DC motor, 9: jib optical encoder)	19
3.3	Underside of jib (4: jib, 13: linear guide, 23: trolley pulley, 24: belt)	20
3.4	Circuit diagram of DC motor	20
3.5	Block diagram of proposed controller	24
3.6	Triangular membership function for (a) error and (b) delta of error input variables	26
3.7	Gaussian membership function for (a) error and (b) delta of error input variables	27
3.8	Trapezoidal membership function for (a) error and (b) delta of error input variables	28
3.9	Generalized bell membership function for (a) error and (b) delta of error input variables	29

3.10	Triangular membership function for voltage output variable	30
3.11	Illustration of how fuzzy rules can cover all possible positions	33
4.1	Rotary crane system without controller in Simulink	35
4.2	Response of trolley position without controller	36
4.3	Rotary crane system with PID controller in Simulink	37
4.4	Rotary crane system with fuzzy logic controller in Simulink	37
4.5	Response of trolley position at input reference 10 cm with PID controller and fuzzy logic controller	38
4.6	Response of trolley position at input reference 20 cm with PID controller and fuzzy logic controller	38
4.7	Response of trolley position at input reference 30 cm with PID controller and fuzzy logic controller	39
4.8	Response of trolley position at input reference 40 cm with PID controller and fuzzy logic controller	39
4.9	Response of trolley position at input reference 10 cm with different types of membership function	41
4.10	Response of trolley position at input reference 20 cm with different types of membership function	42
4.11	Response of trolley position at input reference 30 cm with different types of membership function	42
4.12	Response of trolley position at input reference 40 cm with different types of membership function	43

LIST OF SYMBOLS AND ABBREVIATIONS

μ_e	-	degree of membership function of error
$\mu_{\Delta e}$	-	degree of membership function of delta of error
μ_u	-	degree of membership function of voltage ouput
μ_o	-	output of COG
$\vee$	-	maximum operator
$\wedge$	-	minimum operator
I_a	-	armature current
V_a	-	rated voltage DC motor
J_m	-	equivalent of moment inertia
T_m	-	motor torque
B_m	-	damping ratio
e_b	-	motor back emf
θ_m	-	position in terms of angle
ω_m	-	angular velocity
r_{pulley}	-	radius of trolley pulley from pivot to end of tooth
K	-	motor torque constant factor
R	-	motor terminal resistance
L	-	motor terminal inductance resistance
θ_{ref}	-	reference position in terms of angle
θ_{act}	-	actual position in terms of angle
BOA	-	Bisector of Area
COG	-	Centroid of Gravity
DOF	-	Degree of Freedom
DC	-	Direct Current
FLC	-	Fuzzy Logic Controller

gaussmf	-	Gaussian Membership Function
gbellmf	-	Generalized Bell Membership Function
GUI	-	Graphic User Interface
LQR	-	Linear Quadratic Regulator
MF	-	Membership Function
MOM	-	Mean of Maximum
NB	-	Negative Big
NS	-	Negative Small
PB	-	Positive Big
PID	-	Proportional Integral Derrivative
PS	-	Positive Small
trapmf	-	Trapezoidal Membership Function
trimf	-	Triangular Membership Function
sigmf	-	Sigmoidal Membership Function
Z	-	Zero

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	S-Function Source Code for Triangular Membership Function	49
B	S-Function Source Code for Gaussian Membership Function	55
C	S-Function Source Code for Trapezoidal Membership Function	60
D	S-Function Source Code for Generalized Bell Membership Function	69

CHAPTER 1

INTRODUCTION

1.1 Project overview

A crane is one of major equipment or machine in industries, exists in most places; from domestic industries to naval yards to warehouses. It uses levers and/or pulleys for gripping, lifting and moving loads horizontally, as well as lowering and release the gripper back. The basic task of crane is to move payload (usually heavy load) from one point to another point. There are many types of crane that have been used for this purpose, such as rotary crane, gantry crane, boom crane and others.

Until now, crane was manually operated by skillful and professional person. Safety is the most important thing to consider in handling the crane. So, the crane must be operated in safe operating manner and procedures. Although the guidelines have been sketched to avoid any unwanted incident, still there are some chances for the accident can occur in future due to the operator is a human being. Perhaps, the solution is to substitute the automatic crane system with the best controller strategies as a replacement for the manual-controlled crane system.

1.2 Problem statement

Nowadays, cranes become larger and higher. Due to that, the transportation payload along the trolley system to the desired position needs faster time. Since the payload move in high speed, it will result the payload swing extremely when it suddenly stop after reach the final position. This excessive swing is not only reduces the efficiency of the cranes, even can cause hazard and safety problem in the complicated working environment.

Moreover, skilful operator still needed to control gantry crane manually based on his experiences to reduce and stop the swing immediately at the right position. The failure of controlling crane can cause accident and may harm people surrounding. Therefore, many researchers have given a lot of efforts in developing a control algorithms and designing controllers that can be used and realized in nature. Since to that, many control strategies based on the classic or modern control techniques have been proposed, investigated and tested in the laboratory level for the control of crane such as PID adaptive control and optimal control nonlinear control.

All the design control strategies have the same objective that should take into account which is to minimize the consume time to move the payload from initial position to the final position and reduce the swing of payload during transportation process. Besides, there are several issues to deal in order to design new control strategy. The important ones is the simplification of algorithm structure which make the controller is easy to design and adjust without neglecting the performance of the controller. Therefore, the implementation of practical controller that will deal to the issue must be investigated.

1.3 Project objective

The objectives of this project are;

i) To control the position of trolley by using model-based PID controller and non model-based fuzzy logic controller with different types of membership function via simulation

iii) To compare the performance of position control between PID controller and fuzzy logic controller

iv) To compare the performance of position control between different types of membership function of fuzzy logic controller

1.4 Project scope

The rotary crane system used for this study involving lab scaled; 3-DOF Crane System (manufactured by Quanser). This lab scale rotary crane system consists of 3 subsystems namely payload, jib and tower. But, this study focuses only on the jib part.

The scope of proposed fuzzy logic controller is limited to four membership functions which are triangular, gaussian, trapezoidal and generalized bell as a proposed controller for position control.

1.5 Project report layout

This project report is organized as follows;

i) Chapter 1 briefs the overall background of the study. A quick glimpse of study touched in first sub-topic. The heart of study such as problem statement, project objective, project scope and project report layout is present well through this chapter.

ii) Chapter 2 covers the literature review of previous case study based on fuzzy logic controller background and development. Besides, general information about crane and theoretical revision on fuzzy logic control system also described in this chapter.

iii) Chapter 3 presents the methodology used to design fuzzy logic controller and applied to the rotary crane system. All the components that have been used in designing of fuzzy logic controller are described well in this chapter.

iv) Chapter 4 reports and discuss on the results obtained based on the problem statements as mentioned in the first chapter. The simulation results from PID controller and the new proposed of fuzzy logic controller with different membership function will be analyzed with helps from set of figures and tables.

v) Chapter 5 will go through about the conclusion and recommendation for future study. References cited and supporting appendices are given at the end of this project report while the documentation CD also available and attached on the back cover of this project report for future reference.

CHAPTER 2

LITERATURE REVIEW

2.1 Related work

Since fuzzy logic controller can mimic human behaviour, many researchers applied fuzzy logic controller to control either overhead crane, gantry crane as well as rotary crane. A thorough literature overview was done on the usage of fuzzy logic controller as applied to the various crane systems.

Lee, H. H. and Cho, S. K. (2001) proposed a new fuzzy logic anti swing control for industrial three dimensional overhead cranes. However, PID controller still approached for position control which is based on model controller.

Omar, H.M (2003) proposed a controller with robust and fast for gantry and rotary cranes. The result shows that the fuzzy logic controller has smaller transfer time and overshoots unfortunately, with higher swing angles. Besides, the fuzzy logic controller uses mapping method which needs delayed feedback controller before fuzzy logic can be designed thus resulting time consuming.

Wahyudi & Jalani, J. (2005) designed and implemented robust Fuzzy Logic Controller for An Intelligent Gantry Crane System. The experimental results for anti swing control successfully proved that fuzzy logic controller is better compared to the conventional PID controller. However, the application of the fuzzy logic controller that has been proposed is for gantry crane which is their parameter is totally different with rotary crane.

Othman, M. Z. (2006) proposed a rough controller as a replacement for fuzzy logic controller which is based on mathematical computation to control the overhead travelling crane. The result shows that, it is just satisfactory, even more the quality index for both controllers does not differ very much. The complex mathematical modelling involves in designing process is not practicable.

Ruslee, R. , Jalani, J. & Abdullah, J. (2008) proposed Anti-Swing Control Strategy for Automatic 3 D.O.F. Crane System Using Fuzzy Logic Controller. The simpler and practical design of fuzzy logic controller applied for both position and anti swing control. It is obvious that the performance of fuzzy logic controller is better compared to Linear Quadratic Regulator (LQR) controller.

Based on those related work, the researchers make a great efforts to propose the good controller in the industrial setup to overcome the crane problems. Their applications of each method differ and still, the fuzzy logic controller is better controller compared to other conventional controller yet. Thus, the further investigation of this controller is needed in depth.

The approach of this study is similar to Ruslee, R. , Jalani, J. & Abdullah, J. (2008) in designing the fuzzy logic controller but for position control only. The investigation will be based on the different types of membership function applied on fuzzy logic controller.

2.2 Types of crane

There are many different styles and variation of cranes that abound in the world. Each of them is used for specific tasks but most of them are used for industrial purposes and are considered as heavy equipment machinery. However, in general there are three types of cranes in industries which can be classified in terms of their mechanical structures and dynamics. They are classified as gantry, rotary, and boom cranes.

2.2.1 Gantry crane

Gantry crane has a hoist in a trolley which runs horizontally along gantry rails and usually fitted underneath a beam spanning between uprights which themselves have wheels so that the whole crane can move at right angles to the desired direction of the gantry rails. Gantry cranes are fixed to the ground and give offer a combination of height and lifting capacity as shown in the Figure 2.1.

This type of crane is characterized by a trolley moving over a jib or glider. The trolley's movement can be described with a one-degree-of-freedom model. In some cases, the jib is mounted on another set of orthogonal railings in what is called bridge cranes. In this case, the trolley can move in a two-dimensional horizontal plane. They are common in factories because of their low cost, ease of assembly, and maintenance. They are also used in mines, steel-mill productions lines, and transport industry.

Figure 2.1: Gantry crane

2.2.2 Rotary crane

The rotary crane or also known as tower crane is a modern form of balance crane. It was fixed to the ground or jacked up and supported by the structure is being built. The rotary crane as shown in the Figure 2.2 often gives the best combination of height and lifting. Rotary crane is a common fixture at any major construction site. It is pretty hard to miss and often rise hundreds of feet into the air and can reach out just as far.

The crane was consists of a jib that rotates in a horizontal plane around a fixed vertical axis. The hoist motor and transmissions are located on the mechanical deck on the counter-jib while the trolley motor is located on the jib. The trolley that holds the load can move radically over the jib. Hence, the combined motion of the trolley and jib can place the load at any point in the horizontal plane within the reach of the crane. The load is attached to the trolley using a set of cables.

Figure 2.2: Rotary crane

2.2.3 Boom crane

Shown in the Figure 2.3 was a boom crane type which is very common on ships and in harbors. The typical boom crane was a pivoting structure equipped with double tread wheels. These cranes were placed docksides for the loading and unloading of cargo where they replaced or complemented older lifting method.

In general, a boom crane consists of a rotating base to which a boom is attached. The load hangs from the tip of the boom by a set of cables and pulleys. The rotational movement of the base along with the luff movement of the boom places tip over any point in the horizontal plane that is in reach of the crane. Meanwhile, changing the elevation (luff) angle of the boom causes a change in the radial and vertical positions of the load. The structure of boom cranes supports loads in compression, whereas rotary and gantry cranes support loads in a bending fashion. This makes boom cranes more compact than rotary and gantry cranes of similar capacities. Boom cranes are mounted on ships to transfer cargo between ships or on harbor pavements to transfer cargo between ships and offshore structures.

Figure 2.3: Boom crane

2.3 Fuzzy logic controller system

Fuzzy logic and fuzzy control theories added a new dimension to control systems engineering in the early 1970s. From its beginnings as mostly heuristic, somewhat ad-hoc, more recent and rigorous approaches to fuzzy control theory have helped make it integral part of modem control theory and produced many exciting results.

Fuzzy logic is a technique to embody human like thinking which is much less rigid than the calculations computer generally perform into a control system. Fuzzy controller can be designed to emulate human deductive thinking, that is, the process people use to infer conclusion from what they know. Meanwhile, conventional controller requires formal modeling of the physical reality of any plant. Apart from that, fuzzy control incorporates ambiguous human logic into computer programs. It suit control problem that can’t be easily represented by mathematical model. Design of such controller leads to faster development and implementation cycles due to its unconventional approach.

There are four important elements in the fuzzy logic controller system structure which are fuzzifier, rule base, inference engine and defuzzifier. Details of the fuzzy logic controller system structure can be seen in Figure 2.4 below. Firstly, a crisp set of input data are gathered and converted to a fuzzy set using fuzzy linguistic variables, fuzzy linguistic terms and membership functions. This step also known as fuzzification. Afterwards, an inference is made base on a set of rules. Lastlty, the resulting fuzzy output is mapped to a crisp output using the membership functions, in the defuzzification step.

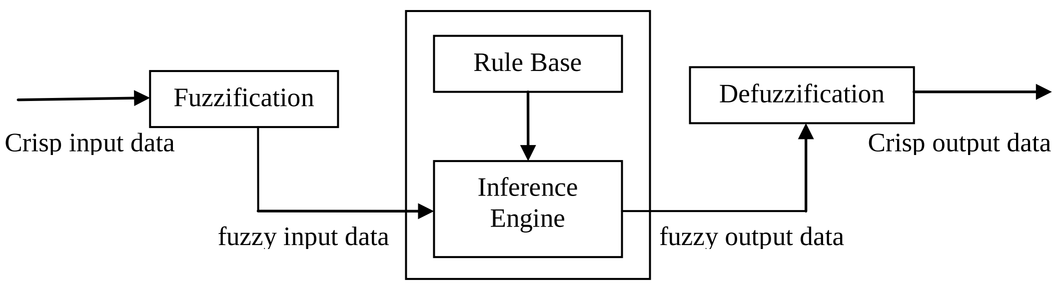

Figure 2.4: Structure of fuzzy logic controller system

2.3.1 Fuzzification

Fuzzification is a process of making a crisp quantity fuzzy. Before this process is taken in action, the definition of the linguistic variables and terms is needed. Linguistic variables are the input or output variables of the system whose values are words or sentences from a natural language, instead of numerical values. A linguistic variable is generally decomposed into asset of linguistic terms. Example, in the air conditioner system, Temperature,T is linguistic variable represents the temperature of a room. To qualify the temperature, terms such as "hot" and "cold" are used in real life. Then, Temperature (T) = {too cold, cold, warm, hot, too hot} can be the set of decomposition for the linguistic variable temperature. Each member of this decomposition is called a linguistic term and can cover a portion of the overall values of the temperature.

Next, to map the non-fuzzy input or crisp input data to fuzzy linguistic terms, membership functions is used. In other words, a membership function is used to quantify a linguistic term. Note that, an important characteristic of fuzzy logic is that a numerical valu does not have to be fuzzified using only one membership function meaning, a value can belong to multiple sets at the same time. Membership function can be measured in percentage from 0% to 100% or as a number 0 to 1. Sometimes membership function is also called as confidence factor. There are different forms or shapes of membership functions such as triangular, gaussian, trapezoidal, generalized bell and sigmoidal. The most common type of membership function used by many applications is triangular. The type of the membership function can be context dependent and it is generally chosen arbitrarily according to the user experience. Figure 2.5 to Figure 2.9 shows the different types of membership function shape.

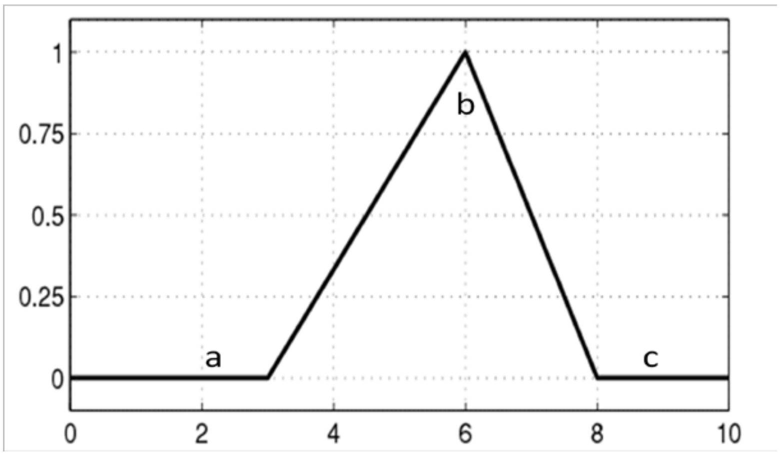

Figure 2.5: Triangular membership function shape

Equation for triangular membership function can be defined as follow;

$$trimf(x;a,b,c)=\left\{\begin{Bmatrix} 0 & x \le a \\ \dfrac{x-a}{b-a} & a \le x \le b \\ \dfrac{c-x}{c-b} & b \le x \le c \\ 0 & c \le x \end{Bmatrix}\right\} \tag{2.1}$$

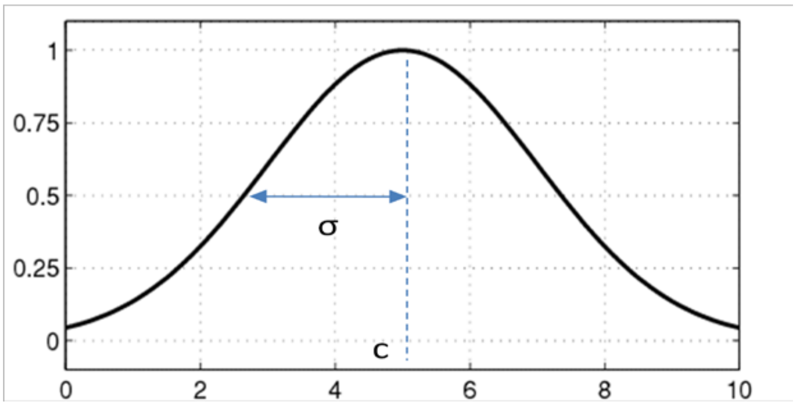

Figure 2.6: Gaussian membership function shape

Equation for gaussian membership function can be defined as follow;

$$gaussmf(x;\sigma,c)=e^{\frac{-(x-c)^2}{2\cdot\sigma^2}} \tag{2.2}$$

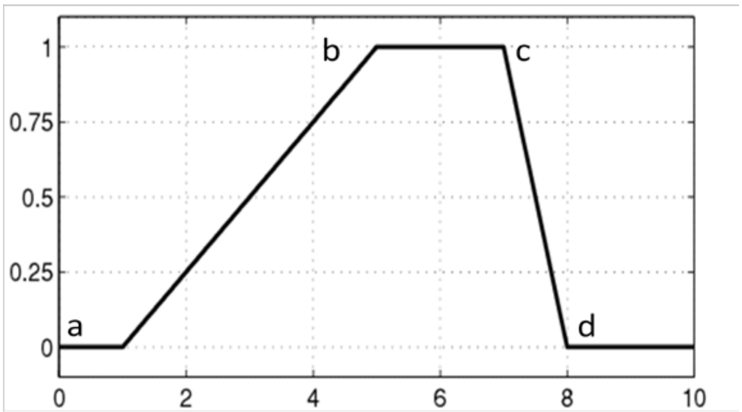

Figure 2.7: Trapezoidal membership function shape

Equation for trapezoidal membership function can be defined as follow;

$$trapmf\,(x;a,b,c)=\left\{\begin{cases} 0 & x\le a \\ \dfrac{x-a}{b-a} & a\le x\le b \\ 1 & b\le x\le c \\ \dfrac{d-x}{d-c} & c\le x\le d \\ 0 & d\le x \end{cases}\right\} \tag{2.3}$$

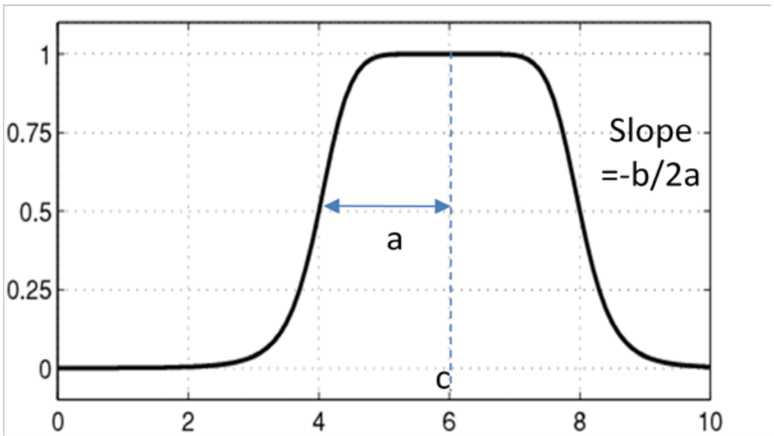

Figure 2.8: Generalized bell membership function shape

Equation for generalized bell membership function can be defined as follow;

$$gbellmf\,(x;a,b,c)=\frac{1}{1+\left|\frac{x-c}{a}\right|^{2b}} \tag{2.4}$$

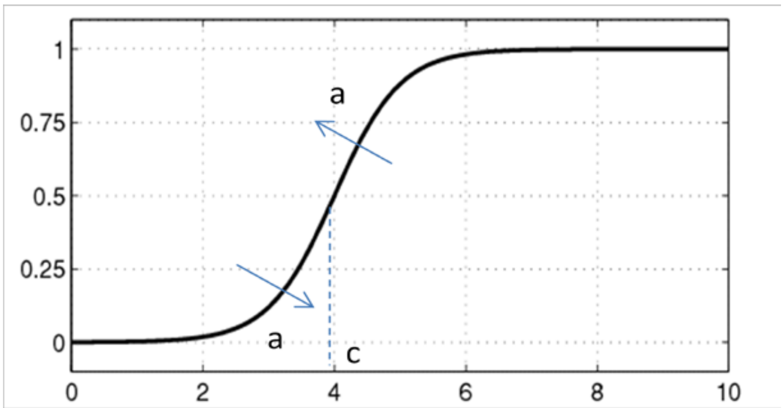

Figure 2.9: Sigmoidal membership function shape

Equation for sigmoidal membership function can be defined as follow;

$$sigmf\,(x;a,c)=\frac{1}{1+e^{-a(x-c)}} \tag{2.5}$$

2.3.2 Rule base

In a fuzzy logic control system, a rule base is constructed to control the output variable. A fuzzy rule is a simple IF-THEN rule with a condition and conclusion. It can be represented by the matrix table. Let say, the air conditioner system with two input linguistic variables of temperature and humidity and one output linguistic variable of motor speed as shown in Table 2.1.

Table 2.1: Example of rule base for air conditioner system

Motor speed		Humidity		
		low	moderate	high
Temperature	cold	medium	slow	slow
	warm	fast	medium	slow
	hot	fast	fast	medium

Row captions in the matrix contain the values that current room temperature can take while column caption contain the values for humidity in the room. Each cell is the resulting command when the input variables take the values in that row and column. Based on the table 2.1, the maximum numbers of rules are nine (9). For instance, the cell (3,3) can be read as follows: IF temperature is hot and humidity is high THEN motor speed is medium.

2.3.3 Inference engine

In general, inference is a process of obtaining new knowledge through existing knowledge. In the context of fuzzy logic control system, it can be defined as a process to obtain the final result of combination of the result of each rule in fuzzy value. There are many methods to perform fuzzy inference method and the most common two of them are Mamdani and Takagi-Sugeno-Kang method.

Mamdani method was proposed by Ebrahim Mamdani as an attempt to control a steam engine and boiler in 1975. It is based on Lofti Zadeh's 1973 paper on fuzzy algorithms for complex system and decision processes. This method uses the minimum operation R_c as a fuzzy implication and the max-min operator for the composition. Suppose a rule base is given in the following form;

IF input x = A AND input y = B

THEN output z = C

After the aggregation process, there is a fuzzy set for each output variable that needs defuzzification. It is possible and in many cases much more efficient, to use a single spike as the output membership functions rather than a distributed fuzzy set. This is sometimes known as a singleton output membership function. It enhances the efficiency of defuzzification process because it greatly simplifies the computation required by the more general Mamdani method, which finds the centroid of two dimensional function.

Meanwhile, Takagi-Sugeno-Kang method was introduced in 1985 and it is similar to the Mamdani method in many aspects. The first two parts of fuzzy inference processes which are fuzzifying the inputs and applying the fuzzy operator are exactly the same. But, the main difference is that the Takagi-Sugeno-Kang output membership function is either linear or constant. A typical rule in Takagi-Sugeno-Kang fuzzy model has the form as follows;

IF input 1 = x AND input 2 = y
THEN output z = ax + by + c

For a zero order Takagi-Sugeno-Kang model, the output z is a constant (a=b=0). The output of z_i of each rule is weighted by the firing strength w_i as follows;

$$w_i = \text{AndMethod}(F_1(x), F_2(y))$$

Where $F_1(x)$ and $F_2(y)$ are the membership functions for input 1 and input 2 respectively. The final output of the system is the weighted average of all rule outputs, computed as;

$$final\ output = \frac{\sum_{i=1}^{N} w_i z_i}{\sum_{i=1}^{N} w_i} \tag{2.6}$$

2.3.4 Defuzzification

After the inference step, the overall result is a fuzzy value. This result should be defuzzified to obtain a final crisp output. This is the purpose of the defuzzification component of a fuzzy logic controller system. Defuzzification is performed according to the membership function of the output variable. There are many different methods for defuzzification such as Centroid of Gravity (COG), Mean of Maximum (MOM), Weighted Average, Bisector of Area (BOA), First of Maxima and Last of Maxima. There is no systematic procedure for choosing a good defuzzification strategy, but the selection of defuzzification procedure is depends on the properties of the application.

Centroid of Gravity (COG) is the most frequent used and the most prevalent and physically appealing of all defuzzification methods. The basic equation of Centroid of Gravity (COG) as below;

$$u_o = \frac{\int_u \mu_u(u)udu}{\int_u \mu_u(u)du} \tag{2.7}$$

where u_o is control output obtained by using Centroid of Gravity (COG) defuzzification method.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will discuss details about designing fuzzy logic controller for rotary crane system controller.

3.2 Proposed plant

The proposed plant including lab scaled rotary crane system also known as 3-DOF Crane System manufactured by Quanser and modeling of DC motor position.

3.2.1 Rotary crane system structure

Basically, the rotary crane system consists of the base plate, tower, jib, trolley, steel cable and payload. The jib of rotary crane system as shown in Figure 3.1 and Figure 3.2 has a motorized gearbox (DC Motor) to move the trolley and equipped with an optical encoder to measure the trolley position. The trolley need to be at the centered position as initial condition. The maximum movement can be made by the trolley was ±40cm or 0.4m. Even the desired position are setup, there still need to take a safety action. At the end both side of the jib has a limit switch as a safety for trolley movement.

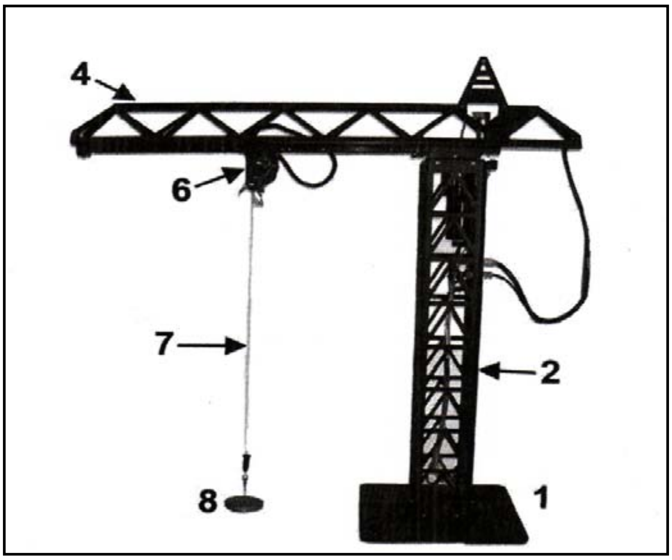

Figure 3.1: Main components of rotary crane system (1: base plate, 2: tower, 4: jib, 6: trolley, 7: steel cable, 8: payload)

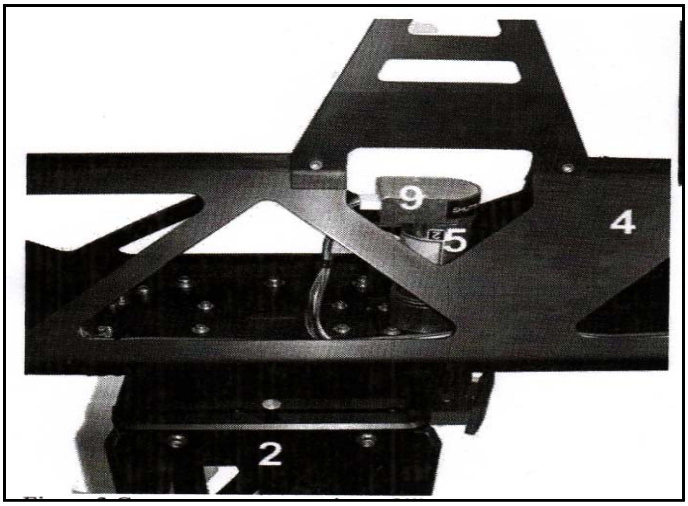

Figure 3.2: Components of jib (2: tower, 4: jib, 5: jib DC motor, 9: jib optical encoder)

The motor shaft of the trolley connected to a 16-tooth pulley, shown in Figure 3.3 that is interlocked with a belt. The trolley is anchored along the underside of the jib to a linear guide and is fastened to the belt such that the motor can be used to position the trolley along the track.

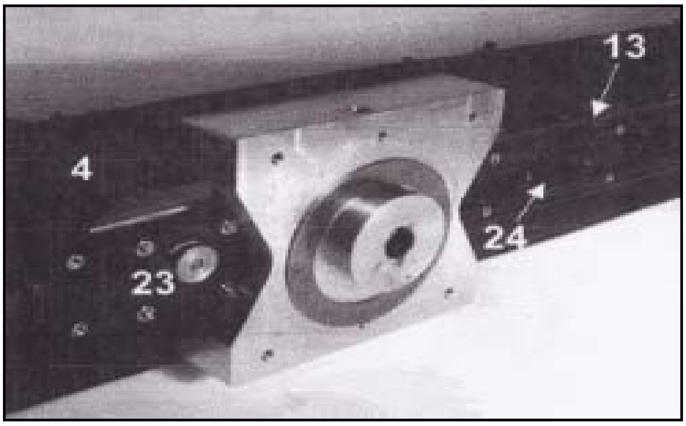

Figure 3.3: Underside of jib (4: jib, 13: linear guide, 23: trolley pulley, 24: belt)

3.2.2 DC motor position modeling

To perform the simulation of the rotary crane system, an appropriate model needs to be established. By neglecting the dynamic model of trolley motion, the plant can be represented by the DC motor circuit diagram as shown in Figure 3.4.

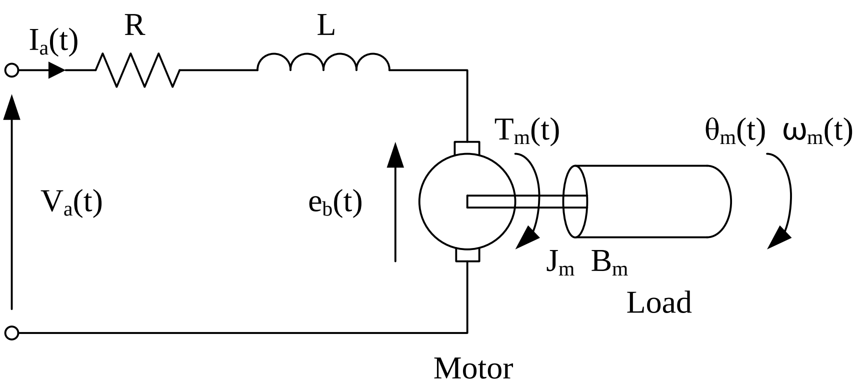

Figure 3.4: Circuit diagram of DC motor

The motor torque, T_m is related to the armature current, I_a by a constant factor of K;

$$T_m = KI_a \tag{3.1}$$

The back emf, e_b is relative to angular velocity, ω_m by;

$$e_b = K\omega_m = K\frac{d\Theta_m}{dt} \tag{3.2}$$

From the Figure 3.4, the following equations can be written based on Newton's Second Law combined with Kirchoff's Law;

Newton's Second Law,

$$T_m = J_m\frac{d^2\Theta_m}{dt} + B_m\frac{d\Theta_m}{dt} \tag{3.3}$$

Substitute equation (3.1) into equation (3.3) to obtain;

$$J_m\frac{d^2\Theta_m}{dt} + B_m\frac{d\Theta_m}{dt} = KI_a \tag{3.4}$$

Kirchoff's Law,

$$L\frac{dI_a}{dt} + R = V_{a-}e_b \tag{3.5}$$

Substitute equation (3.2) into equation (3.5) to obtain;

$$L\frac{dI_a}{dt} + R = V_{a-}K\frac{d\Theta_m}{dt} \tag{3.6}$$

By taking Laplace Transform, equations (3.5) and (3.6) can be expressed in term of s as;

$$J_m s^2\Theta_m(s) + B_m s\Theta_m(s) = KI_a(s) \tag{3.7}$$

$$LsI_a(s) + RI_a(s) = V_a(s) - Ks\Theta_m(s) \tag{3.8}$$

From equation (3.7), $I_a(s)$ can be expressed as;

$$I_a(s) = \frac{s\Theta_m(s)[J_m s + B_m]}{K} \tag{3.9}$$

Substitute equation (3.9) into equation (3.8) to obtain;

$$V_a(s) = \frac{s\Theta_m(s)[J_m s + B_m][Ls + R]}{K} \tag{3.10}$$

Therefore, from the equation (3.10), the transfer functions where the position, Θ_m as an output and the voltage, $V_a(s)$ as an input can be obtained;

$$\frac{\Theta_m(s)}{V_a(s)} = \frac{K}{s[J_m s + B_m][Ls + R]} \tag{3.11}$$

The constants value of voltage,V_a, torque constant factor, K, rotor inertia, J_m, damping ratio,B_m, resistance, R and inductance, L for DC motor must be known. The specifications of DC motor which will be used in the rotary crane system are described in the Table 3.1 below:

Table 3.1: Parameter of jib's DC motor (Faulhaber DC motor)

Symbol	Description	Value	Unit
V_a	Jib motor rated voltage	12	V
I_a	Jib motor current without load	0.093	A
K	Jib motor torque constant	0.0436	N.m/A
J_m	Jib motor equivalent moment of inertia	9.341e-7	kg.m2
R	Jib motor terminal resistance	1.7	Ω
L	Jib motor terminal inductance	6.7	mH
W	Jib motor speed without load	1460	RPM
r_{pulley}	Radius of trolley pulley from pivot to end of tooth	0.0071	m

From the Table 3.1, there is no parameter for damping ratio,B_m of the DC Motor. By using equation (3.4), for$\omega_m = \frac{d\Theta_m}{dt}$,

$$J_m \frac{d\omega_m}{dt} + B_m \omega_m = KI_a \tag{3.12}$$

The speed of motor ω_m is in rad/sec unit. The conversion unit for speed from RPM to rad/sec is given by;

$$\omega_m = \frac{2\pi W}{60} \tag{3.13}$$

By substituting $W = 1460$ into equation (3.13),$\omega_m = 152.8908$

At the steady state (used as analyze data), both I_a and ω_m are stabilized, so that $\frac{d\omega_m}{dt} = 0$. Then, by substituting $\frac{d\omega_m}{dt} = 0$ and $\omega_m = 152.8908$ into equation (3.12), the total equivalent damping ratio, B_m can be calculated by;

$$B_m \times 152.8908 = 0.0436 \times 0.093$$
$$B_m = 2.6521 \times 10^{-5} \text{ Nms}$$

Since, the motor shaft of the trolley connected to a pulley thus, the travel distance of trolley in fully 2π radian rotation of motor shaft can be calculated by;

$$Distance = 2\pi r_{pulley} \tag{3.14}$$

By substituting $r_{pulley} = 0.0071m$ into equation (3.14), $Distance = 4.4611cm$
Thus, maximum movement ±40cm of trolley can be represented by; $\frac{40}{4.4611} \times 2\pi = 56.3773\, radian$. For the purpose of simplification, it is assume that ±50 radian as universe of discourse for error input variables.

3.3 Proposed controller

The structure of the proposed controller for rotary crane system is shown in Figure 3.5. The proposed controller consists of fuzzy logic controller for position control in the completed closed loop system. The designation of fuzzy logic controller is based on expert knowledge which means the knowledge of skillful operator during the handling of rotary crane system is adopted into the rule based design of fuzzy logic controller.

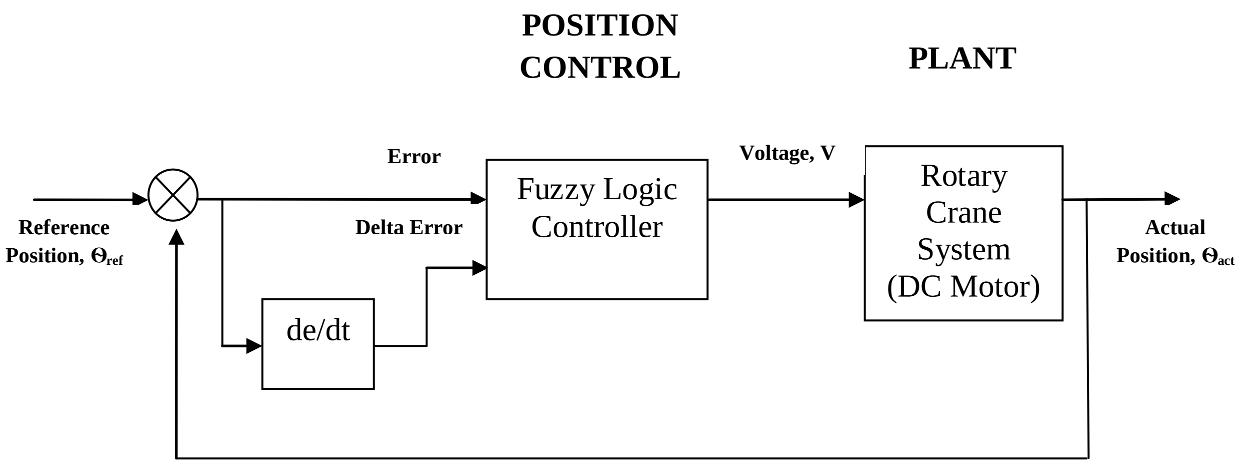

Figure 3.5: Block diagram of proposed controller

3.4 Fuzzy logic controller design

There are four elements to be considered in order to design the fuzzy logic controller which are fuzzification interface, fuzzy rules, fuzzy inference mechanism and defuzzification interface.

REFERENCES

Lee, H. H. and Cho, S. K. (2001). A New Fuzzy-Logic Anti-Swing Control for Industrial Three-Dimensional Overhead Cranes. *Proc. Int. Conference on Robotics & Automation 2001*. Seoul, Korea, pp.2956-2961.

Omar, H.M (2003). *Control of Gantry and Tower Cranes*. M.S. Virginia Tech. Ph.D. Thesis.

Wahyudi & Jalani, J. (2005). Design and Implementation of Logic Controller for Intelligent Gantry Crane System. *Proc. of the 2nd Int. Conference on Mechatronics, ICOM'05*. Kuala Lumpur, Malaysia.

Jalani, J. (2005). *Control Strategies for Automatic Gantry Crane System*. Islamic International University of Malaysia: Master Thesis.

Othman, M. Z. (2006). A New Approach for Controlling Overhead Traveling Crane Using Rough Controller. *Int. Journal of Intelligent Technology 1:3 2006*

Ruslee, R. , Jalani, J. & Abdullah, J. (2008). Anti-Swing Control Strategy for Automatic 3 D.O.F. Crane System Using FLC. *Proc. of the 3rd Int. Conference on Mechatronics, ICOM'08*. Kuala Lumpur, Malaysia.

Wai, P. A. (2007). Analysis on Modeling and Simulink of DC Motor and its Driving System Used for Wheeled Mobile Robot. *World Academy of Science, Engineering and Technology*, pp 32 2007.

Purtojo, Rini Akmeliawati & Wahyudi (2008). Fuzzy-based NCTF Controller for PTP Positioning: Fuzzy Membership and Rule Based Modifications. *Proc. of the 3rd Int. Conference on Mechatronics, ICOM'08*. Kuala Lumpur, Malaysia.

Ahmad, M. A. (2009). Active Sway Suppression Techniques of a Gantry Crane System. *European Journal of Scientific Research* ISSN 1450-216X Vol.27 No.3 (2009), pp.322-333.

Universiti Tun Hussein Onn Malaysia (2011). *Thesis Writing Guide.* Centre for Graduate Studies.