ANTI-SWING CONTROL STRATEGY FOR AUTOMATIC 3 DOF CRANE SYSTEM USING FLC

RUSLINDA BINTI RUSLEE

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Special dedicated to

Ruslee Md Rijin, Mik Wook Salim

&

My love Asmahadi Md Tahir

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ABSTRACT

The 3 Degree-of-Freedom (DOF) crane represents one of the most widely deployed real-world platforms in the world today. It uses levers and pulleys for gripping, lifting and moving loads horizontally, as well as lowering and releasing the gripper to the original position. Hence the system produces swing angle which need to be controlled so that the payload could be transferred efficiently. The existing 3 DOF systems used conventional Linear Quadratic Regulator (LQR) controller to control the position and swing angle. This project report proposed the usage of Fuzzy Logic Controller (FLC) in place of LQR controller. FLC has a simpler and practical design approached. It avoids laborious mathematical formulation and computation thus reducing operating time. The FLC performance for position control and anti-swing control are compared with LQR controller using MATLAB simulation. The simulation results showed, under laboratory limitation, that FLC performed better compared to the conventional LQR controller.

ABSTRAK

Kren automaik 3DOF merupakan salah satu kren digunakan secara meluas di dunia terutamanya di platform industri berat yang mana menggunakan pengumpil, tuil dan takal bagi mencengkam, mengangkut, mengalih serta menggerakkan beban dari satu tempat ke tempat lain secara mendatar, menurunkan serta melepaskan beban tersebut dan kembali kepada kedudukan asal sistem. Oleh yang demikian, perpindahan beban atau muatan ini pastinya akan menghasilkan sedikit sudut ayunan dan sudut ayunan ini perlu dikawal bagi memastikan kelancaran kerja pemindahan beban secara cepat, efektif dan selamat. 3DOF kren ini telah mengamplikasikan sistem kawalan konvensional yang dikenali sebagai sistem kawalan pengatur kuadratik datar bagi mengatasi masalah tersebut. Satu sistem alternatif iaitu sistem logik kabur dicadangkan untuk mengatasi masalah ayunan ini dimana ianya mempunyai reka bentuk yang lebih mudah dan praktikal selain dapat mengurangkan penggunaan matematik yang kompleks bagi menggantikan sistem kawalan yang sedia ada dan ini dapat mengurangkan penggunaan masa. Kebolehan sistem logik kabur bagi kawalan posisi dan anti ayunan ini dibandingkan dengan pencapaian sistem kawalan konvensional iaitu sistem kawalan pengatur kuadratik datar dengan menggunakan perisian simulasi MATLAB. Hasil dari simulasi membuktikan bahawa sistem logik kabur ini juga merupakan satu sistem kawalan yang mempunyai potensi setanding dengan sistem kawalan yang sedia ada bagi mengatasi masalah ayunan dalam sistem kren.

INTRODUCTION

The 3 DOF crane represents one of the most widely deployed real-world platforms in the world today that uses levers and pulleys for gripping, lifting and moving loads horizontally, as well as lowering and release the gripper back. The task of the 3 DOF crane is to move the payload from one point to another point. Hence the system produces swing angle which need to be controlled so that the payload will be transferred quickly, effectively and safely. The 3 DOF crane is separated into three subsystems which are payload, jib and tower. To deal with these systems, a lot of control techniques have been used on the basis of controlling swing angle. Since many controllers can be used to control the system, therefore the most practical and effective controller have been investigated to replace and implemented to this 3 DOF crane system. This project only focuses on controlling jib subsystem. The existing controller of payload and tower subsystem is still used for the controlling purpose. The conventional LQR controller is used to control position and swing angle of the 3 DOF crane. Therefore, the simpler and practical controller approach needs to be applied to the system known as Fuzzy Logic Controller (FLC). In addition, the FLC is known as a non-model based controller approach and can fulfill the design method as well as achieve high performances. The application of Fuzzy Logic Controller in the 3 DOF crane systems is expected to be better than conventional controllers. The design of Fuzzy Logic Controller is also minimize the mathematical computation and reducing time consuming. Hence, FLC is predicted to have simpler design approach and perform better results as compared to conventional controllers.

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LIST OF SYMBOL

A	-	state matrix
B	-	input matrix
C	-	output matrix
D	-	direct transmission
α	-	motion angle perpendicular jib length
γ	-	payload angle
$I_{m,j}$	-	current DC motor
X_j	-	position trolley
X_p	-	position of payload from jib
l_p	-	length of payload
y_p	-	position of payload from tower
m_p	-	mass of trolley
$r_{j,pulley}$	-	radius of trolley pulley from pivot to end of tooth
g	-	gravitational
$m_{trolley}$	-	mass of trolley
J_ψ	-	jib motor equivalent moment of inertia
$K_{g,j}$	-	motor gear ration for jib
$\eta_{g,j}$	-	jib motor gearbox efficiency
$\eta_{m,j}$	-	jib motor efficiency
$K_{t,j}$	-	jib motor torque constant
d(t)	-	desired position
$r_d(t)$	-	radial acceleration
$\gamma_d(t)$	-	rotational acceleration
$\Theta_d(t)$	-	output of plane angle

$X_{ref}(s)$	-	references of trolley position
$X(s)$	-	output position
Θ	-	output swing angle
μ_{u1}	-	degree of membership function of output for position control
μ_{u2}	-	degree of membership function of output for anti-swing control
μ_{x}	-	degree of membership function of error for position control
$\mu_{\overline{x}}$	-	degree of membership function of error rate for position control
μ_{γ}	-	degree of membership function of error for anti-swing control
$\mu_{\overline{\gamma}}$	-	degree of membership function of error rate for anti-swing control
v	-	maximum operator
^	-	minimum operator
u_o	-	output of COA

LIST OF ABBREVIATIONS

CARE	-	Continuous time Algebraic Ricatti Equation
COA	-	Centre of Area
CW	-	clock wise
DARE	-	Discrete time Algebraic Ricatti Equation
FIS	-	Fuzzy Inference System
FLC	-	Fuzzy Logic Controller
gaussmf	-	gaussian membership function (simple curve)
gauss2mf	-	gaussian membership function (two sided composite of different curve)
gbellmf	-	generalized bell membership function
LQR	-	Linear Quadratic Regulator
MF	-	membership function
N	-	Negative
NB	-	Negative Big
NS	-	Negative Small
P	-	Positive
PB	-	Positive Big
PD	-	Propotional Derivative

PID	-	Propotional Integral Derivative
PS	-	Positive Small
trapmf	-	tarpezoidal membership function
trimf	-	triangle membership function
TSK	-	Takagi-Sugeno Kang
Z	-	Zero

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CHAPTER 1

INTRODUCTION

1.1 Project Overview

Crane is a machine that use levers and pulleys for gripping, lifting and moving loads horizontally, as well as lowering and release the gripper back. It is considered as one of the most important machines that are being used in industry to transfer loads from one desired position to another position. These cranes have very strong structures in order to lift heavy payloads in factories, in building construction, on ships, and in harbors. These tasks are performed with the aid of hoisting mechanism that works as an integral part of the crane. Until recently, cranes were manually operated by professional person. But when cranes became larger and they are being moved at high speeds, their manual operation became difficult. In factories, cranes speed up the production processes by moving heavy materials to and from the factory as well as moving the products along production or assembly lines. In building construction, cranes facilitate the transport of building materials to high and critical spots. Similarly on ships and in harbors, cranes save time and consequently money in making the process of loading and unloading ships fast and efficient.

1.2 Problem Statement

3 DOF crane was included in the overhead crane types and are widely used in industry for moving heavy objects. However, the overhead cranes have serious problems such as the acceleration and always induce undesirable load swing, which is frequently aggravated by load hoisting. Such load swing usually degrades work efficiency and sometimes causes load damages and even compromise safety aspects. From a dynamics point of view, the overhead cranes are under actuated mechanical systems. The overhead cranes have fewer control inputs than the degrees of freedom, which complicate the related control problems. The first attempt to control the position and swing angle of the system is done using classical controller, utilizing LQR method. However, this conventional controller involved complex mathematical computation which is time consuming. In this project report, it is proposed to apply FLC mechanism to overcome the problem of exact position and swing effect.

1.3 Objectives Project

The objectives of this project are:

i) To investigate better control strategy to transfer loads using Fuzzy Logic Controller.

ii) To investigate better control strategy to suppress swing using Fuzzy Logic Controller.

iii) To propose FLC which are simple structure and easy to design.

1.4 Scopes Project

The 3 DOF crane is separated into three subsystems which are payload, jib and tower. However, the scope of the study is only focusing on controlling jib subsystem. The existing controller of payload and tower is still used for the controlling purpose.

1.5 Project Report Layout

This project report was organized as follows:

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

ii) **Chapter II** will cover the literature research based on Linear Quadratic Regulator and Fuzzy Logic Controller background and development. Moreover, the study of previous case project that have same filed are also described in this chapter

iii) **Chapter III** represents the methodology used to design Fuzzy Logic Controller by using MATLAB R2006b software. All the components that had been used in design the Fuzzy Logic Controller are described well in this chapter.

iv) **Chapter IV** will report and discuss on the results obtained that reflect on my problem statements as stated in the first chapter. The simulation results from conventional LQR controller and the new proposed of Fuzzy Logic Controller will be analyzed with helps from set of figures and tables.

v) **Chapter V** will go trough about the conclusion and recommendation are suggested for future study. This entire thing is done after completing my dissertation. References cited and supporting appendices are given at the ends of this project report while the documentation CD also available and attached on this project report back cover for future reference.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

The 3 DOF (Degrees of Freedom) Crane represents one of the most widely deployed in the real-world platforms today. The task of the 3 DOF crane is to move the payload from one point to another. Hence the system produces swing angle which need to be controlled so that the payload will be transferred quickly, effectively and safely. Initially the system is control using classical LQR controller to control position and swing angle of the 3 DOF crane. However, using LQR controller involves complex mathematical computation which is time consuming. Therefore, a much simpler controller needs to be applied to the system known as Fuzzy Logic Controller (FLC). The FLC is expected to have simpler design, methodology and algorithm. In the FLC methods, the model and parameters of the 3 DOF Crane systems is disregard. FLC is also known as a non non-model based controller approach and can fulfill the design method as well as achieving high performances.

2.2 Related Work

In order to fully understand the research direction, a thorough literature search was done on the usage of FLC as applied to the crane.

Ho-Hoon Lee and Sung-Kun Cho (2001) presented a new fuzzy logic anti swing control for industrial three dimensional overhead cranes. The control consists of a position servo control to align crane position and rope length, and the fuzzy logic control is used the suppress load swing.

D. M. Dawson et al. (2001) designed two nonlinear energy based coupling control procedure that increase the coupling between the pendulum position and the gantry position. The paper introduced three controllers for an overhead crane system which are the asymptotic regulation of the gantry and payload position for a PD controller and two nonlinear controllers. However, the simulation results for this experiment show that the approaches controller was involved with complex mathematical computation and it was time consuming.

Hanafi M. Omar (2003) designed a controller with robust, fast, and practical for gantry and tower cranes. However, the result shows that the fuzzy controller has smaller transfer time and overshoot but with higher swing angles. This response can be improved by a proper parameter tuning of the membership functions.

Jamaludin Jalani and Wahyudi (2005) designed and implemented robust Fuzzy Logic Controller for an Intelligent Gantry Crane System. The results of their experiment were successfully proved that FLC is better compared to the conventional controller. However, the application of the FLC introduced for gantry crane and their parameter is totally different with 3DOF Crane systems.

Mazin Z. Othman (2006) proposed a rough controller which is based on mathematical computation to control the overhead traveling crane. It is proposed to change the FLC controller. However, the result shows that the quality index for both controllers does not differ very much and also involved in mathematical modeling.

In those related work, the researchers have designed and applied the best controller in the industrial setup to overcome the crane problems. However, their applications of each method differ and the Fuzzy Logic Controller is the best controller that is chosen to realize this project which is simpler controller compared to the conventional LQR controller for 3DOF Crane system. The approaches of this project report is similar to Ho-Hoon Lee and Sung-Kun Cho (2001) in designing the anti-swing control for 3 DOF crane system using fuzzy logic controller. However, in this project, the FLC is applied to the 3DOF crane for industrial process, which is expected to have simpler design, method and algorithm.

2.3 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.

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