CONTROL STRATEGIES FOR AUTOMATIC GANTRY CRANE SYSTEM

BY

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ABSTRACT

Gantry crane is a machine that moves payload from one point to another point. Nowadays, most of gantry cranes use open loop system to control position while anti-swing control is operated manually by skillful operators. The open loop system is sensitive to the parameter variations and disturbances while operator's skills are restricted by fatigue problem and will affect the performance of the gantry crane. In order to overcome the problems, feedback control is adopted in this study. Firstly, classical PID and PD were introduced as position and anti-swing control respectively. The experimental result showed that the PID and PD controllers were successfully controlled both position and swing of the gantry crane especially for small load displacement. However, the positioning performance was degraded due to the saturation of the actuator. In addition, the PID controller design is a time consuming process, since model and parameters of the gantry crane are needed. Secondly, non-model based of fuzzy logic controllers are implemented in the gantry crane system for position and anti-swing control. The experimental result showed that fuzzy logic controllers had resulted on good performances for anti-swing controller. However, the results for position control were inconsistent for small desired position. The tuning process may improve the control performance but it may affect other desired positions. Finally, non-model based of NCTF controller, was proposed for position control of the gantry crane system while the anti-swing control by using fuzzy logic controller remained the same since it gave good performance. The experimental result showed that the NCTF controller produced best results for position control of the gantry crane system compared to other controllers.

ملخص البحث

إن آلة الرفع هي ماكينة تحرك الحمولات من مكان لآخر. و في الوقت الحالي تستخدم معظم آليات الرفع النظام الدائري المفتوح في التحكم بالموقع ، بينما يستخدم العاملون المهرة بصورة طبيعية نظام التحكم الثابت. إن النظام الدائري المفتوح سريع التأثر بدرجة متغيرة من الإختلافات والإضطرابات، بينما مهارات العامل مقيدة بمشكلة الإعياء وهو ما سيؤثر في أداء آلة الرفع.ومن أجل التغلب على هذه المشاكل، فقد تم تبني التحكم في التغذية المرتدة في هذه الدراسة.أولاً، إن أسلوبي PD, PID التقليديين سيتم تقديمهما كأسالوبين لمراقبة للموقع ونظام التحكم الثابت بالتتابع. وقد أوضحت النتيجة التجريبية أن أسلوبي المراقبة PID و PD قد تمكنا بنجاح من التحكم في الموقع وأداء الآلة الرافعة وبصورة خاصة فيما يتعلق بنقل الحمولات الصغيرة. ومع ذلك، فإن الأداء المفترض قد تم عزله بسبب تشبع العامل. بالإضافة إلى أن تصميم أسلوب المراقبة PID عملية مستهلكة للوقت. حيث كانت الحاجة وقتها للنموذج والقيم المتغيرة لآلة الرفع.
ثانياً، إن أنظمة المراقبة القياسية المشوشة التي لا تستند على أنموذج تم تطبيقها في نظام آلة الرفع للمواقع و أنظمة التحكم الثابتة. وأوضحت النتيجة التجريبية، أن أسلوب المراقبة القياسية المشوش نتج عن أداء جيد لنظام التحكم الثابت. ومع ذلك، فإن نتائج إدارة الموقع غير متوافقة مع المواقع الصغيرة المرغوبة. وعملية التوفيق من الممكن أن تحسن أداء الإدارة ولكنها ربما تؤثر في بقية المواقع المرغوب فيها. أخيراً، إن أنظمة المراقبة NCTF التي لا تقوم على الأنموذج تم إقتراحها للمواقع التى تدار بأنظمة آلة الرفع بينما نظام التحكم الثابت بإستخدام أنظمة المراقبة القياسية المشوشة ظلّت كما هي طالما منحت أداء جيدا. وأوضحت النتيجة التجريبية أن أنظمة المراقبة NCTF قدمت نتائج أفضل لإدارة موقع نظام آلة الرفع بالمقارنة مع بقية أنظمة المراقبة.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Mechatronics Engineering.

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DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by footnotes giving explicit references and a bibliography is appended.

Name: Jamaludin Jalani

Signature:.. Date: . 9/6/05 ....

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PUBLICATIONS

i. **Jamaludin**, Wahyudi, Suhaimi and Iswanaini "*Development of Automatic Gantry Crane, Part1: Modeling and Parameters Identification*", Proceeding of the Sixth Industrial Seminar (IES 2004) Campus EEPIS-ITS, Surabaya Indonesia, October 12, 2004, pp. 306-311.

ii. **Jamaludin**, Wahyudi, Suhaimi and Iswanaini "*Development of Automatic Gantry Crane, Part2: Controller Design and Implementation*", Proceeding of the Sixth Industrial Seminar (IES 2004) Campus EEPIS-ITS, Surabaya Indonesia, October 12, 2004, pp. 312-315.

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a_1	system parameter
a_2	system parameter
A	curve area
b	rack damping coefficient
e	error
e_b	back emf
F	summation external forces for linear motion
g	gravity
h	maximum error rate
i	current
J	mass moment of inertia
J_m	moment inertia of motor
J_0	total of moment inertia
J_p	moment of inertia of rack-pinion
K	kinetic energy
K_0	system parameter
K_1	artificial system parameter
K_2	artificial system parameter
K_d	derivative gain
K_i	integral gain
K_g	gear ratio constant
K_{load}	kinetic energy of the load
K_m	motor constant
K_p	proportional gain
$K_{trolley}$	kinetic energy of the trolley
ℓ	length of the string
L	lagrangian
L_{ind}	inductance

m inclination of the NCT near origin

m_1 mass of the trolley

m_2 mass of the load

P potential energy

r pitch radii of rack-pinion

R resistance

t time

T summation external torques for rotational motion

T_m torque

u voltage

u_0 control input voltage

u_p difference actual error rate and NCT

u_r rated input to the actuator

v velocity of the motor

$\bar{v}_L$ velocity of the load

v_{ss} steady state velocity

$\bar{v}_T$ velocity of the trolley

$\bar{v}_{L/T}$ velocity of the load relative to the trolley

x displacement

θ angle of the string moves

$\vee$ maximum operator

$\wedge$ minimum operator

ζ damping ratio

ω_n natural frequency

α simplified object parameter

LIST OF ABBREVIATIONS

COA	Centre of Area
DAQ	Data Acquisition Card
GUI	Graphical User Interface
I/O	Input/Output
N	Negative
NB	Negative Big
NCD	Nonlinear Control Design
NCTF	Nominal Characteristic Trajectory Following
NS	Negative Small
P	Positive
PB	Positive Big
PD	Proportional Derivative
PI	Proportional Integral
PID	Proportional Integral Derivative
PS	Positive Small
PTP	Point to Point
RTW	Real-Time Workshop
TCP/IP	Transmission Control Protocol/Internet Protocol
Z	Zero

CHAPTER 1

INTRODUCTION

1.1 Background

Crane is a machine for gripping, lifting and moving loads horizontally, as well as lowering and release the gripper back, Omar (2003). These tasks are performed with the aid of hoisting mechanism that works as an integral part of the crane. Cranes are widely used in industry for transporting heavy loads and hazardous materials in shipyards, factories, nuclear installations and high building constructions. In general, there are two types of crane namely rotary cranes and gantry cranes. Rotary cranes are commonly use in shipyard and construction site. This type of crane involves rotation movement during operation. The typical gantry crane is shown in Figure 1.1.

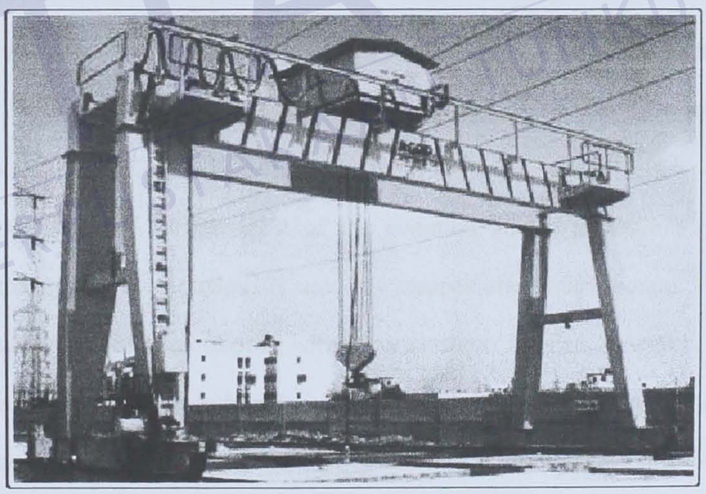

Figure 1.1: Gantry crane

The gantry crane should move loads as fast as possible without causing any excessive movement at the final position, thus it can achieve higher productivity. This type of crane incorporates a trolley which moves over the jib (girder) and translates in a horizontal plane. In some cases, the jib is mounted on another set of orthogonal railings called bridge cranes. Furthermore, the payload is attached to the trolley by a cable. The length can be varied by hoisting mechanism.

Nowadays, most of the current gantry cranes in industry are open loop systems which are operated by operators. The operators use joystick to control position in two directions of vertical and horizontal. When moving it horizontally, a constant acceleration is generated until the maximum velocity is gained. On the other hand, moving vertically is only lowering and lifting the cable, therefore the load can be removed immediately. The joysticks have analog control, which means that the amplitude of the acceleration can be controlled. When the joystick is released the trolley decelerates until it stops. Here, the performance of the gantry crane depends on the skill of the operators. The company that hired the operators needs to train them properly in order for them to work effectively and safely during gantry crane operation.

As mentioned earlier, most of the common gantry cranes are open-loop systems that swing when payload is suddenly stopped after a fast motion. The swing motion can be reduced and stopped without using the controller. However, it will be time consuming and eventually reduce the productivity of the gantry crane system. Even though the skillful operators who operate the crane, they still face some constraints such as fatigue problem. This phenomenon can cause inconsistent performance of the gantry crane systems and might cause accident.

Various attempts in controlling gantry cranes system based on open loop system were proposed. For example, open loop time optimal strategies were applied to the crane by many researchers such as Yamagashi (1974), Sakawa and Shindo (1981), Manson (1982), Auernig and Troger, (1987). They came out with poor results because open loop strategy is sensitive to the system parameters (e.g. rope length) and could not compensate for wind disturbances. Another importance of open loop strategy is the input shaping introduced by Karnopp (1992), Teo (1998) and Singhose (1997). Even though they claimed that input shaping is good in controlling the open loop system but it still faces sensitiveness to the external disturbances and parameter variations.

On the contrary, feedback control is well known to be less sensitive to disturbances and parameter variations. Hence, it is an attractive method for crane control design. Ridout (1989) developed a controller, which feeds back the trolley position, speed and load swing angle. Through this approach, the system damping can be changed during the transferring of the load. Many researchers proposed the controllers based on feedback system. For example Mita and Kanai (1979) proposed optimal control, Boustany and d'Andrea-Novel (1992) introduced adaptive control, and Cheng and Chen (1996) have developed linearization techniques. However, in general closed-loop control systems, it is designed based on the exact model and parameters of the plant. It is known that the mathematical modeling including parameters identification is complicated and time consuming due to nonlinearity dynamics of gantry crane system. Recent work on gantry crane control system was presented by Omar (2003). The author had proposed PD controller for position control and three different methods for anti-swing control namely a classical PD controller, delayed feedback technique and fuzzy logic controller. All these controllers were designed based on mathematical model of the crane except fuzzy logic controller. However, this fuzzy logic controller uses mapping method which needs delayed feedback technique before fuzzy logic controller can be designed. This strategy was time consuming because fuzzy logic controller could not be implemented directly and relied on other controller to fulfill the design.

The scope of a lab-scale gantry crane system was used in the experimental study that only considers the planar movement of trolley with fixed load and length of string. The lifting and unloading of load is not considered and the velocity of the trolley remains constant. The experimental study was implemented to identify parameters of the gantry crane system and to examine performances of the controllers.

1.2 Objective

The objective of the study is to investigate the appropriate control method for gantry crane system. The controller is expected to have simple structure, easy to design and also robust to the parameter uncertainties.

1.3 Methodology

In order to achieve the objectives of this research, the following procedures are considered:

i. The research starts with the understanding of the gantry crane background, analyzes its problems and investigates control theory which has been applied to the gantry crane system.

ii. A mathematical model of lab-scale gantry crane system is developed.

iii. Investigate the conventional control method (PID and PD controllers) which has been applied to the gantry crane system.

iv. Investigate the application of fuzzy logic controller in gantry crane system which is designed based on non-mathematical model.

v. Investigate the application of a nominal characteristic trajectory following (NCTF) controller in the gantry crane system which is also based on non-mathematical model.

vi. Real time implementation of the control algorithm is carried by xPC target kernel toolbox in MATLAB.

vii. Test the controller performances by experiments and analyze the results.

1.4 Organization of Thesis

The thesis is organized as follows:

i. Chapter 2: This chapter will explain how the gantry crane system was modeled mathematically. The mathematical modeling which consists of the model derivation and parameters identification was explained. The experimental setup is explained in detail as well as lab-scale gantry crane system description. Basically the chapter will elaborate more on parameters identification approach since the mathematical model is easily to obtain but the parameters are unknown. A series of experiments is carried out to identify the parameters of the lab-scale gantry crane. Finally, the obtained model and parameters of the gantry crane are validated.

ii. Chapter 3: In order to observe the performances of conventional controller, the design of PID and PD controllers for gantry crane system are discussed in this chapter. The position of the gantry crane is controlled by PID controller while PD controller is for controlling swing angle. Both the PID and PD controllers are tuned by nonlinear control design (NCD) blockset of

MATLAB. The NCD blockset is a tool in the MATLAB that can be used for the purpose of tuning and optimizing of controllers including PID and PD controllers. The implementation of the PID and PD controllers was also described in this chapter. Finally, the robust of the PID and PD controllers were examined through simulation.

iii. Chapter 4: The design and implementation of fuzzy logic controllers for gantry crane system are discussed in this chapter. The fuzzy logic controllers are applied to both position and anti-swing control of the gantry crane system. The performances of the fuzzy logic controllers are analyzed and concluded. The robustness of the FLC is examined through simulation

iv. Chapter 5: Since the fuzzy logic control has inconsistent result for position control of gantry crane system, a practical controller which is called nominal characteristic trajectory following (NCTF) controller is proposed and discussed in this chapter. The NCTF controller is designed based on a simple open-loop experiment of the object. The basic concept, design and implementation of the NCTF controller are explained in this chapter. The performance of the NCTF controller is analyzed and concluded. On the other hand, the fuzzy logic controller which has resulted on good performance for anti-swing control is still discussed and analyzed as well as the examination of its robust performance through simulation.

v. Chapter 6: This chapter summarizes all the results obtained in the previous chapters. New development and improvement are suggested for the future study.

CHAPTER 2

MODELING AND PARAMETERS IDENTIFICATION

2.1 Introduction

Modeling is a process of capturing the relevant information of the system. A model is developed for several reasons such as to solve a problem in short period as well as economical, to ease the manipulation of variables of the plant system and finally able to test the model if it is the best solution for the particular problem. Specifically, plant model is very important for designing a control system. Most of the controllers need a model in design process, Belanger (1995). Usually, the mathematical model is applied to develop a model by applying differential equation for the continuous-times system or difference equation for discrete-time system. Hence, in this chapter the model of gantry crane system is developed and explained mathematically. Moreover, the parameters identification is introduced to obtain unknown parameters. A series of experiments are conducted to identify the parameters of the lab-scale gantry crane. Finally, the obtained model and parameters of the lab-scale gantry crane is validated.

2.2 System description

The lab-scaled of gantry crane system was designed by Suhaimi and Iswanaini (2003) and illustrated in Figure 2.1. In general, the designed lab-scale gantry crane system has three main parts that are trolley system, body frame, and servo amplifier. The trolley system consists of linear bearing, trolley, potentiometers, dc motor, gear and string/load, while body frame consists of rack and shaft.

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