A THREE-DIMENSIONAL GANTRY CRANE SYSTEM USING PROPORTIONAL-DERIVATIVE CONTROLLER WITH INPUT SHAPING APPROACH

ARTDHITA FAJAR PRATIWI

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To my beloved parents

SUHARTO and SURYATI,

my sisters

NOVIA KUSUMA SARI and GHINA LULU FADIYAH,

my big family

and my beloved friend

NOOR ASHIKIN MOHD RAZALI.

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ABSTRACT

This project presents the development of a dynamic model and an efficient control algorithm of a three-dimensional (3D) gantry crane with payload. A 3D gantry crane with simultaneous travelling, traversing, and hoisting is considered. The dynamic equations of motion of the gantry crane system are derived using the Lagrange's method and represented in nonlinear differential equations. Simulation is performed using Matlab/Simulink to investigate the dynamic behaviour of the system both in time and frequency domains. System responses including positions of rail, trolley and payload, and payload sway angle are obtained and analysed. For control of the 3D gantry crane, a proportional-derivative controller with input shaping for input tracking and reduction of payload sway is proposed. The performances of the controller are examined in terms of input tracking capability, level of sway reduction, and robustness of the input shaper. Simulation and experimental exercises using a lab-scaled 3D gantry crane show that the proposed controller is capable of minimising the payload sway while achieving satisfactory input tracking performance. The controller is also shown to be robust up to 50 % error tolerance in the sway frequencies. Moreover, with the experimental results, it is demonstrated that the proposed control is practical and easy to implement in real-time.

ABSTRAK

Projek ini memaparkan pembangunan model dinamik dan kawalan cekap sebuah kren gantri tiga-dimensi (3D) dengan beban. Kren gantri 3D dengan pergerakan serentak secara mendatar, melintang, dan mengangkat telah diambil kira dalam projek ini. Persamaan dinamik pergerakan sistem kren gantri telah diperolehi dengan menggunakan kaedah Lagrange dan diwakilkan dalam bentuk persamaan pembezaan tak lelurus. Simulasi telah dilakukan dengan menggunakan Matlab/Simulink untuk menyelidik sifat-sifat dinamik sistem dalam domain masa dan frekuensi. Tindak balas sistem termasuk kedudukan rel, troli dan beban, dan sudut ayunan beban telah diperolehi dan dianalisa. Bagi kawalan kren gantri 3D ini, sebuah sistem kawalan terbitan-berkadaran dengan pembentukan masukan untuk penjejakan masukan dan pengurangan ayunan beban telah dicadangkan. Prestasi pengawal diperiksa dalam aspek keupayaan penjejakan masukan, aras pengurangan ayunan, dan ketegapan pada pembentuk masukan. Ujian simulasi dan eksperimen dengan menggunakan kren gantri 3D dalam skala makmal menunjukkan bahawa sistem pengawal yang dicadangkan berkeupayaan mengurangi ayunan beban sementara ia juga dapat mencapai prestasi penjejakan masukan yang memuaskan. Sistem pengawal juga menunjukkan sifat yang tegap sehingga 50 % toleransi ralat dalam frekueansi ayunannya. Disamping itu, berdasarkan keputusan eksperimen, ia menunjukkan sistem kawalan yang dicadangkan tersebut adalah pratikal dan mudah untuk diaplikasikan dalam masa sebenar.

TABLE OF CONTENTS

LIST OF TABLE

LIST OF FIGURE

CHAPTER 1

INTRODUCTION

1.1 Background

Cranes are increasingly used in transportation and construction. Those cranes occupy a crucial role within industries. The cranes are used to perform important and challenging manipulation tasks such as construction of bridges, dams, buildings, and high-rise towers. Cranes are also indispensable in commerce, as the cranes are widely used to transport heavy loads and hazardous materials in shipyard, factories and warehouse. Energy exploration and production are also highly dependent on cranes where the cranes are used on oil platforms, in refineries and nuclear power plants.

A crane consists of a hoisting mechanism comprises of a hoisting line and a hook and a support mechanism which is trolley-girder, trolley-jib or a boom. The cable-hook-payload assembly is suspended from a point on the support mechanism. The support mechanism moves the suspension point around the crane workspace. The hoisting mechanism lifts and lowers the payload to avoid obstacles in the path and deposit the payload at the target point.

Cranes can be classified based on the degree of freedom the support mechanism offers the suspension point (Abdel-Rahman *et.al.*, 2003). The support mechanism in a gantry (overhead) crane is composed of a trolley moving over the girder. In some gantry cranes, this girder (bridge) is in turn mounted on another set of orthogonal railings in the horizontal plane. This setup allows the suspension point one or two rectilinear translations in the horizontal plane. In a rotary (tower) crane, the girder (jib) rotates in the horizontal plane about fixed vertical axis. This allows the suspension point two motion patterns in the horizontal plane, a translation and a rotation. The suspension point in a boom crane is fixed at the end of the boom. It has two motion patterns: rotation around two orthogonal axes located at the base of the boom.

A gantry crane is one of the widely used cranes in factories and warehouses (Butler *et. al.*, 1991). The control objective is to move the trolley to a required position as fast as possible with low payload oscillation. Moreover, payloads are required not to oscillate during movement. Speed is an important issue in the industry as it translates into the productivity and efficiency of the system. However, it is well known that fast manoeuvres tend to excite sway angles of the hoisting line, and this can result in significant residual sway that degrades the overall performance of the system. At very low speeds, the payload's sways are not significant and can be ignored. However, at higher speed, these sway angles become larger and significant, and cause the payload hard to settle down during motion and unloading. The overall system performance will be affected when significant sways angle of the payload occurs during and after the movement of a gantry crane. This is a very severe problem especially for the applications in the industries that require high positioning accuracy, small swing angle, short transportation time and high safety (Hua and Shine, 2007). It has also been reported that hoisting increases the sway angles and therefore affects the system performance (Singhose *et. al.*, 2000). With the size of gantry cranes becoming larger and the motion expected to be faster, the process of controlling them become difficult. Moreover, gantry cranes have to be operated under different conditions. The complexity of the problem increases for a three dimensional (3D) gantry crane as more parameters need to be considered and control simultaneously. Due to these requirements, an accurate model and efficient controllers need to be developed and investigated.

1.2 Statement of the Problem

3D gantry crane systems experience significant payload's sway when commanded to perform fast motion. The fast manoeuvres tend to excite sway angles of hoisting line and this can result in significant residual sway that degrades the overall performance of the system.

1.3 Objectives of the Study

The study focuses on the issues of modelling and control of a 3D gantry crane. The main objectives of the study are as follows:

(a) To obtain a dynamic model of a 3D gantry crane based on a new assumption.
(b) To study the dynamic behaviour of the 3D gantry crane.
(c) To develop an efficient and practical control scheme for input tracking control and sway control of the crane system.
(d) To investigate the real-time implementation of the proposed controller on 3D gantry crane.

1.4 Scope of Works

In this work, a 3D gantry crane is considered. Dynamic modelling of the system is developed using Lagrange's equation. Matlab and Simulink are used to simulate and investigate the behaviour of the system. Performance of the dynamic model is verified with the previously published model. In the development of control algorithms, PD controller with input shaping technique that consists of open-loop and closed-loop control strategies is designed and investigated. Simulation using the developed dynamic model is performed to investigate the performances of the controller in terms of input tracking capability and sway reduction of the payload.

The real-time performance of the proposed controller is verified with a lab-scaled 3D gantry crane system.

1.5 Thesis Contributions

From the discussion in the literature review, it is evidenced that there are several outstanding issues especially related to control of a 3D gantry crane system. By focusing on these issues, the thesis makes several contributions in modelling and control of the system. These include:

(a) Modelling and investigations of the dynamic behaviour of a 3D gantry crane
(b) Development of PD controller with input shaping technique for input tracking and payload sway reduction of the system.
(c) Development of a practical control algorithm for a 3D gantry crane.
(d) Development and investigation of PD controller with input shaping technique that minimise the effects of hoisting on the payload sway.

The contributions are reflected with several publications as listed in Appendix A.

1.6 Thesis Organisation

The thesis is organised as follows. Chapter 2 provides a review of the previous modelling and control for gantry cranes. Chapter 3 describes the 3D gantry crane system used in this study and the development of a dynamic model of the system. Chapter 4 focuses on the development of the proposed control algorithm that is verified within simulation and experimental exercises. The simulation results using the proposed controller and performance analysis are presented in Chapter 5. Chapter 6 discusses the real-time implementation of the proposed controller with experimental results. Finally, the conclusions of the thesis as well as the research direction of the work are presented in Chapter 7.

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