POSITION AND SWAY CONTROL OF A NON LINEAR TOWER CRANE SYSTEM USING INPUT SHAPING TECHNIQUES

ALHASSAN AHMAD BALA

A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Mechatronics & Automatic control)

Faculty Electrical Engineering
Universiti Teknologi Malaysia

.

DECEMBER 2015

To my beloved parents and the former Governor of Kano state, Engr. (Dr.) Rabiu Musa Kwankwaso.

ACKNOWLEDGEMENT

I am grateful and thankful to Allah (S.W.T) for giving me the health and courage to successfully undertake this thesis. I would also like to thank my supervisor, Assoc. Prof. Zaharuddin Mohamed, for continuous guidance and encourage throughout this period. Also, I would like to thank the Control and Mechatronics PhD students at Universiti Teknologi Malaysia (UTM) particular Amiru Bature, Auwalu Abdullahi and Ado Haruna for their kind supports.

ABSTRACT

Crane systems are the most widely used tools in the shipping yards and construction sites to transport goods from one point to another. The emergence of high riser-building, encourages the use of modern systems particularly tower crane systems to conveniently execute various tasks within the shortest possible time. However, those systems suffered greatly from undesired swinging during the process. Conversely, this significantly posed problems to the systems, resulting to inaccurate positioning of the payload, unease of operation by the human operator and in some cases even damage to the system. This paper investigates the performance of input shaping techniques for sway control of a tower crane system. Unlike the conventional optimal controllers, input shaping is simple to design and cost effective as it does not require feedback sensors. Several input shapers were implemented and their performances were compared which are useful for future sway control designs. The nonlinear model of the system was derived using the Lagrange's energy equation. To investigate the performance and robustness of input shaping techniques, zero vibration (ZV), zero vibration derivative (ZVD), zero vibration derivative-derivative (ZVDD) and zero vibration derivative-derivative-derivative (ZVDDD) were proposed with a constant cable dimension in an open loop configuration. Simulation and experimental results have shown that ZVDDD with the slowest response has the highest level of sway reduction and robustness to modelling errors as compared to ZV, ZVD and ZVDD. Moreover, to improve the response, a negative amplitude zero vibration derivative-derivative (NAZVDD) was designed and its performance was compared with ZVDD. It is found that NAZVDD gives a faster response with small robustness penalty as compared to ZVDD.

ABSTRAK

Sistem Crane adalah alat yang paling banyak digunakan di kilometer perkapalan dan tapak pembinaan untuk mengangkut barang-barang dari satu titik yang lain. Kemunculan tinggi riser-bangunan, menggalakkan penggunaan sistem moden terutamanya menara sistem kren untuk mudah melaksanakan pelbagai tugas dalam masa yang sesingkat mungkin. Walau bagaimanapun, sistem tersebut menderita akibat berayun yang tidak diingini semasa proses tersebut. Sebaliknya, ini menimbulkan masalah dengan ketara kepada sistem, mengakibatkan kepada kedudukan yang tidak tepat muatan, rasa tidak senang operasi oleh pengendali manusia dan dalam beberapa kes walaupun kerosakan kepada sistem. Kertas ini mengkaji prestasi teknik membentuk input untuk kawalan kekuasaan sistem kren menara. Tidak seperti pengawal optimum konvensional, membentuk input adalah mudah untuk mereka bentuk dan kos efektif kerana ia tidak memerlukan sensor maklum balas. Beberapa pembentuk input telah dilaksanakan dan persembahan mereka berbanding yang berguna untuk reka bentuk kawalan bergoyang masa depan. Model tak linear sistem itu diperoleh dengan menggunakan persamaan tenaga Lagrange. Untuk menyiasat prestasi dan keteguhan teknik input membentuk, sifar getaran (ZV), sifar getaran terbitan (ZVD), sifar getaran derivatif-derivatif (ZVDD) dan getaran sifar derivatif-derivatif-derivatif (ZVDDD) telah dicadangkan dengan satu dimensi kabel berterusan dalam konfigurasi gelung terbuka. Simulasi dan keputusan eksperimen telah menunjukkan bahawa ZVDDD dengan jawapan yang paling perlahan mempunyai tahap tertinggi mengurangkan gegaran dan keteguhan kepada kesilapan pemodelan berbanding ZV, ZVD dan ZVDD.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

MATLAB	-	Matrix Laboratory
ZV	-	Positive zero vibration
ZVD	-	Positive zero vibration derivative
ZVDD	-	Positive zero vibration derivative-derivative
ZVDDD	-	Positive zero vibration derivative-derivative-derivative
NAZVDD	-	Negative amplitude zero vibration derivative-derivative
PI	-	Proportional-integral

CHAPTER 1

INTRODUCTION

1.1 Introduction

Crane systems are the most widely used tools in the industries, ware-houses, shipping yards, construction sites, mining sites, power plants, among others, to perform manipulations or guides products to be transported from one point to another (Zrni et al., 2014; Renuka & Mathew, 2013). The ever increasing need of products of huge sizes, as well as the emergence of high risers, encourages the use of modern systems particularly tower crane systems to conveniently execute various tasks within the shortest possible time. There are commonly three different kinds of crane systems depending upon the application; gantry cranes, tower cranes and boom cranes (Izzuan et al. 2013).

Gantry cranes (see Figure 1.1) consist of a moving element (trolley) which moves along a horizontal rail (jib). Usually the jib is supported by pairs of legs at both ends. When the trolley can only moves in one direction, the crane is known as two dimensional (2D) and when it moves in two directions, it is known as three dimensional (3D). Due to their simple operation and less cost, gantry cranes are commonly used in the industries, mining sites, shipping yards, transport industries etc (Al-mousa and Pratt 2000)

Figure 1.1 Gantry crane system

A rotary (also tower) cranes, consist of jib that moves (rotates) horizontally about a fixed vertical support. The cart can move either linearly as the case of gantry or rotates within the operating range of the crane. The payload is connected to the trolley by a set of cables (see Figure 1.2). Because of these additional flexibility, rotary cranes are commonly used in the construction sites and transport industry (Masoud 2003)

Figure 1.2 Tower crane system

Boom cranes as shown in Figure 1.3, consists of a rotating base where the boom is connected. The payload is attached to the tip of the boom by a set of cables and pulleys. As the base rotates, the boom tip can be placed at any point horizontally within the reach of the crane. Boom cranes offers more flexibility than gantry crane and tower cranes of the same capacity. They are usually mounted on ships or harbour pavements to transfer cargo between offshore structures and ships (Masoud 2003)

Figure 1.3 Boom crane system

However, those systems suffered greatly from undesired deflection and swinging during the process. Conversely, these detrimental phenomenon, significantly posed problems to the systems, resulting to inaccurate positioning of the payload, unease of operation by the human operator and in some cases even a damage to the system (Renuka and Mathew 2013; Yoon et al., 2014).

On the other hand, the need to provide suitable working condition for the human operator and also to minimized maintenance cost due to system failure, thousands of researchers engaged in studying the dynamic behaviour of the crane system and proposed various control strategies in order to achieve optimum performance of the crane systems (Singhose 2009). In this research work, a tower crane system is considered.

1.2 Problem Statement

The major concern with the operation of crane systems is to transport, load and unload the load easily from one point to another as quickly as possible. However, the critical issue that hinders the efficiency of the crane system is the oscillation of the payload. This persistent swinging constitutes; inaccurate positioning of the payload, longer time of task completion, difficult automation by the human operator and damage to the system or the operating environment.

1.3 Objectives

The main objectives of this research work are as follows:

a) To design positive and negative input shapers for sway control of a tower crane.
b) To design a combined closed-loop and input shaping control.
c) To implement and investigate the effectiveness of the controller using simulation and experiment.

1.4 Scope of Study

This project is limited to:

a) A tower crane system
b) Design of positive and negative input shapers
c) MATLAB software for the simulation of a tower crane nonlinear model
d) Implementation of the controllers in real-time on a lab-scale tower crane.

1.5 Significances and Original Contributions of This Study

This work made several contributions to the improvement of the nonlinear tower cranes some of which have been published (see Appendix A). This includes:

a) Study of the dynamic behaviour of the tower crane
b) Designed of positive and negative input shaping control algorithms for sway reduction of the payload.

1.6 Thesis Structure and Organization

This research work is organised as follows. Chapter 1 elaborates the general overview of the crane systems, Chapter 2 provides the review of the related literature on the crane systems in relation to the modelling and control of the cranes. Chapter 3 describes the description of the tower crane, derivation of the mathematical model of the system as well as the control design. Chapter 4 discusses implementation of input shaping schemes on tower crane system, chapter 5 presents and discusses the obtained results. Finally, Chapter 6 presents the conclusion and the future recommendations.

REFERENCES

Al-mousa, A.A. & Pratt, T., 2000. *Control of Rotary Cranes Using Fuzzy Logic and Time-Delayed Position Feedback Control*. Virginia Polytechnic Institute and State University.

Bartolini, G., Pisano, A. & Usai, E., 2002. Second-order sliding-mode control of container cranes. *Automatica*, 38(10), pp.1783–1790.

Blackburn, D. et al., 2010. Command Shaping for Nonlinear Crane Dynamics. *Journal of Vibration and Control*, 16(477), pp.1–25.

Chen, H.C.H., Gao, B.G.B. & Zhang, X.Z.X., 2005. Dynamical modelling and nonlinear control of a 3D crane. *2005 International Conference on Control and Automation*, 2, pp.1085–1090.

Hyla, P., 2012. The Crane Control Systems : A Survey. *IEEE*, pp.505–509.

Ismail, R.M.T.R. et al., 2009. Nonlinear Dynamic Modelling and Analysis of a 3-D Overhead Gantry Crane System with Payload Variation. *Third UKSim European Symposium on Computer Modeling and Simulation*, pp.350–354.

Izzuan, H. et al., 2013. Dynamic Behaviour of a Nonlinear Gantry Crane System. *Procedia Technology*, pp.419–425.

Jaafar, H.I. & Sulaima, M.F., 2013. Optimal PID Controller Parameters for Nonlinear Gantry Crane System via MOPSO Technique. *IEEE Conference on Sustainable Utilization and Development in Engineering and Technology*, pp.86–91.

Ju, F., Choo, Y.S. & Cui, F.S., 2006. Dynamic response of tower crane induced by the pendulum motion of the payload. *International Journal of Solids and Structures*, 43, pp.376–389.

Kuo, P., Hosein, A. & Farmanborda, M.S., 2015. Nonlinear output feedback control of a flexible link using adaptive neural network : stability analysis. *Journal of Vibration and Control*, 19(11), pp.1674–1689.

Le, T.A. et al., 2012. Nonlinear controls of a rotating tower crane in conjunction with trolley motion. *Systems and Control Engineering*, 227(5), pp.451–460.

Lee, K. et al., 1997. Variable structure control applied to underactuated robots Variable structure control applied to underactuated robots. *Robotica*, 15(03), pp.313–318.

Maged, M. & Shehata, G., 2014. Anti-sway control of a tower crane using inverse dynamics. *IEEE*, 14(8), pp.978–984.

Maleki, E. & Singhose, W., 2010. Dynamics and Zero Vibration Input Shaping Control of a Small-Scale Boom Crane. *2010 American Control Conference*, pp.2296–2301.

Masoud, A., 2003. Dynamics and Control of Cranes : A Review. *Vibration and Control*, 9, pp.863–908.

Mohamed, Z., 2008. Hybrid Input Shaping and Feedback Control Schemes of a Flexible Robot Manipulator. *Proceedings of the 17th World Congress The International Federation of Automatic Control*, pp.11714–11719.

Nafa, F., Labiod, S. & Chekireb, H., 2013. Direct adaptive fuzzy sliding mode decoupling control for a class of underactuated mechanical systems. *Turkish Journal of Electrical Engineering & Computer Sciences*, 21, pp.1615–1630.

Ngo, Q.H. & Hong, K., 2012. Sliding-Mode Antisway Control of an Offshore Container Crane. *ASME Transactions on Mechatronics*, 17(2), pp.201–209.

Poty, A. et al., 2003. ZV and ZVD shapers for explicit fractional derivative systems. *11th International Conference on Advanced Robotics*, (July 2015), pp.1–7.

Renuka, V.S. & Mathew, A.T., 2013. Precise Modelling of a Gantry Crane System Including Friction , 3D Angular Swing and Hoisting Cable Flexibility. *International Journal on Theoretical and Applied Research in Mechanical Engineering (IJTARME)*, 2, pp.119–125.

Singhose, W., 2009. Command shaping for flexible systems: A review of the first 50 years. *International Journal of Precision Engineering and Manufacturing*, 10(4), pp.153–168.

Smith, O.J.., 1957. Posicast Control of Darnped Oscillatory Systems. *proceedings of*

IRE, pp.1249–1255.

Smoczek, J., 2014. Fuzzy crane control with sensorless payload deflection feedback for vibration reduction. *Mechanical Systems and Signal Processing*, 46(1), pp.70–81.

Tai, C. & Andrew, K., 2014. Review of Control and Sensor System of Flexible Manipulator. *Journal of Intelligent Robot System*, 77, pp.187–213.

Taylor, P., Li, X. & Yu, W., 2012. Intelligent Automation & Soft Computing Anti-Swing Control For An Overhead Crane With Fuzzy Compensation. *Intelligent Automation & Soft Computing*, 18(1), pp.1–11.

Tuan, L.A. et al., 2014. Second-Order Sliding Mode Control of a 3D Overhead Crane with Uncertain System Parameters. *International Journal of Precision Engineering and Manufacturing*, 15(5), pp.811–819.

Tuan, L.A. & Lee, S., 2013. Sliding mode controls of double-pendulum crane systems. *Journal of Mechanical Science and Technology*, 27(6), pp.1863–1873.

Vaughan, J., Maleki, E. & Singhose, W., 2010. Advantages of Using Command Shaping Over Feedback for Crane Control. *2010 American Control Conference*, pp.2308–2313.

Vaughan, J., Yano, a & Singhose, W.E., 2009. Robust Negative Input Shapers for Vibration Suppression. *Journal of Dynamic Systems, Measurement, and Control*, 131(3), p.31014.

Vaughan, J., Yano, A. & Singhose, W., 2008a. Performance comparison of robust input shapers. *2008 American Control Conference*, pp.3257–3262.

Vaughan, J., Yano, A. & Singhose, W., 2007. Performance comparison of robust negative input shapers. *Proceedings of the American Control Conference*, pp.2111–2116.

Vaughan, J., Yano, A. & Singhose, W., 2008b. Performance comparison of robust negative input shapers. *Proceedings of the American Control Conference*, 315, pp.3257–3262.

Vyhlídal, T., Kučera, V. & Hromčík, M., 2013. Automatica Signal shaper with a distributed delay : Spectral analysis and design. *Automatica*, 49(11), pp.3484–

3489.

Yoon, J. et al., 2014. Control of Crane Payloads That Bounce During Hoisting. *IEEE Transactions on Control Systems Technology*, 22(3), pp.1233–1238.

Zain, M.Z. & Tokhi, M.O., 2006. Hybrid learning control schemes with input shaping of a flexible manipulator system. *Mechatronics*, 16, pp.209–219.

Zrni, N.Đ., Ga, V.M. & Bo, S.M., 2014. Dynamic responses of a gantry crane system due to a moving body considered as moving oscillator. *Archives of Civil and Mechanical Engineering*, pp.2–9.