INPUT SHAPING-BASED CONTROL SCHEMES FOR A THREE DIMENSIONAL GANTRY CRANE

MOHAMMAD JAVAD MAGHSOUDI

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Electrical Engineering)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

APRIL 2015

DEDICATION

To my dearly beloved wife, Fatemeh for her support and encouragement.
To my lovely daughter Saba for making my life beautiful.
To my dearest parents, for their love and blessing.

ACKNOWLEDGEMENT

First and foremost, praise and thank be to Almighty Allah, the most Gracious and the most Merciful.

I would like to express my sincere appreciation to my main supervisor Assoc. Prof. Dr. Zaharuddin Mohamed for his kindly guidance, masterly supervision, worthwhile advice and friendly assistance in this research and preparation of this thesis. My deepest gratitude also goes to my second supervisor, Dr. Abdul Rashid Husain for his kind support.

I would like to thank my beloved wife, Fatemeh, for her love, patience, understanding and unwavering support and to my lovely daughter, Saba for cheering up my day.

I would like to thank my parents, brothers and sisters for all their supports and encouragements.

Last but not the least, I would also like to thank the Malaysian Ministry of Education for their financial support granted through Malaysian International Scholarship.

ABSTRACT

The motion induced sway of oscillatory systems such as gantry cranes may decrease the efficiency of production lines. In this thesis, modelling and development of input shaping-based control schemes for a three dimensional (3D) lab-scaled gantry crane are proposed. Several input shaping schemes are investigated in open and closed-loop systems. The controller performances are investigated in terms of trolley position and sway responses of the 3D crane. Firstly, a new distributed Delay Zero Vibration (DZV) shaper is implemented and compared with Zero Vibration (ZV) shaper and Zero Vibration Derivative (ZVD) shaper. Simulation and experimental results show that all the shapers are able to reduce payload sway significantly while maintaining desired position response specifications. Robustness tests with ±20% error in natural frequency show that DZV shaper exhibits asymmetric robustness behaviour as compared to ZV and ZVD shapers. Secondly, as analytical technique could only provide good performance for linear systems, meta-heuristic based input shaper is proposed to reduce sway of a gantry crane which is a nonlinear system. The results show that designing meta-heuristic-based input shapers provides 30% to 50% improvement as compared to the analytical-based shapers. Subsequently, a particle swarm optimization based optimal performance control scheme is developed in closed-loop system. Simulation and experimental results demonstrate that the controller gives zero overshoot with 60% and 20% improvements in settling time and integrated absolute error value of position response respectively, as compared to a specific designed PID-PID anti swing controller for the lab-scaled gantry crane. It is found that crane control with changing cable length is still a problem to be solved. An adaptive input shaping control scheme that can adapt to variation of cable’s length is developed. Simulation with real crane dimensions and experimental results verify that the controller provides 50% reduction in payload sway for different operational commands with hoisting as compared to the average travel length approach.

ABSTRAK

Ayunan hasil pergerakan sistem berayun seperti kren gantri akan mengurangkan keberkesanan proses pembuatan. Tesis ini membentangkan pemodelan dan pembangunan skema kawalan berasaskan pembentuk masukan untuk kren gantri tiga dimensi (3D) berskala makmal. Beberapa skema pembentuk masukan telah dikaji dalam sistem gelung buka dan gelung tutup. Prestasi pengawal dikaji berdasarkan sambutan kedudukan troli dan ayunan kren 3D. Pertama, pembentuk Getaran Sifar dengan Lengah teragih (DZV) digunakan dan dibandingkan dengan pembentuk Getaran Sifar (ZV) dan pembentuk Pembezaan Getaran Sifar (ZVD). Keputusan simulasi dan eksperimen menunjukkan semua pembentuk berupaya mengurangkan ayunan beban secara berkesan disamping mencapai spesifikasi sambutan masa yang diperlukan. Ujikaji ketegapan dengan ±20% ralat dalam frekuensi tabii menunjukkan pembentuk DZV mempunyai ciri-ciri ketegapan yang tidak simetri berbanding pembentuk ZV dan DZV. Disebabkan kaedah analitik hanya dapat memberikan keputusan yang baik untuk sistem lelurus, pembentuk masukan berasaskan meta-heuristik dicadangkan untuk mengurangkan ayunan kren gantri. Keputusan menunjukkan pembentuk masukan berasaskan meta-heuristik menghasilkan ayunan yang lebih baik dalam julat 30% hingga 50% berbanding pembentuk masukan berasaskan analitik. Kemudian, skema kawalan prestasi optima berasaskan pengoptimuman kerumunan zarah dibangunkan dalam sistem gelung tutup. Keputusan simulasi dan eksperimen menunjukkan bahawa pengawal tersebut menghasilkan sambutan kedudukan dengan lajakan sifar dan pembaikan sebanyak 60% dan 20% dalam masa menetap dan nilai ralat purata kamiran berbanding pangawal anti-ayunan PID-PID. Disebabkan kawalan kren dengan perubahan panjang kabel masih merupakan masalah yang perlu diselesaikan, skema kawalan pembentuk masukan penyesuaian yang berupaya untuk menyesuaikan kepada perubahan panjang kabel dibangunkan. Keputusan simulasi dalam dimensi kren sebenar dan eksperimen menunjukkan bahawa pengawal ini berupaya menghasilkan pengurangan ayunan beban sebanyak 50% berbanding kaedah panjang perjalanan purata untuk berbagai jenis operasi kren.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

A_j - amplitude of the j^{th} impulse

D - initial amplitude of DZV delay

F_x - force driving the moving rail

F_y - force driving the trolley

F_z - force lifting the payload

G_i - position of the best particle thus far in the entire swarm

K_d - derivative gain

K_i - integral gain

K_p - proportional gain

P - local best position of the particle

T - reaction force in the payload rope acting on the trolley

T_x - components of the force T

T_y - components of the force T

T_z - components of the force T

V_i - the present velocity of the particle

X_{des} - desired position

X_i - the present position of the particle

a_{c1} - acceleration constant

a_{c2} - acceleration constant

$e(t)$ - system error

f_x, f_y, f_z - corresponding friction forces

g - gravitational constant

i_w - inertia weight

l - length of the lift-line

m_p - payload mass

m_r - moving rail

m_t - trolley mass (including gear box, encoders and DC motor)

r_1 - positive random number produced by a uniform distribution

r_2 - positive random number produced by a uniform distribution

t_0 - time of the impulse

t_j - time of the j^{th} impulse

t_m - time of the last impulse

x - delay input

y - delay output

α - angle of lift-line with Y axis

β - angle between negative part of Z axis and projection of the payload rope onto the XZ plane

$\delta(t)$ - dirac delta function

ζ - damping ratio of the system

ψ - maximum range of delay

$\omega(\varepsilon)$ - delay distribution over the interval $[0,\psi]$

ω_n - natural frequency

LIST OF ABBREVIATIONS

3D - Three-dimensional
ATL - Average travel length
DC - Direct current
DZV - Distributed delay Zero Vibration
IAE - Integrated Absolute Error
MAX - Maximum
MIMO - Multi-Input Multi-Output
PC - Personal Computer
PD - Proportional Derivative
PID - proportional-Integral-Derivative
PSO - Particle Swarm Optimization
UM - Unity Magnitude
ZV - Zero Vibration
ZVD - Zero Vibration Derivative

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

Generally, role of crane in human life is very important. Cranes are mostly utilized in construction of structures like bridges, dams, buildings, and high-rise towers. They are used for transportation of heavy loads and hazardous materials in shipyard, factories and warehouses. Cranes are also used in energy-based industries such as nuclear power plants and oil platforms in refineries. The task of a crane is to lift a load from a source place and transfer it to a target place. For this purpose, the mechanism of a crane should consist of a hoisting system including hoisting line and a hook for vertical movements of the load. Moreover, it needs a support mechanism which is cart-girder, cart-jib or a boom that moves the load around the crane workspace in horizontal space. It should be mentioned that there are different type of cranes such as gantry, overhead, jib, tower and boom cranes (Abdel-Rahman *et al.*, 2003). For this study a gantry crane is considered as this is one of the widely used cranes in factories and warehouses (Butler *et al.*, 1991).

One of the significant factors affecting productivity and efficiency of the industrial systems is speed. However, it is obvious that for a flexible system such as a gantry crane increasing the speed of manoeuvres cause the flexible system to oscillate more. This oscillation can result in considerable residual sway that negatively affects performance of the systems (Gholabi *et al.*, 2013). At low speeds, the payload's sways are not considerable and can be neglected. However, at higher speed, these sway angles prevent the payload to settle down during movement and unloading. This problem will be crucial particularly for industrial applications where operators should manipulate the cranes (Peng *et al.*, 2012). To address the mentioned issues, an efficient controller should be designed to improve the system performance.

1.2 Statement of the Problem

To increase the production speed the commands to the crane should be fast but this type of commands causes undesirable residual oscillation of payload in three dimensional (3D) gantry cranes. This low damped sway definitely decreases the efficiency of production line and may cause some serious damages to the production area.

1.3 Objectives of the Study

The work focuses mainly on the control of a 3D gantry crane. The main objectives of the study are as follows:

(a) To implement and investigate a new input shaping technique on a 3D gantry crane
(b) To design and implement meta-heuristic based input shapers for a non-simplified model of a 3D gantry crane
(c) To design and implement a PSO-based PID controller to cater two control objectives including fast and accurate positioning and low payload sway
(d) To design and implement an open-loop adaptive input shaping controller for the 3D crane with varying cable lengths

1.4 Scope of Works

This work has been conducted within the following scope:

1) Matlab and Simulink are used to simulate and investigate the behaviour of the system
2) Experiments are conducted based on a lab-scaled 3D gantry crane
3) The cable is considered to be inextensible
4) Horizontal movements are restricted to 55 cm and hoisting range is between 0-75 *cm*
5) ZV, ZVD, UM-ZV, UM-ZVD and DZV shapers are considered as input shapers
6) PSO is considered in the development of a meta-heuristic based input shaping scheme
7) PID controller is utilized for closed-loop control design
8) Input is limited based on movement’s restrictions of the lab-scaled gantry crane
9) Maximum input for all three directions is considered as 1 N.
10) Cable length is the only variable characteristic of the crane

1.5 Thesis Contributions

This study may have several contributions in modelling and control of the system as follows:

(a) Development of a DZV based control scheme for payload sway control of a 3D gantry crane

(b) Development of a meta-heuristic based input shapers for a non-simplified model of a 3D gantry crane

(c) Development of a PSO-based PID controller including an input shaper for input tracking and payload sway reduction of the system.

(d) Development of an adaptive input shaping controller for handling varying cable lengths

1.6 Thesis Organisation

This thesis is organised as follows. Chapter 2 provides a review of the existing modelling and control for a 3D gantry crane. Chapter 3 describes research methodology of the current study. Chapter 4 describes the 3D gantry crane system considered in this study and incorporating payload’s damping, and dead zone of actuator into the dynamic model. Experimental results are presented for verification and assessment of the developed model. Also, implementation of DZV shaper for control of the 3D gantry crane is described. Development of a PSO-based input shaping scheme for payload sway control of the 3D gantry crane is described in chapter 5. Moreover, an optimal performance controller including PID control algorithm and input shaping techniques is also proposed in chapter 5. Adaptive input shaping scheme is proposed in Chapter 6. Finally, the conclusions of the thesis as well as the research direction of the work are presented in Chapter 7.

REFERENCES

Abdel-Rahman, E. M., Nayfeh, A. H. and Masoud, Z. N. (2003). Dynamics and Control of Cranes: A Review. *Journal of Vibration and Control*. 9(7), 863-908.

Abe, A. (2009). Trajectory Planning for Residual Vibration Suppression of a Two-Link Rigid-Flexible Manipulator Considering Large Deformation. *Mechanism and Machine Theory*. 44(9), 1627-1639.

Alam, M. S. and Tokhi, M. O. (2007a). Design of a Command Shaper for Vibration Control of Flexible Systems: A Genetic Algorithm Optimisation Approach. *Low Frequency Noise, Vibration and Active Control*. 26(4), 295-310.

Alam, M. S. and Tokhi, M. O. (2007b). Design of Command Shaper using Gain-Delay Units and Particle Swarm Optimisation Algorithm for Vibration Control of Flexible Systems. *International Journal of Acoustics and Vibration*. 12(3), 99-108.

Alam, M. S. and Tokhi, M. O. (2008a). Designing Feedforward Command Shapers with Multi-Objective Genetic Optimisation for Vibration Control of a Single-Link Flexible Manipulator. *Engineering Applications of Artificial Intelligence*. 21(2), 229-246.

Alam, M. S. and Tokhi, M. O. (2008b). Hybrid Fuzzy Logic Control with Genetic Optimisation for a Single-Link Flexible Manipulator. *Engineering Applications of Artificial Intelligence*. 21(6), 858-873.

Alam, M. S. and Tokhi, M. O. (2009). Selection and Designing of Command Shaper for Vibration Control of Flexible Manipulators: A Multi-Objective Optimization Approach. *International Journal of Acoustics and Vibration*. 14(4), 179-188.

Aldebrez, F. M., Alam, M. S. and Tokhi, M. O. (2005). Input-Shaping with GA-Tuned PID for Target Tracking and Vibration Reduction. *Proceedings of IEEE International Symposium on Intelligent Control and 13th IEEE*

Mediterranean Conference on Control and Automation. Limassol, Cyprus, 485-490.

Aldebrez, F. M., Alam, M. S. and Tokhi, M. O. (2006). Hybrid Control Scheme for Tracking Performance of a Flexible System. *International Conference on Climbing and Walking Robots and the Support Technologies for Mobile Machines*. London, UK, 543-550.

Algarni, A. Z., Moustafa, K. A. F. and Nizami, S. (1995). Optimal-Control of Overhead Cranes. *Control Engineering Practice*. 3(9), 1277-1284.

Alsop, C. F., Forster, G. A. and Holmes, F. R. (1965). Ore Unloader Automation: A Feasibility Study. *Proceedings of IFAC on Systems Engineering for Control Systems*. Tokyo, Japan, 295-305.

Auernig, J. W. and Troger, H. (1987). Time Optimal Control of Overhead Cranes with Hoisting of the Load. *Automatica*. 23(4), 437-447.

Bera, S. C., Sarkar, R. and Mandal, N. (2012). An Opto-Isolator Based Linearization Technique of a Typical Thyristor Driven Pump. *ISA Transactions*. 51(1), 220-228.

Biswas, S. K. (2004). Optimal Control of Gantry Crane for Minimum Payload Oscillations. *Proceedings of Dynamic Systems and Applications*. Atlanta, USA, 12-19.

Blackburn, D., Lawrence, J., Danielson, J., Singhose, W., Kamoi, T. and Taura, A. (2010). Radial-Motion Assisted Command Shapers for Nonlinear Tower Crane Rotational Slewing. *Control Engineering Practice*. 18(5), 523-531.

Bourdachesiguerdidjane, H. (1995). Optimal-Control of a Container Crane by Fliss Linearization. *International Journal of Computer and Systems Sciences*. 33(5), 82-88.

Boustany, F. and d'Andrea-Novel, B. (1992a). Adaptive-Control of Non-Completely Controlled Mechanical Systems Using Dynamic Feedback Linearization and Estimation Design. *International Journal of Adaptive Control and Signal Processing*. 6(6), 589-610.

Boustany, F. and d'Andrea-Novel, B. (1992b). Adaptive Control of an Overhead Crane Using Dynamic Feedback Linearization and Estimation Design. *Proceedings of IEEE International Conference on Robotics and Automation*. Nice, France, 1963-1968.

Bradley, T., Hall, T., Xie, Q., Singhose, W. and Lawrence, J. (2006). Input Shaping for Nonlinear Drive Systems. *ASME International Mechanical Engineering Congress and Exposition*. Chicago, USA, 633-640.

Butler, H., Honderd, G. and Van Amerongen, J. (1991). Model Reference Adaptive Control of a Gantry Crane Scale Model. *IEEE Control Systems Magazine*. 11(1), 57-62.

Carmeli, S. and Mauri, M. (2013). HIL Test Bench to Test Anti-Swing Fuzzy Control of an Overhead Crane. *Proceedings of IEEE International Conference on Mechatronics* Vicenza, Italy, 754-760.

Chang, Y. C. and Shaw, J. S. (2012). Adaptive Hierarchical Sliding Control of Overhead Crane System with Haar Wavelet Function Estimator. *Journal of the Chinese Society of Mechanical Engineers*. 33(3), 193-202.

Chen, K. S. and Ou, K. S. (2010). Simulations and Experimental Investigations on Residual Vibration Suppression of Electromagnetically Actuated Structures Using Command Shaping Methods. *Journal of Vibration and Control*. 16(11), 1713-1734.

Chen, S. Y. and Lin, F. J. (2013). Decentralized PID Neural Network Control for Five Degree-of-Freedom Active Magnetic Bearing. *Engineering Applications of Artificial Intelligence*. 26(3), 962-973.

Chen, Y. F. and Huang, A. C. (2014). Oscillation Reduction for Overhead Cranes with Time-Varying Payload and Rope Length. *Journal of the Chinese Institute of Engineers*. 37(2), 259-267.

Chen, Z. M., Meng, W. J. and Zhang, J. G. (2012). Intelligent Anti-Swing Control for Bridge Crane. *Journal of Central South University*. 19, 2774-2781.

Chen, Z. M., Meng, W. J., Zhao, M. H. and Zhang, J. G. (2010). Hybrid Robust Control for Gantry Crane System. In Tan, H. H. (Ed.) *Applied Mechanics and Mechanical Engineering* (Vol. 29, pp. 2082-2088). USA: Tranc Tech Publications Inc.

Cheng, C. C. and Chen, C. Y. (1996). Controller Design for an Overhead Crane System with Uncertainty. *Control Engineering Practice*. 4(5), 645-653.

Cho, H. C., Fadali, M. S., Lee, Y. J. and Lee, K. S. (2006). Neural Robust Control for Perturbed Crane Systems. *Journal of Mechanical Science and Technology*. 20(5), 591-601.

Cho, H. C., Lee, J. W., Lee, Y. J. and Lee, K. S. (2008). Lyapunov Theory Based Robust Control of Complicated Nonlinear Mechanical Systems with Uncertainty. *Journal of Mechanical Science and Technology*. 22(11), 2142-2150.

Cho, H. C. and Lee, K. S. (2008). Adaptive Control and Stability Analysis of Nonlinear Crane Systems with Perturbation. *Journal of Mechanical Science and Technology*. 22(6), 1091-1098.

Choi, S. U., Kim, J. H., Lee, J. W., Lee, Y. J. and Lee, K. S. (2001). A Study on Gantry Crane Control Using Neural Network Two Degree of PID Controller. *Proceedings of IEEE International Symposium on Industrial Electronics*. L'Aquila, Italy, 1896-1900.

Cole, M. O. T. (2011). A Discrete-Time Approach to Impulse-Based Adaptive Input Shaping for Motion Control without Residual Vibration. *Automatica*. 47(11), 2504-2510.

Cole, M. O. T. and Wongratanaphisan, T. (2013). A Direct Method of Adaptive FIR Input Shaping for Motion Control with Zero Residual Vibration. *IEEE/ASME Transactions on Mechatronics*. 18(1), 316-327.

Crain, E., Singhose, W. and Seering, W. (1996). Derivation and Properties of Convolved and Simultaneous Two-Mode Input Shapers. *IFAC World Congress*. San Francisco, CA, 441-446.

Cutforth, C. F. and Pao, L. Y. (2004). Adaptive Input Shaping for Maneuvering Flexible Structures. *Automatica*. 40(4), 685-693.

d'Andréa-Novel, B., Boustany, F. and Conrad, F. (1992). Control of an Overhead Crane: Stabilization of Flexibilities. In Zoléesio, J. (Ed.) *Boundary Control and Boundary Variation* (Vol. 178, pp. 1-26). Germany: Springer Berlin Heidelberg.

d'Andréa-Novel, B., Boustany, F., Conrad, F. and Rao, B. P. (1994). Feedback Stabilization of a Hybrid PDE-ODE System: Application to an Overhead Crane. *Mathematics of Control, Signals and Systems*. 7(1), 1-22.

Daqaq, M. F. and Masoud, Z. N. (2006). Nonlinear Input-Shaping Controller for Quay-Side Container Cranes. *Nonlinear Dynamics*. 45(1), 149-170.

de Moura Oliveira, P., Solteiro Pires, E. and Cunha, J. (2011). Particle Swarm Optimization for Gantry Control: A Teaching Experiment. In Antunes, L. &

Pinto, H. S. (Eds.) *Progress in Artificial Intelligence* (Vol. 7026). Germany: Springer Berlin Heidelberg.

Debbarma, S., Saikia, L. C. and Sinha, N. (2013). AGC of a Multi-Area Thermal System under Deregulated Environment Using a Non-Integer Controller. *Electric Power Systems Research*. 95(1), 175-183.

Dong, M. X., Li, R. C. and Xu, Q. Z. (2012). Effect of Input Shaping on Response of Inertia Plants. *Applied Mechanics and Materials*. 121, 2676-2680.

Drapeau, V. and Wang, D. (1993). Verification of a Closed-Loop Shaped-Input Controller for a Five-Bar-Linkage Manipulator. *Proceedings of IEEE International Conference on Robotics and Automation*. Atlanta, GA, 216-221.

Ellis, G. (2012). *Control System Design Guide: Using Your Computer to Understand and Diagnose Feedback Controllers*. (Forth ed.) USA: Butterworth-Heinemann.

Fang, Y., Dixon, W. E., Dawson, D. M. and Zergeroglu, E. (2003). Nonlinear Coupling Control Laws for an Underactuated Overhead Crane System. *IEEE/ASME Transactions on Mechatronics*. 8(3), 418-423.

Field, J. A. (1961). The Optimization of the Performance of an Ore Bridge. *Transactions of the Engineering Institute of Canada*. 5(3), 163-169.

Fortgang, J., Singhose, W., de Juanes Márquez, J. and Perez, J. (2011). Command Shaping Control for Micro-Milling Operations. *International Journal of Control, Automation and Systems*. 9(6), 1136-1145.

Gao, B. T., Chen, H. J. and Zhang, X. H. (2005). Design of a Nonlinear Controller for Gantry Crane Payload. *Proceedings of IEEE Chinese Control and Decision Conference*. Guilin, China, 196-202.

Gao, B. T., Chen, H. J., Zhang, X. H. and Qi, H. (2006). A Practical Optimal Controller for Underactuated Gantry Crane Systems. *Proceedings of IEEE International Symposium on Systems and Control in Aerospace and Astronautics*. Harbin, China, 726-730.

Gholabi, A., Ebrahimi, M., Yousefi, G. R., Ghayour, M., Ebrahimi, A. and Jali, H. (2013). Sensorless Anti-Swing Control for Overhead Crane Using Voltage and Current Measurements. *Journal of Vibration and Control*. In press.

Graichen, K., Egretzberger, M. and Kugi, A. (2010). A Suboptimal Approach to Real-Time Model Predictive Control of Nonlinear Systems. *At-Automatisierungstechnik*. 58(8), 447-456.

Guo, W. and Liu, D. (2007). Adaptive Sliding Mode Fuzzy Control for a Class of Underactuated Mechanical Systems. In Huang, D. S., Heutte, L. & Loog, M. (Eds.) *Advanced Intelligent Computing Theories and Applications. With Aspects of Theoretical and Methodological Issues* (Vol. 4681, pp. 345-354). Germany: Springer Berlin Heidelberg.

Gürleyük, S. S. (2007). Optimal Unity-Magnitude Input Shaper Duration Analysis. *Archive of Applied Mechanics*. 77(1), 63-71.

Gürleyük, S. S. (2011). Designing Unity Magnitude Input Shaping by Using PWM Technique. *Mechatronics*. 21(1), 125-131.

Hongxia, J., Wanli, L. and Singhose, W. (2011). Using Two-Mode Input Shaping to Repress the Residual Vibration of Cherry Pickers. *Proceedings of IEEE International Conference on Measuring Technology and Mechatronics Automation*. Washington, DC, USA, 1091-1094.

Hua, Y. J. and Shine, Y. K. (2007). Adaptive Coupling Control for Overhead Crane Systems. *Mechatronics*. 17(2-3), 143-152.

Huey, J. R. and Singhose, W. (2005). Stability Analysis of Closed-Loop Input Shaping Control. *16th IFAC World Congress*. Prague, Czech Republic, 1260-1266.

Huey, J. R. and Singhose, W. (2012). Design of Proportional-Derivative Feedback and Input Shaping for Control of Inertia Plants. *IET Control Theory and Applications*. 6(3), 357-364.

Huey, J. R., Sorensen, K. L. and Singhose, W. (2008). Useful Applications of Closed-Loop Signal Shaping Controllers. *Control Engineering Practice*. 16(7), 836-846.

Hyde, J. M. and Seering, W. (1991). Using Input Command Pre-Shaping to Suppress Multiple Mode Vibration. *Proceedings of IEEE International Conference on Robotics and Automation*. CA, USA, 2604-2609.

Inteco Company (2007). 3D Crane, User’s Manual. http://www.inteco.com.pl/Docs/3DCrane_um.pdf

Jaafar, H. I., Mohamed, Z., Abidin, A. F. Z. and Ghani, Z. A. (2012). PSO-Tuned PID Controller for a Nonlinear Gantry Crane System. *Proceedings of IEEE*

International Conference on Control System, Computing and Engineering. Penang, Malaysia, 515-519.

Jaafar, H. I., Sulaima, M. F., Mohamed, Z. and Jamian, J. J. (2013). Optimal PID Controller Parameters for Nonlinear Gantry Crane System via MOPSO Technique. *Proceedings of IEEE Conference on Sustainable Utilization and Development in Engineering and Technology*. Selangor, Malaysia, 86-91.

Jerman, B., Podržaj, P. and Kramar, J. (2004). An investigation of slewing-crane dynamics during slewing motion—development and verification of a mathematical model. *International Journal of Mechanical Sciences*. 46(5), 729-750.

Jones, J. F. and Petterson, B. J. (1988). Oscillation Damped Movement of Suspended Objects. *Proceedings of IEEE International Conference on Robotics and Automation*. Philadelphia, PA, 956-962.

Kang, C. G. and Kwak, J. H. (2011). Robustness Improvement by Convolving Two ZV Input Shapers. *Proceedings of IEEE International Conference on Control, Automation and Systems*. KINEX, Korea, 730-733.

Kapila, V., Tzes, A. and Yan, Q. (1999). Closed-Loop Input Shaping for Flexible Structures Using Time-Delay Control. *Proceedings of IEEE Conference on Decision and Control*. Phoenix, Arizona USA 1561-1566.

Karkoub, M. A. and Zribi, M. (2001). Robust Control Schemes for an Overhead Crane. *Journal of Vibration and Control*. 7(3), 395-416.

Kenison, M. and Singhose, W. (2002). Concurrent Design of Input Shaping and Proportional Plus Derivative Feedback Control. *Transactions of ASME: Journal of Dynamic Systems Measurement and Control*. 124(3), 398-405.

Kennedy, J. and Eberhart, R. (1995). Particle Swarm Optimization. *Proceedings of IEEE International Conference on Neural Networks*. Perth, Australia, 1942-1948

Kiss, B., Levine, J. and Mullhaupt, P. H. (2000). A Simple Output Feedback PD Controller for Nonlinear Cranes. *Proceedings of IEEE Conference on Decision and Control*. Sydney, Australia, 5097-5101.

Ko, C. N. (2011). A Fuzzy PID Controller Based on Hybrid Optimization Approach for an Overhead Crane. In Li, S. T. H., Tu, K. Y., Tsai, C. C., Hsu, C. C., Tseng, C. C., Vadakkepat, P., Baltes, J., Anderson, J., Wong, C. C., Jesse, N., Kuo, C. H. & Yang, H. C. (Eds.) *Next Wave in Robotics* (Vol. 212, pp. 202-209). Germany: Springer Berlin Heidelberg.

Lau, A. M. and Pao, Y. L. (2003). Input Shaping and Time-Optimal Control of Flexible Structures. *Automatica*. 39(5), 893-900.

Lawrence, J. and Singhose, W. (2005). Design of minicrane for education and research. 6th Int. *Conference on Research and Education in Mechatronics,* Annecy, France. 1344-1350.

Lawrence, J. and Singhose, W. (2010). Command Shaping Slewing Motions for Tower Cranes. *Transactions of ASME: Journal of Vibration and Acoustics*. 132(1), 1-11.

Le Anh, T., Kim, J. J., Lee, S. G., Lim, T. G. and Luong, C. N. (2014). Second-Order Sliding Mode Control of a 3D Overhead Crane with Uncertain System Parameters. *International Journal of Precision Engineering and Manufacturing*. 15(5), 811-819.

Li, X. and Yu, W. (2012). Anti-Swing Control for an Overhead Crane with Fuzzy Compensation. *Intelligent Automation and Soft Computing*. 18(1), 1-11.

Maleki, E. and Singhose, W. (2010). Dynamics and Zero Vibration Input Shaping Control of a Small-Scale Boom Crane. *Proceedings of IEEE American Control Conference*. Baltimore, MD, USA, 2296-2301.

Maleki, E. and Singhose, W. (2012). Swing Dynamics and Input-Shaping Control of Human-Operated Double-Pendulum Boom Cranes. *Journal of Computational and Nonlinear Dynamics*. 7(3), 1-11.

Marinovic, I., Sprecic, D. and Jerman, B. (2012). A Slewing Crane Payload Dynamics. *Tehnicki Vjesnik-Technical Gazette*. 19(4), 907-916.

Masoud, Z., Alhazza, K., Abu-Nada, E. and Majeed, M. (2014). A Hybrid Command-Shaper for Double-Pendulum Overhead Cranes. *Journal of Vibration and Control*. 20(1), 24-37.

Masoud, Z. N. and Alhazza, K. A. (2014). Frequency-Modulation Input Shaping Control of Double-Pendulum Overhead Cranes. *Journal of Dynamic Systems, Measurement, and Control*. 136(2), 021005.

Mohamed, Z., Martins, J. M., Tokhi, M. O., da Costa, J. S. and Botto, M. A. (2005). Vibration Control of a Very Flexible Manipulator System. *Control Engineering Practice*. 13(3), 267-277.

Mohamed, Z. and Tokhi, M. O. (2002). Vibration Control of a Single-Link Flexible Manipulator Using Command Shaping Techniques. *Proceedings of the Institution of Mechanical Engineers Part I-Journal of Systems and Control Engineering*. 216(I2), 191-210.

Mohamed, Z. and Tokhi, M. O. (2003). Hybrid Control Schemes for Input Tracking and Vibration Suppression of a Flexible Manipulator. *Proceedings of the Institution of Mechanical Engineers Part I-Journal of Systems and Control Engineering*. 217(2), 23-34.

Mohamed, Z. and Tokhi, M. O. (2004). Command Shaping Techniques for Vibration Control of a Flexible Robot Manipulator. *Mechatronics*. 14(1), 69-90.

Moreno, L., Acosta, L., Mendez, J. A., Torres, S., Hamilton, A. and Marichal, G. N. (1998). A Self-Tuning Neuromorphic Controller: Application to the Crane Problem. *Control Engineering Practice*. 6(12), 1475-1483.

Moustafa, K. A. F., Gad, E. H., El-Moneer, A. M. A. and Ismail, M. I. S. (2005). Modelling and Control of Overhead Cranes with Flexible Variable-Length Cable by Finite Element Method. *Transactions of the Institute of Measurement and Control*. 27(1), 1-20.

Moustafa, K. A. F., Harib, K. H. and Omar, F. (2013). Optimum Controller Design of an Overhead Crane: Monte Carlo Versus Pre-Filter-Based Designs. *Transactions of the Institute of Measurement and Control*. 35(2), 219-226.

Moustafa, K. A. F., Ismail, M. I. S., Gad, E. H. and El-Moneer, A. M. A. (2006). Fuzzy Control of Flexible Cable Overhead Cranes with Load Hoisting. *Transactions of the Institute of Measurement and Control*. 28(4), 371-386.

Nafa, F., Labiod, S. and Chekired, H. (2013). Direct Adaptive Fuzzy Sliding Mode Decoupling Control for a Class of Underactuated Mechanical Systems. *Turkish Journal of Electrical Engineering and Computer Sciences*. 21(6), 1615-1630.

Pai, M. C. (2011). Closed-Loop Input Shaping Control of Vibration in Flexible Structures Using Discrete-time Sliding Mode. *International Journal of Robust and Nonlinear Control*. 21(7), 725-737.

Pal, A. K. and Mudi, R. K. (2012). An Adaptive Fuzzy Controller for Overhead Crane. *Proceedings of IEEE International Conference on Advanced Communication Control and Computing Technologies*. Ramanathapuram, India, 300-304.

Pao, L. and Singhose, W. (1995). On the Equivalence of Minimum Time Input Shaping with Traditional Time-Optimal Control. *Proceedings of the IEEE Conference on Control Applications*. Albany, NY, 1120-1125.

Pao, L. and Singhose, W. (1996). Unity Magnitude Input Shapers and Their Relation to Time-Optimal Control. *IFAC World Congress*. San Francisco, CA, USA, 385-390.

Park, M. S., Chwa, D. and Hong, S. K. (2007). Adaptive Fuzzy Nonlinear Anti-Sway Trajectory Tracking Control of Uncertain Overhead Cranes with High-Speed Load Hoisting Motion. *Proceedings of IEEE International Conference on Control, Automation and Systems*. Seoul, Korea, 2886-2891.

Pauluk, M., Korytowski, A., Turnau, A. and Szymkat, M. (2001). Time Optimal Control of 3D Crane. *Proceedings of IEEE International Conference on Methods and Models in Automation and Robotics*. Międzyzdroje, Poland, 122-128.

Peláez, G., Pelaez, G., Perez, J. M., Vizán, A. and Bautista, E. (2005). Input Shaping Reference Commands for Trajectory Following Cartesian Machines. *Control Engineering Practice*. 13(8), 941-958.

Peng, K. C. C., Singhose, W. and Frakes, D. H. (2012). Hand-Motion Crane Control Using Radio-Frequency Real-Time Location Systems. *IEEE/ASME Transactions on Mechatronics*. 17(3), 464-471.

Pereira, E., Trapero, J. R., Díaz, I. M. and Feliu, V. (2009). Adaptive Input Shaping for Manoeuvring Flexible Structures Using an Algebraic Identification Technique. *Automatica*. 45(4), 1046-1051.

Pereira, E., Trapero, J. R., Díaz, I. M. and Feliu, V. (2011). Adaptive Input Shaping for Single-Link Flexible Manipulators Using an Algebraic Identification. *Control Engineering Practice*. 20(2), 138-147.

Piazzi, A. and Visioli, A. (2000). Minimum-Time System-Inversion-Based Motion Planning for Residual Vibration Reduction. *IEEE/ASME Transactions on Mechatronics*. 5(1), 12-22.

Potter, J., Singhose, W. and Costelloy, M. (2011). Reducing Swing of Model Helicopter Sling Load Using Input Shaping. *Proceedings of IEEE International Conference on Control and Automation*. Santiago, Chile, 348-353.

Potter, J. J. and Singhose, W. (2014). Effects of Input Shaping on Manual Control of Flexible and Time-Delayed Systems. *Human Factors: The Journal of the Human Factors and Ergonomics Society*. In press.

Qian, D., Tong, S. and Yi, J. (2013). Adaptive Control Based on Incremental Hierarchical Sliding Mode for Overhead Crane Systems. *Applied Mathematics and Information Sciences*. 7(4), 1359-1364.

Ragunathan, S., Frakes, D., Peng, K. and Singhose, W. (2011). Filtering Effects on Input-Shaped Command Signals for Effective Crane Control. *Proceedings of IEEE International Conference on Control and Automation.* Jeju Island, South Korea, 1097-1101.

Ridout, A. J. (1989). Anti-Swing Control of the Overhead Crane Using Linear Feedback. *Journal of Electrical and Electronics Engineering*. 9(1), 17-26.

Ristanović, M., Ćojbašić, Ž. and Lazić, D. (2012). Intelligent Control of DC Motor Driven Electromechanical FIN Actuator. *Control Engineering Practice*. 20(6), 610-617.

Rogers, K. and Seering, W. (1996). Input Shaping for Limiting Loads and Vibration in Systems with On-Off Actuators. *AIAA Guidance, Navigation, and Control Conference*. San Diego, USA,

Saad, N. and Arrofiq, M. (2012). A PLC-Based Modified-Fuzzy Controller for PWM-Driven Induction Motor Drive with Constant V/Hz Ratio Control. *Robotics and Computer-integrated Manufacturing*. 28(2), 95-112.

Saeidi, H., Naraghi, M. and Raie, A. A. (2013). A Neural Network Self Tuner Based on Input Shapers Behavior for Anti Sway System of Gantry Cranes. *Journal of Vibration and Control*. 19(13), 1936-1949.

Saikia, L. C., Nanda, J. and Mishra, S. (2011). Performance Comparison of Several Classical Controllers in AGC for Multi-Area Interconnected Thermal System. *International Journal of Electrical Power and Energy Systems*. 33(3), 394-401.

Saikia, L. C., Sinha, N. and Nanda, J. (2013). Maiden Application of Bacterial Foraging Based Fuzzy IDD Controller in AGC of a Multi-Area Hydrothermal System. *International Journal of Electrical Power and Energy Systems*. 45(1), 98-106.

Singer, N. C. and Seering, W. (1990). Preshaping Command Inputs to Reduce System Vibration. *Journal of Dynamic Systems, Measurement, and Control*. 112(1), 76-82.

Singer, N. C., Singhose, W. and Kriikku, E. (1997). An Input Shaping Controller Enabling Cranes to Move without Sway. *ANS 7th topical meeting on robotics and remote systems*. Aiken, USA, 225-231.

Singhose, W. (1990). *A Vector Diagram Approach to Shaping Inputs for Vibration Reduction.* Ph. D. Thesis, MIT, USA.

Singhose, W. (2009). Command Shaping for Flexible Systems: A Review of the First 50 Years. *International Journal of Precision Engineering And Manufacturing*. 10(4), 153-168.

Singhose, W., Derezinski, S. and Singer, N. C. (1996). Extra-Insensitive Input Shapers for Controlling Flexible Spacecraft. *Journal of Guidance, Control, and Dynamics*. 19(2), 385-391.

Singhose, W. and Pao, L. (1997). A Comparison of Input Shaping and Time-Optimal Flexible-Body Control. *Control Engineering Practice*. 5(4), 459-467.

Singhose, W., Porter, L., Kenison, M. and Kriikku, E. (2000). Effects of Hoisting on the Input Shaping Control of Gantry Cranes. *Control Engineering Practice*. 8(10), 1159-1165.

Singhose, W., Porter, L. and Seering, W. (1997a). Input Shaped Control of a Planar Gantry Crane with Hoisting. *Proceedings of IEEE American Control Conference*. Albuquereue, 97-100.

Singhose, W., Porter, L. and Singer, N. C. (1995). Vibration Reduction Using Multi-Hump Extra-Insensitive Input Shapers. *Proceedings of the American Control Conference*. Seattle, USA, 3830-3834.

Singhose, W., Seering, W. and Singer, N. C. (1990). Shaping Inputs to Reduce Vibration: A Vector Diagram Approach. *Proceedings of IEEE International Conference on Robotics and Automation*. Chinchinatti, Ohio, USA, 922-927.

Singhose, W., Seering, W. and Singer, N. C. (1994a). Residual Vibration Reduction Using Vector Diagrams to Generate Shaped Inputs. *Journal of Mechanical Design*. 116(2), 654-659.

Singhose, W., Seering, W. and Singer, N. C. (1997b). Time-Optimal Negative Input Shapers. *Journal of Dynamic Systems, Measurement, and Control*. 119(2), 198-205.

Singhose, W., Singer, N. C. and Seering, W. (1994b). Design and Implementation of Time-Optimal Negative Input Shapers. *Proceedings of International Mechanical Engineering Congress and Exposition*. Chicago, 151-157.

Singhose, W. and Vaughan, J. (2011). Reducing Vibration by Digital Filtering and Input Shaping. *IEEE Transactions on Control Systems Technology*. 19(6), 1410-1420.

Smith, O. J. M. (1957). Posicast Control of Damped Oscillatory Systems. *Proceedings of the IRE*. 45(9), 1249-1255.

Smoczek, J. (2013). Evolutionary Optimization of Interval Mathematics-Based Design of a TSK Fuzzy Controller for Anti-Sway Crane Control. *International Journal of Applied Mathematics and Computer Science*. 23(4), 749-759.

Smoczek, J. (2014). Fuzzy Crane Control with Sensorless Payload Deflection Feedback for Vibration Reduction. *Mechanical Systems and Signal Processing*. 46(1), 70-81.

Smoczek, J. and Szpytko, J. (2013). Fuzzy Logic-Based Adaptive Control System Prototypying for Laboratory Scaled Overhead Crane. *Proceedings of IEEE International Conference on Methods and Models in Automation and Robotics*. Miedzyzdroje, Poland, 92-97.

Smoczek, J. and Szpytko, J. (2014). Evolutionary Algorithm-Based Design of a Fuzzy TBF Predictive Model and TSK Fuzzy Anti-Sway Crane Control System. *Engineering Applications of Artificial Intelligence*. 28, 190-200.

Smoczek, J., Szpytko, J. and Hyla, P. (2014). Interval Analysis Approach to Prototype the Robust Control of the Laboratory Overhead Crane. *In IOP Conference Series: Materials Science and Engineering*. 65(1), 1-6.

Solihin, M. I., Akmeliawati, R. and Legowo, A. (2011). Robust Feedback Control Design Using PSO-Based Optimisation: A Case Study in Gantry Crane Control. *International Journal of Mechatronics and Automation*. 1(2), 121-131.

Solihin, M. I., Kamal, M. and Legowo, A. (2008a). Objective Function Selection of GA-Based PID Control Optimization for Automatic Gantry Crane. *Proceedings of IEEE International Conference on Computer and Communication Engineering*. Kuala Lumpur, Malaysia, 883-887.

Solihin, M. I., Kamal, M. and Legowo, A. (2008b). Optimal PID Controller Tuning of Automatic Gantry Crane Using PSO Algorithm. *IEEE International Symposium on Mechatronics and its Applications*. Amman, Jordan, 1-5.

Solihin, M. I. and Legowo, A. (2010). Fuzzy-Tuned PID Anti-Swing Control of Automatic Gantry Crane. *Journal of Vibration and Control*. 16(1), 127-145.

Solihin, M. I., Wahyudi, Kamal, M. A. S. and Legowo, A. (2008c). Objective Function Selection of GA-Based PID Control Optimization for Automatic Gantry Crane. *Proceedings of IEEE International Conference on Computer and Communication Engineering*. Kuala Lumpur, Malaysia, 883-887.

Solihin, M. I., Wahyudi, Legowo, A. and Akmeliawati, R. (2009). Robust PID Anti-Swing Control of Automatic Gantry Crane Based on Kharitonov's Stability. *Proceedings of IEEE International Conference on Industrial Electronics and Applications*. Xi’an, China, 270-275.

Song, G., Buck, N. V. and Agrawal, B. N. (1999). Spacecraft Vibration Reduction Using Pulse-Width Pulse-Frequency Modulated Input Shaper. *Journal of Guidance, Control, and Dynamics*. 22(3), 433-440.

Sorensen, K. L., Cross, P. W., Singhose, W. and Prakash, S. (2011). Vibration Analysis and Mitigation of Dead-Zone on Systems Using Two-Impulse Zero-Vibration Input Shaping. *Journal of Computational and Nonlinear Dynamics*. 6(1), 1-7.

Sorensen, K. L., Hekman, K. and Singhose, W. (2010). Finite-State Input Shaping. *IEEE Transactions on Control Systems Technology*. 18(3), 664-672.

Sorensen, K. L. and Singhose, W. (2008). Command-Induced Vibration Analysis Using Input Shaping Principles. *Automatica*. 44(9), 2392-2397.

Sorensen, K. L., Singhose, W. and Dickerson, S. (2007). A Controller Enabling Precise Positioning and Sway Reduction in Bridge and Gantry Cranes. *Control Engineering Practice*. 15(7), 825-837.

Staehlin, U. and Singh, T. (2003). Design of Closed-Loop Input Shaping Controllers. *Proceedings of the American Control Conference*. Denver, USA, 5167-5172.

Sun, N. and Fang, Y. (2014). Nonlinear Tracking Control of Underactuated Cranes with Load Transferring and Lowering: Theory and Experimentation. *Automatica*. 50(9), 2350-2357.

Sun, N., Fang, Y., Zhang, X. and (2012). A Novel Nonlinear Coupling Control Approach for Overhead Cranes: Theory and Implementation. *Proceedings of American Control Conference* Montréal, Canada, 6276-6281.

Tsai, C. C., Wu, H. L. and Chuang, K. H. (2012). Intelligent Sliding-Mode Motion Control Using Fuzzy Wavelet Networks for Automatic 3D Overhead Cranes. *Proceedings of Sice Annual Conference*. Akita, Japan, 1256-1261.

Tuan, L. A., Janchiv, A., Kim, G. H. and Lee, S. G. (2011). Feedback Linearization Control of Overhead Cranes with Varying Cable Length. *Proceedings of IEEE International Conference on Control, Automation and Systems*. New York, USA, 906-911.

Tzes, A. and Yurkovich, S. (1993). An Adaptive Input Shaping Control Scheme for Vibration Suppression in Slewing Flexible Structures. *IEEE Transactions on Control Systems Technology*. 1(2), 114-121.

Van den Broeck, L., Diehl, M. and Swevers, J. (2009). Performant Design of an Input Shaping Prefilter via Embedded Optimization. *Proceedings of American Control Conference*. St. Louis, MO, USA, 166-171.

Van den Broeck, L., Diehl, M. and Swevers, J. (2010). Embedded Optimization for Input Shaping. *IEEE Transactions on Control Systems Technology*. 18(5), 1146-1154.

Van den Broeck, L., Diehl, M. and Swevers, J. (2011). A Model Predictive Control Approach for Time Optimal Point-to-Point Motion Control. *Mechatronics*. 21(7), 1203-1212.

Vaughan, J., Karajgikar, A. and Singhose, W. (2011). A Study of Crane Operator Performance Comparing PD-Control and Input Shaping. *Proceedings of American Control Conference*. San Francisco, California, USA, 545-550.

Vaughan, J., Maleki, E. and Singhose, W. (2010). Advantages of Using Command Shaping over Feedback for Crane Control. *Proceedings of American Control Conference* Baltimore, MD, USA, 2308-2313.

Vaughan, J. and Singhose, W. (2009). Input Shapers for Reducing Overshoot in Human-Operated Flexible Systems. *Procedings of American Control Conference*. St. Louis, MO, USA, 178-183.

Vaughan, J. and Singhose, W. (2014). The Influence of Time Delay on Crane Operator Performance *Delay Systems* (Vol. 1, pp. 329-342). Switzerland: Springer International Publishing.

Vazquez, C. and Collado, J. (2009). Optimal Delayed Control for an Overhead Crane. *Proceedings of IEEE International Conference on Electrical Engineering, Computing Science and Automation Control*. Toluca, Mexico, 109-114.

Vyhlídal, T., Kučera, V. and Hromčík, M. (2013). Signal Shaper with a Distributed Delay: Spectral Analysis and Design. *Automatica*. 49(11), 3484-3489.

Wang, Z., Chen, Z. and Zhang, J. (2012). On PSO Based Fuzzy Neural Network Sliding Mode Control for Overhead Crane. In Wang, Y. & Li, T. (Eds.) *Practical Applications of Intelligent Systems* (Vol. 124, pp. 563-572). Germany: Springer Berlin Heidelberg.

Woods, S. and Szyszkowski, W. (2014). Optimal Manoeuvres of Underactuated Linear Mechanical Systems: The Case of Controlling Gantry Crane Operations. *Journal of Applied Mathematics*. In press.

Xiao, Y. and Weiyao, L. (2012). Optimal Composite Nonlinear Feedback Control for a Gantry Crane System. *Proceedings of Chinese Control Conference* Yantai, China, 601-606.

Xu, W. M., Liu, B., Chu, J. X. and Zhou, X. W. (2012). An Anti-Swing and Positioning Controller for Overhead Cranes Based on Multi-Sliding Mode Method. In Chen, W. Z., Dai, P. Q., Chen, Y. L., Chen, D. N. & Jiang, Z. Y. (Eds.) *Automation Equipment and Systems* (Vol. 468-471, pp. 328-334). Stafa-Zurich: Trans Tech Publications Ltd.

Yang Jung, H. and Yang Kunag, S. (2006). Adaptive Control for 3D Overhead Crane Systems. *Proccedings of American Control Conference*. Minneapolis, MN, USA, 1832-1837.

Yang, T. W. and O'Connor, W. J. (2006). Wave Based Robust Control of a Crane System. *Proceedings of IEEE International Conference on Intelligent Robots and Systems*. Beijing, China, 2724-2729.

Yang, Y. J. H., Lai, K. S., Yuan, J. and Hsu, W. C. (2005). Nonlinear Adaptive Motion Controller Design for Overhead Crane Systems. In Hamza, M. H. (Ed.) *Proceedings of the Eighth IASTED International Conference on Intelligent Systems and Control* (pp. 235-240). Cambridge, MA, USA: Acta Press.

Yavuz, H., Mıstıkoğlu, S. and Kapucu, S. (2012). Hybrid Input Shaping to Suppress Residual Vibration of Flexible Systems. *Journal of Vibration and Control*. 18(1), 132-140.

Ye, D., Jin, W. and Li, D. (2012). Study on Overhead Crane Anti-Swing System with Self-Adjustable Fuzzy Control. In Hou, Z. X. (Ed.) *Measuring Technology and Mechatronics Automation IV* (Vol. 128, pp. 1050-1053). USA: Trans Tech Publications Inc.

Yoshida, Y. and Tabata, H. (2008). Visual Feedback Control of an Overhead Crane and its Combination with Time-Optimal Control. *Proceedings of IEEE/ASME International Conference on Advanced Intelligent Mechatronics*. Xian, China, 1114-1119.

Yushu, B. and Zhihui, G. (2013). Parameter Optimization of Controllable Local Degree of Freedom for Reducing Vibration of Flexible Manipulator. *Chinese Journal of Aeronautics*. 26(2), 487-494.

Zain, M. Z. M., Alam, M. S., Tokhi, M. O. and Mohamed, Z. (2006a). Simulation and Experimental Studies of Hybrid Learning Control with Acceleration Feedback for Flexible Manipulators. *International Conference on Climbing and Walking Robots*. Brussels, Belgium, 567-574.

Zain, M. Z. M., Tokhi, M. O. and Alam, M. S. (2005). Robustness of Hybrid Learning Acceleration Feedback Control Scheme in Flexible Manipulators. *Proceedings of World Academy of Science, Engineering and Technology*. Istanbul, Turkey, 143-146.

Zain, M. Z. M., Tokhi, M. O. and Mohamed, Z. (2006b). Hybrid Learning Control Schemes with Input Shaping of a Flexible Manipulator System. *Mechatronics*. 16(3-4), 209-219.

Zain, M. Z. M., Tokhi, M. O. and Mohamed, Z. (2006c). Hybrid Learning Control Schemes with Input Shaping of a Flexible Manipulator System. *Mechatronics*. 16(3), 209-219.

Zhang, H. Y., Wang, J. and Lu, G. D. (2014). Hierarchical Fuzzy-Tuned Multi-Objective Optimization Control for Gantry Cranes. *Proceedings of the Institution of Mechanical Engineers Part C-Journal of Mechanical Engineering Science*. 228(7), 1119-1131.

Zhao, Y. and Gao, H. (2012). Fuzzy-Model-Based Control of an Overhead Crane with Input Delay and Actuator Saturation. *IEEE Transactions on Fuzzy Systems*. 20(1), 181-186.

Zmić, N., Ostrić, D. and Brkić, A. (1997). Mathematical Modeling of Gantry Cranes. *Bulletins for Applied and Computing Mathematics*. LXXXI-A(1312), 185-194.