ADAPTIVE SLIDING MODE CONTROL WITH DISTURBANCE OBSERVER FOR A CLASS OF ELECTRO-HYDRAULIC ACTUATOR SYSTEM

ZULFATMAN

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

MAY 2015

This thesis is gratefully dedicated to my beloved family for their prayers and supports.

ACKNOWLEDGEMENT

First and foremost, I would like to thank Almighty Allah, who is the most Gracious, Merciful, Omniscient and Omnipotent for the continuous blessing and giving me the strength and opportunity in completing this study.

I wish to give my special thanks to both my project supervisor Prof. Dr. Mohd. Fua'ad Rahmat, and co-supervisor Assoc. Prof. Dr. Abdul Rashid Husain who have given constant guidance, support and valuable advices with their brilliant ideas on many important occasions during the past few years.

I am incredibly grateful to my family. My beloved wife Ela Diana, my lovely sons Arga and Zyad, my parents Helmy and Asnah, my parents in law Zahrul Rabain and Arminiwati, my brothers and sister Elizan, Eli, Efigo, Efriadi, Epi and Ton who have given their unconditional love, emotional support, and patient during all these years.

I am also thankful to my colleagues Rozaimi, Sahazati, Ling, Najib, Noorhazirah and Siti Marhainis, and also my friends Cici, Fitra, Dedi, Faruq, Oky, Lily, Cica, Reiza, Iis and all PPI-UTM members for many valuable discussions, their important advice, their encouragement, and the fun times in the completion of this study.

ABSTRACT

Position tracking control has become one of the most popular studies in the control of Electro-Hydraulic Actuator (EHA) systems. However, it deals with highly nonlinear behaviours, uncertainties and external disturbances, which significantly affect the control performance. In the class of nonlinear robust control, Sliding Mode Control (SMC) has become an effective approach for systems experiencing these issues due to its discontinuous nature. But, employing SMC as a stand-alone controller may not be effective for EHA systems with time-varying external disturbance, and integration is needed. Hence, the objective of this study is to formulate and implement a robust SMC in adaptive control form integrated with Nonlinear Disturbance Observer (NDO) to guarantee robustness, position tracking accuracy, and smoothness of the control actions to an EHA system in the presence of uncertainties and disturbances. The EHA system was modelled as a nonlinear system which contains nonlinearities, uncertainties and disturbances. The SMC was developed in integration with NDO, in which switching gain of the SMC is designed to be adaptive on the bounds of uncertainties and disturbances, and updated by the NDO through an adaptation mechanism. Stability of the SMC and the NDO are guaranteed by the Lyapunov function candidate. Simulation and experimental results show that capability of the integrated controller to improve the smoothness of the control actions is as good as the stand-alone adaptive SMC with varying boundary layers technique. Also, it is capable to maintain the tracking accuracy about 25% better than the stand-alone SMC. Integration of the NDO into the SMC offers a better compromise between position tracking accuracy and control actions smoothness in position tracking control technique based-SMC.

ABSTRAK

Kawalan penjejakan posisi sudah menjadi salah satu kajian yang paling popular dalam kawalan sistem Aktuator Elektro-Hidraulik (EHA). Walau bagaimanapun, ia mempunyai isu-isu tingkah laku ketaklinearan yang tinggi, ketidakpastian dan gangguan luaran yang mempengaruhi prestasi kawalan. Dalam kelas kawalan tegap tidak linear, Kawalan Ragam Gelincir (SMC) adalah satu teknik yang paling berkesan untuk sistem yang mengalami isu-isu terbabit. Tetapi, penggunaan SMC sebagai sebuah pengawal tunggal tidak akan berkesan bagi sistem EHA dengan gangguan luaran berubah waktu, dan ia perlu berintegrasi dengan teknik lain. Oleh itu, tujuan kajian ini adalah untuk merumus dan menggunakan teknik kawalan tegap SMC dalam bentuk ubah suai bersepadu dengan Pencerap Gangguan Tidak Linear (NDO) bagi menjamin ketegapan, ketepatan penjejakan posisi dan kelicinan isyarat kawalan sistem EHA terhadap ketidakpastian dan gangguan. Sistem EHA dimodelkan sebagai sistem tidak linear yang beisikan unsur ketidaklinearan, ketidakpastian dan gangguan-gangguan. SMC dibangun berintegrasi dengan NDO, di mana gandaan pensuisan pada SMC telah direka untuk menyesuaikan diri pada batas-batas ketidakpastian dan gangguan, dan dikemaskini oleh NDO melalui mekanisme penyesuaian. Kestabilan SMC dan NDO dijamin oleh fungsi Lyapunov. Hasil simulasi dan eksperimen menunjukkan bahawa kemampuan sistem kawalan yang berintegrasi dalam meningkatkan kelicinan tindakan kawalan sama baiknya dengan SMC yang menggunakan teknik lapisan sempadan berubah. Juga, ia mampu mengekalkan ketepatan penjejakan 25% lebih baik daripada SMC konvensional. Integrasi NDO ke dalam SMC menawarkan kompromi yang lebih baik antara ketepatan penjejakan posisi dan kelicinan isyarat kawalan dalam teknik kawalan penjejakan posisi berasaskan SMC.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

A_1, A_2 - Cross section area of the two chambers (m^2)

a_p - Piston acceleration (m/s^2)

C_d - Discharge coefficient

C_{v1}, C_{v2} - Valve orifice coefficients

d_i - Lumped internal disturbance

d_e - External load disturbance

$\hat{D}$ - Estimate of disturbance

e - Error trajectory

e_D - Nonlinear disturbance observer error

f - Nonlinear dynamics

$\hat{f}$ - Nominal part of nonlinear dynamics

Δf - Uncertainties of nonlinear dynamics

F_a - Hydraulic actuating force (N)

F_{ed} - External load disturbance force (N)

F_f - Hydraulic friction force (N)

f_d - Lumped uncertain nonlinearities

g - Control gain

g_{min}, g_{max} - Lower and upper bounds of the control gain

$\hat{g}$ - Control gain estimation

k - Spring constant (N/m)

H - Reaching time function

k_a - Servo valve gain (m/V)

k_v - Viscous friction (N s/m)

k_{ed} - Load disturbance spring constant

L	-	Disturbance observer gain
m	-	Total mass of the piston and load (kg)
p_1, p_2	-	Pressure in chambers 1 and 2 (Pa)
p_s	-	Supply pressure (Pa)
K	-	Discontinuous switching gain
S	-	Sliding surface
u, u_{eq}, u_n	-	Total, equivalent and nominal control (V)
V	-	Lyapunov function
v_p	-	Piston velocity (m/s)
V_1, V_2	-	Total volume in chambers 1 and 2 (m^3)
V_{i1}, V_{i2}	-	Initial volume in chambers 1 and 2 (m^3)
V_l	-	Pipelines volume (m^3)
V_t	-	Volume between pump and valve (m^3)
w_1 , w_2	-	Spool valve area gradients 1 and 2 (m^2)
x_d	-	Desired position (m)
x_L	-	Total stroke of piston (m)
x_p	-	Piston position (m)
$_e$	-	Effective bulk modulus (Pa)
¤	-	Thickness of boundary layer
∘	-	Fluid mass density (kg/m^3)

LIST OF ABBREVIATIONS

ASMC - Adaptive Sliding Mode Control
DAQ - Data Acquisition System
DO - Disturbance Observer
DOBC - Disturbance Observer Based Control
EHA - Electro-Hydraulic Actuator
GPC - Generalized Predictive Control
LQG - Linear Quadratic Gaussian
LQR - Linear Quadratic Regulator
LVDT - Linear Variable Differential Transformer
MAP - Mean Positioning Accuracy
MRAC - Model Reference Adaptive Control
NDO - Nonlinear Disturbance Observer
NDOBC - Nonlinear Disturbance Observer Based Control
PID - Proportional-Integral-Derivative
QFT - Quantitative Feedback Theory
SMC - Sliding Mode Control
SMCF - Sliding Mode Controller and Filter
SSCI - Sum of Squared Control Input
SSTE - Sum of Squared Tracking Error
RI - Robustness Index
VSC - Variable Structure Control
VSF - Variable Structure Filter

CHAPTER 1

INTRODUCTION

1.1 Background

Electro-hydraulic actuator (EHA) systems have grown to be one of the most popular actuators in modern applications for several decades. EHA systems can be found easily in production assembly lines, robotics, automotive, aircraft, submarine operations, mining processes, etc. This is due to the fact that EHA systems have fast and smooth response characteristics and high power density. EHA systems also have excellent capability in positioning that gives a significant influence to the above applications especially in position tracking control issues. However, as introduced in Yao *et al.* (2000), EHA systems exhibit highly nonlinear behaviours, such as nonlinear servo valve flow-pressure characteristics, variations in control volumes, dead-band, stiffness, internal leakage, and associated friction. Apart from the nonlinear natures, parametric uncertainties, uncertain nonlinearities and disturbances also become large extent of EHA systems. Hence, consideration on these issues to obtain more accurate model in the modelling of EHA systems is essential.

In the effort to address the nonlinearities and uncertainties issues in the EHA systems, various control techniques have been proposed. The simplest approach is to adopt the linear control techniques. However, due to the linearization on the systems, some significant dynamic properties are potentially lost. Therefore, nonlinear robust control method is one of the most suitable methods for EHA systems and has received a very large attention from researchers in the nonlinear control area. In the class of robust control, sliding mode control (SMC) is envisaged to be a realistic option for a class of nonlinear systems. It is competent to counteract uncertainties and disturbances when the states are constrained to the sliding surface which satisfies matching condition. It provides a systematic method to maintain the stability and satisfactory performance despite modelling imperfections. The main advantages of SMC include faster dynamic response, robust to parameter variations, simplicity in control design, and easy for implementation. Pertaining to these advantages, various approaches of SMC have been successfully proposed by Liu and Handroos (1999), Bonchis *et al.* (2001), Mihajlov *et al.* (2002), Chen *et al.* (2005), Guan and Pan (2008), Cerman and Husek (2012) and Zhang *et al.* (2014) for EHA systems.

Based on the fundamental idea of SMC in Utkin (1977) and continued by Gao and Hung (1993), a discontinuous control gain starts to work in discontinuous action on the sliding mode when trajectories of the system reach the sliding surface. The discontinuous gain which ensures a closed-loop system is robust to uncertainties and disturbances. For guaranteed stability, the discontinuous gain of SMC must be larger than the uncertainties and disturbances as stated by Yoo and Chung (1992). However, the control action displays high frequency oscillations that is well known as chattering, which is highly undesirable and leads to low control accuracy. Due to this fact, various approaches have been developed for chattering reduction. Slotine and Sastry (1983) and Kachroo and Tomizuka (1996) tried to solve the issue with a thin boundary layer. Bondarev *et al.* (1985) and Liu and Peng (2000) offered the observer-based method. Hassan *et al.* (2001) introduced a reaching law method. Bartolini *et al.* (1998) employed second order SMC. Chen *et al.* (2005) applied a simple varying boundary layers technique. Levant (2005) and Lee and Utkin (2007) proposed quasi-continuous high-order SMC and suppression method. Then, Tseng and Chen (2010) presented low-pass filtering for chattering with high-level measurement noise.

Selection of a constant value for the discontinuous gain of SMC may guarantee robustness of the controller, but it tends to result in a large switching control activity around the control signal. This excessive switching will lead to large control chattering. The first attempt to develop adaptation method for the discontinuous gain was by Bartolini *et al.* (1999). In the SMC with discontinuous gain adaptation method, the gain is calculated from the bounds of uncertainties and disturbances to guarantee a closed-loop system insensitive to the system uncertainties and disturbances. Consequently, magnitude of the discontinuous action will change linearly following variation of the uncertainties and disturbances. In the design of SMC for EHA systems, Bonchis *et al.* (2001), Mihajlov *et al.* (2002), Chen *et al.* (2005), Guan and Pan (2008), and Cerman and Husek (2012) have succesfully proposed various discontinuous gain adaptation methods in robust adaptive SMC scheme, in which the uncertainties, the control gain and the disturbances were assumed to be bounded. Morover, all of these schemes were developed as stand-alone SMC without the reaching law method.

Aside from the nonlinearities, the presence of external disturbance may cause EHA model to have more complex structure of disturbances. Due to the complexity of the structure, bounds of the uncertainties and disturbances may not be easily obtained. Over-estimation on the bounds may cause unnecessary large control activity and could possibly damage the actuators. Therefore, in some practical implementations the bounds have been assumed to be bounded to satisfy and meet the requirement of the designer. However, the structure of robust adaptive SMC with bounded uncertainties and disturbances would not be able to accommodate the uncertainties and disturbance that exceed the bound, which leads to instability and inaccurate tracking. Such that, integration of an observer based method into robust adaptive SMC through an adaptation mechanism would be a suitable approach for the problem.

Simple adaptation mechanisms for upper bounds estimation on the norm of the uncertainties with boundary layer in Leung *et al*. (1991) and Yoo and Chung (1992) were the early developments for robust adaptive SMC. In these adaptation mechanisms, the discontinuous gain increases whenever the switching function does not converge to zero. To solve the unbounded growth of the discontinuous gain, a modified adaptation mechanism was developed by Wheeler *et al*. (1998). A unique adaptation mechanism using artificial neural network using 2-sigma network was also applied by Buckner (2002) to estimate upper and lower bounds of uncertainty. The bounds were provided to update the switching-gain in real-time. Similarity of those techniques is limitation of their capability to observe the existence of disturbances. Following this, uncertainty and disturbance estimator (UDE) was developed by Talole and Padke (2008) without discontinuous control and without requirement on the knowledge of uncertainties and disturbances or their bounds. Drawback of this adaptation mechanism is that the structure of the UDE was only prepared for a linear time invariant system. Another technique was the use of nonlinear disturbance observer (NDO) as proposed by Chen and Chen (2010), Yang *et al*. (2013), and Ginoya *et al*. (2014) with an appropriate gain function to approximate the unknown disturbance for a nonlinear system. However, structure of the NDO was designed and employed only for second order nonlinear system model.

For EHA systems that demonstrate strong effects of nonlinear behaviours and time-varying external disturbance, the NDO in Chen and Chen (2010) may be possible to be modified for EHA system model and integrated to the adaptive SMC by using adaptation mechanism. However, in the proposed NDO, integration of the NDO to the adaptive SMC was designed to provide the NDO to directly update the disturbance estimate function in equivalent control law of the SMC. This type of adaptation mechanism may be able to minimize the chattering effect and guarantee the stability of the asymptotic estimation, but it may lead the integrated controller into instability and less accurate tracking in large changes of external disturbance. In order to increase the stability, the adaptation mechanism can be designed to provide the NDO output to directly update the discontinuous gain of the SMC.

1.2 Problem Statement

Highly nonlinear behaviours, uncertain dynamics and disturbances have become the main problems in the development of an EHA system. Simplification on these problems in obtaining a model for the system may cause the obtained model potentially lost its significant dynamic properties and less accurate. Hence, further consideration on the nonlinear behaviours, uncertain dynamics and disturbances in modelling process of an EHA system is indispensable to improve accuracy of the EHA system model formulation and to gain the model to be more similar to the real system.

In the class of robust control, SMC has been employed by researchers for many years as an effective strategy to deal with nonlinearities, uncertainties and disturbances. However, chattering has still been the main problem in the development of SMC, which caused by the discontinuous action of SMC to counteract uncertainties and disturbances. The problem becomes more complex when the uncertainties and disturbances change in time. Hence, structure of SMC needs to be developed in adaptive form to reduce chattering and to adapt with the change of uncertainties and disturbances. Moreover, in the presence of external disturbance in EHA system, due to stability and tracking accuracy reasons, the system may not be possible to be controlled just by stand-alone adaptive SMC with bounded uncertainties and disturbances. Since the discontinuous gain of the SMC is calculated based on the bounds of the uncertainties and disturbances, the SMC needs to integrate with an observer to estimate the real values of the bounds through an adaptation mechanism to update the SMC gain.

The implementation of the proposed control strategy in the real system is another challenge in control system development. Capabilities of the proposed control strategy to improve the robustness, control action smoothness and position tracking performance of the EHA system need to be verified in the real system. The verification could be employed on the real EHA system test bed in the laboratory.

1.3 Objectives of the Study

The objectives of this study are as follows:

i. To formulate a good mathematical representation for an EHA system in nonlinear model in consideration of friction, internal leakage, actuator asymmetry, model uncertainties and disturbances.

ii. To propose a new control strategy that integrates adaptive robust SMC and NDO through an adaptation mechanism to deal with the existence of slow-varying external disturbance in the EHA system.

iii. To validate the real-time implementation of the proposed control strategy abilities on the real EHA system in terms of robustness, position tracking accuracy, and control action smoothness.

1.4 Research Scopes and Limitations

The scopes and limitations of the study are as follows:

i. Model formulation and simulation works on EHA system were developed based on the characteristics and behaviours of the existing EHA system in the test-bed including its limitations in terms of design and equipments.

ii. The exact amount of the internal leakage was very difficult to obtain, so the internal leakage was assumed to be a constant positive value.

iii. The external load disturbance was assumed to be known and linearly dependent to the piston position (displacement) in tracking reference trajectories, which were generated in slow-varying. Such that, the disturbance is recognized as slow-varying external disturbance.

iv. Due to the limitation of the test-bed design, the test bed is available only to produce external disturbance until 75 mm positive displacement.

v. Nonlinearities that were considered in the study include friction, internal leakage, actuator asymmetry and dead zone.

1.5 Significant Findings

The significant findings of this study are as follows:

i. A good representation of dynamics model of an EHA system under consideration on friction, internal leakage, actuator asymmetry, model uncertainties and disturbances.
ii. Development of an adaptive robust control based-SMC to deal with an EHA system dynamics.
iii. Development of an NDO that is available to estimate the external disturbance in the third order model of an EHA system.
iv. A new integrated control strategy that combines the adaptive SMC and the NDO through an adaptation mechanism to deal with time-varying external disturbance.

1.6 Organization of the Thesis

Chapter 2 deals with literatures related to EHA systems and the development of control strategies for the system. It begins with a brief overview on EHA systems basic principle, main equipments and development. This is followed by a general review on behaviours and characteristics of EHA systems. Current works in EHA systems modelling also be part of this chapter. The chapter is ended with a complete review on existing control strategies for EHA systems, especially in position control area, and a critical review on relation of SMC and NDO in adaptive control form.

Chapter 3 presents the proposed model, simulation and experimental set-up, and model validation of the EHA system. The proposed model includes nonlinear behaviours of the system such as friction, internal leakage, actuator asymmetry and dead-zone. Design of the EHA system test bed, system parameters, reference trajectories, and control performance indexes are part of the simulation and experimental set-up appear in the last part of the chapter.

In Chapter 4, the proposed control strategy based-SMC and its integration with NDO for the EHA system are offered. In the beginning an adaptive continuous-time SMC is introduced to improve the performance of the EHA system. The robustness and position tracking accuracy are the main concerns in evaluating the proposed control. At the end of the first part of the chapter, due to chattering phenomena consideration, a varying boundary layer technique is added to the proposed control for more accurate tracking and smoother control activities. Completing the initial proposed control strategy, in the second part of the chapter the NDO design is introduced to improve the performance of the initial proposed control strategy through an effective integration mechanism, which is the main contribution of the study. The effectiveness and capability of the NDO and the adaptation mechanism are examined for slow-varying external disturbance.

Results and discussion for the proposed model validation and the proposed control evaluation in both simulation and experiment appear in Chapter 5. The results are presented visually with graphs and quantitatively with performance indexes tables. The discussion goes step by step following the development of the proposed model and the proposed control strategy. At the end of this section, the simulation and the experimental results for the proposed control development are also summarized and compared for each reference trajectory.

Chapter 6 offers the conclusion of the discussion of this study. It is also completed with suggestions for future research.

REFERENCES

Ahn, K. K., Nam, D. N. C. and Jin, M. (2014). Adaptive Backstepping Control of an Electrohydraulic Actuator. *IEEE/ASME Trans. on Mech.*, 19(3), 987-995.

Alaydi, J. Y. (2008). Mathematical Modeling for Pump Controlled System of Hydraulic Drive Unit of Single Bucket Excavator Digging Mechanism. *Jordan J. of Mech. and Ind. Eng,* 2(3), 157-162.

Alleyne, A. and Liu, R. (1999). On the Limitations of Force Tracking Control for Hydraulic Servosystems. *ASME J. of Dynamic Systems, Measurement, and Control*, 121(2), 184-190.

Alleyne, A. and Liu, R. (2000). A Simplified Approach to Force Control for Electro-Hydraulic Systems. *Control Eng. Practice*, 8(2000), 1347-1356.

Altintas, Y. and Lane, A. J. (1997). Design of an Electro-Hydraulic CNC Press Brake. *Int. J. of Machine Tools and Manufacture,* 37(1), 45-59.

Antonelli, M.G., Bucci, G., Ciancetta, F. and Fiorucci, E. (2014). Automatic Test Equipment for Avionics Electro-Mechanical Actuators (EMAs). *Measurement*, 57, 71-84.

Ayalew, B. (2008). Improved Inner-Loop Decentralised Control of Electrohydraulic Actuators in Road Simulation. *Int. J. of Vehicle Systems Modelling and Testing,* 3(1-2), 94-113.

Ayalew, B. (2010). Two Equivalent Control Structures for an Electrohydraulic Actuator. *Proc. of the Institution of Mechanical Engineers. Part I: Journal of Systems and Control Engineering,* 224(5), 599-609.

Baghestan, K., Rezaei, S.M., Talebi, H.A. and Zareinejad, M. (2014). Robust Force Control in Novel Electro-Hydraulic Structure Using Polytopic Uncertainty Representation. ISA Transaction, 53(2014), 1873-1880.

Bartolini, G., Ferrara, A., Levant, A., Usai, E. (1999). *Variable Structure Systems, Sliding Mode and Nonlinear Control: On Second Order Sliding Mode Control*. Springer, 329-350.

Bartolini, G., Ferrara, A., Usai, E. (1998). Chattering Avoidance by Second Order Sliding Mode Control. IEEE Trans. on Automatic Control, 43(2), 241-246.

Becan, M. R. (2005). Fuzzy Boundary Layer Solution to Nonlinear Hydraulic Position Control Problem. *Proc. of World Academy of Science, Engineering and Technology* 5, 206-208.

Bessa, W. M., Dutra, M. S. and Kreuzer, E. (2010). Sliding Mode Control with Adaptive Fuzzy Dead-Zone Compensation of an Electro-Hydraulic Servo-system. *J. of Intelligent and Robotic Systems: Theory and Applications,* 58(1), 3-16.

Blackburn, J. F., Reethof, G. and Shearer, J. L. (1960). *Fluid Power Control*: New York: Technology Press of M. I. T. and John Wiley.

Bobrow, J. E. and Lum, K. (1996). Adaptive, High Bandwidth Control of a Hydraulic Actuator. *ASME J. of Dynamic Systems, Measurement, and Control,* 118(4), 714-720.

Bonchis, A., Corke, P. I. and Rye, D. C. (2002). Experimental Evaluation of Position Control Methods for Hydraulic Systems. *IEEE Trans. on Control Systems Technology,* 10(6), 876-882.

Bonchis, A., Corke, P. I., Rye, D. C. and Ha, Q. P. (2001). Variable Structure Methods in Hydraulic Servo Systems Control. *Automatica,* 37, 589-595.

Bondarev, A. G., Bondarev, S. A., Kostylyeva, N. Ye., Utkin, V. I. (1985). Sliding Modes in Systems with Asymptotic State Observers. *Automation and Remote Control*, 46, 679–684.

Buckner, G. D. (2002). Intelligent Bounds on Modelling Uncertainty: Applications to Sliding Mode Control. *IEEE Trans. on Syst. Man. and Cybernetic-Part C: Application and Reviews*, 32(2), 113-124.

Cao, Y. and Dai, X. (2015). Modeling for Performance Degradation Induced by Wear of a Hydraulic Actuator of a Hydraulic Excavator. *J. of Mechanical Engineering Science*, 229(3), 556-565.

Canudas de Wit, C. (1995). Olsson, H.; Astrom, K. J.; Lischinsky, P.: A New Model for Control of Systems with Friction. *IEEE Trans. on Automatic Control*, 40(3), 419-425.

Cerman, O. and Husek, H. (2012), Adaptive Fuzzy Sliding Mode Control for Electro-Hydraulic Servo Mechanism. *Expert Systems with Applications*. 39, 10269–10277.

Cetin, S. and Akkaya, A. V. (2010). Simulation and Hybrid Fuzzy-PID Control for Positioning of a hydraulic system. *Nonlinear Dynamics,* 61(3), 465-476.

Cetinkunt, S., Pinsopon, U., Chen, C., Egelja, A. and Anwar, S. (2004). Positive Flow Control of Closed-Center Electrohydraulic Implement-By-Wire Systems for Mobile Equipment Applications. *Mechatronics,* 14(4), 403-420.

Chan, S. P. (1995). A Disturbance Observer for Robot Manipulators with Application to Electronic Components Assembly. *IEEE Trans. Ind. Electronics*, 42, 487–493.

Chang, P. H. and Lee, S.-J. (2002). A Straight-Line Motion Tracking Control of Hydraulic Excavator System. *Mechatronics,* 12(1), 119-138.

Chen, M. and Chen,W-H. (2010). Sliding Mode Control for A Class of Uncertain Nonlinear System Based on Disturbance Observer. *Int. J. Adapt. Control Signal Process,* 24(1), 51–64.

Chen, C.-K. and Zeng, W.-C. (2003). The Iterative Learning Control for The Position Tracking of The Hydraulic Cylinder. *JSME Int. Journal, Series C: Mechanical Systems, Machine Elements and Manufacturing,* 46(2), 720-726.

Chen, C.-Y., Liu, L.-Q., Cheng, C.-C. and Chiu, G. T.-C. (2008). Fuzzy Controller Design for Synchronous Motion in a Dual-cylinder Electro-hydraulic System. *Control Eng. Practice,* 16(6), 658-673.

Chen, H.-M., Renn, J.-C. and Su, J.-P. (2005). Sliding Mode Control with Varying Boundary Layers for An Electro-hydraulic Position Servo System. *Int. J. of Adv. Manufacturing Technology,* 26(1-2), 117-123.

Chen, W-H., Ballance, D.J., Gawthrop, P.J., O’Reilly, J. (2000). A Nonlinear Disturbance Observer for Robotic Manipulators. *IEEE Trans. Industrial Electronics*, 47(4), 932–938.

Chen, W-H. (2004), Disturbance Observer Based Control for Nonlinear Systems. *IEEE Trans. on Mechatronics,* 9(4), 706–710.

Chiang, M. H. and Huang, C. C. (2004). Experimental Implementation of Complex Path Tracking Control for Large Robotic Hydraulic Excavators. *Int. J. of Adv. Manufacturing Technology,* 23(1-2), 126-132.

Chiang, M. H., Yang, F. L., Chen, Y. N. and Yeh, Y. P. (2005). Integrated Control of Clamping Force and Energy-Saving in Hydraulic Injection Moulding Machines Using Decoupling Fuzzy Sliding-Mode Control. *Int. J. of Adv. Manufacturing Technology,* 27(1-2), 53-62.

Choux, M. and Hovland, G. (2010). Adaptive Backstepping Control of Nonlinear Hydraulic-mechanical System Including Calve Dynamics. *Modeling, Identification and Control,* 31(1), 35-44.

Chuang, C.-W. and Shiu, L.-C. (2004). CPLD based DIVSC of Hydraulic Position Control Systems. *Computers and Electrical Engineering*, 30(7), 527-541.

Cobo, M., Ingram, R. and Cetinkunt, S. (1998). Modeling, Identification, and Real-Time Control of Bucket Hydraulic System for A Wheel Type Loader Earth Moving Equipment. *Mechatronics,* 8(8), 863-885.

Coelho, L. d. S. and Cunha, M. A. B. (2011). Adaptive Cascade Control of a Hydraulic Actuator with an Adaptive Dead-zone Compensation and Optimization Based on Evolutionary Algorithms. *Expert Systems with Applications*, 38(2011), 12262-12269.

Di Rito, G., Denti, E. and Galatolo, R. (2008). Development and Experimental Validation of Real-Time Executable Models of Primary Fly-by-Wire Actuators. *Proc. of the Institution of Mechanical Engineers. Part I: Journal of Systems and Control Engineering,* 222(6), 523-542.

Di Rito, G. and Galatolo, R. (2012). Experimental Assessment of the Dynamic Stiffness of a Fault-Tolerant Fly-by-Wire Hydraulic Actuator. *J. of Aerospace Engineering*, 226(6), 679-690.

Drakunov, S., Ozguner, U., Dix, P. and Ashrafi, B. (1995). ABS Control Using Optimum Search Via Sliding Modes. *IEEE Trans. on Control Systems Technology,* 3(1), 79-85.

Erylmaz, B. and Wilson, B.H. (2000). Combining Leakage and Orifice Flows in A Hydraulic Servo Valve Model. *ASME J. of Dynamic Systems, Measurement, and Control*, 122, 576-579.

Eryilmaz, B. and Wilson, B. H. (2001). Improved Tracking Control of Hydraulic Systems. *ASME J. of Dynamic Systems, Measurement, and Control,* 123, 457-462.

Esfandiari, M. and Sepehri, N. (2013). Stability Analysis of QFT Controllers Designed for Hydraulic Actuators Using Takagi-Sugeno Fuzzy Modelling Approach. *ASME/BATH 2013 Symposium on Fluid Flow and Motion Control*, Sarasota, Florida, USA, October 6-9, 2013.

Fales, R. and Kelkar, A. (2009). Robust Control Design for A Wheel Loader Using H∞ and Feedback Linearization Based Methods. *ISA Trans.,* 48(3), 312-320.

Fales, R., Spencer, E., Chipperfield, K., Wagner, F. and Kelkar, A. (2005). Modeling and Control of A Wheel Loader with A Human-in-The-Loop Assessment Using Virtual Reality. *ASME J. of Dynamic Systems, Measurement, and Control,* 127(3), 415-423.

Fan, R. and Lu, Z. (2007). Fixed Points on the Nonlinear Dynamic Properties of Hydraulic Engine Mounts and Parameter Identification Method: Experiment and Theory. *J. of Sound and Vibration,* 305(4-5), 703-727.

Finney, J. M., de Pennington, A., Bloor, M. S. and Gill, G. S. (1985). A Pole-Assignment Controller for an Electrohydraulic Cylinder Drive. *ASME J. of Dynamic Systems, Measurement, and Control,* 107 (2), 144-150.

Fung, R.-F. and Yang, R.-T. (1998). Application of VSC in Position Control of a Nonlinear Electrohydraulic Servo System. *Computers and Structures,* 66(4), 365-372.

Fujimoto, Y. and Kawamura A. (1995). Robust Servo-System Based on Two Degree-of-Freedom Control with Sliding Mode, *IEEE Trans. Industrial Electronics,* 42(3), 272–280.

Gao, W. and Hung, J. C. (1993). A Variable Structure Control of Nonlinear Systems: A New Approach. *IEEE Trans. on Ind. Electronics*, 40(1), 45-55.

Ghazali, R. (2013). *Identification and Adaptive Robust Control of Electro-Hydraulic Actuator System*. PhD Thesis. Universiti Teknologi Malaysia.

Ginoya, D., Shendge, P. D., Phadke, S. B. (2014). Sliding Mode Control for Mismatched Uncertain Systems Using an Extended Disturbance Observer, *IEEE Trans. on Industrial Electronics,* 61(4), 1983-1992.

Goodall, R., Freudenthaler, G. and Dixon, R. (2014). Hydraulic Actuation Technology for Full- and Semi-Active Railway Suspensions. *Vehicle System Dynamics: Int. J. of Vehicle Mechanics and Mobility*, 52(12), 1642-1657.

Guan, C. and Pan, S. (2008a). Adaptive Sliding Mode Control of Electro-hydraulic System with Nonlinear Unknown Parameters. *Control Eng. Practice*, 16(11), 1275-1284.

Guan, C. and Pan, S. (2008b). Nonlinear Adaptive Robust Control of Single-rod Electro-hydraulic Actuator with Unknown Nonlinear Parameters. *IEEE Trans. on Control Systems Technology*, 16(3), 434-445.

Guo, H. B., Liu, Y., Liu, G. and Li, H. (2008). Cascade Control of A Hydraulically Driven 6-DOF Parallel Robot Manipulator Based on A Sliding Mode. *Control Eng. Practice,* 16(9), 1055-1068.

Guo, K., Wei, J., Fang, J., Feng, R. and Wang, X. (2015). Position Tracking Control of Electro-Hydraulic Single-Rod Actuator Based on Extended Disturbance Observer. *Mechatronics*, 27(2015), 47-56.

Ha, Q. P., Nguyen, Q. H., Rye, D. C. and Durrant-Whyte, H. F. (2000). Impedance Control of A Hydraulically Actuated Robotic Excavator. *Automation in Construction*, 9(5), 421-435.

Ha, Q. P., Nguyen, Q. H., Rye, D. C. and Durrant-Whyte, H. F. (2001). Fuzzy Sliding-Mode Controllers with Applications. *IEEE Trans. on Industrial Electronics,* 48(1), 38-46.

Hassan, I.M.M., Mohamed, A.M. and Saleh, A.I. (2001). Variable Structure Control of a Magnetic Suspension System. *Proc. of the 2001 IEEE Conf. on Control Appl.*, Mexico City, Mexico, Sept. 5-7, 333-338.

Hung, J.Y., Gao, W. and Hung, J.C., “Variable Structure Control: A Survey,” *IEEE Trans. on Industrial Electronics*, 40(1), 2-22.

Jelali, M. and Kroll, A. (2003). *Hydraulic Servo-systems: Modelling, Identification and Control*: Springer - Verlag London Limited.

Jerzy, W., Andrzej, S., Marian, W. and Thomasz, K. (2008). Hysteretic Effects of Dry Friction: Modelling and Experimental Studies. *Phil. Trans. R. Soc. A,* 366, 747-765.

Kachroo, P. and Tomizuka, M. (1996), Chattering Reduction and Error Convergence in the Sliding Mode Control of A Class of Nonlinear Systems. *IEEE Trans. on Automatic Control*, 41(7), 1063-1068.

Kaddissi, C., Kenne, J.-P. and Saad, M. (2011), Indirect Adaptive Control of an Electrohydraulic Servo System Based on Nonlinear Backstepping. *IEEE/ASME Trans. on Mechatronics*, 16(6), 1171-1176.

Kalyoncu, M. and Haydim, M. (2009). Mathematical Modelling and Fuzzy Logic Based Position Control of An Electrohydraulic Servosystem with Internal Leakage. *Mechatronics,* 19(6), 847-858.

Karpenko, M. and Sepehri, N. (2003). Robust Position Control of an Electrohydraulic Actuator with a Faulty Actuator Piston Seal. *ASME J. of Dynamic Systems, Measurement, and Control,* 125(3), 413-423.

Karpenko, M. and Sepehri, N. (2009). Hardware-in-the-Loop Simulator for Research on Fault Tolerant Control of Electrohydraulic Actuators in A Flight Control Application. *Mechatronics,* 19(7), 1067-1077.

Karpenko, M. and Sepehri, N. (2010a). On Quantitative Feedback Design for Robust Position Control of Hydraulic Actuators. *Control Eng. Practice,* 18(3), 289-299.

Karpenko, M. and Sepehri, N. (2010b). Quantitative Fault Tolerant Control Design For A Leaking Hydraulic Actuator. *ASME J. of Dynamic Systems, Measurement, and Control,* 132(5), 1-7.

Karpenko, M. and Sepehri, N. (2012). Electro-Hydraulic Force Control Design of A Hardware-In-the Loop Load Emulator Using a Nonlinear QFT technique. *Control Eng. Practice,* 20(2012), 598-609.

Kim, B. K. and Chung, W. K. (2003). Advanced Disturbance Observer Design for Mechanical Positioning Systems. *IEEE Trans. on Industrial Electronics*, 50 (6), 1207-1216.

Kim, D. H. and Tsao, T.-C. (2000). A Linearized Electrohydraulic Servovalve Model for Valve Dynamics Sensitivity Analysis and Control System Design. *ASME J. of Dynamic Systems, Measurement, and Control,* 122, 179-187.

Kirecci, A., Topalbekiroglu, M. and Eker, I. (2003). Experimental Evaluation of a Model Reference Adaptive Control for a Hydraulic Robot: A Case Study. *Robotica,* 21(1), 71–78.

Knohl, T. and Unbehauen, H. (2000). Adaptive Position Control of Electro-hydraulic Servo Systems Using ANN. *Mechatronics,* 10(1-2), 127-143.

Le, L., Zoppi, M., Jilich, M., Bo, H., Zlatanov, D. and Molfino, R. (2015). Application of a Biphasic Actuator in the Design of the CloPeMa Robot Gripper. *J. of Mechanisms and Robotics-Trans. of the ASME,* 7(1), 1-8.

Lee, H. and Utkin, V.I. (2007). Chattering Suppression Methods in Sliding Mode Control Systems. *Annual Review in Control,* 31(2007), 179-188.

Lee, S. R. and Srinivasan, K. (1989). On-line Identification of Process Models in Closed-Loop Material Testing. *ASME J. of Dynamic Systems, Measurement, and Control,* 111(2), 172-179.

Lee, J. H., Ko, J. S., Chung, S. K., Lee, D. S., Lee, J. J., Youn, M. J. (1994). Continuous Variable Structure Controller for BLDDSM Position Control With Prescribed Tracking Performance. *IEEE Trans. Industrial Electronics*, 41(5), 483–491.

Lewis, E.E. and Stern, H. (1962). *Design of Hydraulic Control Systems*: McGraw-Hill.

Leung, T. P., Zhou Q.-J., Su C.-Y. (1991). An Adaptive Variable Structure Model Following Control Design for Robot Manipulators. *IEEE Trans. on Automatic Control*, 36(1), 347-353.

Levant, A. (2005). Quasi-Continuous High-Order Sliding-Mode Controllers. *IEEE Trans. on Automatic Control,* 50(11), 1812-1816.

Li, G. and Khajepour, A. (2005). Robust Control of a Hydraulically Driven Flexible Arm Using Backstepping Technique. *J. of Sound and Vibration,* 280(3-5), 759-775.

Li, S., Ruan, J., Pei, X., Yu, Z. Q. and Zhu, F. M. (2006). Electrohydraulic Synchronizing Servo Control of a Robotic Arm. *Journal of Physics: Conference Series,* 48(1), 1268-1272.

Lischinsky, P., Canudas de Wit, C., Morel, G. (1999) Friction Compensation for an Industrial Hydraulic Robot. *IEEE Control Systems*, February, 25-32.

Liu, Y. and Handroos, H. (1999). Sliding Mode Control for A Class of Hydraulic Position Servo. *Mechatronics*, 9(1), 111-123.

Liu, C-S. and Peng, H. (2000). Disturbance Observer Based Tracking Control. *J. of Dynamic Systems, Measurements and Control*, 122, 332-335.

Liu, S., and Yao, B. (2004). Programmable Valves: A Solution to Bypass Deadband Problem of Electro-hydraulic Systems. *Proceeding of the 2004 American Control Conference,* 30 June-2 July, Boston, United States.

Liu, L-P., Fu, Z., Song, Xiaona. (2012). Sliding Mode Control with Disturbance Observer for A Class of Nonlinear Systems. *Int. J. of Automation and Computing*, 9(5), 487-491.

Lo, S.-W. and Yang, T.-C. (2004). Closed-loop Control of the Blank Holding Force in Sheet Metal Forming With A New Embedded-Type Displacement Sensor. Int. *J. of Adv. Manufacturing Technology*, 24(7-8), 553-559.

Loukianov, A. G., Rivera, J., Orlov, Y. V. and Teraoka, E. Y. M. (2009). Robust Trajectory Tracking for an Electrohydraulic Actuator. *IEEE Trans. on Industrial Electronics*, 56(9), 3523-3531.

Loukianov, A.G., Sanchez, E. and Lizalde, C. (2008). Force Tracking Neural Block Control for An Electro-Hydraulic Actuator via Second-Order Sliding Mode. *Int. J. Robust Nonlinear Control,*18, 319–332.

Lu,Y. S. (2009). Sliding-Mode Disturbance Observer with Switching-gain Adaptation and Its Application to Optical Disk Drives. *IEEE Trans. Industrial Electronics*, 56(9), 3743–3750.

Lucente, G., Montanari, M. and Rossi, C. (2007). Modelling of an Automated Manual Transmission System. *Mechatronics,* 17(2-3), 73-91.

Man, Z. And Yu, X. (1997). Terminal Sliding Mode Control of MIMO systems. IEEE Trans. On Circuits and Systems-Part 1, 44, 1065-1070.

McCloy, D. and Martin, H. R. (1973). *The Control of Fluid Power*: New York: Wiley.

Merritt, H. E. (1967). *Hydraulic Control Systems*. New York: John Wiley & Sons, Inc.

Mihajlov, M., Nikolic, V. and Antic, D. (2002). Position Control of an Electro-Hydraulic Servo System using Sliding Mode Control Enhanced by Fuzzy PI Controller. *FACTA UNIVERSITATIS Series: Mech. Eng.,*1(9), 1217 - 1230.

Milam, M.B., Mushambi, K. and Murray, R.M. (2000). A New Computational Approach to Real-Time Trajectory Generation for Constrained Mechanical Systems. *Proc. of the 39th IEEE Conf. on Decision and Control (Volume 1)*, Sydney, Dec. 12-15, 845-851.

Milic, V., Situm, Z. and Essert, M. (2010). Robust H∞ Position Control Synthesis of an Electro-Hydraulic Servo System. *ISA Trans.*, 49(4), 535-542.

Moers, A. J. M., De Volder, M. F. L. and Reynaerts, D. (2012). Integrated High Pressure Micro-Hydraulic Actuation and Control for Surgical Instruments. *Biomed Microdevices*, 14, 69–708.

Nabulsi, S., Sarria, J. F., Montes, H. and Armada, M. A. (2009). High-Resolution Indirect Feet-Ground Interaction Measurement for Hydraulic-Legged Robots. *IEEE Trans. on Instrum. and Measurement*, 58(10), 3396-3404.

Namvar, M. and Aghili, F. (2003). A Combined Scheme for Identification and Robust Torque Control of Hydraulic Actuators. *ASME J. of Dynamic Systems, Measurement, and Control*, 125(4), 595-606.

Niksefat, N. and Sepehri, N. (2002). A QFT Fault-Tolerant Control for Electrohydraulic Positioning Systems. *IEEE Trans. on Control Systems Technology*, 10(4), 626-632.

Olsson, H.; Astrom, K.J., Cadunas de Wit, C., Gafvert, M., Lischinsky, P. (1998). Friction Models and Friction Compensation. *Euro J. on Cont*. 4(3), 176-195.

Pinsopon, U., Hwang, T., Cetinkunt, S., Ingram, R., Zhang, Q., Cobo, M., Koehler, D. and Ottman, R. (1999). Hydraulic Actuator Control with Open-Centre Electrohydraulic Valve Using A Cerebellar Model Articulation Controller Neural Network Algorithm. *Proc. of the Institution of Mechanical Engineers. Part I: J. of Systems and Control Engineering*, 213(1), 33-48.

Plummer, A. R. and Vaughan, N. D. (1996). Robust Adaptive Control for Hydraulic Servosystems. *ASME J. of Dynamic Systems, Measurement, and Control,* 118, 237-244.

Plummer, A. R. and Vaughan, N. D. (1997). Decoupling Pole-Placement Control with Application to a Multi-Channel Electro-Hydraulic Servosystem. *Control Eng. Practice,* 5(3), 313-323.

Pluta, J. (2008). Hydraulic Press with LS System for Modelling of Plastic Working Operations. *Acta Montanistica Slovaca,* 13(1), 152-157

Renn, J.-C. and Tsai, C. (2005). Development of An Unconventional Electro-Hydraulic Proportional Valve with Fuzzy-Logic Controller for Hydraulic Presses. *Int. J. of Adv. Manufacturing Technology,* 26(1-2), 10-16.

Ruan, J., Pei, X. and Zhu, F. M. (2006). Identification and Modeling of Electrohydraulic Force Control of the Material Test System (MTS). *J. of Physics: Conference Series*, 48, 1322–1326.

Rubagotti, M., Carminati, M., Clemente, G., Grassetti, R. and Ferrara, A. (2012). Modeling and Control of an Airbrake Electro-Hydraulic Smart Actuator. *Asian Journal of Control*, 14(5), 1159-1170.

Salah, M. H., Frick, P. M., Wagner, J. R. and Dawson, D. M. (2009). Hydraulic Actuated Automotive Cooling Systems-Nonlinear Control and Test. *Control Eng. Practice,* 17(5), 609-621.

Sam, Y. M., Osman, J. H. S. and Ghani, M. R. A. (2004). A Class of Proportional-Integral Sliding Mode Control with Application to Active Suspension System. *Systems and Control Letters,* 51(3-4), 217-223.

Schrijver, E. and Van Dijk, J. (2002). Disturbance Observers for Rigid Mechanical Systems: Equivalence,Stability, and Design. *ASME, J. of Dynamic Systems, Measurements and Control*, 124(4), 539-548.

Sekhavat, P., Sepehri, N. and Wu, Q. (2006). Impact Stabilizing Controller for Hydraulic Actuators With Friction: Theory and Experiments. *Control Eng. Practice,* 14(12), 1423-1433.

Sekhavat, P., Wu, Q., Sepehri, N. (2004) Lyapunov-Based Friction Compensation for Accurate Positioning of a Hydraulic Actuator. *Proc. of the 2004 American Control Conf.*, Boston, USA. June 30 – July 2, 418-423.

Sepehri, N. and Wu, G. (1998). Experimental Evaluation of Generalized Predictive Control Applied to A Hydraulic Actuator. *Robotica* 16(4), 463–474.

Sha, D., Bajic, V. B. and Yang, H. (2002). New Nodel and Sliding Mode Control of Hydraulic Elevator Velocity Tracking System. *Simulation Practice and Theory*, 9(6-8), 365-385.

Shih, M.-C. and Tsai, C.-P. (1995). Servohydraulic Cylinder Position Control Using a Neuro-Fuzzy Controller. *Mechatronics,* 5(5), 497-512.

Slotine, J.J.E. and Sastry, S.S. (1983). Tracking Control of Nonlinear Systems Using Sliding Surfaces, With Application to Robot Manipulators. *Int. J. Control*, 38(2), 465-492.

Sohl, G. A. and Bobrow, J. E. (1999). Experiments and Simulations on the Nonlinear Control of a Hydraulic Servosystem. *IEEE Trans. on Control Systems Technology,* 7(2), 238-247.

Su, C.Y. and Leung, T.P. (1993). A Sliding Mode Controller with Bound Estimation for Robot Manipulators. *IEEE Trans. on Robotics and Automation*, 9 (2), 208-214.

Tafazoli, S., Silva, C. W. d. and Lawrence, P. D. (1998). Tracking Control of an Electrohydraulic Manipulator in the Presence of Friction. *IEEE Trans. on Control Systems Technology,* 6(3), 401-411.

Talole, S. E. and Phadke, S. B. (2008). Model Following Sliding Mode Control Based on Uncertainty and Disturbance Estimator. *J. of Dynamic Systems, Measurements and Control*, 130(3), 034501, 1-5

Tran, X. B., Hafizah, N. and Yanada, H. (2012). Modeling of Dynamic Friction Behaviors of Hydraulic Cylinders. *Mechatronics*, 22(2012), 65-75.

Tsai, C.-C., Hsieh, S.-M. and Kao, H.-E. (2009). Chattering Reduction of Sliding Mode Control by Low-Pass Filtering The Control Signal. *Mechatronics*, 19(2), 147-155.

Tseng, M.-L. and Chen, M.-S. (2010). Mechatronic Design and Injection Speed Control of An Ultra High-Speed Plastic Injection Molding Machine. *Asian Journal Control*, 12(3), 394-398.

Ursu, I., Tecuceanu, G., Ursu, F. and Cristea, R. (2006). Neuro-Fuzzy Control is Sometimes Better Than Crisp Control. *Acta Univ. Apulensis,* 11, 259-269.

Utkin, V.I. (1977). Variable Structure Systems with Sliding Modes. *IEEE Trans. on Automatic Control*, 22, 212-222.

Valdiero, A. C., Guenther, R., De Negri, V. J. (2005). New Methodology for Identification of the Dead Zone Inproportional Directional Hydraulic Valves. *Proc. of the 18th Brazilian Cong. of Mech. Eng.* São Paulo, Brazil.

Viersma, T. J. (1980). *Analysis, Synthesis, and Design of Hydraulic Servosystems and Pipelines*: Elsevier Scientific Pub. Co.

Wang, S., Habibi, S., Burton R. and Sampson, E. (2006). Sliding Mode Control for a Model of an Electrohydraulic Actuator System with Discontinuous Nonlinear Friction. *Proc. of the 2006 American Control Conf.*, Minneapolis, Minnesota, USA, June 14-16, 5897-5904.

Wang, S., Burton, R. and Habibi, S. (2011). Sliding Mode Controller and Filter Applied to an Electrohydraulic Actuator System. *ASME J. of Dynamic Systems, Measurement, and Control,* 133(2), Art. No. 024504.

Wheeler, G., Su, C-Y., Stepanenko Y. (1998). A Sliding Mode Control with Improved Adaptation Laws for The Upper Bounds on Norm of The Uncertainties. *Automatica*, 34(12), 1657-1661.

Wonohadidjojo, D. M., Kothapalli, G. and Hassan, M. Y. (2013). Position Control of Electro-hydraulic Actuator System Using Fuzzy Logic Controller Optimized by Particle Swarm Optimization. *Int. J. of Automation and Computing*, 10(3), 181-193.

Witters, M. and Swevers, J. (2010). Black-box Model Identification for a Continuously Variable, Electro-hydraulic Semi-active Damper. *Mechanical Systems and Signal Processing*, 24(1), 4-18.

Won, D. and Kim, W. (2015). Disturbance Observer Based Backstepping for Position Control of Electro-hydraulic Actuator Systems. *Int. J. of Control, Automation, and Systems*, 13(2), 488-493.

Wu, M.-C. and Shih, M.-C. (2003). Simulated and Experimental Study of Hydraulic Anti-lock Braking System Using Sliding-Mode PWM Control. *Mechatronics,* 13(4), 331-351.

Yang, J., Li, S., Yu, X. (2013). Sliding-mode Control for Systems with Mismatched Uncertainties Via a Disturbance Observer, *IEEE Trans. on Industrial Electronics,* 60, 160–169.

Yang, J., Chen, W. H., Li, S. (2011). Non-linear Disturbance-Observer Based Robust Control for Systems with Mismatched Disturbances/Uncertainties, *IET Control Theory Appl.,* 5(18), 2053–2062.

Yao, B., Bu, F., Reedy, J. and Chiu, G. T.-C. (2000). Adaptive Robust Motion Control of Single-Rod Hydraulic Actuators: Theory and Experiments. *IEEE/ASME Trans. on Mechatronics,* 5(1), 79-91.

Yoo D. S. and Chung M. J. (1992), A Variable Structure Control with Simple Adaptation Laws for Upper Bounds on Norm of The Uncertainties. *IEEE Trans. on Automatic Control*, 37(6), 860-864.

Young, K. D. and Drakunov, S. (1992). Sliding Mode Control with Chattering Reduction. *Proc. 1992 American Control Conf.,* Chicago, IL, June 1992, 1291–1292.

Yu, H., Feng, Z.-J. and Wang, X.-Y. (2004). Nonlinear Control for A Class of Hydraulic Servo System. *J. of Zhejiang Univ.: Science,* 5(11), 1413-1417.

Zeng, H. and Sepehri, N. (2008). Tracking Control of Hydraulic Actuators Using a LuGre friction Model Compensation. *ASME J. of Dynamic Systems, Measurement, and Control,* 130(1), No. 014502.

Zhang, H., Liu, X. and Wang, J. (2014). Power H_{inf} Sliding Mode Control with Pole-Placement for a Fluid Power Electrohydraulic Actuator (EHA) System. *Int. J. of Adv. Manufacturing Technology,* 73, 1095-1104.

Zhang, Q., Meinhold, D. R. and Krone, J. J. (1999). Valve Transform Fuzzy Tuning Algorithm for Open-Centre Electro-hydraulic Systems. *J. of Agricultural Engineering Research,* 73(4), 331-339.

Zhang, Q., Wu, D., Reid, J. F. and Benson, E. R. (2002). Model Recognition and Validation for An Off-road Vehicle Electrohydraulic Steering Controller. *Mechatronics,* 12(6), 845-858.

Zhang, Y., Alleyne, A. G. and Zheng, D. (2005). A Hybrid Control Strategy for Active Vibration Isolation with Electrohydraulic Actuators. *Control Eng. Practice,* 13(3), 279-289.

Zhao, T. and Virvalo, T. (1995). Development of Fuzzy State Controller and Its Application to a Hydraulic Position Servo. *Fuzzy Sets and Systems,* 70(2-3), 213-221.

Zheng, D. and Alleyne, A. (2003). Modeling and Control of an Electro-Hydraulic Injection Molding Machine With Smoothed Fill-to-Pack Transition. *ASME J. of Manufacturing Science and Engineering,* 125(1), 154-163.

Zhu, D., Mobasher, B. and Rajan S.D. (2012). Non-contacting Strain Measurement for Cement-Based Composites in Dynamic Tensile Testing. *Cement and Concrete Composites*, 34, 147-155.

Ziaei, K. and Sepehri, N. (2001). Design of a Nonlinear Adaptive Controller for an Electrohydraulic Actuator. *ASME J. of Dynamic Systems, Measurement, and Control,* 123(3), 449-456.