PSO-TUNED PID SLIDING SURFACE OF SLIDING MODE CONTROL FOR AN ELECTRO-HYDRAULIC ACTUATOR SYSTEM

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MASTER OF SCIENCE
IN ELECTRICAL ENGINEERING

2017

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A thesis submitted
in fulfilment of the requirement for the award of Master of Science
in Electrical Engineering

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MELAKA MALAYSIA

2017

DECLARATION

I declare that this thesis entitled "PSO-Tuned PID Sliding Surface of Sliding Mode Control for an Electro-Hydraulic Actuator System" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Signature	:	………………….
Name	:	Chong Chee Soon
Date	:	………………….

APPROVAL

I hereby declare that I have read this dissertation and in my opinion, this dissertation is sufficient in terms of scope and quality for the award of Master of Science in Electrical Engineering.

Signature	:	…………………………
Supervisor Name	:	Dr. Rozaimi Bin Ghazali
Date	:	…………………………

DEDICATION

To my beloved family members

ABSTRACT

It is well known that the control engineering applications are widely implemented in the industrial fields through the assistance of the Electro-Hydraulic Actuator (EHA) system. The EHA system is commonly exposed to the parameter variations, disturbances, and uncertainties, which are caused by the changes in the operating conditions including supply pressure, total moving mass, and friction. Thus, due to the changes and uncertain operating conditions, an optimization to the system's controller is necessary in order to obtain a more robust system performance. This thesis presents the optimization on the Proportional-Integral-Derivative (PID) sliding surface of the Sliding Mode Control (SMC) scheme by using Particle Swarm Optimization (PSO) algorithm, applied to EHA system particularly for positioning tracking control. The EHA system is modelled according to the theories of the physical law, which taking into account the effect of nonlinearities, uncertainties, and disturbances occurred in the system. A robust control strategy is then formulated based on the control laws of the SMC, where the design of the sliding surface is integrated with the PID controller. The proposed control strategy is designed based on the EHA system that is subjected to the nonlinear characteristics and model uncertainties. Then, the PSO, which is based on the inspiration of the swarming behaviour has been utilized to seek for the optimum PID sliding surface parameters. The conventional tuning technique for the PID controller, which is known as Ziegler-Nichols (ZN) has been used to obtain the initial value of the PID sliding surface. Finally, the comparison has been made by applying the obtained parameters through the ZN and PSO tuning technique to the conventional PID controller and the PID sliding surface of the SMC. The findings indicate that the proposed robust SMC with PSO-PID sliding surface is preserved to ensure the actuator robust and stable under the variation of the system operating condition, which produce 26% improvement in terms of robustness characteristic that gave a better positioning tracking performance and reduced the controller effort as compared to the conventional PID controller.

ABSTRAK

Seperti yang diketahui aplikasi kejuruteraan kawalan telah meluas digunakan di bidang industri dengan bantuan sistem penggerak elektro-hidraulik (EHA). Sistem EHA biasanya terdedah kepada perubahan-perubahan parameter, gangguan, dan ketidakpastian, yang disebabkan oleh perubahan yang berlaku di dalam keadaan operasi termasuk bekalan tekanan, jumlah jisim bergerak, dan geseran. Oleh itu, disebabkan oleh perubahan dan ketidakpastian di dalam keadaan operasi, pengoptimuman terhadap pengawal di dalam sistem diperlukan untuk mendapatkan prestasi sistem yang lebih tegap. Tesis ini mengemukakan pengoptimuman pada permukaan gelangsar pengawal kadaran-kamiran-terbitan (PID) yang terdapat di dalam kawalan ragam gelangsar (SMC) dengan menggunakan algoritma pengoptimuman pengumpulan zarah (PSO), yang digunakan pada sistem penggerak elektro-hidraulik (EHA) khususnya untuk kawalan penjejakan kedudukan. Sistem EHA telah dimodel berdasarkan teori hukum fizik, yang mengambilkira kesan ketaklinearan, ketidakpastian, dan gangguan yang berlaku di dalam sistem. Satu strategi kawalan tegap kemudianya dirumus berdasarkan hukum kawalan SMC, dimana rekabentuk permukaan gelangsar disepadukan dengan pengawal PID. Strategi kawalan yang dicadangkan telah direkabentuk berdasarkan sistem EHA yang telah terdedah kepada ciri-ciri ketaklinearan dan ketidakpastian model. Kemudiannya, PSO yang berdasarkan inspirasi kelakuan pengumpulan telah digunakan bagi mencari parameter permukaan gelangsar PID yang optimum. Teknik penalaan pengawal PID yang konvensional, yang dikenali sebagai Ziegler-Nichols (ZN) telah digunakan untuk mendapatkan nilai awal permukaan gelangsar PID. Akhirnya, perbandingan telah dibuat dengan menggunakan nilai-nilai yang telah diperolehi melalui teknik penalaan ZN dan PSO terhadap pengawal konvensional PID dan permukaan gelangsar PID bagi SMC. Keputusan menunjukkan bahawa pengawal tegap SMC dengan permukaan gelangsar PSO-PID dapat dikekalkan dalam memastikan ketegapan dan kestabilan penggerak di bawah perubahan keadaan operasi sistem, yang menghasilkan penambahbaikan sebanyak 26% dari ciri ketegapan dan memberi prestasi penjejakan kedudukan yang lebih baik dan meringankan daya pengawal berbanding dengan pengawal PID yang konvensional.

ACKNOWLEDGEMENTS

First and foremost, I would like to take this opportunity to express my sincere acknowledgement to my supervisor Dr. Rozaimi Bin Ghazali from Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka (UTeM) for his supervision, support and encouragement towards the completion of this thesis.

I would also like to express my profound gratitude to Mr. Hazriq Izzuan Bin Jaafar from Faculty of Electrical Engineering, UTeM, who is the co-supervisor of this project, and the members of CeRIA laboratory for their advice and suggestions during the establishment of this thesis. All their recommendations and advice have provided me with an insightful view in the development of the project.

Special thanks to Fundamental Research Grant Scheme (FRGS) Grant No. FRGS/1/2014/TK03/FKE/02/F00214, Short Term Grant No. (PJP/2015/FKE(8C)/S01440), Centre for Robotics and Industrial Automation (CeRIA), and Ministry of Higher Education (MOHE) for the financial and technical support that had been given throughout this project.

Last but not least, special thanks to all my family members, peers, and UTeM staff for their moral support. Thanks to everyone that were involved directly or indirectly in the development of this project and the writing of this thesis.

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LIST OF ABBREVIATIONS

APA	-	Absolute positioning accuracy
ABSC	-	Adaptive back-stepping control
ACO	-	Ant colony optimization
ABC	-	Artificial bee colony
AVSS	-	Active vehicle suspension system
BC	-	Block control
CPLD	-	Complex programmable logic device
CS	-	Cuckoo search
DE	-	Differential evolution
EHA	-	Electro-hydraulic actuator
EHS	-	Electro-hydraulic servo
FSC	-	Fuzzy state controller
FNN	-	Fuzzy neural-network
FLC	-	Fuzzy logic controller
GSP	-	Gough stewart platform
GA	-	Genetic algorithm
HLE	-	Human lower-limb exoskeleton
HFPIDCR	-	Hybrid FPID controller with couple rules
IO	-	Input-output
LQG	-	Linear quadratic gaussian

LQR	-	Linear quadratic regulator
MRAC	-	Model references adaptive control
MPA	-	Mean positioning accuracy
NN	-	Neural network
N-M	-	Nelder mead
PSO	-	Particle swarm optimization
PID	-	Proportional-integral-derivative
PVSS	-	Passive vehicle suspension system
QFT	-	Quantitative feedback theory
RI	-	Robustness index
RMSE	-	Root-mean-square-error
$RMSE_{nom}$	-	Root-mean-square-error for nominal plant condition
$RMSE_{var}$	-	Root-mean-square-error for plant's parameters varied condition
RT	-	Reference trajectory
SMC	-	Sliding mode control
SMCF	-	Sliding mode control and filter
SISO	-	Single-input and single-output
SA	-	Simulated annealing
VSC	-	Variable structure control
VSF	-	Variable structure filter
WPA	-	Weighted positioning accuracy
ZN	-	Ziegler-Nichols

LIST OF SYMBOLS

V_v	-	The voltage signal flow to the torque of the motor
L_c	-	The inductance in the coil
R_c	-	The resistance in the coil
I_v	-	The current signal flow to the servo-valve
Q_R	-	The return flow of the fluid
P_R	-	The return pressure of the fluid
Q_S	-	The supply flow of the fluid
P_S	-	The supply pressure of the fluid
Q_1, Q_2	-	The fluid flow in control port A and B
P_1, P_2	-	The pressure flow in control port A and B
x_v	-	The position of the spool-valve
ζ_v	-	The damping ratio of the servo-valve
ω_v	-	The natural frequency of the servo-valve
Q	-	The flow rate of the fluid
K_v, K_{v1}, K_{v2}	-	The gain of the servo-valve
ΔP_v	-	The pressure difference in the servo-valve
P_s	-	The supply pressure
V_t	-	The piping volume connected between the pump and the servo-valve
Q_{pump}	-	The constant flow rate from the pump volume
Q_L	-	The flow rate from the servo-valve volume

V_1, V_2	-	The volume of each chamber in hydraulic cylinder actuator
V_{line}	-	The pipeline volume
x_s	-	The cylinder total stroke
A_1, A_2	-	The chamber area respectively
x_p	-	The actuator current position
q_1, q_2	-	The external leakage of hydraulic actuator
q_{12}, q_{21}	-	The internal leakage of hydraulic actuator
K_s	-	The coefficient of the spring
B_s	-	The coefficient of the damper
M_p	-	The moving mass
F_p	-	Total force of the hydraulic actuator
k_p, k_i, k_d	-	The gain for proportional, integral, and derivative
λ -	-	forgetting factor
φ	-	matrix regression
i	-	The value of particle or agent
d	-	The dimension of the problem
w	-	The inertia weight
k	-	The iteration of particle or agent
k+1	-	The future iteration of particle or agent
v	-	The velocity of the algorithm
s	-	The searching point of the algorithm
c_1	-	The self-coefficient
c_2	-	The group / swarm-coefficient
$rand_1$	-	The random value of self-coefficient
$rand_2$	-	The random value of group-coefficient

pbest	-	The particle's self or personal best value
gbest	-	The particle's group / swarm or global best value

LIST OF PUBLICATIONS

List of Journals

Published:

1. Soon, C. C., Ghazali, R., Jaafar, H. I. and Hussein, S. Y. S., 2015. “PID Controller Tuning Optimization using Gradient Descent Technique for an Electro-hydraulic Servo System,” *J. Teknol. Sci. Eng.*, vol. 77, no. 21, pp. 33–39. (Indexed by SCOPUS)
2. Soon, C. C., Ghazali, R., Jaafar, H. I., Hussein, S. Y. S., Sam, Y. M. and Rahmat, M. F., 2016. “Controller Parameter Optimization for an Electro-hydraulic Actuator System based on Particle Swarm Optimization,” *J. Teknol. Sci. Eng.*, vol. 78, no. 6–13, pp. 101–108. (Indexed by SCOPUS)

Accepted for Publication:

1. Soon, C. C., Ghazali, R., Jaafar, H. I., Hussein, S. Y. S., Sam, Y. M. and Rahmat, M. F., 2016. “The Effects of Parameter Variation in Open-Loop and Closed-Loop Control Scheme for an Electro-hydraulic Actuator System,” *Accepted for publication in International Journal of Control and Automation*, vol. 9, no. 11, Notice of Acceptance: 20 Jan 2016, Expected to be Published: Nov 2016. (indexed by SCOPUS)
2. Soon, C. C., Ghazali, R., Jaafar, H. I., Hussein, S. Y. S., Rozali, S. M. and Rashid, M. Z. A., 2016. "Position Tracking Optimization for an Electro-hydraulic Actuator System," *Accepted for publication in Journal of Telecommunication, Electronic and*

Computer Engineering (JTEC). Notice of Acceptance: 26 May 2016. (indexed by SCOPUS)

3. Soon, C. C., Ghazali, R., Jaafar, H. I., Hussein, S. Y. S., Rozali, S. M. and Rashid, M. Z. A., 2016. " Optimization of Sliding Mode Control Using Particle Algorithm for an Electro-Hydraulic Actuator System," *Accepted for publication in Journal of Telecommunication, Electronic and Computer Engineering (JTEC)*. Notice of Acceptance: 26 May 2016. (indexed by SCOPUS)

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2. Soon, C. C., Ghazali, R., Jaafar, H. I. and Hussein, S. Y. S., 2016. "Optimal PID Sliding Surface for Sliding Mode Control based on Particle Swarm Optimization Algorithm for an Electro-hydraulic Actuator System," *Proceedings of Mechanical Engineering Research Day 2016 (MERD'16)*, 31 Mac, Melaka, Malaysia. (indexed by Thomson Reuters, Web of Science)

Accepted for Publication:

1. Soon, C. C., Ghazali, R., Jaafar, H. I. and Hussein, S. Y. S., 2016. “Robustness Analysis of an Optimized Controller via Particle Swarm Algorithm,” *Accepted for publication in International Conference on Computational Science and Engineering,*

ICCSE. Notice of Acceptance: 29 April 2016. Kota Kinabalu, Sabah, Malaysia. (Indexed by SCOPUS)

LIST OF APPENDIX

CHAPTER 1

INTRODUCTION

1.1 Introduction to Electro-hydraulic Actuator System

The power distribution by fluid power is historical and well acknowledge discipline, which is an energy transmitted through the medium of pressurized fluid. The growing of fluid power technology has fulfilled the demand in the control of an increased quantities of mass with higher precision and acceleration through the lowest power consumption. The hydraulic servomechanism with the characteristic of high power-to-weight ratio became an ideal component, especially dealing with the requirement of high weight and precise motion with the limited working space.

In the areas of manufacturing assembly line, machining tools, and aerodynamic control, quick response with accurateness at the high power level are the crucial factors that yielding the integration of the electronic components into the hydraulic servomechanism. In the field of electronics, the data and information can be easily processed and transduced (Maskrey and Thayer, 1978), while the demand in high force and high speed can be delivered by the hydraulic servomechanism. Thus, an integration that absorbs the features of both electronic and hydraulic servomechanism forming the Electro-Hydraulic Actuator (EHA) system, which produces more reliable, more efficient, and better performance that could meet one expectations.