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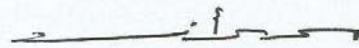
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OPTIMIZED BACK-STEPPING CONTROLLER FOR POSITION TRACKING OF  
ELECTRO-HYDRAULIC ACTUATORS


SAHAZATI MD ROZALI

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 2014

I declare that this thesis entitled "*Optimized Back-Stepping Controller for Position Tracking of Electro-Hydraulic Actuators*" 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 candidature of any other degree.

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*For my beloved family...*

*Muhammad Nizam Kamarudin, Huwaida Muhammad Nizam, Asiah Hassan,  
Allahyarham Md Rozali Md Sanam, Shahrul Aszad Md Rozali and Norsafwanah Md  
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## ABSTRACT

Electro-hydraulic actuator servo system is commonly found in various types of force and position tracking applications. Nonlinearities of the system come from either the system itself or external disturbance signals. These dynamic characteristics make the controller design for the system to be quite challenging. In order to provide satisfactory system performance for high accuracy trajectory tracking, this thesis presents a model of electro-hydraulic actuator servo system with external disturbance included to the actuator of the system. Backstepping controller is proposed in formulating position tracking control algorithm for this system. The designed controller is integrated with Particle Swarm Optimisation (PSO) and Gravitational Search Algorithm (GSA) techniques as an adaptation method such that the controller adjusts its performance automatically based on the dynamic requirement of the system. The combination of the designed controller with these optimisation techniques is verified by giving different types of known perturbation signals to the system's actuator. Then, the performance of the system with this controller is compared in terms of its tracking output, tracking error and Sum of Squared Error (SSE) as performance indices for each algorithm. The simulation results show that the output of the system tracked the reference input given with both integration of backstepping with PSO and GSA. However, backstepping-PSO produces smaller value of SSE which is around 0.5 as compared to SSE generated by backstepping-GSA.

## ABSTRAK

Penggerak sistem servo elektro hidrolik biasa ditemui dalam pelbagai jenis aplikasi pengesanan daya dan kedudukan. Ketidaklinearan sistem berpunca daripada sistem itu atau isyarat gangguan luar. Ciri dinamik ini menyukarkan rekabentuk pengawal sistem. Untuk menghasilkan sistem yang dapat mengesan kedudukan dengan jitu, tesis ini menerangkan model penggerak sistem servo elektro hidrolik dengan gangguan luar diberikan kepada penggerak sistem. Pengawal langkah belakang dicadangkan sebagai algoritma pengesanan kedudukan sistem ini. Pengawal yang direkabentuk ini digabungkan dengan teknik zarah kerumunan pengoptiman (PSO) dan algoritma carian graviti (GSA) sebagai langkah penyesuaian supaya pengawal tersebut mengawal prestasinya secara automatik berdasarkan keperluan dinamik sistem. Setiap kombinasi pengawal yang direkabentuk dengan teknik pengoptiman ini dinilai dengan memberi isyarat gangguan yang diketahui dan berbeza kepada penggerak sistem. Seterusnya, prestasi sistem dengan menggunakan dua kombinasi pengawal ini dibandingkan dari aspek keluaran sistem, ralat kedudukan dan jumlah ralat selaras sebagai indeks prestasi untuk setiap algoritma. Keputusan simulasi menunjukkan keluaran sistem berjaya mengesan kedudukan isyarat masukan rujukan yang diberi dengan menggunakan integrasi pengawal langkah belakang dengan teknik PSO dan GSA. Walaubagaimanapun, pengawal langkah belakang-zarah kerumunan pengoptiman menghasilkan jumlah ralat selaras (SSE) yang lebih kecil pada nilai lebih kurang 0.5 berbanding dengan SSE yang dihasilkan oleh pengawal langkah belakang-algoritma carian graviti.

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## LIST OF ABBREVIATIONS

3D	-	three dimensional
ARC	-	adaptive robust controller
ARX	-	autoregressive with exogenous
CAD	-	computer aided design
CLF	-	control Lyapunov function
EHA	-	electro hydraulic actuator
GA	-	genetic algorithm
GSA	-	gravitational search algorithm
IATE	-	integral absolute time error
ILC	-	iterative learning control
MIMO	-	multi input multi output
PI	-	proportional integral
PID	-	proportional integral derivative
PSO	-	particle swarm optimisation
QFT	-	quantitative feedback theory
RMSE	-	root mean square error
SISO	-	single input single output
SVC	-	static var compensator

## LIST OF SYMBOLS

$A_1$	-	area of chamber 1
$A_2$	-	area of chamber 2
$B_s$	-	viscous damper
$F_L$	-	external disturbance
$F_f$	-	friction
$K_s$	-	dynamics equation of spring
$L_c$	-	coil inductance
$M_p$	-	moving mass
$P_1$	-	pressure from chamber 1
$P_2$	-	pressure from chamber 2
$Q_L$	-	volume flow rate
$Q_{pump}$	-	constant volume flow rate
$R_c$	-	coil resistance
$V_1$	-	volume of chamber 1
$V_2$	-	volume of chamber 2
$V_{line}$	-	volume of the pipeline
$V_t$	-	volume in the piping between servo valve
$c_d$	-	coefficient of volumetric flow of the valve port
$k_c$	-	coefficient involving bulk modulus and EHA volume

$k_l$	-	coefficient of servo valve
$q_1, q_2$	-	external leakages in the hydraulic actuator
$q_{12}, q_{21}$	-	internal leakages in the hydraulic actuator
$x_p$	-	current position of the hydraulic cylinder
$x_s$	-	total stroke of the hydraulic cylinder
$x_v$	-	spool valve position
$\beta_e$	-	effective bulk modulus
$\zeta_v$	-	servo valve damping ratio
$\omega_v$	-	servo valve natural frequency
$P_a$	-	supply pressure
$P_o$	-	return pressure
$S$	-	piston area
$fit$	-	fitness
$G$	-	global best
$i$	-	number of agents
$SSE$	-	sum of squared error
$t$	-	number of iteration
$c$	-	cognitive coefficient
$f$	-	coefficient of viscous friction
$k$	-	coefficient of aerodynamic elastic force
$m$	-	load at the EHS rod
$s$	-	social coefficient
$w$	-	valve port width
$\rho$	-	oil density