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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

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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 Rozali…

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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.

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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

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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

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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
β_e	-	effective bulk modulus
ζ_v	-	servo valve damping ratio
ω_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
ρ	-	oil density

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