Faculty of Electrical Engineering

OPTIMAL DESIGN AND POSITIONING CONTROL PERFORMANCE OF A 2-DOF ROBOTIC FINGER

Mohamad Adzeem bin Mohamad Yuden

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OPTIMAL DESIGN AND POSITIONING CONTROL PERFORMANCE OF A 2-DOF ROBOTIC FINGER

MOHAMAD ADZEEM BIN MOHAMAD YUDEN

A thesis submitted
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DECLARATION

I declare that this thesis entitled "Optimal Design and Positioning Control Performance of a 2-DOF Robotic Finger" 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.

Signature	:	………………………………
Name	:	Mohamad Adzeem bin Mohamad Yuden
Date	:	………………………………

APPROVAL

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

Signature	:	……………………………………
Supervisor's Name	:	Assoc. Prof. Dr. Mariam binti Md Ghazaly
Date	:	……………………………………

DEDICATION

To my beloved mother and father

ABSTRACT

This research focuses on the positioning control performances of two degrees of freedom (2-DOF) robotic finger mechanism in achieving precision motion control. The research outcomes were expected to contribute in wider robotic hands for precision applications and suggest that the advantages of 2-DOF robotic finger can be carried over to precision and dexterous tasks. The research investigates the design of a 2-DOF robotic finger mechanism and its control strategies for achieving high precision grasping as initial research towards developing a multi-fingered robotic hand system. Behaviors such as instability, large steady-state error and poor transient performance often occurred in the robotic hand mechanism. Therefore, the goal of this research is to design a 2-DOF robotic finger mechanism and compare the performances of several controllers for positioning motion control and evaluate the effectiveness of controllers by Point-to-Point (PTP) control and tracking control. In this research, the proposed controllers will depend on the angular position control of each motor joints, i.e. the position control of the 2-DOF robotic finger mechanism. In order to achieve the research objectives, the research was implemented in three (3) main phases. Phase 1 involve the optimization of the robotic hand design using Finite Element Analysis (FEA) using Solidworks software and its experimental setup. In Phase 2, the robotic finger mechanism mathematical modeling and system identification methods were discussed and compared. In phase 3, two categories of control system experiments were carried out which are the open-loop control system and the closed-loop control system. For open-loop system, the evaluation was done using the step input signal. Meanwhile, the closed-loop system was carried out for uncompensated and compensated system using several reference angles. Three different control startegies namely (i) Proportional Integral Derivative (PID) controller (ii) Fuzzy Logic controller (FLC) and (iii) Linear Quadratic Regulator (LQR) controller were chosen to be compared via simulation and experimental works. The controller results were validated by Point-to-Point (PTP) control and tracking control with frequency from 0.1 Hz to 0.5 Hz at different reference amplitudes. From the analyze results, it is proven that the Fuzzy controller gave the best performances and has higher level of adaptability for the PTP control with improvements in both response time by 97.9 % (0.075 s) and steady-state error by 99.5 % (0.01 °) in compared to the uncompensated system. Meanwhile, it was concluded that LQR controller exhibits the best tracking control performances. The LQR controller had demonstrated an improvement in steady-state error by 98.5 % (0.11 °) over the uncompensated system in a series of experimental tracking tests. It was also concluded that the 2-DOF robotic finger mechanism had also succeeded the grasping tasks with the specific reference trajectory using the Fuzzy controller.

ABSTRAK

Kajian ini menumpukan kepada prestasi kawalan kedudukan mekanisme jari robot dua tahap kebebasan (2-DOF) dalam mencapai ketepatan gerakan. Hasil penyelidikan dijangka menyumbang kepada tangan robot yang lebih luas untuk penggunaan ketepatan dan mencadangkan bahawa kelebihan jari robot 2-DOF dapat dibawa kepada tugas-tugas yang mahir dan tepat. Penyelidikan ini mengkaji reka bentuk mekanisme jari robot 2-DOF dan kaedah-kaedah kawalannya untuk mencapai ketepatan genggaman yang tinggi sebagai langkah penyelidikan awal ke arah menghasilkan sistem tangan robot pelbagai jari. Kelakuan seperti ketidakstabilan, kesilapan keadaan mantap yang besar dan prestasi fana yang lemah sering terjadi dalam mekanisme tangan robot. Oleh itu, matlamat penyelidikan ini adalah untuk merekabentuk mekanisme jari robot 2-DOF dan membandingkan prestasi beberapa pengawal untuk mengawal pergerakan dan menilai keberkesanan pengawal dengan cara kawalan titik-ke-titik (PTP) dan kawalan penjejakan. Dalam kajian ini, pengawal yang dicadangkan bergantung kepada posisi kawalan setiap sudut sendi motor, iaitu kedudukan kawalan mekanisme jari robot 2-DOF. Untuk mencapai matlamat penyelidikan ini, penyelidikan telah dilaksanakan dalam tiga (3) fasa utama. Tahap 1 melibatkan pengoptimuman reka bentuk tangan robot menggunakan analisis unsur terhingga (FEA) menggunakan perisian Solidworks dan persediaan ujikaji. Dalam Fasa 2, kaedah model matematik dan pengenalan sistem mekanisme jari robot dibincangkan dan dibandingkan. Dalam fasa 3, dua kategori ujikaji sistem kawalan telah dijalankan iaitu sistem gelung terbuka dan sistem gelung tertutup. Bagi sistem gelung terbuka, penilaian dilakukan menggunakan isyarat masukan langkah. Sementara itu, sistem gelung tertutup telah dijalankan untuk sistem tanpa pampasan dan sistem pampasan menggunakan beberapa sudut rujukan. Tiga kawalan yang berbeza iaitu (i) pengawal berkadar dengan kemahiran dan terbitan (PID) (ii) Pengawal Logik Fuzzy (FLC) dan (iii) Pengawal Kuadrat Latar Belakang (LQR) telah dipilih untuk dibandingkan dengan penyelakuan dan kerja ujikaji. Hasil pengawal disahkan oleh kawalan titik-ke-titik (PTP) dan kawalan penjejakan dengan frekuensi dari 0.1 Hz hingga 0.5 Hz pada amplitud rujukan yang berlainan. Dari hasil analisa, terbukti bahawa pengawal Fuzzy memberikan prestasi yang terbaik dan mempunyai tahap penyesuaian yang lebih tinggi untuk kawalan PTP dengan peningkatan dalam kedua-dua masa tindak balas sebanyak 97.9% (0.075 s) dan ralat keadaan mantap sebanyak 99.5% (0.01 °) berbanding dengan sistem yang tidak dikompensasikan. Sementara itu, disimpulkan bahawa pengawal LQR mempamerkan prestasi kawalan penjejakan terbaik. Pengawal LQR telah menunjukkan peningkatan dalam ralat keadaan mantap sebanyak 98.5% (0.11 °) ke atas sistem tidak dikompensasikan dalam satu siri eksperimen ujian penjejakan. Disimpulkan juga bahawa mekanisme jari robot 2-DOF juga telah berjaya melakukan genggaman kerja dengan trajektori rujukan khusus menggunakan pengawal Fuzzy.

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LIST OF ABBREVIATIONS

ABS	-	Acrylonitrile butadiene styrene
ANN	-	Artificial neural network
D	-	Derivative
DC	-	Direct current
DLR	-	Deutsches Luft and Raumfahrt
DOF	-	Degree of freedom
FEA	-	Finite element analysis
FLC	-	Fuzzy logic controller
GA	-	Genetic algorithm
H_∞	-	H - infinity
I	-	Integral
LQR	-	Linear quadratic regulator
MIT	-	Massachusetts Institute of Technology
P	-	Proportional
PC	-	Personal computer
PC	-	Polycarbonate
PI	-	Proportional integral
PID	-	Proportional integral derivative
PLA	-	Polylactid acid
PWM	-	Pulse-width modulation

PTP	-	Point-to-point
SSE	-	Steady-state error
3D	-	Three dimensional

LIST OF SYMBOLS

Mathematical Symbol:

A	-	Ampere
e	-	Position error
e_{max}	-	Maximum tracking error
F	-	Force
G	-	Gravity = 9.81 m/s
K_i	-	Integral gain
K_p	-	Proportional gain
K_u	-	Ultimate proportional gain
kg	-	Kilogram
M	-	Mass
m	-	Meter
N	-	Newton
P	-	Pressure
rad	-	Radian
s	-	Second
t	-	Time
T	-	Torque
T_r	-	Rise time
T_s	-	Sampling time

T_{settle}	-	Settling time
V	-	Voltage
w	-	Angular velocity of motor
°	-	Degree
θ	-	Angle
θ_r	-	Reference angle
π	-	Pi
Ω	-	Ohm
%	-	Percentage
$\%OS$	-	Overshoot percentage
∞	-	Infinity
$+$	-	Plus
$-$	-	Minus
$\pm$	-	Plus or minus
/	-	Divide
=	-	Equal

System Model Symbol:

Dm	-	Viscous damping coefficient of motor and load
E_a	-	Armature voltage
I_a	-	Armature current
J_m	-	Moment of inertia of motor and load
K_b	-	Motor back-emf constant
K_t	-	Motor torque constant
L_a	-	Armature inducatance