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Tracking Control Performance of a 2-DOF Robotic Finger using PID and LQR Controller

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ABSTRACT – This research focuses on the tracking control performances of two degrees of freedom (2-DOF) robotic finger mechanism in achieving precision motion control 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. 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. Two control strategies namely (i) Proportional Integral Derivative (PID) controller and (ii) Linear Quadratic Regulator (LQR) controller were chosen to be compared via simulation and experimental works. The controller results were validated by tracking control with frequency from 0.1 Hz to 0.5 Hz at different reference amplitudes. From the analyze results, 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 °) in a series of experimental tracking tests.

1.0 INTRODUCTION

Nowadays, robotic hands are widely used in the industry sector. The demands of high precision performance of robotic hands system have drastically increased in recent years. Other than that, the application of high precision performance of robotic hand system has radically increased in recent years especially in industrial sector. The problems when controlling robotic finger mechanism are the control inputs itself as well as the external disturbances which will give effect to flexural vibrations and positioning error on the robotic finger mechanism structures [1-2]. Besides that, some of the robotic hands could not function well in real time because it takes a longer period to evaluate the target joint angle from the fingertip position [3]. Conventional control of these robotic hands also requires too much concentration from one input for one DOF. Therefore, the robotic hands require precise motion control which enables them to follow the exact trajectory to achieve a targeted outcome. Thus, high motion control controller design is desired for enhancing precision motion performance of the robotic hand system.

2.0 METHODOLOGY

Figure 1 shows the overview of the experimental setup of the 2-DOF robotic finger mechanism. In this research, the developed robotic hand design consists of three fingers and a thumb. Each finger has two links and consist of 2-DOF, while thumb has three links and 3-DOF to allow adduction and abduction movement. For each finger, it consists of two DC micro motor namely Motor 1 and Motor 2, planetary gearhead, bevel gear and optical encoder in order to evaluate the tracking performance of the finger mechanism. In order to evaluate the tracking control performances of two degrees of freedom (2-DOF) robotic finger mechanism, two control strategies namely (i) Proportional Integral Derivative (PID) controller and (ii) Linear Quadratic Regulator (LQR) controller were chosen.

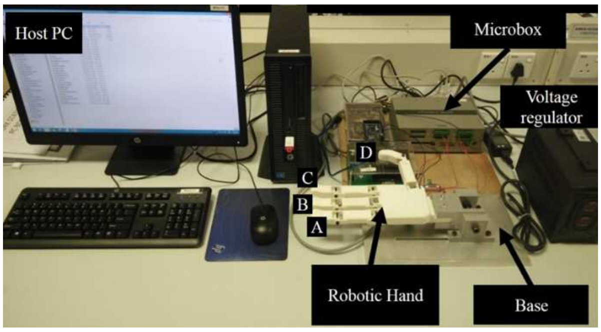

Figure 1 Experimental Setup

3.0 RESULTS AND DISCUSSION

3.1 PID and LQR Controller Design Procedures

The PID control method is developed to enhance the system performance of the 2-DOF robotic finger such as response time, steady-state error and percentage of overshoot, whilst LQR controller is expected to compensate for the fast changing error in tracking trajectory.

In this research, PID controller is designed using Ziegler-Nichols closed-loop tuning method such that the output parameter responses quickly and minimizing the error during position control. Figure 2 shows the block diagram structure of a 2-DOF robotic finger mechanism for PID position control used in this research. Table 1 shows the Ziegler-Nichols tuning formula method applied. The PID controller comprises of proportional,

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integral and derivative components and the general equation of the P, PI and PID controller is shown in Equation (1). The obtained ultimate gain value, K_u is 54.6 and period of oscillation, P_u is 0.015.

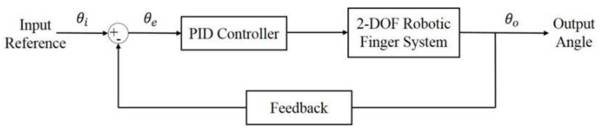

Figure 2 The block diagram structure of the compensated closed-loop system with PID controller

Table 1 Ziegler-Nichols tuning formula method

Control Type	K_p	K_i	K_d
P	$0.50 \times K_u$	-	-
PI	$0.45 \times K_u$	$0.85 \times P_u$	-
PID	$0.60 \times K_u$	$0.50 \times P_u$	$0.13 \times P_u$

$$G_{PID} = K_p + \frac{K_i}{s} + K_d s \quad (1)$$

LQR controller is based on the state space system and acquires the optimal control input by solving the Algebraic Riccati equation. Figure 3 shows the LQR control system used in this research. The objective of LQR controller design is to determine the state-feedback control vector, K_{LQR} that would provide the control vector, $u(t)$. A linear time-invariant system is considered as shown in Equation (2).

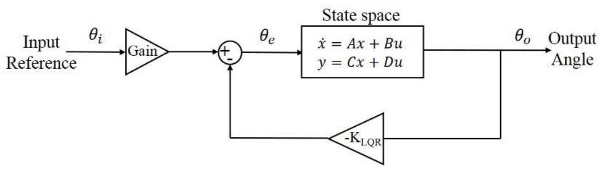

Figure 3 The block diagram structure of the compensated closed-loop system with LQR controller

$$\dot{x}(t) = Ax(t) + Bu(t) \quad (2)$$

where, $\dot{x}$ is the state variable and u is the control input variables.

3.2 Tracking Controller Performances

The analysis was carried out from the view of frequency and angle variation in sinusoidal input reference for the compensated closed-loop tracking control. The experimental sinusoidal tracking responses of the PID and LQR controlled system for Motor 1 are presented in Figure 4. The maximum error for each experiment set is tabulated in Table 2. These results depicted that LQR control approach exhibit better functioning and accuracy as compared to PID controller. The LQR controller demonstrated improvements in steady-state error by 98.5 % (0.11 °) in a series of experimental tracking tests.

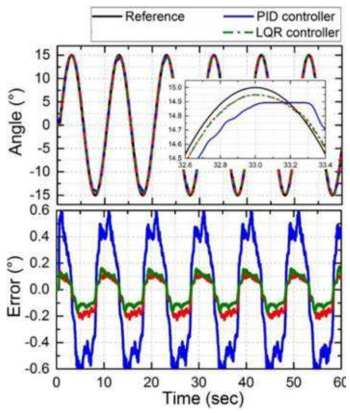

Figure 4 Closed-loop sinusoidal tracking response at frequency of 0.1 Hz with reference angle 15 °

Table 2 Maximum error for tracking tests of Motor 1

Controller Type		PID	LQR
Frequency (Hz)	Reference Angle (°)	Maximum Error (°)	Maximum Error (°)
0.1	15	0.44216	0.10541
	40	0.98796	0.17610
0.5	15	1.52462	0.30207
	40	3.72011	0.61006

4.0 CONCLUSION

In conclusion, the results depicted that the tracking control of the 2-DOF robotic finger mechanism can be satisfactorily controlled via LQR control approach. The LQR controller demonstrated improvements in steady-state error by 98.5 % (0.11 °) over the uncompensated closed-loop system in a series of experimental tests.

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