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The Effect of Varying PID Gains on Position Transient Response of a Robotic Hand System

Salleh, N. M., Shauri, R. L. A.*, Nasir, K., Remeli, N. H. and Kamal, M. M.

Faculty of Electrical Engineering, Universiti Teknologi MARA (UiTM), 40450 Shah Alam, Selangor, Malaysia

ABSTRACT

In an earlier study, a three-fingered robot hand was developed for assembly work. Proportional Integral Derivative (PID) control was used to control the position of a DC micromotor measured by an encoder. However, PID control alone could not cater the nonlinearities due to friction of gears and varying loads applied to the finger. Therefore, in order to develop an intelligent control algorithm in future, the effects of varying PID gains need to be investigated to distinguish the optimal value that could produce the best transient response performance. This paper discusses the effect of varying PID gains on position transient response of the joint motor of robot hand through real-time experiments. Several ranges of K_P, K_I and K_D were identified based on the required transient response parameters such as percentage overshoot (%OS), settling time (T_S) of within 2%, steady state error (SSE) and rise time (T_R). The gains are tuned across the range by a fixed interval with the tuning order starting from K_P, K_I and K_D. It can be observed that the suitable ranges of PID are 0.3 to 0.5 for K_P, 1.15 to 1.45 for K_I and 0.10 to 0.14 for K_D. Meanwhile, the optimum value of 0.4, 1.45 and 0.10 for K_P, K_I and K_D respectively is found to produce 0 of % OS, 5.09 sec of T_S and 2.48 sec of T_R. Hence, the gains can be applied to the development of an improved position control using intelligent method for the robot hand in future works.

Keywords: : PID control, PID parameter tuning, position control, transient response, real-time experiment

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E-mail addresses:
sharizasalleh@gmail.com (Salleh, N. M.),
ruhizan@salam.uitm.edu.my (Shauri, R. L. A.),
khairunnisanasir@yahoo.com (Nasir, K.),
hananiremeli@gmail.com (Remeli, N. H.),
mahani724@salam.uitm.edu.my (Kamal, M. M.)
*Corresponding Author

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INTRODUCTION

Current research and development in robotic technologies are aiming at creating robust and autonomous manufacturing system (Brogårdh, 2007; Lovchik & Diftler 1999). Producing robots that could imitate human capabilities is beneficial in many fields such as medical, rehabilitation, industry, and even military. It is not only the operating system that is important but also the robot design.

Lovchik and Diftler (1999) produced a robot hand for teleoperation in outer space. Meanwhile, the presence of robot manipulators in the industry could solve the shortage of skilled labour, thus, reducing production cost.

Programming is important to make the robot fully automated. In the integrated programming, it has one main component which is a control system. The controller is a component which has to generate an appropriate control signal and it is applied in systems and process control and needs to be optimised in order to obtain a good control system stability in an intelligent autonomous system. The most common controller used in industries is Conventional Proportional Integral Derivative (PID) control. This is due to its practicality and simple mathematical equation involved. For example, Li and Yu (2011) applied PID Controller to control 7-DOF exoskeleton. PID controller is tuned using their own novel tuning approach based on common conventional tuning methods. Meanwhile, Sonoda and Godler (2011) developed a robotic finger with twisted string actuation controlled by PI controller.

However, new researches combined PID with embedded intelligent control algorithms such as Fuzzy Control Logic (FLC), Adaptive Neuro Fuzzy Inference System (ANFIS), Artificial Neural Network (ANN) and Genetic Algorithm (GA) to improve the tuning of PID gains. Yu, Li and Carmona (2013) examined the application of robotic hand for patient's rehabilitation. The support device must be a simple structure, light weight, low-cost, easy maintenance, and uses soft actuator. The fuzzy-PID method has been used to accommodate the varying loads of patient hands for control. Some examples of intelligent control system combined with Fuzzy-PID is found in (Erden & Leblebicioglu, 2004). This study is to develop a three-joint robot leg that can be used for any required positions. The fuzzy-PID controller was designed for this three-joint robot leg for accurate position and trajectory tracking control. To create the rules for Fuzzy, it needs optimal investigation to understand transient behaviour by optimum trajectories planned by the user. The result shows selected control method has better outcome than conventional PID Controller. Chopra, Singla and Dewan (2014) studied embedded intelligent system control to improve linearity of PID control compared with intelligent control. The results showed that PID with embedded intelligent control performed better than stand-alone PID control for non-linear systems. However, this study only used simulations and not real time control. Even though the intelligent system is applied into the control systems, the PID control is still required. The results using PID control will be used as references to manipulate any control method in future control design.

In previous study, a robot hand which consists of three fingers and a palm was developed. All the seven joints are actuated by DC micromotors. The finger mechanism was analysed by Shauri, Remeli, Jani and Jaafar (2014) and Azri and Shauri (2014). However, the robot hand requires an intelligent PID control to produce precise motions. It can be observed in a separate experiment that the tuning of PID gains (K_P, K_I and K_D) could not be solved using Ziegler Nichols method. Therefore, this paper investigates the effect of varying PID gains on the transient response of the finger joint position through real-time experiment. Trial and error method was used for this purpose because the dynamic equation of the motor was not available. The range of PID gains that complies the required transient response parameters are first determined. Then, the comparisons between the transient responses of the gains between the ranges are compared to determine the optimum value of each K_P, K_I and K_D. The analysis is based on transient response parameters which included percentage overshoot (%OS), settling time (T_S) of within 2% of a given step input, steady state error (SSE) and rise time (T_R).

PID Control and Transient Response

PID control is generally used for controlling automation system and processes in industrial plants. Even though PID controller does not involve complex mathematical calculation, it can assure the satisfaction in performances of a wide range of process plants (Visioli, 2001). The PID control is an acceptable controller, easy to be understood and adequate for many practical systems (Wang et al., 1999). However, gain parameters need to be tuned to make sure it could produce good transient parameter performances.

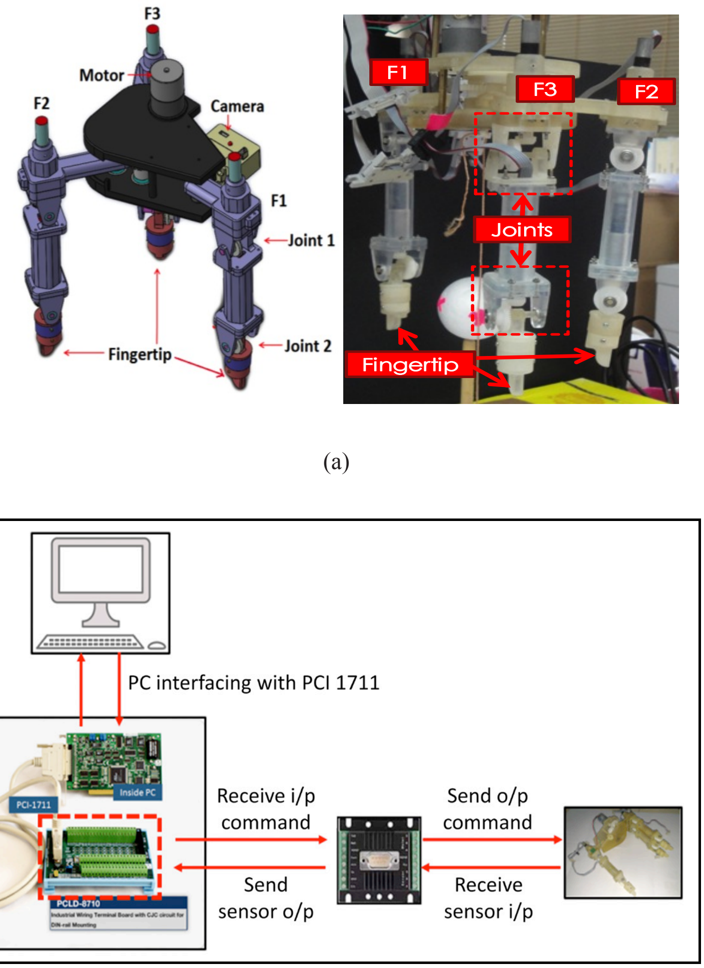
In control systems, transient response can be defined as the behaviour of the system following a sudden change in its input. The transient response parameters that have been used to evaluate the control system performance in order to attain the optimum value for gain parameters are as follows:

- Maximum Overshoot (%OS): The excess value of output response beyond the desired value of angle position at the peak time. It is also calculated as percentage of exceeded value to the input step response.
- Settling Time (T_S): The time required for the transient's damped oscillations to settle and maintain their values within ±2% or ±5% of the steady-state value. In this study, the ±2% of T_S is used.
- Rise Time (T_R): The time required by the response to rise between 10% and 90% of the final value.

Real-Time Control System and Architecture

Figure 1(a) shows the robot hand which consists of three fingers and a palm. It also consists of the controller, interfacing device, motor driver, actuator and sensor as shown in Figure 1(b). Every two joints of each finger are actuated by DC micromotors. An interfacing contains two devices which are Advantech PCI-1711 interfacing card and PCLD-8710 input output terminal connected using 68-pin SCSI cable. Analog voltage from the terminal is sent to the motor driver to actuate the DC micromotor and a magnetic encoder measures the actual position in terms of signal pulses.

The MATLAB Simulink software with real-time control toolbox is used to control the DC micromotor position in a real time. An advantage of using MATLAB real-time control compared with microcontrollers is that the control parameters can be directly changed by the user without having to rebuild and upload the programming. In this paper, one of the fingertips has been used to investigate the tuned gain parameters to the performance of position control. The results of this investigation can be used as reference for setting the gain parameters of other fingers in future studies.



(a)

(b)

Figure 1. Robot hand system: (a) Three-fingered robot hand (Shauri et al., 2014); and (b) Software and hardware interfacing

Identification of Range for PID Gains

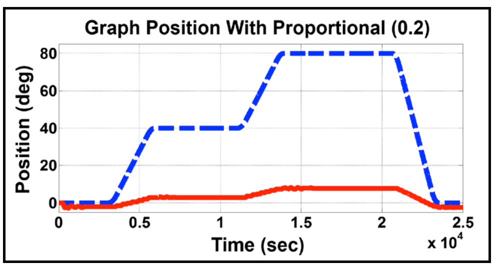
The PID gains for lower and upper limits are determined based on the transient response performance for each varying gain. The required transient response parameters are 0% of OS and short duration of T_S, and T_R. First, the K_P tuning began with a value which is close to zero, then increased by 0.1 interval to find the response with least ripple and steady state error. While K_P gain is tuned, the K_I and K_D are set to zero. Once the optimal value of K_P is determined, K_I is tuned by 0.15 interval. Optimum value of K_I is selected based on the fastest response with the minimum %OS.

Finally, the K_P and K_I, K_D is tuned by increasing the interval by 0.02 until the transient response could arrive at its desired position in the shortest T_S and T_R, 0% of OS and without ripples on the signal. Every transient response from the tuning steps was compared and analysed manually.

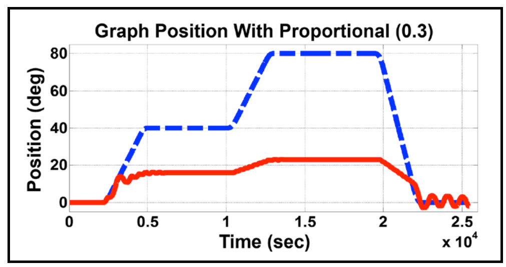
RESULTS AND DISCUSSION

Proportional Gains Parameter Tuning

From graphs as shown in Figure 2, it can be observed that the values of K_P between 0.3 and 0.5 are accepted as the best range of K_P. K_P at 0.5 is selected as the best value due to its lowest SSE. Among the tested range of K_P, 0.2 gives the highest SSE while K_P at 0.6 gives the lowest SSE but it starts to produce ripples on the signal. It can be concluded that the ripples will occur after K_P is set above 0.6. The comparison between the SSE values for each varying K_P ranging between 0.2 and 2.2 is shown in Table 1.



(a)



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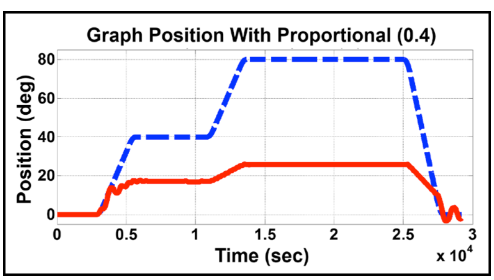

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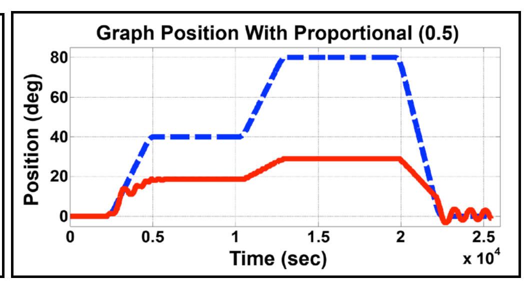

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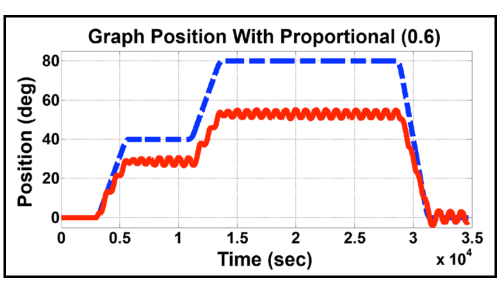

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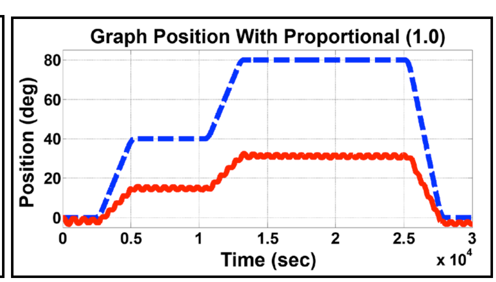

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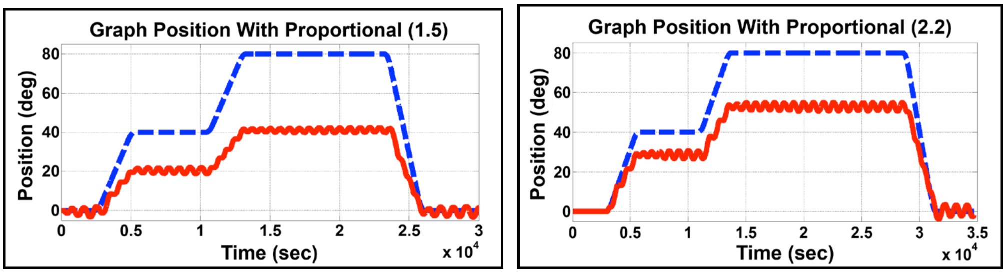

(g) (h)

Figure 2. Effect of varying proportional gain K_P (K_P, 0, 0): (a) 0.2, 0, 0; (b) 0.3, 0, 0; (c) 0.4, 0, 0; (d) 0.5, 0, 0; (e) 0.6, 0, 0, (f) 1.0, 0, 0; (g) 1.5, 0, 0; and (h) 2.2, 0, 0

Table 1
Proportional gain tuning

Proportional Gain (K_P)	SSE
0.2	72.27
0.3	57.08
0.4	54.12
0.5	51.03
0.6	29.16
1.0	49.48
1.5	40.06
2.2	29.16

Integral Gains Parameter Tuning

The results as shown in Table 2 indicate that K_P at 0.4 gives the lowest T_S and T_R compared with K_P at 0.5. Furthermore, when the position returned from 80 to 0, the % OS for K_P at 0.4 gives lower value than K_P at 0.5. Therefore, the new optimum value of 0.4 for K_P is used for the K_I tuning within the range of 0.85 to 1.60.

From the same table, the value of K_I between 1.15 and 1.45 are accepted as the best range of K_I. To obtain the optimal K_I, this range is compared based on the best value of the transient parameters. K_I at 1.60 gives lowest T_S but also an amount of 4.22% of OS when the position returned from 80 to 0. Meanwhile, K_I at 1.45 gives acceptable T_S with lowest T_R and % OS compared with the other K_I values. Thus, 1.45 is chosen as the optimal value for K_I. The transient response for each varying K_I is shown in Figure 3.

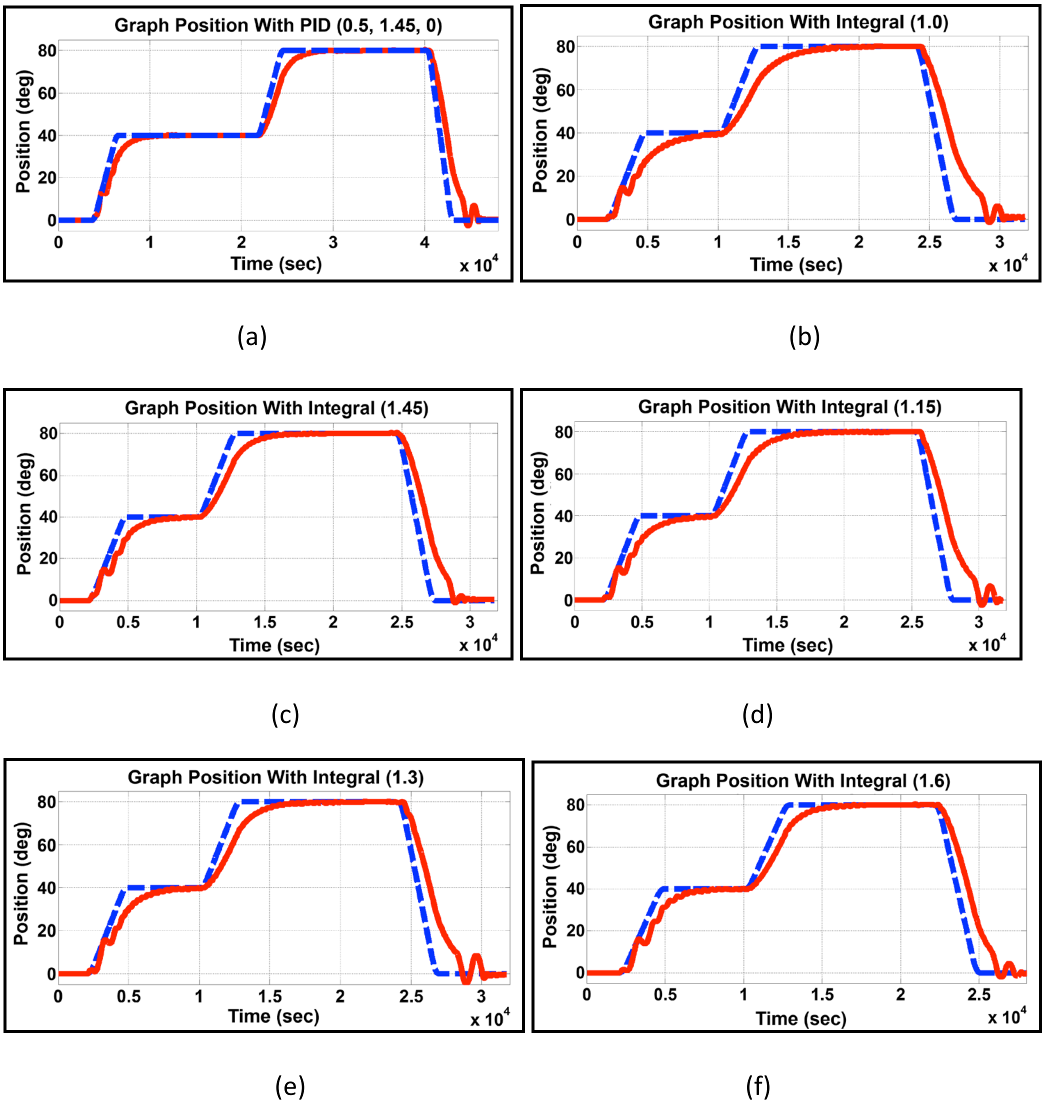

Figure 3. Effect of varying integral gain K_I (K_P, K_I, 0): (a) 0.5, 1.45, 0; (b) 0.4, 1.0, 0; (c) 0.4, 1.15, 0; (d) 0.4, 1.45, 0; (e) 0.4, 1.3, 0; and (f) 0.4, 1.6, 0

Table 2
Integral gain tuning

(K_P, K_I,0)	Transient Parameters		
	T_S	T_R	%OS (at 0°)
0.5,1.45, 0	5.42	2.50	6.89
0.4,1.00,0	6.51	3.04	6.05
0.4,1.15,0	5.84	2.74	6.54
0.4,1.30,0	5.52	2.57	8.37
0.4,1.45,0	5.15	2.39	2.18
0.4,1.60,0	4.71	2.70	4.22

Derivative Gains Parameter Tuning

After the optimum values for K_P and K_I was determined, K_D varied between 0.08 and 0.16. The results in Table 3 show that the acceptable range of K_D is between 0.10 to 0.12 where the optimal value of 0.10 produces the lowest T_R and T_S. Besides, the same value is able to eliminate the ripples and overshoots that occur with the other K_D values. Several sets of other K_P, K_I and K_D which are closer to the value of the optimum K_P: 0.4, K_I: 1.45 and K_D: 0.10 were tested. The comparison between the transient response performance is shown in Table 4 and in Figure 5. It can be concluded that the optimum value of PID gives lowest T_S, T_R and 0% of OS.

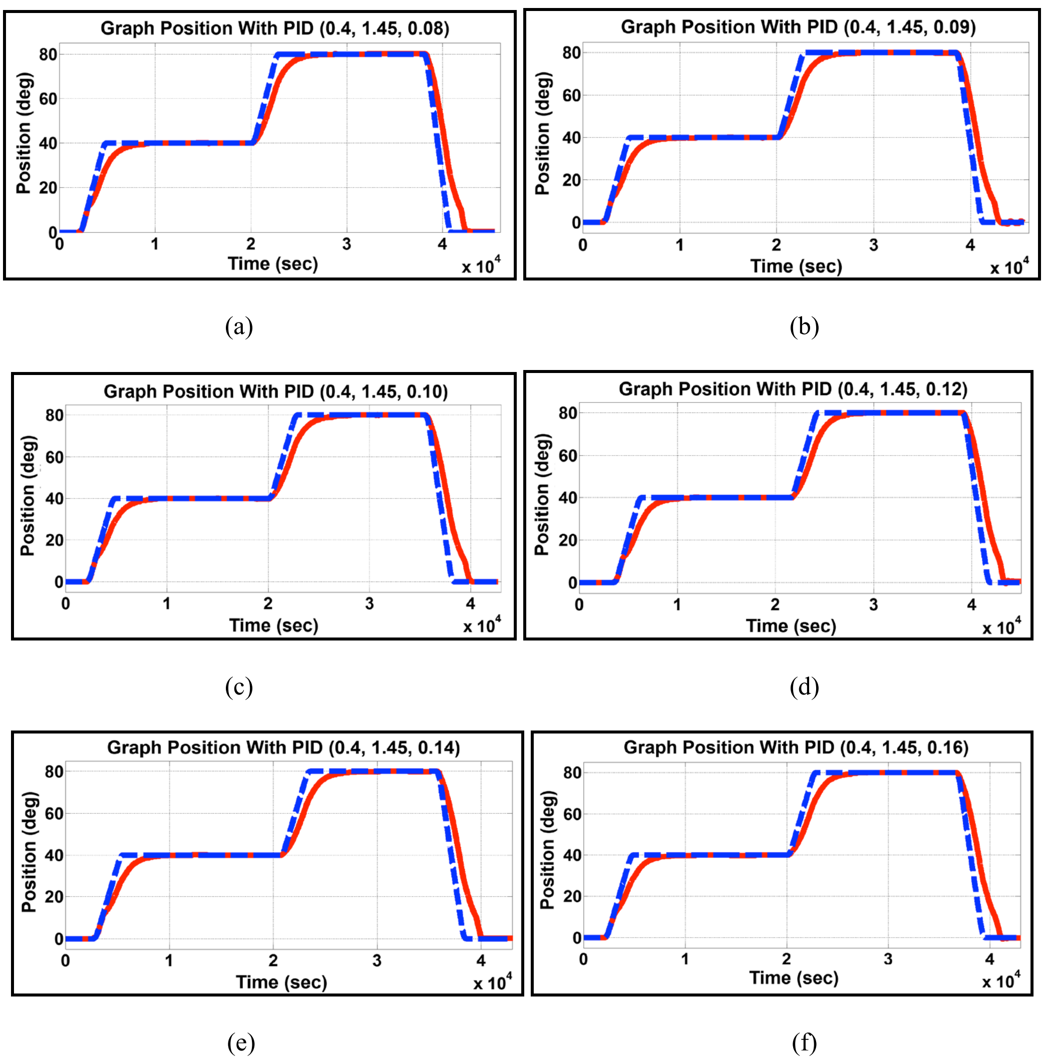

Figure 4. Effect of varying derivative gain K_D (K_P, K_I, K_D): (a) 0.4, 1.5, 0.08; (b) 0.4, 1.45, 0.09; (c) 0.4, 1.45, 0.10; (d) 0.4, 1.45, 0.12; (e) 0.4, 1.45, 0.14; and (f) 0.4, 1.45, 0.16

Table 3
Derivative gain tuning

Derivative Gain	Transient Parameters	
(K_D)	T_S	T_R
0.08	5.26	2.52
0.09	5.17	2.53
0.10	5.09	2.48
0.12	5.23	2.50
0.14	5.10	2.53
0.16	5.27	2.54

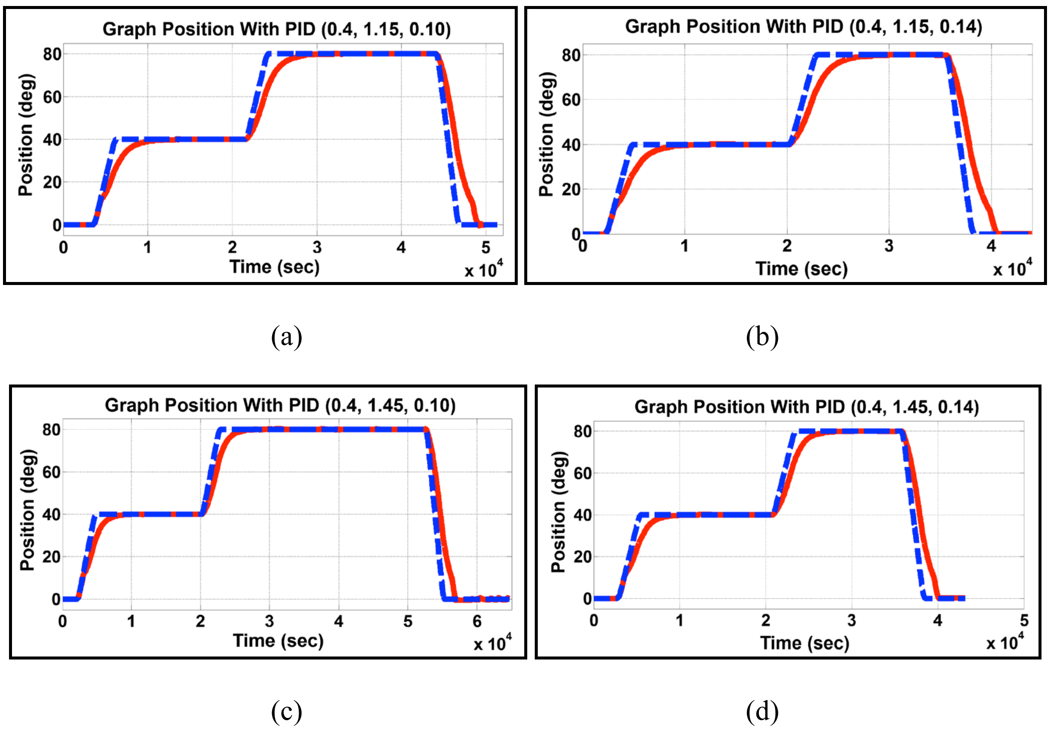

Figure 5. Effect of varying PID gains (K_P, K_I, K_D): (a) 0.4, 1.15, 0.10; (b) 0.4, 1.15, 0.14; (c) 0.4, 1.45

Table 4
Transient parameter of varying PID

PID Gains			Transient Parameters	
K_P	K_I	K_D	T_S (sec)	T_R (sec)
0.4	1.15	0.10	6.14	2.81
0.4	1.45	0.10	5.09	2.48
0.4	1.15	0.14	6.16	2.88
0.4	1.45	0.14	5.10	2.53

CONCLUSION

This study examined the varying PID gains on position transient response of a robotic hand system using a trial and error method. The results showed K_P, K_I and K_D at 0.4, 1.45 and 0.10 respectively are the optimum values to give 5.09 sec T_S, 2.48 sec T_R and 0% of OS. The suitable range of the K_P, K_I and K_D was obtained and will be used to design PID-Fuzzy Control for robot hand in future works.

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