PI Position-based Force Control for Robotic Grasping of Compliance objects

ANWAR RAJAWANA †1 PARAMIN NERANON †1
KITTIKHUN TONGPULL †1 PORNCHAI PHUKPATTARANONT †1

Abstract: Many researchers have studied on how to control robot hands in grasping tasks; however, there are few studies have focused on robot grasping compliance object. Thus, this study proposes PI position-based force control algorithm for a robot hand which can appropriately grab compliance objects. A set of experiments has been carried out to determine optimal PI gains. The compliance objects with different stiffness values can be simulated using a cantilever beam with a variety of lengths. By using Ziegler–Nichols method, a set of optimal PI gains can be calculated by indicating using Root Mean Square of force error. This founding can be further used in Fuzzy-PI force control for the robot hand which can automatically select a set of PI gains for a variety of compliance objects.

Keywords: PI position-based force control, Robot hand and Ziegler–Nichols method

1. Introduction

Over the past few years, much research has been studied on robotic control algorithms for object grasping tasks [1-2]. As reviewed, it can be found that PI control is a famous choice to be implemented for the position- based force control. After an extensive review of relevant academic research, it was decided to initially apply simple proportional plus integral (PI) control. The PI robot force control algorithm is preferable to proportional-integral- derivative (PID) control since the derivative term is sensitive to noise and this could lead to a destabilizing effect on the robotic force control system. Although, the derivative gain which gives a reduction in the system overshoot and settling time has been removed, the overshoot response can be controlled using an appropriate proportional gain. The researchers have also advised that the proportional integral (PI) control is appropriate for robot force/position control in order to provide the smallest possible force control error, and because this technique facilitates an increase in the accuracy and stability of the control system. Therefore, the PI force control is adopted in this research.

2. Experimental Preparation

This study has proposed the optimal PI force/position control for a AR10 robot hand in compliance object grasping tasks. Figure 1 illustrates the overall block diagram of the robot hand control. It consists of an Arduino Mega2560 which acquires the measured force signals from the fingers, linear actuators used to drive the robot fingers and the 3D finger force sensors attached to the finger tips. An AR10 Robot hand was designed human hand-like that can be used in this research and it has 10 degrees of freedom (DOF). Linear servo motors (which include potentiometer encoders) were applied. The force measuring system of the robot fingers while grasping the object involves the Opto-force 3D sensors (OMD-20-SE-40N) which were mouthed at the end of fingers and sent data in real-time to the microcontroller.

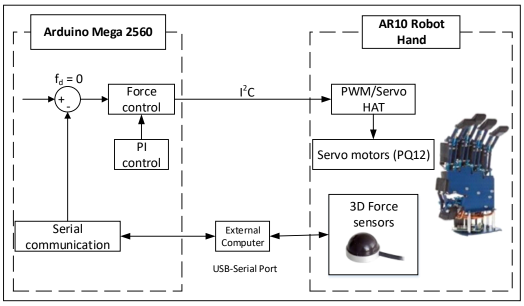

Figure 1 Overall schematic block diagram of robot hand control.

3. PI Controller using Ziegler–Nichols method

PI control is widely used in industrial control systems and a variety of other applications requiring continuously modulated control. The control computes an error value *e(t)* as the difference between a desired force value and a measured force value and applies a correction based on proportional and integral terms. The PI control algorithm can be expressed as the following equation:

$$y = k_p e(t) + k_i \int_0^t e(t)dt + k_d \frac{de(t)}{dt} \quad (1)$$

where, k_p = proportional gain, k_i = integral gain, k_d = derivative gain and $e(t)$ = force error

Proportional integral control gain tuning is the important stage to achieve an effective control response of the system. Various techniques for PID gain tuning have been developed, such as the Ziegler-Nichols, Cohen-Coon, Chien-Hrones-Reswick or manual techniques; however, Ziegler–Nichols tuning method is common used and easily implemented. Thus this technique is adopted. The PI gains: k_p and k_i, are initially set to be zero, and after that k_p will start increasing until oscillating output signal occurs. This reaches k_u and T_u (oscillation period) and then k_p, and k_i can be calculated using Table 1.

Table 1. Ziegler–Nichols tuning method

Control Type	k_p	k_i	k_d
P	0.50 k_u	-	-
PI	0.45 k_u	T_u /1.2	-
PID	0.60 k_u	T_u /2	T_u /8

†1 Prince of Songkla University

3.1 Root mean square error

The performance of the PI tuning can be analyzed based on the root mean square error (*E_RMS*) of the desired and actual forces. The performance of the system response can be evaluated in terms of the variation in the error forces, in which the lower the variation in error force, the better the performance of the system. The equation used to calculate the magnitude of error deviations of *E_RMS* is expressed as:

$$E\_RMS = \sqrt{\frac{1}{n}\sum_{j=1}^{n}(y_j - \hat{y}_i)^2}, \qquad (2)$$

where, n is the number of evaluated values,
y_j is the forces exerted by a participant and
$\hat{y}_i$ is the demanded force.

4. PI force control results

4.1 Experimental Setup

Each robot finger has two degrees of freedom (DOF) and it can perform extension and flexion on the x-y plane. The position of the end of the finger is calculated by using the 4-bar linkage equation. The experimental involves one of the AR-10 robot fingers which has to perform on the 0.15 *m*-cantilever beam using stainless steel by vertical pushing. Pushing on different displacement can simulate various stiffness values of compliance objects and it can express as:

$$k = \frac{3EI}{l^3} \qquad (2)$$

where, k = Stiffness, l = Length (*mm*),
E = Elastic Modulus (N/m^2) = 1.9 x 10^{11} N/m and
I = Moment of Inertia (m^4) = 1.053 x 10^{-12} m^4.

The robot's finger was mounted with the Opto-force 3D sensor in order to detect the real pushing force exerted by the robot finger. Five different points were marked on the cantilever beam of 0.03, 0.06, 0.09, 0.12 and 0.15 *m*. In addition, it can be assumed that the pushing force vertically acts onto the object with a constant demanded force of 1.5 *N* at any length, as shown in Figure 2.

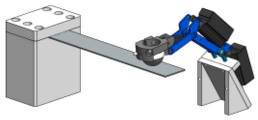

Figure 2 Force control experimental set-up

4.2 The experimental results

In this experiment, PI gains have adopted by using the Ziegler–Nichols tuning method. The first experimental length was set at 0.15 *m*, and by using Ziegler–Nichols technique, it gives k_p and k_i of 3.4 and 1.0 respectively. For finning tune, the k_p gain was initially set between 3.2-3.6 with 0.1 resolution, whereas the k_i of 1.0 does not change. The best performance of the k_p tuning gain can be detected by the minimum *E_RMS* and the experimental results demonstrates in Table 2. After that the optimized k_p gain is fixed to be used in the next test which is the k_i tuning method. In order to achieve fine tuning of k_i gain, it can be varied between 0.8-1.20 with 0.1 resolution. Again the best performance of the k_i tuning gain can be classified by the minimum *E_RMS* and the experimental results can be shown in Table 3. Repeat all the steps of the experiments at the pushing force lengths of 0.03, 0.06, 0.09 and 0.12 *m* respectively. The overall results can be illustrated in Table 4.

Table 2. The example results of evaluation of k_p at length 0.15 *m*

k_i Gain	k_p Gain	*E_RMS* (*N*)
1.0	3.2	0.02
	3.3	0.03
	3.4	0.03
	3.5	0.10
	3.6	0.03

Table 3. The example results of evaluation of k_i at length 0.15 *m*

k_p Gain	k_i Gain	*E_RMS* (*N*)
3.2	0.8	0.05
	0.9	0.04
	1.0	0.02
	1.1	0.02
	1.2	0.03

Table 4. The results of evaluation of k_p and k_i at each length

Length (*m*)	k_p Gain	k_i Gain	*E_RMS* (*N*)	Overshoot (*N*)
0.03	0.80	0.10	0.08	0.42
0.06	1.05	0.18	0.05	0.26
0.09	1.60	0.32	0.03	0.23
0.12	2.30	0.43	0.02	0.03
0.15	3.20	1.00	0.02	0.01

5. Conclusion

This research aimed to present the improvement of the force control on the robot fingers as a function of various stiffness values of the compliance objects. A set of optimal PI gains was successfully calculated. Based on the experimental results, it was confirmed that that the optimal performance of the force control can be determined by using the *E_RMS* value. The pushing force acting on the cantilever beam at the different lengths of 0.03, 0.06, 0.09, 0.12 and 0.15 *m* (that simulates a variety of object's stiffness values). The k_p gains of 0.80, 1.05, 1.60, 2.30 and 3.20, and the k_i gains of 0.10, 0.18, 0.32, 0.43 and 1.00 respectively are adopted. These experimental results will be future used in Fuzzy-PI force control applied for the robot hand which can automatically select a set of PI gains for a variety of compliance objects.

Reference

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