A Robust PID Control Algorithm for a Servo Manipulator with Friction

Jaehyun Jin*, Byungsuk Park*, Hyojik Lee*, Jisup Yoon*

* Remote Handling Technology Department, Korea Atomic Energy Research Institute, Yusung-Gu, Daejon, Korea
(Tel : 82-42-868-8259; E-mail: donworry@kaeri.re.kr, nbspark@, hyojik@, jsyoon@)

Abstract: In this paper, a control algorithm for a servo manipulator is focused on. A servo manipulator system has been developed for remotely handling radioactive materials in a hot cell. It is driven by servo motors. The torque from a servo motor is transferred through a reducer to the corresponding axis. The PID control algorithm is a simple and effective algorithm for such application. However, since friction degrades the algorithm's performance, friction has to be considered and compensated. The major aberrations are the positional tracking errors and the limit cycle. The authors have considered a switching term to a conventional PID algorithm to reduce the friction's effect. It has been tested by a hardware test.

Keywords: Servo manipulator, PID control, sliding control, parameter uncertainty, friction.

1. INTRODUCTION

A servo manipulator system has been developed for remotely handling radioactive materials in a hot cell [1]. Unlike a robot manipulator, a servo manipulator is monitored and controlled by an operator all the time. A robot manipulator performs a taught or programmed task without an operator. Generally, a servo manipulator consists of a master arm and a slave arm. The slave arm is a device for working instead of people such as lifting and handling an object, and the master arm is an input device for the slave arm.

Servo motors have generally been used to control or drive a servo manipulator. They are reliable driving power sources for servo control problems. In this paper, practical problems related with a servo motor are discussed. During the development of a servo manipulator, a control problem of a servo motor has been an important issue. The practical problems are parameter uncertainty and frictional effect. This paper aims to discuss the practical problems and the process of identifying and reducing the effects of parameter uncertainty and friction. An extensive survey of friction has been introduced in [2].

Parameter uncertainty of a servo motor and friction affect the tracking performance. A poor tracking, a limit cycle and windup may occur. The two problems have been dealt with for many years and many remedies have been proposed. Among them, a simple and effective one is applied to the servo manipulator control and the results are presented.

2. PARAMETER UNCERTAINTY AND FRICTION

Generally, a servo motor is represented as the 1st order system,

$$G(z) = \frac{\varpi(z)}{u(z)} = \frac{b}{z-a}. \tag{1}$$

$\varpi(z)$ is the angular speed and $u(z)$ is the control input. a and b are the parameters representing motor's characteristics. The first step of a control problem is to ascertain or obtain the parameter values of a and b. These may be calculated from physical data or identified from input and output data. Here, the identification method is used [3].

Fig. 1 represents an example of the angular speed response. Actually, the speed is calculated as (see Fig. 5 also),

$$\varpi(k) = \frac{\theta(k) - \theta(k-1)}{\Delta T}. \tag{2}$$

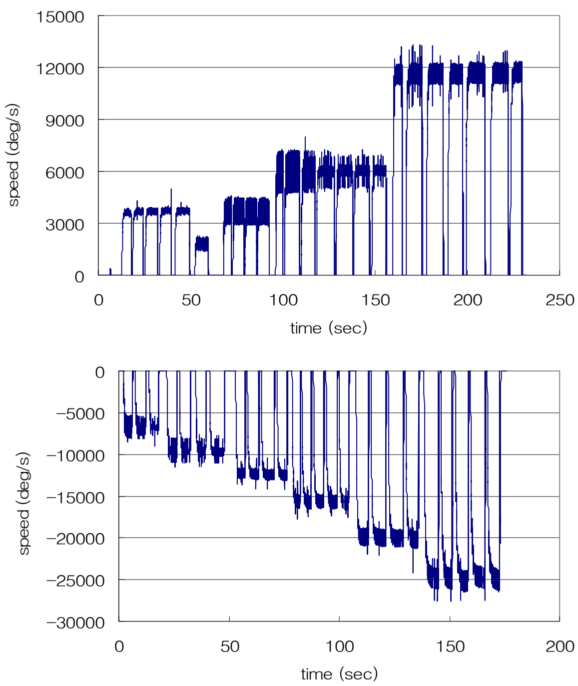


Fig. 1 Angular speed responses.

Fig. 2 is the estimated values for a and b of (1). The parameter a varies between 0.91 and 0.97 and the parameter b varies between 17000 and 52000.

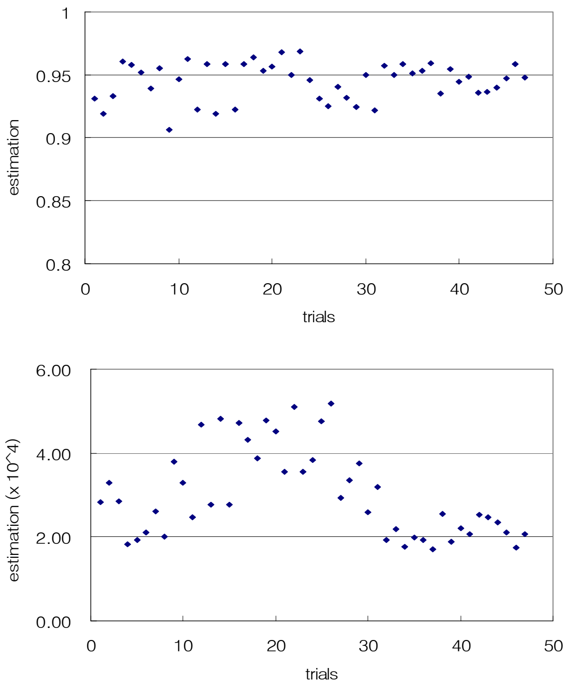


Fig. 2 Estimated values of *a* and *b*.

Friction is a bothersome factor hindering positional tracking. It may also cause a limit cycle if it combines with the integrating control. A limit cycle is mainly due to the stick friction. Fig. 3 shows a tracking response to a low speed command and Fig. 4 shows the limit cycle due to friction.

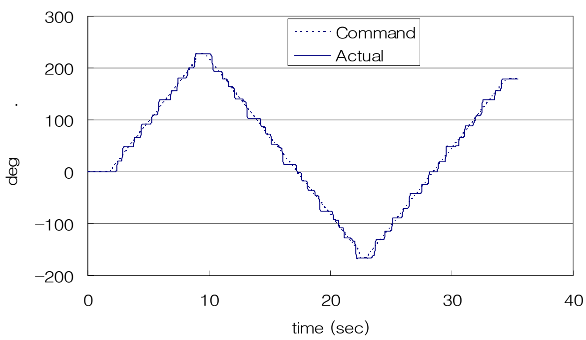


Fig. 3 Low speed tracking.

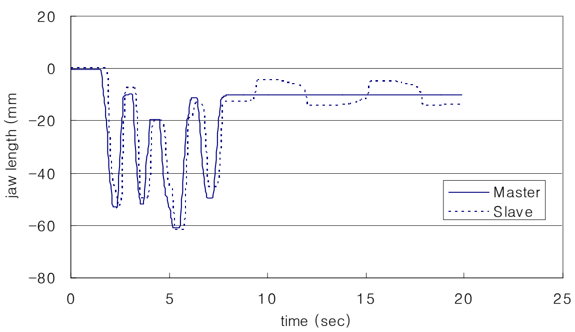


Fig. 4 The limit cycle due to friction.

Two common problems related with a servo motor have been introduced. There may be no servo system free from the problems. Only reducing the effect is possible. In this article, simple and effective methods to reduce such effect are used and compared. The selected baseline control algorithm is a PID type. A PID method is practical and effective for a SISO system. In addition to the baseline algorithm, optional terms are added to reduce the effect of parameter uncertainty and friction.

3. SERVO MANIPULATOR CONTROL

A PID controller is selected a baseline controller. A PID controller is general and practical, and it is used in many applications. The PID controller is represented as following,

$$C(z) = K_P + K_I \frac{1+z^{-1}}{1-z^{-1}} + K_D(1-z^{-1}) . \qquad (3)$$

Fig.5 shows the control architecture of an axis. There are two loops: inner and outer. The inner loop is for speed control and the outer for position control.

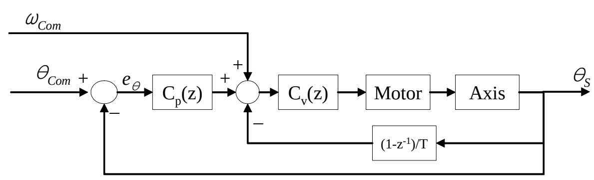


Fig. 5 The control block diagram.

The approaches to reduce the effect of friction are divided into two groups [2]. One is to consider a friction model and estimate its parameters [4-6], and the other is to treat friction as disturbance [7-10]. Here, the second approach is selected because of easy implementations. Actually, a friction model is difficult to estimate its parameters by tests.

In this article, we have applied three methods to the control of a servo motor: dither, PID with switching, and TDC with switching. Switching is based on the sliding mode theory. Fig. 6 shows the servo manipulator controlled by servo motors.

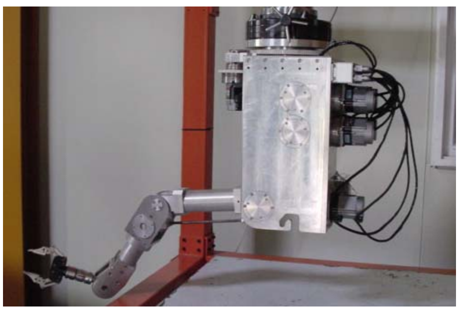


Fig. 6 The servo manipulator system to be tested.

The servo motors are Tamakawa motors. We will test one of them for developing a robust control algorithm. The motor is disconnected from the manipulator for safety. The control gains have to be re-tuned if the motor is connected to the manipulator. The control update frequency is 50 hz. The test program has been run on a 3.0 GHz Pentium IV PC.

The baseline PID control has been tuned by trial and error. The selected gains are as followings,

Speed loop : K_P =0.0000225, K_I = 0.000005,

Position loop : K_P =1.0 , K_I =0.002.

Fig. 7 shows tracking responses corresponding to high speed and low speed commands. For the low speed response, stick and slip is shown.

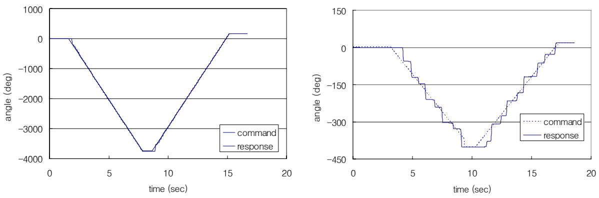
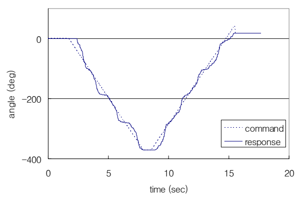


Fig.7 Positional tracking response (high speed and low speed).

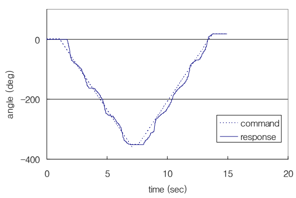
Dither is a high frequency signal added to the command. It is usually represented as a sinusoidal perturbation,

$$\bar{\theta}_{com}(t) = \theta_{com}(t) + \varepsilon \sin(\varpi_d t). \quad (4)$$

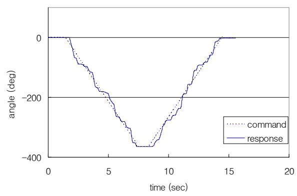
It is just a persistent excitation which is not related with the states of a system. We have tested the algorithm with different values of ε and ϖ_d. Fig. 8 shows the low speed tracking responses. The last one shows poor performance relatively. The values of ε are very high because the friction effect is relatively high at the low speed.



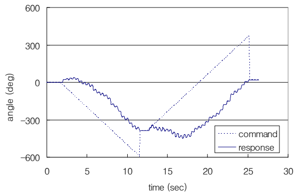
(1200 deg, 30 hz)



(1200 deg, 75 hz)



(1200 deg, 15 hz)



(6000 deg, 15 hz)

Fig. 8 Positional tracking response (dither added).

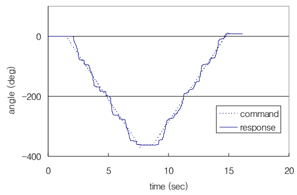
Switching control is useful to treat disturbance or uncertainty. Sliding mode control is representative. Switching control is added to the baseline PID.

$$u = u_{PID} + K\,\mathrm{sgn}(s) \quad (5)$$

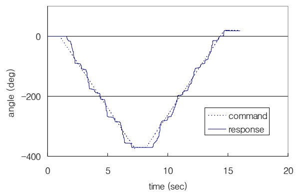
Switching function s is determined as

$$s = \dot{e} + k_s e\,, \quad (6)$$

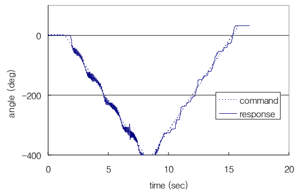
where e is the positional error. Fig. 9 shows the tracking response corresponding to (5) with different values of K and k_s. The last one which contains the positional error in the switching function shows the best tracking performance. The third one induces undesirable vibrations during tracking.



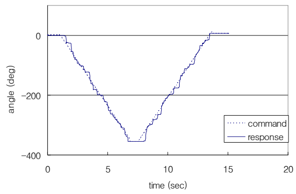
(K=0.0234, k_s=0)



(K=0.0176, k_s=0)



(K=0.0293, k_s=0)



(K=0.0234, k_s=14)

Fig. 9 Positional tracking response (switching added).

TDC (time delayed control) is also one of effective controls to treat disturbances. However, Since TDC itself is not effective to reduce the effect of friction [8, 9], switching control is also introduced as,

$$s = \dot{e} + 2\zeta\varpi_n e \quad (7)$$

$$\begin{aligned} u(k) &= u(k-1) \\ &+ g\left[\ddot{\theta}_d(k) - \ddot{\theta}(k-1) + 2\zeta\varpi_n \dot{e}(k) + \varpi_n^2 e(k)\right] \quad (8) \\ &+ K\,\mathrm{sgn}(s) \end{aligned}$$

Fig. 10 shows the tracking response corresponding to (8). The tracking performance is similar to the fourth of Fig. 9.

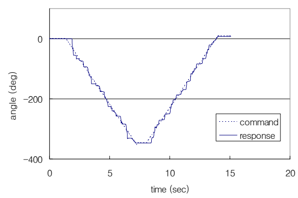
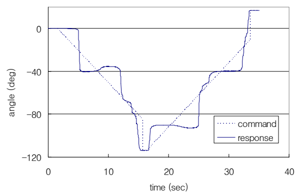
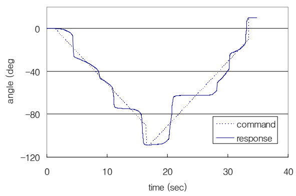


Fig. 10 Postional tracking response (TDC with switching, ζ =0.7, ϖ_n =10, K =0.0234, g =5x10^{-7})

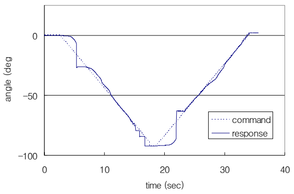
We have applied the tuned algorithms to a very low speed (1 rpm) command tracking. The results are shown in Fig. 11. In the region of low speeds, the effect of friction is relatively great. The third one's tracking performance is the best one.



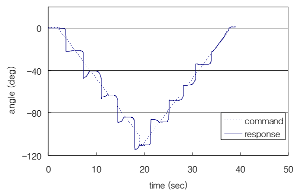
Dither



PID (K=0.0234, k_s=0)



PID (K=0.0234, k_s=14)



TDC with switching

Fig. 11 Positional tracking response (a very low speed command of 1 rpm)

4. CONCLUSION

In this paper, control algorithms for a servo manipulator are focused on. Especially, three algorithms have been compared to reduce the effect of friction: dither, a PID with switching control, ad TDC with switching control. The three methods worked well for a low speed (10 rpm) and a high speed (100 rpm) command. For a very low speed (1 rpm) command, a PID with switching control has shown the best tracking performance. This method will be used to control a servo manipulator.

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