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HYBRID I-PD CONTROL FOR PNEUMATIC CYLINDERS WITH FUZZY THEORY

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Abstract A pneumatic cylinder has been used in the production facilities of various industries. However, it is difficult to achieve deciding the precise position of the piston rod, due to the nonlinear properties arising from the air compression and the friction. In recent years, the fuzzy control algorithm has been frequently applied to various kinds of sysems on account of its simple algorithm, good adaptability to complex or nonlinear systems and so on. On the other hand, the PID or I-PD control has been used in many engineering fields because of the excellent performance. However, it is known that each one of them has disadvantages.

In this paper, we propose a hybrid control which is strived to obtain the advantages of each other. It is shown that the proposed hybrid control performs better than the conventional I-PD control through the experimental results.

Keywords Pneumatic Cylinder, Fuzzy control, I-PD control, Hybrid Control, Smooth Switching Over

1. INTRODUCTION

In many production facilities of various industries, a pneumatic cylinder system has been used as an actuator for industrial robots and mechatronics, because it is simple, cheap, small and economic. However, high performance can not be easily achieved with the pneumatic cylinder system which has the high nonlinear properties, owing to arising from air compression and the friction of the device itself. That is why it has mainly been used for relatively simple tasks such as end-to-end movement. In recent years, it is expected for use of stopping at the middle position precisely with the advance of robotics and mechatronics.

As it is well known, the PID or I-PD control method has been widely used in many engineering fields. That is why it is easy for most of engineers in many industries to understand the pysical property of I, P and D control parameters clearly and the structure is simple.

The optimal control method is one of most popular schemes to decide the control gains. However, it is necessary for control engineers to identify the accurate transfer function. When we assume that parameters of the transfer function are contstant, the identified parameters include modelling errors. For instance, these errors are caused by static friction, kinematic friction, inertia, air compression and so on. In case of application of it to a pneumatic cylinder system, the controlled object has so remarkable nonlinear properties that the response to be desired can not be obtained.

Recently, the fuzzy control algorithm has been remarkably and frequently applied to various kinds of systems. The ability to control a system in uncertainty or unknown environments, for example which are complex or high nonlinear systems, is one of the most important characteristics of any intelligent control system. Fuzzy theory provides a systematic framework for dealing with different types of uncertainty within single conceptual framework. In addition, fuzzy theory would enable the control system to better emulate human decision-making processes as well as allow for imprecise information and uncertain environments.

In this paper, we propose a hybrid control which is strived to obtain the advantages of I-PD and fuzzy control. The purpose of this paper is to improve the dynamic response in the pneumatic cylinder when reference position or load is changed. It is shown that the proposed hybrid control performs better than the conventional I-PD control through the experimental results.

2. STRUCTURE OF A PNEUMATIC CYLINDER SYSTEM

Figure 1 shows the pneumatic servo system which is used in this research. The output of magnesacle sensor has a sin wave. This sin wave is converted to the pulse wave by the detector circuit. We count the pulse wave with the counter circuit and obtain the current position. We get a manipulate variable calculated by a personal computer (PC-9821 Xs). This manipulate variable is converted to an analog signal by the 12 bit D/A converter. This signal is amplified with the power amplifier, and drives the pneumatic cylinder through the proportional control valve. We have used the pneumatic cylinder (CA1BQ63-300) and the proportional control valve (VEP3120-1) made by SMC. The magnesacle sensor is made by Sony. The resolving power of that is 10μm. To decrease static friction of the proportion solenoid valve, the dither signal (Frequency : 60[Hz], Amplitude : 1.9[V]) is added to the proportional control valve.

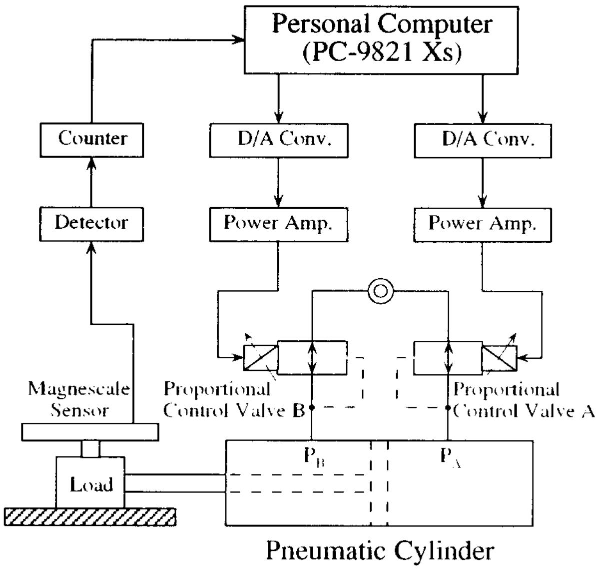

Figure 1. Structure of a Pneumatic Cylinder System

3. FUZZY CONTROL SYSTEM

In this chapter, we describe the fuzzy control.

3.1 Structure of Fuzzy Controller

Figure 2 shows a block diagram of the fuzzy controller, which is identical to the hybrid controller. In the figure e and $\dot{e}$ correspond to collections of input values. Here, we get e, which is the error between set point and output values from controlled object, and $\dot{e}$ which is the velocity, respectively. And the output value from fuzzy controller is a manupulated valiable which is calculated by using a couple of membership functions and fuzzy rule table, which will be described in detail in a later subheading.

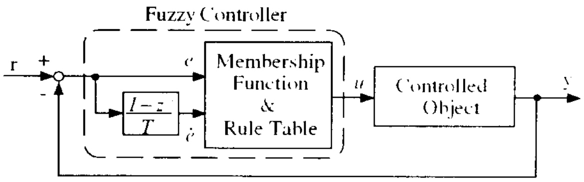

Figure 2. A block diagram of the fuzzy controller.

3.2 Fuzzy reasoning

Although reasoning by analogy had been exploited in many areas of Artificial Intelligence, this study applied fuzzy reasoning with simple monotonic method to simplify the calculation. The proposition has the general form as follows:

If e *is* A_{1i} *and* $\dot{e}$ *is* A_{2i} *then* u *is* u_i

where A_1 and A_2 are fuzzy sets and u is manipulated valiable. Then the reasoning results are calculated as follows:

$$\hat{u}_j = \frac{\sum_{j=1}^{N} \mu_j u_j}{\sum_{j=1}^{N} \mu_j} \qquad (1)$$

where N is the number of the elements of a rule table , μ_j is the degree of memblership in fuzzy sets corresponding to the element number (j), and $\hat{u}_j$ is calculated value.

3.3 Adjustment of Membership Functions and a Rule Table

We use a couple of membership functions and a fuzzy rule table, which are displayed in Figure 3 and Table 1 as follows:

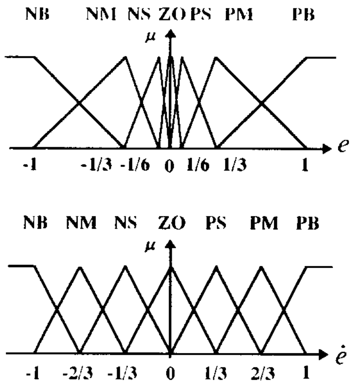

Figure 3. The shape of membership functions

Table 1. A fuzzy rule table

e \ $\dot{e}$	NB	NM	NS	ZO	PS	PM	PB
NB	XIII	XIII	XIII	XIII	XIII	XIII	XIII
NM	XII	XII	XII	XI	XI	XI	XI
NS	X	X	X	IX	IX	IX	IX
ZO	X	IX	VIII	VII	VI	V	IV
PS	V	V	V	V	IV	IV	IV
PM	III	III	III	III	II	II	II
PB	I	I	I	I	I	I	I

In order to realize the precise position control close to the desired value, the more the error is reduced, the narrower range the membership function has. The elements of a fuzzy rule table is designed by trial and error procedures.

4. I-PD CONTROL SYSTEM

In this study, we assume the pulse transfer function of pneumatic sylinder to be second order system. The discrete state variable equation is described as follows:

$$x(k+1) = Ax(k) + bu(k)$$
$$y(k) = cx(k) \qquad (2)$$

Here, the system matricex are as follows:

$$A = \begin{bmatrix} 1.0 & 9.377275e-03 \\ 0.0 & 8.780954e-01 \end{bmatrix},\ b = \begin{bmatrix} 3.549535e-02 \\ 6.948560e-00 \end{bmatrix},\ c = \begin{bmatrix} 1.0 \\ 0.0 \end{bmatrix}^T \qquad (3)$$

We use the frequency response method for identification of pneumatic sylinder. Provided that the sampling interval is 10 msec, the pneumatic sylinder carried a load of 30kgf mass and moved at a distance of 50 mm, the feedback gains are determined by optimal control method as follows:

$$f_I = [9.435630e-03],\ f_{PD} = [2.529620e-01 \quad 1.505274e-02] \qquad (4)$$

We use the real time observer to estimate state variables.

5. PERFORMANCE OF FUZZY CONTROL AND I-PD CONTROL

Figure 4, 5 show the experimental results of the step responses in case of application of the fuzzy control and the conventional I-PD control to the pneumatic cylinder, respectively, also the moving at a distance is 50 mm. The imaginary dither method and the technique of shotting air are applied to all experiments in order to improve the accuracy of position control. Even if changing the loading mass on the tip of piston rod or the moving at a distance, the I-PD control gains were fixed to the optimal control gains and the elements of fuzzy rule table were fixed too, which were shown in the chapter 3 and 4, also the sampling interval was 10 msec in all experiments . Here, the solid line is the step response of loading 30kgf mass and the dotted line is one of loading 70kgf mass.

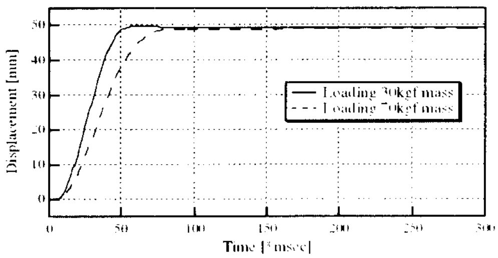

Figure 4. The step response of the fuzzy control

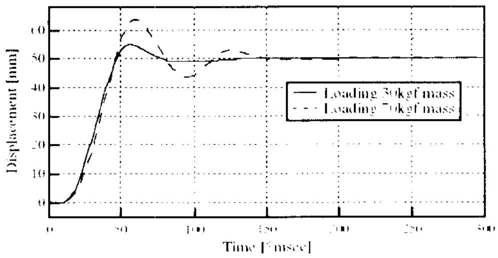

Figure 5. The step response of the conventional I-PD control

It can be shown from Figure 4 that we obtained better performance in the response of transient state as far as the fuzzy control was concerned, however there was off-set left over in the response of stationary state. On the other hand it can be shown from Figure 5 that we obtained the better performance in the response of stationary state as far as the conventional I-PD control was concerned, however the heavier loading mass was, the larger overshoot there was left over in the response of transient state.

On comparing the fuzzy control with the conventional I-PD contorl, the summary of these results is shown below.

--- *Fuzzy Control* ---

○ The fuzzy contorl performs better than the conventional I-PD control in the response of transient state against changing a load of mass.

○ There is off-set left over in the response of starionary state.

--- *The conventional I-PD control* ---

○ The conventional I-PD control perfoms more accurate than the fuzzy control in the response close to the desired value.

○ The more heavier loading mass is, the worse the response of transient state is.

6. HYBRID I-PD CONTROL WITH FUZZY THEORY

In accordance with the consideration of the former chapter, we think of putting both the advantages to good use and making up for both the disadvantages. In other words, we poporsed a hybrid I-PD control with fuzzy theory, which is applied the I-PD and fuzzy control to the response remote from the desired value and is switched over the I-PD control in the response close to one smoothly. When switching over, a membership function is utilized for not arising from the unstable phenomena which is based upon the discontinuous control action

6.1 Structure of a Hybrid I-PD Control with Fuzzy Theory

Figure 6 shows a block diagram of the hybrid I-PD control with fuzzy theory. In this control system, the purpose of appling to the I-PD control is to control the position accurately in the response close to the desired value, futhermore that of applying to the fuzzy control is to reduce the overshoot and to improve the sensibility of the I-PD control in the response remote from one.

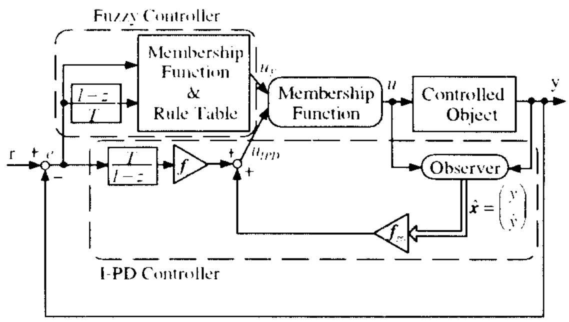

Figure 6. A block diagram of the hybrid I-PD control with fuzzy theory

It is the same with a structure of the fuzzy control and the I-PD control as with what it is described in the chapter 3 and 4. The fuzzy controller has the input values of e and $\dot{e}$,which are normalized by the contstant values corresponding to each value. The output values from both the controllers are u_F and u_{IPD} which are calculated respectively. A membership function which is shown in the Figure 7 calculates the membership values of $\mu(e)$. The starting point of switching over is 10% desired value. Now the manipulated variables are determined as follows:

$$u = u_{IPD} + \mu(e)\cdot u_F \qquad (5)$$

where u is the manipulated variable.

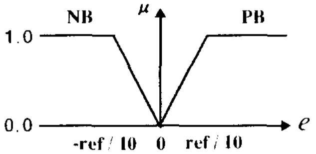

Figure 7. The shape of membership function

6.2 Experimental ressults

We show the experimental results of appling the proposed method to the pneumatic cylinder. All experiments utilize the optimal gains and the fuzzy table which make it a condition what are shown in the chapter 5. Also the sampling intervsl is 10 msec.

First, Figure 8 shows the response in case of loading 30kgf mass. The solid line is the response of the proposed method, the dotted one is that of the conventional I-PD control. In the response of the proposed method, it finds that there is not the overshoot left over and the rise time is earlier than the other one.

Next, Figure 9 shows the step resonse in case of moving at a distance of 150mm. It finds that there is not the overshoot left over and the setting time is earlier than the other one. This result suggests that our method copes with the change of a characteristic which is changed by moving at a distance.

Finally, Figure 10 shows the response in case of loading 70kgf mass. This result suggests that our method is superior in the performance to the conventional I-PD control.

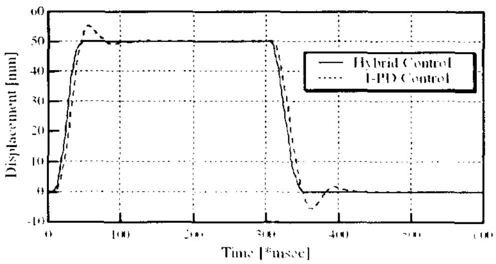

Figure 8. The response in case of loading 30kgf mass

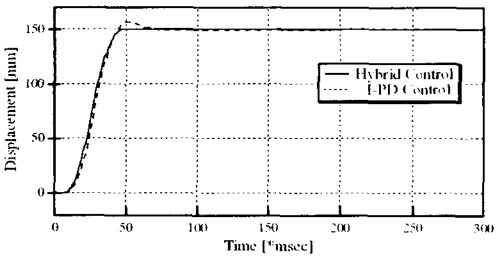

Figure 9. The step response in case of moving at a distance of 150mm

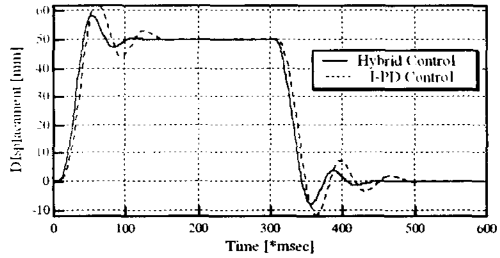

Figure 9. The response in case of loading 70kgf mass

6. CONCLUSION

This paper is intended for the position control for a pneumatic cylinder which is widely used in engineering fields. To summarize our interpretation of these results, we can confirm as described later.

To make comparison between the fuzzy control and the conventional I-PD control, the fomer is superior in the response of transient state to the latter. However, it is the off-set left over in the response of stationary state. In order to obtain the solution of the problem, we proposed the hybrid I-PD control for pneumatic cylinders with fuzzy theory, which is smoothly switched over the response close to the desired value according to the membership function. And we examined the efficency of our method by applying to pneumatic cylinder system. In conclusion, the proposed hybrid control performs better than the conventional I-PD control against change of loading mass without improvement of parameters on a rule table and the optimal gains.

We think the more effective method of designing the membership function which is used to design the hybrid control and so on.

ACKNOWLEDGMEN T

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