INTELLIGENT FUZZY CONTROL OF PNEUMATIC SERVO SYSTEM WITH STATIC FRICTION

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ABSTRACT: Pneumatic actuator with many advantages is widely used in the industrial field by a simple ON-OFF control because of having nonlinear characteristic such as static friction. In this paper, we propose an intelligent (predictive fuzzy) control method for a pneumatic servo nonlinear system with static friction. The real machine experiment confirmed the improvement of the speed of response and the stop accuracy and the effectiveness of the proposed method.

Keywords: Predictive fuzzy control, Pneumatic servo system, Position control

1 INTRODUCTION

The pneumatic servo system has the advantages of safety and environmental integrity, and is applied in a lot of fields of the industrial world. Moreover, the pneumatic actuator as soft operation is possible, is expected to use to the support system which comes in contact with person in the field such as a small, light manipulator and equipment for rehabilitation[1]. In this research, the service such as drinking water is assumed to physically handicapped one, and the development of the control system using the pneumatic rotary actuator is advanced (Figure 1).

However, this pneumatic system possesses a nonlinear element negatively affecting the control performance such as dynamic characteristic change by the change in the load or the temperature, low stiffness and response delay of pressure by compressibility of air, and sliding friction between piston and cylinder. Especially, because the influence by the static friction force is large in a small actuator, and dead time exists too, it is difficult to operate the system according to the desire in the past PID control that the design and mounting are easy. Therefore, it is widely used for an easy ON-OFF control in the industrial field. Dealing with these problems, the trial on the improvement of the control performance is done[2].

Up to now, the effectiveness of an intelligent control to a nonlinear system with a pneumatic cylinder has been verified in this laboratory[3]. In this research, a control building in man's control knowledge and grasping the characteristic of the system is done to the nonlinear servo system using the pneumatic rotary actuator, to improve the steady-state and the transient performance. The intelligent (pedictive fuzzy[4]) control system which considers static friction is constructed, and the effectiveness of the intelligent control system is confirmed by the real machine experiment.

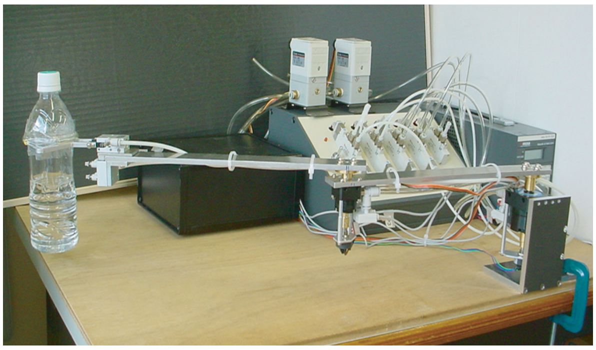


Figure 1: Manipulator using pneumatic rotary actuator

2 PNAUMATIC SERVO SYSTEM

The composition of the pneumatic servo system by this research is shown in Figure 2. The pneumatic rotary actuator is a double vane type (made by the SMC company), 30*mm* in the inside diameter, and 90*deg* in rotation angle. It can use the pressure from 0.15MPa to 1.0MPa, The theory output and from it is $0.5N \cdot m$–$7.5N \cdot m$. The load of 0.5*kg* or less is held by the chuck in the arm point. Two control valves use the pressure regulator with PID control which will be done so that error between a present output pressure value and the target pressure signal from PC may vanish. Supply pressure P_s to the first side of the control valve is assumed to be 0.4MPa, and a part pressure in the second side is assumed to be a constant value of 0.2MPa. The rotation angle position is output as a voltage signal from a rotary potentiometer fixed to output axis of the actuator, and is taken into PC after converting A/D of 12 bit . Then, the instruction from PC is output to the control valve as an analog quantity by D/A converter of 12 bit. The pneumatic rotary actuator is driven and the load is carried by the differential pressure in a right and left room.

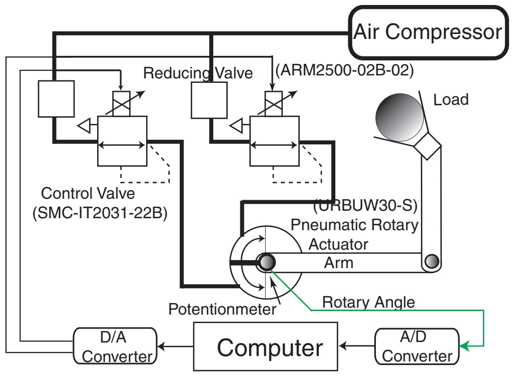


Figure 2: Pneumatic servo system

3 OUTLINE OF CONTROL SYSTEM

3.1 Consideration of problem

When a past PD control method is used, the problem to the static friction and the change in the load is considered.

3.1.1 *Existence of static friction*

A control was done by the same PD gain when the load was assumed to be 0*kg*(zero) and 0.2*kg* and 0.5*kg*, and target value (0.5*rad*) was given at the time of 10 seconds. The response results are shown in Figure 3. The delay time of rising up was about 0.5 seconds in Figure 3(a). The reason why the delay occurs is that static friction exists in the actuator. The pneumatic rotary actuator began to move when the pressure output(Figure 3(b)) grew from the state of geostationary more than static friction force.

Also, although there is the control differential pressure (Figure 3(b)) at the time of 12 seconds, the result was not able to be corrected because this pressure was smaller than static friction force, and the vane stopped as it was. As a result, the stop error like Figure 3(a) was caused.

3.1.2 *Change in load*

As shown in Figure 3(a) they have been understood that the risetime and the over short are different with change in mass and that the response possesses a different stop error for the existence of static friction, too.

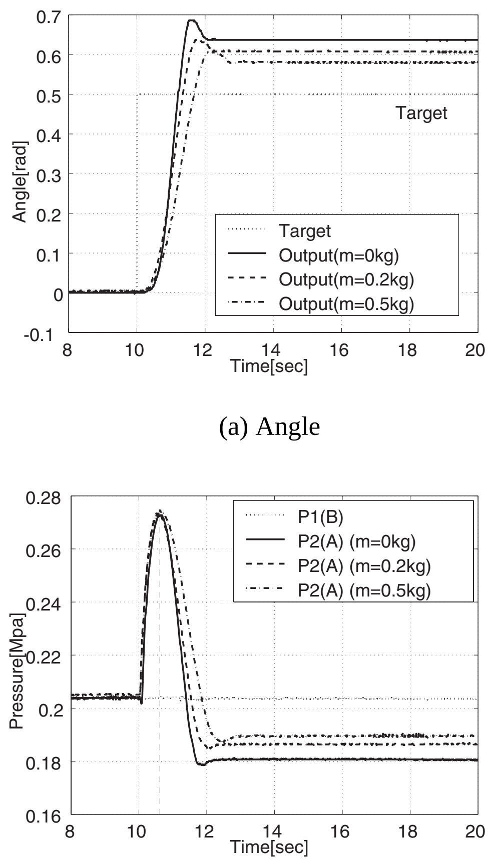
3.2 Methods of solution

To solve these problems, a control system is constructed with an intelligent control (predictive fuzzy control [4]) method in this research.

The control purpose of this system is two as follows .

(1)It responds to the target value fast.
(2)The stop accuracy is improved.

First, the calculated mass is substituted for the object model[5] for these control purposes, and a concrete expression is decided, and the control knowledge is used. Next, the stop position is predicted, a fuzzy proposition such as ”The control error is very small” and ”Do not overshoot” is evaluated, and the control instruction is decided by results of the evaluation. The intelligent control system of the pneumatic servo system is constructed by using the predictive fuzzy control method to predict state in the future as shown in Figure 4.



(a) Angle

(b)Pressure

Figure 3: Results of experiment to different mass load by PD control

4 INTELLIGENT CONTROL SYSTEM

4.1 Predictive fuzzy control

The operation of the control instruction is described as an experience rule from the experience of developing the control system by the past PID control. To do

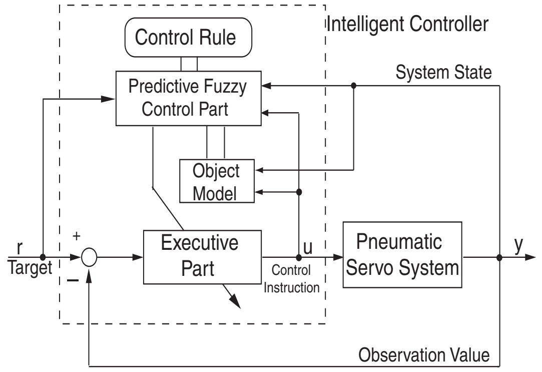


Figure 4: Control system

the predictive fuzzy control, the PID controller equation which contains constant term C which is more than static friction torque may be written as

$$u_k = K_p e_k + K_i \sum e_k - K_d \frac{y_k - y_{k-1}}{T_s} + C \qquad (1)$$

Where K_p, K_i, K_d is each gain of PID control, T_s is the sampling period, k is the sampling time, u_k is the quantity of control at k sampling time, e_k is the control error at k sampling time, and y_k is the vane angle position at k sampling time.
Concretely, the control instruction is selected while hourly evaluating the following rules.

- If it is possible to control almost accurately by present K_p, K_p is maintained.
- If it is possible to control accurately by changing present K_p to the candidate value which is, K_p is changed to the candidate value which is.
- If it is possible to control accurately with what % of present K_p is increased and decreased, that percentage of K_p is increased and decreased.
- If the control input can be accurately controlled as constant force C, the control input is assumed to be constant force C.

Where K_i, K_d is constant and C=0 when K_p is changed and $K_p = K_i = K_d = 0$ when $C \neq 0$.

4.2 Fuzzy sets of evaluation indices

A fuzzy set which evaluates the control error at t_1, t_2 second later from time now is defined about the stop accuracy as follows.

- $t_1(t_2)$ second later from time now

  - The control error is small, and it does not overshoot.

  R1-VG(R2-VG) : R1(R2) is Very Good

  - The control error is almost small, and it does not overshoot.

  R1-GD(R2-GD) : R1(R2) is Good

4.3 Modeling of controlled system

4.3.1 *Model of pressure regulator*

It is possible to approximate the relation in a first-order lag system containing dead time between the impressed voltage to the pressure regulator and the pressure in the pneumatic rotary actuator. The transfer function G_P of output pressure P to input voltage E can be described as follows.

$$G_P(s) = \frac{P(s)}{E(s)} = \frac{\alpha e^{-Ls}}{\tau s + 1} \qquad (2)$$

Where α is the conversion gain from voltage to pressure, $L = 0.04$ is the dead time, τ is the time constant. As for units, L and τ are all in *sec*.

4.3.2 *Operation of actuator*

The equation of motion of a vane angle position θ are

$$I \frac{d^2\theta}{dt^2} + D \frac{d\theta}{dt} = T \qquad (3)$$

$$I = m_r \frac{{L_1}^2}{3} + m \frac{r^2}{2} + m{L_1}^2 \qquad (4)$$

$$T_a = K_1(P_R - P_L) \qquad (5)$$

The relation of torque T of the arm and torque T_a of the pneumatic rotary actuator by static friction can be written as

$$T = \begin{cases} T_a & (\dot{\theta} \neq 0; \dot{\theta} = 0, T_a > F_s) \\ 0 & (\dot{\theta} = 0, T_a \leq F_s) \end{cases} \qquad (6)$$

Where D is the viscous damping coefficient, and the units of D are $N\cdot$ s/m. I is the total moment of inertia of the arm and the load, and the units of I are kg$\cdot$ m^2. m_r is the weight of the arm, m is the mass of the object, and the units of m_r,m are kg. L_1 is the length of the arm, r is the radius of the object (bottle and glass), and the units of L_1,r are m, K_1 is the conversion coefficient from the pressure to the torque of the operating pneumatic rotary actuator. T_a is the torque of the pneumatic rotary actuator, F_s is the static friction torque, T is the torque of the arm, and the units of T_a,F_s,T are $N\cdot$ m.

4.3.3 *Relation between torque and angle*

The transfer function G_θ of output angle θ of vane to input torque T of the actuator is

$$G_\theta(s) = \frac{\theta(s)}{T(s)} = \frac{\mu}{s\{Is + D\}} \qquad (7)$$

4.4 Intelligent control rule

As the control strategy, the proportion control coefficient $K_p = 2.0, 4.0, 6.0$ is assumed to be a basic assumption value, and $K_d = 1.0$ is be a constant. The control purpose is evaluated as a candidate which the value $(x = 1.0 \pm 0.2n, n = 1, ..., 5)$ of x times last $K_p(t-1)$ is made. Moreover, constant C is evaluated as $(1.0 \cdot sgn(e_k))$. The predicted output is shown in Figure 5.

The predictive fuzzy control rules are used as follows.

1. if(K_p is 1.0 $\rightarrow R_1$ is GD and R_2 is GD) then K_p is 1.0

2. if(K_p is 2.0 $\rightarrow R_1$ is VG and R_2 is VG) then K_p is 2.0

3. if(K_p is 4.0 $\rightarrow R_1$ is VG and R_2 is VG) then K_p is 4.0

4. if(K_p is 6.0 $\rightarrow R_1$ is VG and R_2 is VG) then K_p is 6.0

n. if(K_p is $K_p(t-1) \cdot x \rightarrow R_1$ is VG and R_2 is VG) then K_p is $K_p(t-1) \cdot x$

15.if(C is $1.0 \cdot sgn(e_k) \rightarrow R_1$ is VG and R_2 is VG) then C is $1.0 \cdot sgn(e_k)$

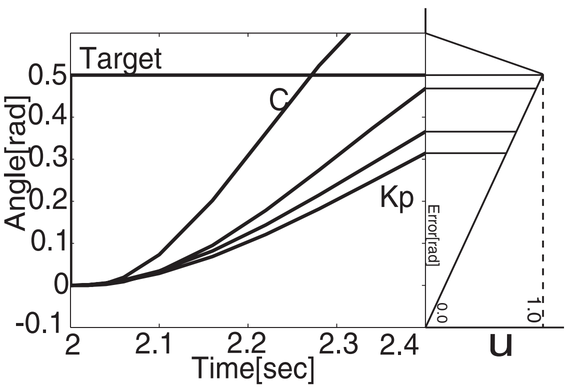


Figure 5: Predictive output to candidate

4.5 Inference of predictive fuzzy control

The inference process of the predictive fuzzy control is shown in Figure 6. First of all, the candidate of control parameter is assumed, the state in the future will be calculated with the object model by whom static friction is built in. Next, a fuzzy multipurpose evaluation is done based on a fuzzy purpose, and the control strategy with the maximum evaluation value is decided. Finally, the calculation value in the execution part is output as a control instruction.

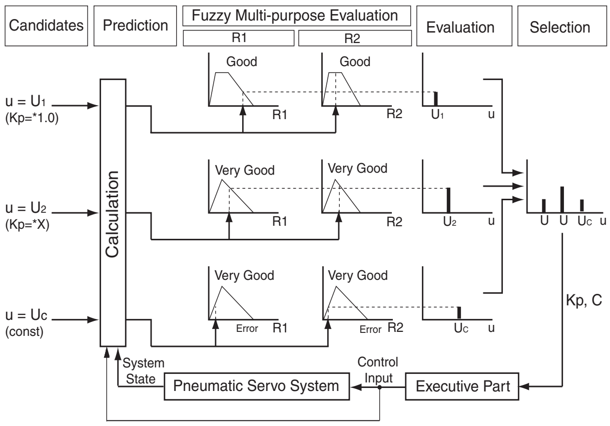


Figure 6: Inference process of predictive fuzzy control

5 RESULTS OF EXPERIMENT

To confirm the effectiveness of the proposed control method, we did experiments on a real machine by the PD control and the predictive fuzzy control, in the situation in which static friction cannot be disregarded. An initial value of the actuator was $0rad$. The target value was set as $0.5rad$. The results in the load which was assumed to be $0.2kg$ are shown in Figure 7.

In Figure 7(a), rising up of the response was late though the error was able to be decreased in the PD control when the Kp(=1.0) gain is small. The overshoot of the response was caused, and the vibration occurred too though the rise time shortened when the Kp(=1.5) gain was enlarged. On the other hand, rising up was able to be fast regardless of the existence of static friction in the predictive fuzzy control, and it was possible to follow to the target value excellently.

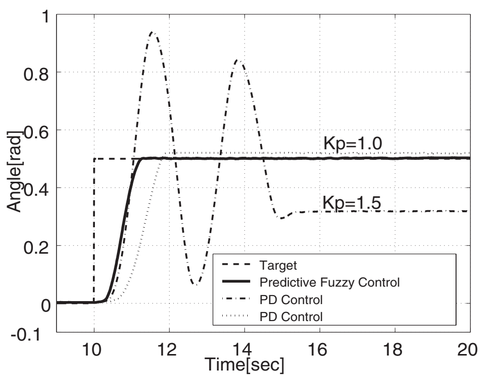
Also, as shown in Figure 7 (b), the voltage ($u_k = 1V$) of control instruction according to a predictive fuzzy control is much higher than that when gain Kp is 1.0 and 1.5 by the PD control untill about 10.2 seconds when the step input is given at the time of 10 seconds. This is a result of selecting the fuzzy rule containing constant torque C to remove the influence of static friction.

The steady-state and the transient performance of this servo system are improved by the predictive fuzzy method.

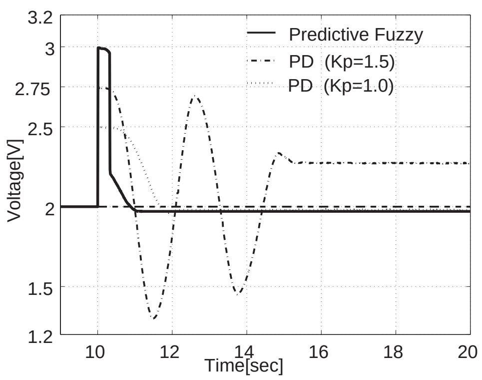
6 CONCLUSIONS

In this paper, we developed the nonlinear pneumatic servo system by an intelligent control (predictive fuzzy control method) which considered static friction. Experiments were done on a real machine under the condition of a constant load for the problem of static friction, and confirmed the effectiveness of the system.

Next step, we will do experiments on a real machine using the manipulator with the pneumatic rotary



(a) Angle



(b)Voltage

Figure 7: Results of experiment by PD control and predictive fuzzy control

actuator by thinking about the change in the load, and to confirm the effectiveness of this control system.

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