A FUZZY ADJUSTABLE CONTROLLER FOR AN ANTIBACKLASH TWIN WORM INDEX MECHANISM

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Nonlinear friction substantially affects the positioning accuracy of a machine, especially in torque controlled antibacklash twin worm index mechanism. A fuzzy controller is designed to achieve better positioning accuracy and robustness by using system parameters obtained from identification. Experimental results show that repeatability is improved as compared to the PDF controller.

Key Word : Fuzzy Control, Index System, Antibacklash Mechanism

1. Introduction

Backlash and friction are two important factors that will affect the accuracy of machine tools. The Twin Worm Index Mechanism [1] uses two one-way clutches and two torque clutches to eliminate backlash. Although the effect of backlash may be negligible in this system, nonlinear friction becomes another important factor in controller design. Most researchers dealt with frictional problems by direct compensation [2-5]. However, once the friction varies with position as in present mechanism, this method may become invalid. Other controllers have also been studied, such as PDF Control [6], sliding mode control [7] and neural network [8]. Despite of these researches, nonlinear friction remains a significant problem in practical applications.

Fuzzy Logic is now widely applied to many fields, especially to nonlinear systems. One application found in literature is in motor control [9,10]. Hwang *et. al.*, combined fuzzy logic and bang-bang control to reduce servo chattering. Cao [11] tried to use fuzzy logic to compensate for stick-slip friction. In general, the performance of a nonlinear system can be improved by fuzzy controllers. Therefore, this paper attempts to combine fuzzy logic and traditional PD controller in order to improve nonlinear friction effects and thus achieve better robustness.

2. Twin Worm Antibacklash Mechanism

This mechanism (Fig. 1) is composed of two worms to drive a worm wheel. Two one-way clutches and two torque clutches are placed between gears to control the input power flow. Fig. 1 also shows the power flow of a clockwise torque input. Under this condition, worm A acts as the control worm and worm B acts as the load

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worm. As the input reverses, the order of the control worm and load worm also reverses i.e. worm B becomes the control worm and worm A the load worm. Since in principle the worms and the worm wheel will remain in contact with each other, no matter how the input torque direction changes, the backlash can be effectively eliminated in this mechanism.

The friction (T_{fric}) is assumed as

$$T_{fric}=T_s+T_d$$

where T_s represents the static friction and T_d represents the dynamic friction. Both T_s and T_d are dependent on position and have periodic features, which can be shown from experiment results.

This mechanism is a high order nonlinear system; however, the dynamic model is assumed to be

$$T_{in} = J \cdot \ddot{x} + T_{fric}$$

Viscous friction can be neglected. The system parameter will be found in system identification experiments.

3. Controller Design

A fuzzy adjustable controller based on traditional PD controller is proposed. For traditional PD controller, steady-state error usually exists in this frictional system and overshoot may occur due to uncertainty in friction. However, if the parameters of PD controller can be automatically adjusted, the steady-state error might be reduced so that the positioning accuracy could be improved. Based on this concept, two kinds of input variables, (i)steady-state error and (ii)error and velocity, are tried for the fuzzy logic and then the parameters are automatically determined by fuzzy rules.

If a PD controller with its poles placed on negetive real axis is applied to this system, A steady-state error exists due to friction. The relationship can be written as

$$T_{fric}=K_pE$$

where T_{fric} is the friction torque, K_p is the proportional constant, and E is the steady-state error. If K_p is increased by δK_p, the system will reach another steady state again. The theoretical dynamic response is shown in Fig.2, where $K_{p(i)}$ is the i'th proportional constant, $E_{(i)}$ is the corresponding i'th steady-state error, and $T_{fric(i)}$ is the friction when the i'th steady state is reached. Their relationship can be written as

$$K_{p(i+1)}=K_{p(i)}+\delta K_{p(i)} \quad i=1\ldots n$$
$$T_{fric(i)}=K_{p(i)}E_{(i)} \quad i=1\ldots n$$

According to the discussion above, the controller will first be designed by only one input variable, i.e. the steady-state error $E_{(i)}$. And the output variable of fuzzy logic will be δK_p. When the initial K_p and K_d make this system reach the first steady state, fuzzy rules will determine a δK_p to drive the system to a new steady state. This process will not stop until the steady-state error reaches zero.

Triangular membership function is adopted for input variable (E). While steady-state error becomes smaller, K_p must be larger to overcome the friction. The fuzzy rules can thus be written as

If E is small, δK_p is large.
If E is medium, δK_p is medium.
If E is large, δK_p is small.

Because the poles are chosen on a fixed place, K_d will be calculated once K_p is determined. Based on the above descriptions, the one-variable fuzzy adjustable controller is designed to tackle friction problems.

However, only one input variable may be insufficient to achieve satisfactory results; therefore, two input variables, error and velocity, are introduced into fuzzy logic to improve the controller performance. This controller will by itself adjust the parameters once the system begins its motion while the former one adjusts its parameter only when the system reaches steady state. The membership functions of error and velocity are also chosen as triangular shape. Error is still divided into three divisions and velocity is divided into five divisions. The design of fuzzy rules becomes more complicated. By experiences from preliminary experiments, eight fuzzy rules are designed as follows.

If error is large and velocity is small, δK_p is small;
If error is large and velocity is positive large, δK_p is small;
If error is medium and velocity is positive large, δK_p is medium;
If error is small and velocity is positive large, δK_p is small;
If error is small and velocity is negetive large, δK_p is small;
If error is small and velocity is negetive medium, δK_p is medium;
If error is medium and velocity is positive medium, δK_p is medium;
If error is medium and velocity is small, δK_p is medium ;
No adjustment for other conditions.

According to above, two fuzzy adjustable controller are designed and implemented in later experiments.

4. Simulation and Experiment

The schematic diagram of the experimental system is shown in Fig.3. For position measurement of the worm wheel, a Canon M1 encoder is used, which produces 50,000 pulses/rev and achieves 6.48 arc-second resolution. A PC is used to read the position data from the decoder, and send the voltage command through the DAC to the linear power amplifier that drives a BALDOR SD45-20 DC servo motor.

For simulation, MATLAB is employed. Friction model used in simulation is the Karnopp model [12]. This model does not capture some details of physical phenomenon, but is numerically efficient.

For the case of single input variable, the positioning accuracy of 6.48 arc-sec. can be achieved, but limit cycles may occur at some positions. For the case of two input variables, limit cycle problem is solved while the same accuracy is still achieved. However, because of nonlinear friction characteristics, this accuracy can not be assured at any position of this mechanism (Fig.4). In order to find out how friction affects controller performance and compare this controller with PDF controller, experiments were performed at various positions where the friction increases with position, and where friction decreases with position. Experiments at random position were also performed. All of the above experiments were carried out with the same parameters and their results are listed in Table 1. From the table, PDF controller seems to show better repeatability than the fuzzy controller at the position where friction increases with position. The reason is that PDF was optimally tuned for that position. However, for other positions, fuzzy adjustable controller has in general smaller average positioning error, better repeatability and robustness than PDF controller with the same parameter at the position mentioned above.

5. References

[1] Yang,T.H., "Double Acting Type Dynamic Back Spacing Removed Driving System," US patent No. 5265488

[2] Armstrong, B.,"Friction: Experimental Determination, Modeling and Compensation,"*Proc. 1988 IEEE Inter. Conf. Robotics Auto.*, V.3, 1988, pp. 1422-1427.

[3] Phillips, S.,M. and Ballou, K.,R.,"Friction Modeling and Compensation for an Industrial Robot",*J. of Robotic Sys. 10(7)*, 1993, pp.947-971.

[4] Canudas, C. "Robust Control for Servo-Mechanisms under Inexact Friction Compensation,"*Automatica* ,V.29, No.3, 993, pp.757-761.

[5] Southward, S.C.,Radcliffe, C.J. and MacCluer, C.T., "Robust Nonlinear Stick-slip Friction Compensation," *Trans. ASME Dynamic Syst., Meas. & Contr.*, V.113 , 1991, pp.639-645.

[6] Huang, C.J. ,Yen, J.Y, Ou, C.C, Lu, S.S. , "Combination of TTDD and PDF Control for Backlashless Operation", Bull. Coll. of Engin., National Taiwan University , No.66, 1996 , pp.1-11

[7] Tou, J. and Schultheiss, P. M., "Static and Sliding Friction in Feedback Systems", *J. Appl. Phys.*, V.24, No.9, 1953, pp. 1210-1217

[8] Ciliz, M.K. and Tomizuka, M.,"Modeling and Compensation of Frictional Uncertainties in Motion Control: A neural network based approach," *Proc. Am. Contr. Confer.*, Seattle ,Washington, 1995, pp. 3269-3273

[9] Kung, Y.S. and Liaw, C.M.,"A Fuzzy Controller Improving a Linear Modeling Controller for Motor Drives", *IEEE Trans. on Fuzzy Systems,* Vol.2,

No.3 , 1994. pp.194-201
[10] Hwang, T.Y., Yen, J.Y. and Lu, S.S. "Bang-Bang based Fuzzy Controller for Time Optimal and Minimum Chattering Servo Systems", *Electric Machines and Power Systems* , 1995. pp.25-35
[11] Cao, C. T., "Fuzzy Compensator for Stick-slip Friction", *Mechatronics,* V.3, No.6, 1993. pp. 783-794 .
[12] Karnopp, D., "Computer simulation of Stick-slip Friction in Mechanical Dynamic Systems," *ASME J. Dyn. Syst., Meas. and Contr.*, Vol.107 ,1985. pp. 100-103.

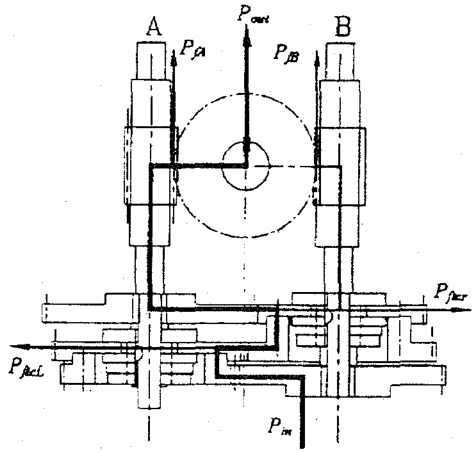

Fig. 1 Power flow of the mechanism

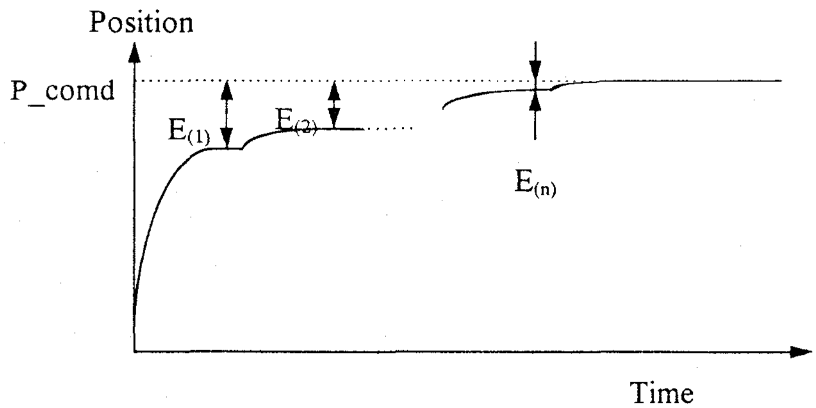

Fig.2 Dynamic response of parameter adjustment

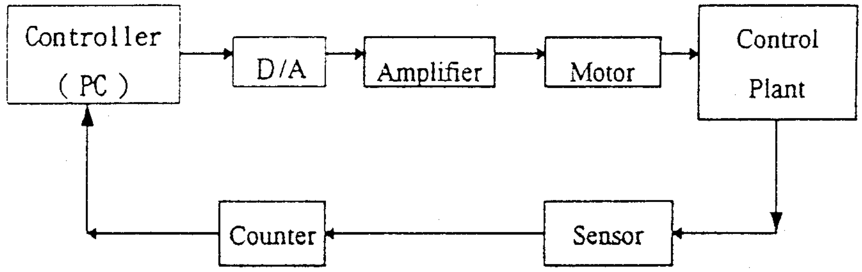

Fig.3 Schematic diagram of the experimental system

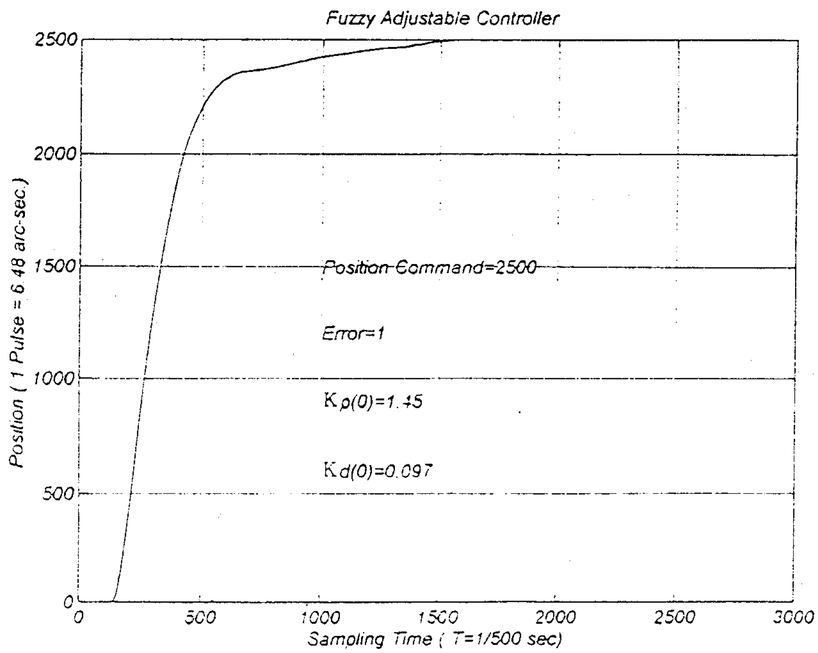

Fig.4 Dynamic response of two-variable fuzzy controller

Table 1. Experimental results of position error at different positions
(1 Pulse=6.48 sec.)

Position	Friction increase		Friction decrease		Random position	
Controller	Fuzzy	PDF	Fuzzy	PDF	Fuzzy	PDF
Avg Deviation	1.88	1.14	3.72	9.22	3.72	21.2
Average	2.4	1.1	-9.1	-13.3	-6.4	-17.0