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Implementation of a Lyapunov Function Based Fuzzy Controller for the Precise Positioning of DC Servo Motor

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Abstract

In this paper, a fuzzy control technique using adjustable scale factors and Lyapunov Function for the precise position control of DC servo system is introduced. The suitable scale factors were selected and the stable control input using the stability theory of Lyapunov function can be applied.

Therefore, the controlled system have the robustness against disturbances and can be stabilized because of reinforced adaptivity.

This proposed fuzzy controller is implemented on a 80586 micro-computer which have of fuzzy inference routine part, manipulating part of scale factors and DT-2801 data aquisition board.

Key Words : Fuzzy control, Position Control, DC servo system, Lyapunov Function, Stability

1. Introduction

Servo motors are used for the control systems for the precise small machinery such as robot manipulators, printer, tape recorder etc. Specially, they are necessary for position control. The parameters of PID control as the classical control theory must be not only tuned depending on the environmental changes but also can not cope adaptivly with the internal or external disturbances and the system nonlinearity.[1]

By the way, Fuzzy control can overcome these problems because of the eigenic flexibility as nonlinear controller based on expert's experiences and intuitions. But there are some difficulties in the optimization of fuzzy rules and the quantization of control variables. Other difficulty is the fact that when scale factor is too small, the disturance accomdating ability is decreased, and when the factor is too large, the system can be unstable because of over-injection of control input.[2] Therefore, a new technique combining the conventional fuzzy control with the Lyapunov stability theory which can determine stable control inputs is needed.[3,4]

In this paper, the Lyapunov-function based fuzzy controller are proposed for the precise position control of DC servo motor. The simulated and implemented Fuzzy-Lyapunov controller showed satisfactory dynamics in steady state error, reaching time, and overshoot.

2. Fuzzy control algorithm

2.1 Fuzzy control

First of all, Fuzzy control rules must be determined. These generalized control rules are acquired from the dynamics of DC servo motor with the feedback control, as in figure 1.

The mathematical model of DC servo motor is as follows:[5]

$$L_a\frac{di_a}{dt}+R_a i_a+K_b\frac{d\theta}{dt}=U \qquad (1)$$

$$J\frac{d'^2\theta}{dt^2}+B\frac{d\theta}{dt}+T_L=K_T\, i_a \qquad (2)$$

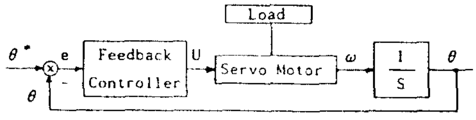

Fig. 1 Servo system with feedback controller

The fundamental dynamics is shown in figure 2.

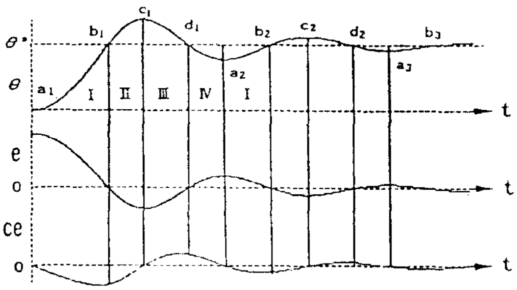

Fig. 2 Dynamic Responses of Feedback Control.

where, $\theta*$: reference of rotation angle [rad]
θ : measured rotation angle [rad]
$e = \theta^* - \theta$: error.
ce = de/dt : change of error
U : control input [V]

Membership functions are described by triangular type. The patterns of membership functions for e, ce, and U are shown in figure 3.

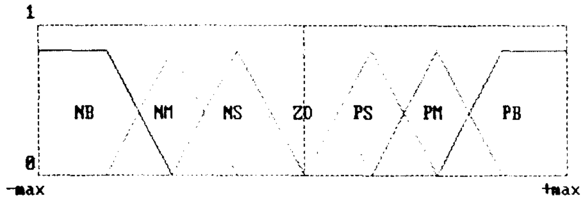

Fig. 3 Membership Functions of e, ce and U

In order to design a Fuzzy controller based on figure 2, the typical fuzzy rules using antecedent variables (e, ce), and consequent variables(U) are given as the equation (3).

If e is NB and ce is NS Then U is NM (3)

The initial control rules can be summarized as Table 1.

Table 1. Fuzzy Rules

ce \ U \ e	NB	NM	NS	ZO	PS	PM	PB
PB	NB	NB	NB	NB	NM	NS	ZO
PM	NB	NB	NM	NM	NS	ZO	PS
PS	NB	NM	NM	NS	ZO	PS	PM
ZO	NB	NM	NS	ZO	PS	PM	PB
NS	NM	NS	ZO	PS	PM	PM	PB
NM	NS	ZO	PS	PM	PM	PB	PB
NB	ZO	PS	PM	PB	PB	PB	PB

where, NB : Negative Big, NM : Negative Medium
NS : Negative Small, ZO : Zero
PS : Positive Small, PM : Positive Medium
PB : Positive Big

The Center method of Gravity by Braae and Rutherford was adopted to infer the defuzzified control input. And the suitable scale factors were selected in order to make a good matching for a practical system[9].

2.2 Addition of Lypunov function to Fuzzy Control

In the fuzzy control, there is two important problems. If the error is very small, the input become to be almost same by the membership functions near zero. Therefore the errorless convergence to the steady state cannot be acquired and the system accompanies the continuous vibration with the constant residual deviation.

The other problem is the deficiency of adaptability coping with excessive internal or external disturbances, because the membership functions have constant width values. Therefore, the suitable scale factors must be determined using special technique. However, the too small scale factors can make the robustness reduce and the too large factors can make the system unstable. In order to solve these problems, the stabilization algorithm using Lyapunov function is added. This technique can determine stable control inputs and can make reduce the settling time by appling the large input in the transient mode.

The general Lyapunov function of quadratic type is constructed using error term. Futhermore, the fuzzy rules to improve the transient dynamics are updated by many trial and errors.

Table 2. Improved Fuzzy Rules

ce U e	NB	NM	NS	ZO	PS	PM	PB
PB							
PM							
PS							
ZO			NS	ZO	PS		PB
NS				ZO			
NM					PS		
NB						PM	

That is, the stabilized input assuring certain stability can be determined from the Lyapunov function as eq(4).

$$V(e, ce) = E^{T}QE \qquad (4)$$

$$\text{where, } E = \begin{bmatrix} e \\ ce \end{bmatrix}$$

Q : Weighting Matrix

Appling eq.(1) and (2) to the time derivative of eq.(4), the resultant equation is as eq(5).

$$\frac{dV}{dt} = 2ce\{ e-(\frac{K_tK_b+BR_a}{JR_a})\frac{de}{dt} - \frac{K_t}{JR_a}U + \frac{T_L}{J}\}$$
$$= 2\ ce\ f(e,\ U) \qquad (5)$$

According to Lyapunov stability theory, $\dot{V}(e, ce)$ must be negative. If ce>0 in eq(5), θ decreases and eq(6) must be satisfied to decrease undershoot and to cope with disturbances..

$$U > \frac{1}{K_t}\{JR_a\ e-(K_tK_b+BR_a)ce+R_aT_L\} \qquad (6)$$

Also, if ce<0, θ increases and eq(7) must be sastified to prevent from expanding exessively scale factors.

$$U < \frac{1}{K_t}\{JR_a\ e-(K_tK_b+BR_a)ce+R_aT_L\} \qquad (7)$$

3. Design of stable fuzzy controller

3.1 Design of Controller

The block diagram of DC servo system with stable fuzzy controller is shown in figure 4.

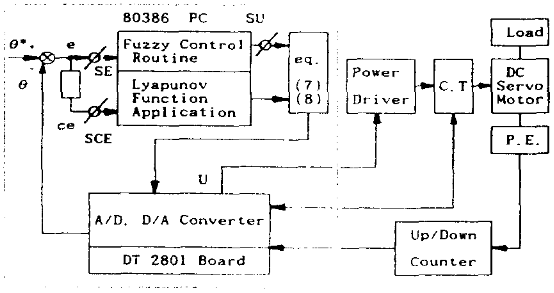

Fig.4 Block Diagram of DC Servo System with Fuzzy Controller.

Specifications of DC servo motor are shown in table 3.

Table 3. Specifications of DC servo motor and encoder.

DC Servo Motor	
Ra = 1.300 [Ω] Jm = 0.00016[Kg·cm·sec2] Kb = 0.04098 [V·s/rad] Rated Voltage Un = 15.0[V] Rated Current In = 3.56 [A] Rated Power Pn = 60 [W]	La = 0.00170 [H] Bm = 0.00272 [kg·cm·sec] KT = Ki = 0.08687 [kg·cm/A] Rated Torque Tn= 2.35 [Kg.cm] Rated Speed Nn = 3000[rpm] TAMAGAWA SEIKI TS1415N4
Pulse Encoder	
NO : TS1905N46E6 Output Voltage : 5 - 40 [V] Resolution : 500 [C/T]	Max.Frequency Response:33[KHz] Output Current : 100 [mA]

The command angle, $\theta^*(t)$, was 15[rad] and the input voltage of servo motor was limited within ± 10[V]. As in figure 4, Fuzzy controller was consisted of a 80586 microprocessor and DT-2801 board. The output pulse of the light encoder was transmitted to UP/DOWN counter in DT-2801 board. The error e was multipiled by scale factor SE and the change of error ce was multiplied by SCE. The control input U are multiplied by SU so that can make the system stable. And DT-2801 D/A converter transfer the control signals into the power drive circuit. The successive analog inputs were applied to the plant by the power OP amplifier of bridge type which were sensitive even for a very small change. The absolutely stable controls without the harmonics or the dead time were applied. But the harmonics or the dead time can never be evitable by the conventional bridge inverters.

3.2 Simulation results

The application of Lyapunov function to Fuzzy control can improve the defects of the conventional Fuzzy control. Figure 5 and 6 respectively show the results of a convetional Fuzzy controller and the proposed Fuzzy-Lyapunov controller.

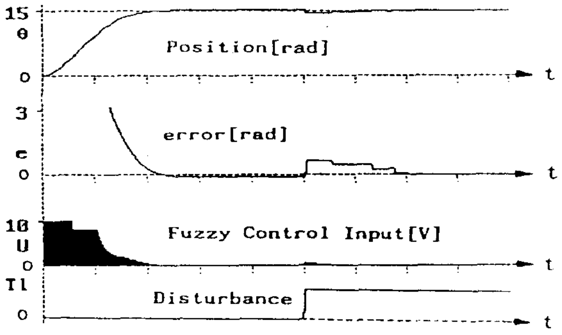

Fig. 5 Dynamic Responses of Fuzzy Controller. (Full Load Applied at 500[ms], (100[ms/div])).

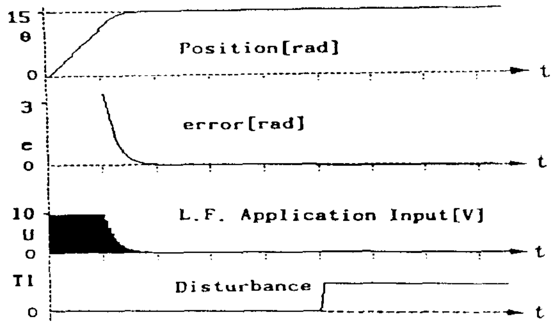

Fig. 6 Dynamic Responses of Fuzzy-Lyapunov Controller (Full Load Applied at 500[ms], (100[ms/div])).

When the system is loaded at the time of 500[ms], the reaching time of a Fuzzy-Lyapunov controller was 185[ms], about 20[ms] shorter than that of a Fuzzy controller. Its overshoot is 0.45[%], about 1.88[%] lesser than one. The maximum position errors were 3.73[%] for a Fuzzy controller and 0.157[%] for a Fuzzy-Lyapunov controller at full load application.

3.3 Experimental results

The experimental results were shown in fig. 7 and fig.8.

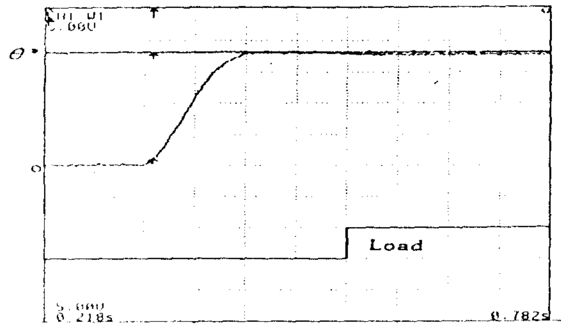

Fig. 7 Experimental Results of Fuzzy Controller (4[rad/div], 100[ms/div])(Full Load Applied at 400[ms])

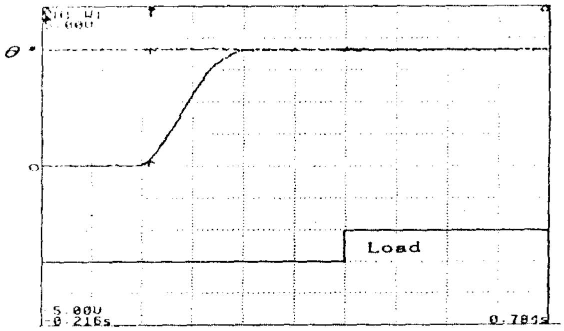

Fig. 8 Experimental Results of Fuzzy-Lyapunov Controller (4[rad/div], 100[ms/div])(Full Load Applied at 400[ms])

The response of Fuzzy controller as fig.7 shows Reaching time of 200[ms], overshoot of 2.2[%] and steady state error of 1.8[%]. But, The one of Fuzzy-Lyapunov controller as fig. 8 shows overshoot of 0.4[%] and the maximum position error of 0.2[%]. Its max. error was about 3.13[%] lesser than that of a Fuzzy controller and also its the reaching time was reduced by 15[ms] without the steady state deviations even for a full-loaded practical system. The summarized results are shown in table 4.

Table 4. Experimental Results.

	R.T. [ms]	OV [%]	S.S. error[%]	E_{max}D. error[%]
Fuzzy	200	2.20	1.80	3.33
F.L.C	185	0.40	0.10	0.20

※ S.S. :Steady State. R.T. :Reaching Time
E_{max}D.:Maximum Error after Disturbance Addition
OV. :Overshoot, F.L.C :Fuzzy-Lyapunov Controller

4. Conclusion

In this paper the Fuzzy-Lyapunov controller that can determine the stable control inputs satisfying the stabilization conditions of Lyapunov was proposed. This proposed controller was implemented The high precision DC servo systems was implemented using PC as a fuzzy logic controller and the data acquisition board DT-2801.

The results were very satisfactory comparing with the conventional controller in the steady state deviation, the reaching time and the maximum overshoot.

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