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Autotuning Fuzzy PID Controller for position Control of DC Servo Motor

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Abstract- This paper describes an autotuning fuzzy PID controller for a position control of DC servo motor. Because ZNM(Ziegler-Nichols Method) with relay feedback has the difficulty in re-tuning the PID parameters and adaptive method has complex algorithm, a new method to overcome those problems is required. The proposed scheme determines the initial PID gains by using ZNM with relay feedback, and then re-tunes the optimal PID parameters by using fuzzy expert system whenever control conditions are changed. To show the validity of the proposed method, a position control of DC servo motor is illustrated by computer simulation and is experimented by a designed controller.

Keywords : Autotuning, PID, Fuzzy, DC servo motor

1. Introduction

The PID controller is by far the most common control algorithm. It provides several improtant functions: it provides feedback, it has the ability to eliminate stead-state offsets through the integral action, the controller can anticipate the future through the derivative action. Much good control practice is engineered into it. PID controllers are sufficient for many control problems, particularly where there are benign process dynamics and modest preformance requirements.[1]

However PID controller needs to tune control parameters appropriately. In 1942, Ziegler and Nicholes introduced a tuning mehtod, so called ZNM (Ziegler-Nichols tuning method). In the method, PID controller parameters are obtained by using ultimate gain(K_c) and ultimate frequency(f_c).[2,3] For the on-line of ZNM, Åström and Hägglund introduced relay feedback, in 1984. At the oscillation by using relay feedback, K_c and f_c can be obtained and control parameters are obtained using them. But the PID controller using relay feedback is basically similar to the controller using ZNM. So, when setpoint is changed, overshoot is about 30%. It is not desirable to operate the process near instablity. Besides, it is impossible to re-tune the controller parameters when the operation condition of system is changed.[4,5]

If the adaptive controller is adopted as a internal machanism and priori-information needed for designing adaptive controller is taken automatically in the system, the above problems can be overcome. Because the controller contains the defects of adaptive controller, adopting it to industrial field is not easy.[6-8]

Therefore, we aim at the development of the fuzzy expert system based on fuzzy rule. That is, the autotuning method based on relay feedback was chosen as initial tuning method and then fuzzy expert system was designed to obtain more accurate PID controller parameters automatically. Its validity was verified experimentally by designing on-line autotuning device for the position control of DC servomotor.

2. The Tuning Methods of PID Controller Parameters

The PID controller is used widely in the area of industrial process control that is not easy to make the accurate model of the system. The control performance is influenced heavily according to the controller parameters. Therefore, obtaining the optimal parameters is a matter of primary concern in the PID control. ZNM and relay feedback method are used to determine PID control parameters in unknown system. For the real time re-tuning of PID controller parameters, adaptive method and the expert tuning method using output pattern are used.

2.1 The Ziegler-Nichols'Tuning Method

Two classical methods were presented by Ziegler and Nichos in 1942. One is the step response method and the other is the frequency response method. In the step response method, control parameters are obtained from the slope of the step response and delay time when the step input is applied. The frequency response method gives simple formulas for the parameters of the controller in terms of the ultimate gain(K_c) and ultimate period(T_c) obtained by increasing the only proportional gain in a PID controller like equation (1), until the stability boundary is reached. The method is based on the observation that many systems can be made unstable under proportional feedback by choosing sufficiently high gain in the proportional feedback. Assume that the gain is successfully adjusted so that the process is almost at the stability boundary. K_c and f_c are obtained at the condition.

$$G_c(s) = K_P[\ 1 + \frac{1}{T_i s} + T_d s] \qquad (1)$$

Controller	K_p	T_i	T_d
P	$K_c/2.0$	-	-
PI	$K_c/2.2$	Tc/1.2	-
PID	$K_c/1.7$	Tc/2.0	Tc/8.0

Table.1 Quarter decay tuning formular

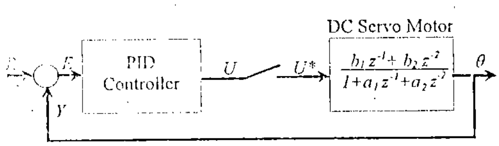


Fig.1 Feedback control system with PID controller

Generally, the method follows Quarter decay rule as shown in Table.1 to obtain the PID controller parameters. K_p, T_i and T_d represent respectively proportional gain, integral time and derivative time. We can use this method for unknown system. It is, however, difficult to automate this method or perform it in such a way that the amplitude of the oscillation is kept under control. Operating the process near instability is also dangerous. Another method for automatic determination of ultimate point is suggested below.

2.2 The Relay Feedback Method

The method based on the observation that the appropriate oscillation can be generated by relay feedback. The system is thus connected as shown in Fig.2. For many systems, there will then be an oscillation where the control variable is a square wave and the process output is close to a sinusoid.
In case that the system has a properties of low pass filter, the magnitude of error signal is expressed as equation (3) and the vibration at ultimate period appears

$$u(t) = \begin{cases} +d & \text{if } e(t) \geq 0 \\ -d & \text{if } e(t) < 0 \end{cases} \qquad (2)$$

where e(t) : output error
d : the magnitude of relay

at the condition of equation(4).

$$a = \frac{4d}{\pi} \mid G_p(j\,2\pi f_c) \mid \qquad (3)$$

$$\arg\ G_p(j\,2\pi f_c) = -\pi\ , \qquad (4)$$

$$K_c = \frac{4d}{\pi a} = \frac{1}{\mid G_p(j\,2\pi f_c) \mid}$$

From equation (3)and (4), K_c is determined by the magnitude d of relay output, the ultimate period $T_c(1/f_c)$ and the magnitude of error a.

After obtaining K_c and T_c from relay feedback, the relay is replaced by PID controller in the system. But the relay feedback method guarantees only the initial PID controller parameters, and cannot re-tune the controller parameters when the condition of controller is changed.

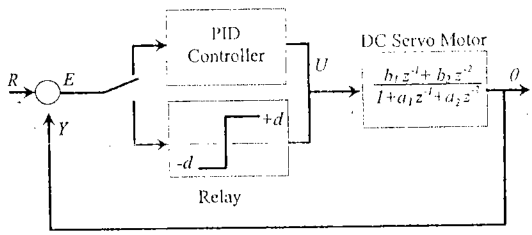


Fig.2 PID control system with relay feedback

3. Autotuning Methods by proposed Fuzzy Expert System

The adaptive controller must estimate system parameters or need to have exact system model. The

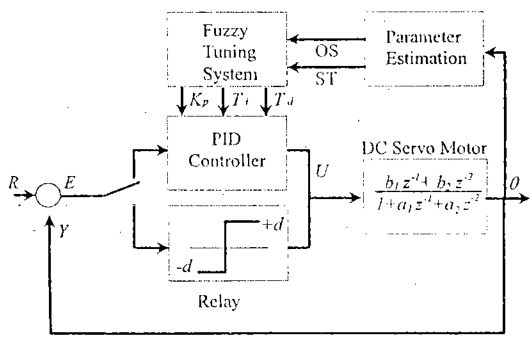


Fig.3 Proposed auto-tuning PID control system

controller has difficult problems in the time variable system and, non-linear system.

Therefore, we propose fuzzy expert system to autotune the unknown system. First, the initial PID control parameters obtained from relay feedback method are applied to the PID controller, and then the overshoot and settling time are obtained from output response. They are used as fuzzy input variables at the fuzzy expert system. The parameters can be tuned automatically. The proposed control system is composed of relay, PID controller and fuzzy expert system. The structure is shown in Fig.3.

3.1 Pre-Determination of initial Parameters

For the system operation, the initial controller parameters should be determined. In this study, we determine the initial parameters by relay feedback method for unknown system.

3.2 Fuzzy Expert System for Parameter Tuning

The input variables in the fuzzy expert system are overshoot and settling time. The fuzzy rule produces the PID control parameters using the fuzzy input variables as shown in Fig.4. Fuzzy expert system has 5 ×5 fuzzy space and 25 rules.

Settling Time (columns), Overshoot (rows)

K_p

ZE	ZE	ZE	ZE	PS
NS	NB	NB	ZE	PS
NS	NB	NB	NB	PS
NS	NB	NB	NB	NB
NB	NS	NS	NS	NB

T_i

ZE	NS	NB	NB	NB
NS	ZE	NB	ZE	ZE
NB	NB	ZE	NS	ZE
NB	NB	NB	NB	NB
NB	NB	NB	NB	NB

T_d

ZE	PS	ZE	ZE	ZE
ZE	ZE	ZE	ZE	ZE
NS	ZE	NS	ZE	ZE
NS	NS	ZE	NS	ZE
NS	NS	NS	NS	NS

Fig.4 Fuzzy reles for tuning parameter

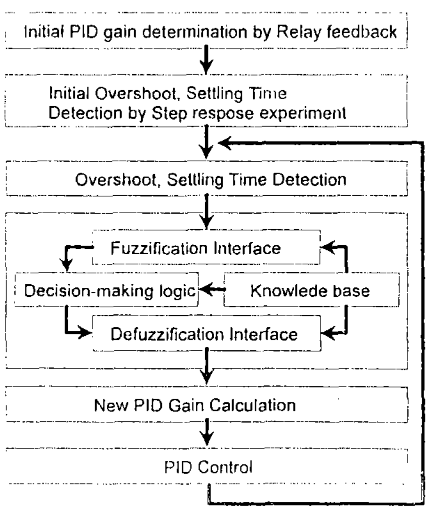


Fig5. Process of tuning parameter

Because it is difficult to express expert's knowledge and experience with linguistic rules, fuzzy rules are identified by the numerical data. The data are values of overshoot and settling according to various PID parameters. Triangle membership function is used. Mandini's method is used for reasoning and the center of area method is applied for defuzzification.

The process of autotuning of PID contrller parameters using proposed fuzzy logic is shown in Fig.5.

4. Simulation

The proposed autotuning fuzzy PID controller is adopted to the position control of DC servo motor. That is, the DC servo motor and digital PID controller are represented in Z-transform. The proposed autotuning algorithm is applied to the system. The output response to the change of step input and setpoint are investigated by simulation.

4.1 DC Servo Motor Modeling

The block diagram is shown in Fig.6.

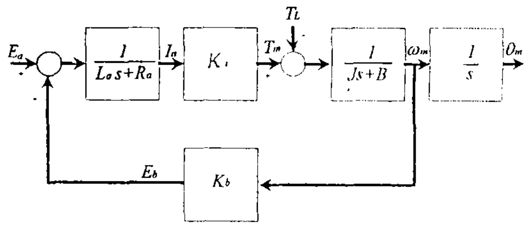


Fig.6 Block diagram of DC motor

From this, the transfer function between anglular velocity ω and the input voltage V is obtained as following equation.

$$\frac{\omega(s)}{V(s)} = \frac{K_t}{BR(1+s\tau_e)(1+s\tau_m)+K_t^2} \quad (5)$$

$$\frac{\omega(s)}{V(s)} = \frac{K}{1+s\tau}$$

$$K = \frac{K_t}{BR+K_t^2} \quad (6)$$

$$\tau = \frac{BR\tau_m}{BR+K_t^2}$$

where

K_t : torque constant,

τ_m : mechenical time constant

τ_e : electrical time constant

B : a viscous frictional coefficient

R : armature resistance

And the transfer function between position θ and input voltage V is expressed as follows

$$\frac{\theta(s)}{V(s)} = \frac{K}{S(1+S\tau)} \qquad (7)$$

The transfer function in the Z-plane is shown in equation(8).

$$\frac{\theta(z)}{V(z)} = \frac{b_1 z^{-1} + b_2 z^{-2}}{1 + a_1 z^{-1} + a_2 z^{-2}}$$

$$\begin{aligned} a_1 &= -(1+a_2) \\ a_2 &= e^{-T/\tau} \\ b_1 &= K[\ T - \tau(1-e^{-T/\tau})] \\ b_2 &= K[\ \tau(1-e^{-T/\tau}) - Te^{-T/\tau}] \end{aligned} \qquad (8)$$

4.2 Digital Modeling of PID Controller.

For the position control of DC servo motor, a digital PID controller is designed. The control input $u(t)$ of PID controller is shown as follows.

$$u(t) = K[\ e(t) + \frac{1}{T_i}\int e(t)dt + T_d\frac{de(t)}{dt}] \qquad (9)$$

Above equation can be expressed in Z-transform, that is, $H(z)$ is represented as follows

$$H(z) = K[\ 1 + \frac{1}{T_i}\frac{Tz}{z-1} + \frac{T_d}{T}\frac{z-1}{z}] \qquad (10)$$

where T : sampling time

The element of PID control parameters are expressed in difference equation as shown in equation.11.

$$\begin{aligned} P(k) &= K[\ r(k) - y(k)] \\ I(k+1) &= I(k) + \frac{KT}{T_i}e(k) \end{aligned} \qquad (11)$$

$$D(k) = \frac{2T_d - TN}{2T_d + TN}D(k-1) - \frac{2KNT_d}{2T_d+TN}[\ y(k) - y(k-1)]$$

where

$r(k)$: reference input value
$y(k)$: measured value
$P(k)$: proportional action term
$I(k)$: integrial action term
$D(k)$: derivative action term
N : coefficient in Tustin's approximation

4.3 Tuning Procedure and characteristics

The initial PID controller parameters are obtained from the relay feedback method. In case of relay feedback method, the output response of DC servo motor is shown in Fig.7. From this, the ultimate amplitude and

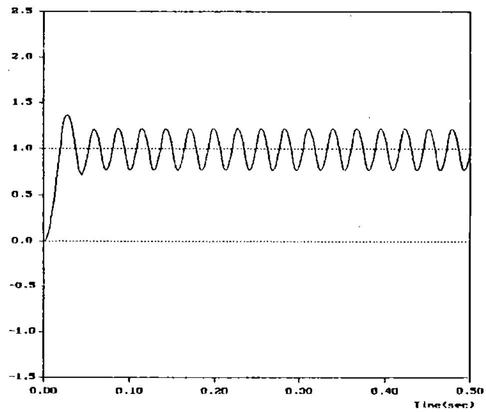
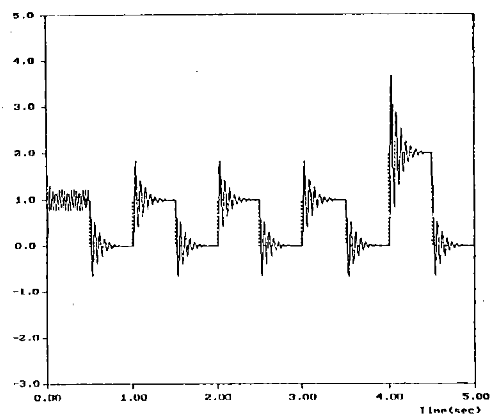
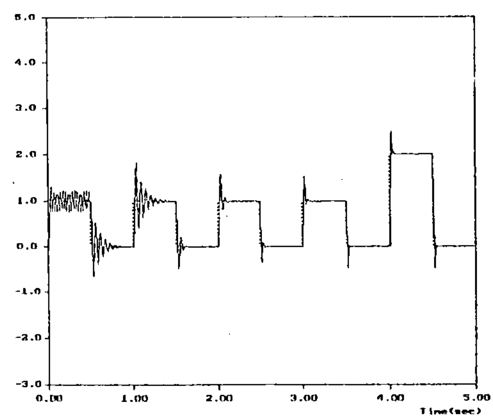


Fig.7 Output of Relay feedback



(a)



(b)

Fig.8 Tuning procedure
a) Relay feedback method
b) Proposed method

ultimate period are detected and are derived from Quarter decay rule, after that, the parameters are applied to the PID controller automatically. Fig.8 (a) shows the response to the step input in DC servo motor adopting the initial PID control parameters obtained form relay feedback. The parameters of DC servo motor K, τ are set respectively to 70, 0.07. To tune the control parameters more elaborately than that of relay feedback method, the fuzzy tuning algorithm is adopted to the system, that is, overshoot and settling time are detected from the initial response, and then, they are used as fuzzy input variables. The new PID parameters based on fuzzy rule are obtained. After several tuning process, optimal parameters having the least overshoot and settling time are determined. The output response is shown in Fig.8 (b).

We compare the proposed autotuning method with the relay feedback method. Two cases are compared in Fig.8 a),b). Relay feedback method cannot re-tune the control parameters. When the setpoint of system is changed, the relay feedback method cannot improve the response. But the proposed fuzzy expert system can re-tune the PID controller parameters automatically.

5. Experiment and Result

To verify the utility of proposed method, the autotuning fuzzy PID controller is implemented using PC386, D/A converter and counter.

5.1 Implementation of proposed PID controller.

The configuration of hardware is shown in Fig.9. Digital PID controller, relay and fuzzy autotuning algorithm are implemented using PC386. Control input $u(t)$ obtained by PID control algorithm is changed into analog value by D/A C, and then it is changed into the PWM signal and amplified through AMP. DC servo motor is drived by the PWM signal. During the DC servo motor driving, the pulse generated by the encoder is transfered to direction detector and counter. The position is obtained from the counter

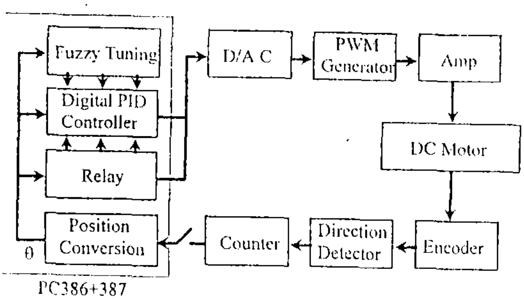
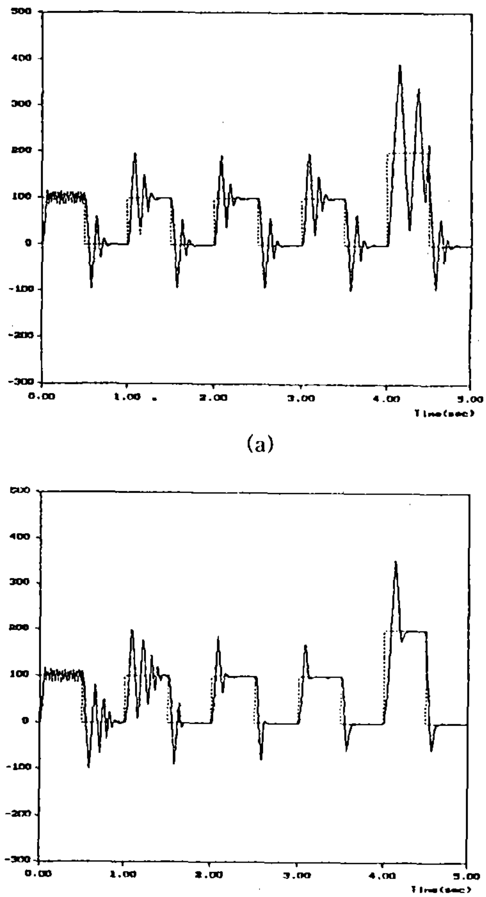


Fig.9 Configuration of the PID controller for position control

5.2 Experimental Result

The ultimate amplitude and ultimate period are obtained from the relay feedback experiment, and then, the initial PID parameters are derived from Table.1. We operate the system with the initial parameters and observe the input variables of fuzzy rule from the response pattern and then obtain the new control parameters by the fuzzy rule. At Fig.10, we compare the system using the only relay feedback method for position control with the system using the proposed fuzzy expert system. In case of setpoint change, relay feedback method doesn't show improvement. But the proposed method shows the accurate tuning of control parameters and the improvement of control performance.



(a)

(b)

Fig.10 Position control experiment
a) Relay feedback
b) Proposed method

6. Conclusion

In this study, we take relay feedback method to tune the initial PID controller parameters for unknown system and take the fuzzy expert system to re-tune the controller parameters more accurately. We solve the two difficult problems by proposed algorithm. We can retune the PID control parameters and improve the complex algorithm of adaptive method.

After the computer simulation using the proposed method, we see the improvement of response to initial control parameters in unknown system. We implemented the controller of DC servo motor for position control and obtain the excellent persuit performance for setpoint. We think that the implemented controller of DC servomotor for position control is worthy of utilizing in the industrial factory. For the future, if we more accurately fuzzify the input varible based on expert's experience and produce fuzzy rule, or produce automatically fuzzy rule, we would make more improved controller.

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