

The Research of FUZZY PID Control Application in DC Motor of Automatic Doors

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Abstract-Currently, DC motor of automatic doors speed regulating system utilizes PID control which has parameters tuning difficulties, poor stability, and imprecise control. To solve the above existent problem, this paper adopts the control strategy of fuzzy algorithm combining with PID control, introducing method of fuzzy PID control used in DC motor speed regulating system of automatic doors. Through establishing DC motor mathematical model, MATLAB simulation of PID control and fuzzy PID control are compared in this paper, the simulation results show the fuzzy PID control has fast dynamic response, high control precision, small overshoot and the control system is stable, its robustness and adaptability is strong. Control demand of the system can be satisfied and the safety operation of automatic doors can be ensured by fuzzy PID control.

Key words-DC motor ; PID ; fuzzy control ; MATLAB simulation

I. INTRODUCTION

With the safe, efficient, energy-saving features, automatic doors are widely used in many occasions. DC motor, with the features of wide range of stepless speed regulation, strong overload capacity, fast response speed, good stability, ease of maintenance and so on, applies in various fields [1]. Given the advantages of DC motors, the DC motor can be used in driving motor of automatic doors control system.

The research shows that PID control has features of simple structure, good stability, high reliability, which meets the DC motor speed regulating system control requirements of automatic doors. The method of PID control was widely adopted to improve the traits of DC motor speed regulating system, which has become an interesting topic for many scholars in recent years. Ding Chong [2], using digital PI control scheme of current and speed double closed loop, achieved DC motor speed regulating. ZHAO Xiu-fen[3] applied the incremental PID control strategies in DC motor speed regulating system, made the control system more accurate .

With the Continuous improvement for the requirement of system control, PID control system can not meet the control requirements, and it has exposed its limitations, such as the parameters can not be set online, dead zone is too large, the positioning accuracy is not high. For the nonlinear system and time-varying system, the effect of PID control is inefficient. With the development of control theory, a more advanced control strategies, fuzzy PID, was gradually adopted in the control system. Ding Hai-shan [4] using unknown nonlinear function of the fuzzy tree identification method in off-line identification system, improves the control performance. TAN Guan-zheng[5] proposed a new optimal fuzzy PID controller that has the best control effect to a given object. Because of the complexity of the control algorithm of the methods referred above, the methods are not easy to achieve and implement in project, therefore, this paper establishes the simulation of fuzzy PID control in DC motor speed regulating system, expecting to apply fuzzy PID control in the field of automatic doors to improve the performance of DC motor speed regulating system of automatic doors. This paper firstly analyzes the principle of DC motor speed regulating and creates a mathematical model of DC motor, then designs the MATLAB simulation of PID control and MATLAB simulation of fuzzy PID control, finally makes simulation comparison of two control methods and analyses the results of the simulation comparison.

II. Principle of DC Motor Speed Regulating

The knowledge of DC motor shows, the speed of separately excited DC motor

$$n = \frac{U_d - I_d R_d}{C_e \Phi} = \frac{U_d}{C_e \Phi} - \frac{I_d R_d}{C_e \Phi} = n_0 - \Delta n \quad (1)$$

Where n- motor speed,

U_d -the armature voltage,

I_d -the armature current,

R_d -the total resistance of the armature circuit,

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C_e- electric potential coefficient which was determined by motor structure

Φ-excitation flux

It can be seen from the above formula, as long as one parameter of armature voltage U_d or excitation flux Φ or the armature circuit total resistance R_d changes, the DC motor speed will change. The method of changing armature voltage is simple and effective. Speed regulating was achieved by changing armature voltage. By the above formula, in the fixation load situation, increasing the value of U_d can increase the value of n, the system using change armature voltage to regulate speed is called variable voltage speed control system. It is the most widely adopted speed regulating method.

III. DC Motor Mathematical Model

By the Kirchhoff's voltage law, it can be obtained,

$$U_d = e + I_d R_d + L_d \frac{dI_d}{dt} \quad (2)$$

Where e- motor armature counter electromotive force

U_d -the armature voltage

L_d- inductance of armature circuit

I_d -the armature current

R_d - the total resistance of armature circuit

$$e = C_e n \quad (3)$$

Where C_e- electric potential coefficient which was determined by motor structure, n-motor speed

Make (3) into (2), We can obtain that,

$$U_d = C_e n + I_d R_d + L_d \frac{dI_d}{dt} \quad (4)$$

By the mechanical motion equations of motor, we can obtain,

$$T - T_L = \frac{GD^2}{375} \frac{dn}{dt} \quad (5)$$

Where T - electromagnetic torque of motor

T_L-load torque of motor,

In the case of no-load (5) can be transformed as,

$$T = \frac{GD^2}{375} \frac{dn}{dt} \quad (6)$$

$$\text{From } T = C_T I_d \quad (7)$$

Where C_T-electromagnetic torque constant

By (6) and (7), it can be obtained,

$$I_d = \frac{GD^2}{375 C_T} \frac{dn}{dt} \quad (8)$$

Make (8) into (4), we can get the following function,

$$L_d \frac{GD^2}{375 C_e C_T} \frac{d^2 n}{dt^2} + \frac{GD^2 R_d}{375 C_e C_T} \frac{dn}{dt} + n = \frac{U_d}{C_e} \quad (9)$$

$$T_d = \frac{L_d}{R_d}, \quad T_m = \frac{GD^2 R_d}{375 C_e C_T} \quad (10)$$

Where

Then (9) can be transformed as,

$$T_d T_m \frac{d^2 n}{dt^2} + T_m \frac{dn}{dt} + n = \frac{U_d}{C_e} \quad (11)$$

Make Laplace transform for (11)

$$T_d T_m S^2 N(S) + T_m S N(S) + N(S) = \frac{U_d(S)}{C_e} \quad (12)$$

Transfer function of separately excited DC motor can be obtained,

$$G(S) = \frac{N(S)}{U_d(S)} = \frac{1}{C_e} \frac{1}{T_d T_m S^2 + T_m S + 1} \quad (13)$$

IV. DC motor speed regulating system simulation design

A. PID Control Simulation Design

The output u(t) of the controller is determined not only by proportional to the error signal e(t), but also proportional to the integral of e(t) and the derivative of e(t). So that it is called proportional and integral and derivative controller. It is short for PID controller[6]. Time-domain equations of PID controller is

$$u(t) = K_p [e(t) + \frac{1}{T_i} \int_0^t e(t) dt + T_d \frac{de(t)}{dt}] \quad (14)$$

Where K_P is proportional coefficient, T_i is the integral time constant and T_d is the differential time constant. When K_P becomes larger, the response of system will be more rapid and steady-state error of system will be less. But the oscillation is more intense, the adjustment time will be longer. When K_P is too large, the system will tend to be unstable. When K_P is too small, the system response will be tardy. When T_i is small, integral role of the system will be strengthened, which will make the system tend to be instable, but it can eliminate the steady-state error and improve control precision. When T_d is large, the overshoot will be large, but adjustment time will be short. When T_d is too small, overshoot will also be large, and adjustment time will be long. Only the parameters K_P, T_i, T_d of PID control is set properly, can the performance of control system be more superior.

Proportion, integral and differential can make system more stable, dynamic response faster and overshoot less. The PID control principle block diagram is shown in figure 1.

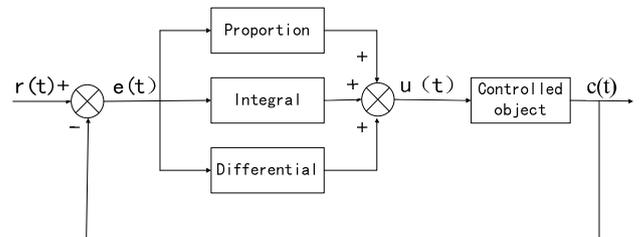


Figure 1 . principle chart of PID control

It can be seen from the figure 1, the error signal $e(t)=r(t)-c(t)$, the error signal $e(t)$ adjusted by proportion, integral, differential becomes $u(t)$ and $u(t)$ controls the object to decrease deviation signal.

Simulink is a visualization control system imitation integrated environment in Matlab. It is an assistant in modeling and simulation for complex control system. In Simulink condition, users can use the mouse or keyboard to complete all the process of the diagram system simulation. And the result can be more intuitive, fast and accurate. In this simulation experiment, transfer function of simulation objects is $G(S)=1/S^2+2S+1$. Figure 2 shows simulation structure diagram of the PID control method in the Simulink simulation environment.

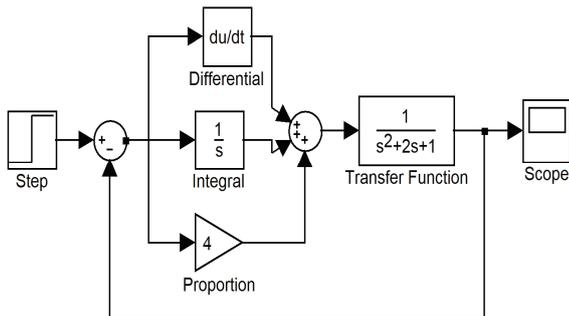


Figure 2 . simulation structure chart of PID control

B. Simulation Design of Fuzzy PID Control

The fuzzy PID control has a more obvious superiority compared with the PID control, fuzzy PID control is often selected in control nonlinear system and time-varying system. The fuzzy PID control is used to control system that requires high control precision, upper sensitivity, fast response speed. Fuzzy PID control utilizes expert adjusting knowledge to establish adjustment rules if-then model, and uses fuzzy logic reasoning to adjust PID parameters in real time, which makes control object to achieve ideal control state.

Fuzzy controller is the core of fuzzy PID control system. Fuzzy controller is made up of fuzzed, rule base, fuzzy reasoning, de-fuzzy. The role of each part is separately as follows: the fuzzed transforms accurate quantity of input to fuzzy quantity; rule base is control rule sets that are obtained by experience or other methods; fuzzy reasoning explains and utilizes expert experience of rule base to achieve optimum control; de-fuzzy outputs accurate amount that is converted by fuzzy reasoning conclusion. The structure chart of fuzzy PID control is shown in figure 3.

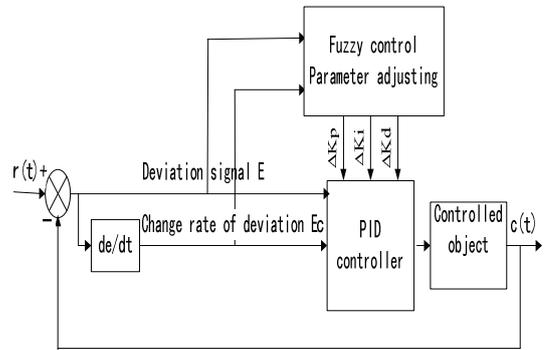


Figure 3 . structure chart of fuzzy PID control

It can be seen from Figure 3 that the system consists of a fuzzy controller and a PID controller. Deviation and the change rate of deviation are the input of fuzzy control system. The changes of the three PID parameters are the outputs. Based on the previously established rules of the fuzzy control, we can make fuzzy reasoning and modify the value of PID parameters on-line, so as to achieve the PID parameters self-tuning. So that controlled object has a good dynamic and static performance. The transfer function of control object is $G(S) = 1/S^2+2S+1$. The fuzzy PID control simulation is shown in Figure 4.

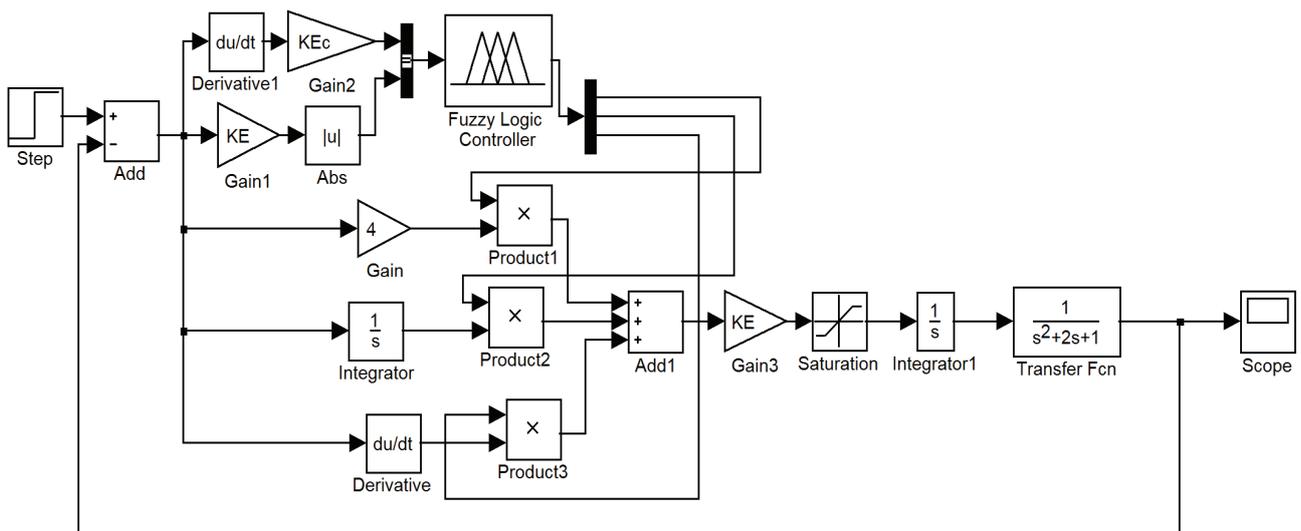


Figure 4 . simulation structure chart of fuzzy PID control

Firstly, fuzzy PID control method finds the relations among the three parameters K_p, K_i, K_d of PID controller and the a value of deviation $|E|$ and the value of deviation change rate $|E_c|$. The value of $|E|$ and value of $|E_c|$ are continuously detected in the control process, then the three parameters are modified on-line according the fuzzy control rules to meet the control requirements. In this paper, the domain of fuzzy sets of $|E|$, K_p, K_i, K_d is $[-6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6]$. The word set is $[NB, NM, NS, 0, PS, PM, PB]$. The corresponding linguistic variable fuzzy set is $[\text{negative large, negative middle, negative small, zero, positive small, positive middle, positive big}]$. The domain of fuzzy sets of $|E_c|$ is $[-6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6]$. The word set is $[NB, NS, 0, PS, PB]$. The corresponding linguistic variable fuzzy set is $[\text{negative large, negative small, zero, positive small, positive big}]$.

The paper summarizes the parameter setting rules:

- [1] When $|E|$ is large, to achieve a stronger dynamic response performance, we can set larger K_p and smaller K_d . To avoid the overshoot of system response being too large, the integral role should be limited, generally, K_i is set as 0.
- [2] When $|E|$ is medium size, in order to achieve a smaller overshoot of the system response, K_p can be set smaller. At this time, the value of K_p has greater impact for the system response. The value of K_i should be moderate.
- [3] When $|E|$ is small, to make the system stable, the value of K_p and K_i should be set larger. At this point, in order to avoid the system oscillation near the set value, the value of K_d should refer to the value of $|E_c|$. When the value of $|E_c|$ is small, the value of K_d can be larger, when the value of $|E_c|$ is larger, the value of K_d can be small, usually, it is set as medium [7]. According to the setting principles of K_p, K_i, K_d , the fuzzy rules table can be obtained, as table 1.

TABLE I. FUZZY RULE CHART OF K_p, K_i, K_d

| $K_p, K_i, K_d \backslash E_c$ | E | | | | | |
|--------------------------------|----------|----------|----------|----------|----------|--|
| | NB | NS | ZO | PS | PB | |
| NB | PB:NB:PS | PM:NM:NB | PM:NM:NB | PS:NS:NB | ZO:ZO:PS | |
| NM | PB:NB:PS | PM:NM:NB | PS:NS:NM | PS:NS:NM | ZO:ZO:ZO | |
| NS | PM:NB:ZO | PM:NS:NM | PS:NS:NM | ZO:ZO:NS | NS:PS:ZO | |
| ZO | PM:NM:ZO | PS:NS:NS | ZO:ZO:NS | NS:PS:NS | NM:PM:ZO | |
| PS | PS:NM:ZO | ZO:ZO:ZO | NS:PS:ZO | NS:PS:ZO | NM:PB:ZO | |
| PM | PS:ZO:PB | NS:PS:PS | NM:PS:PS | NM:PM:PS | NB:PB:PM | |
| PB | ZO:ZO:PB | NM:PS:PM | NM:PM:PM | NM:PM:PS | NB:PB:PB | |

V. The simulation results

Figure 5 is a step response curve of PID control system. Figure 6 is the step response curve of fuzzy PID control system.

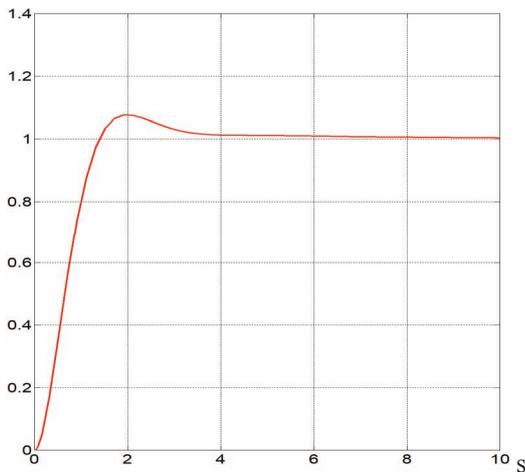


Figure 5 . step response curve of PID control

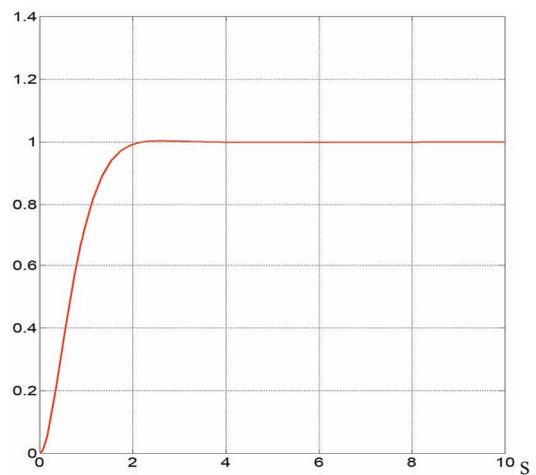


Figure 6 . step response curve of fuzzy PID control

In figure 5, the step response curve of DC motor speed regulating system simulation controlled by PID has large overshoot and long adjustment time. In figure 6, the step response curve of DC motor speed regulating system simulation controlled by fuzzy PID has fast dynamic response and small overshoot.

VI. Conclusions

Through the contrast of two kinds of control method of DC motor speed regulating system in Simulink simulation environment. The superiority of fuzzy PID control method can be proved. The contrast results indicate that fuzzy PID control adopted in DC motor speed regulating of automatic doors can make control system more stable, anti-interference ability stronger, overshoot smaller, response speed faster and robustness stronger. It also ensures that automatic doors work efficiently and safely. If the fuzzy PID control is applied in automatic doors field, personal safety can be guaranteed, moreover, certain economic benefits and social benefits can be obtained.

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