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The Study of Numerical Simulation Based on Fuzzy PID Controller

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***Keywords* — Adaptive Control, Fuzzy Control, PID Control, System dynamic characteristics, Simulation Experiments, Simulink**

***Abstract* — This study aims to explore the application of an adaptive fuzzy PID (proportional integral differential) controller in system control. This controller combines the characteristics of fuzzy control and PID control and dynamically adjusts the parameters of the PID controller through a fuzzy inference mechanism to achieve adaptive adjustment of the system's dynamic characteristics. Firstly, by taking the control object of an industrial process as an example, the transfer function of the controlled object is determined to determine the initial parameters of the PID controller. Subsequently, a fuzzy inference module was introduced to adjust the proportional, integral, and differential coefficients of the PID controller through fuzzy rules based on the current state and error situation of the system. The simulation results show that, compared to traditional PID controllers, the adaptive fuzzy PID controller has achieved significant improvements in dynamic response speed and stability. Especially in the face of complex and rapidly changing control systems.*

I. INTRODUCTION

With the increasing complexity and diversity of modern engineering systems, the PID (proportional integral differential) controller, as a classical control strategy, has been widely used in many application fields due to its simple algorithm, good robustness, and high reliability [1–4]. It is especially suitable for deterministic control systems that can establish accurate mathematical models. However, the actual industrial production process makes it difficult to establish an accurate mathematical model due to its nonlinear and time-varying uncertainty characteristics. Thus, the application of a traditional PID controller often needs to empirically adjust the parameters, and the control performance of the system with frequent dynamic characteristic changes is easily affected.

In order to deal with this problem [5–7], adaptive control strategies have become a research direction of great concern. Fuzzy control is a control method based on fuzzy logic that can effectively deal with fuzzy and uncertain systems. Combining fuzzy control and PID control, an adaptive controller can be constructed, and the parameters of the PID controller can be adjusted in real time through fuzzy reasoning mechanisms to create dynamic system characteristics.

The purpose of this paper is to study the application effect of a fuzzy PID adaptive controller through numerical simulation. First, the initial value setting of the PID controller is determined by modeling and analyzing the target system [8]. Then, the fuzzy reasoning module is introduced to adjust PID parameters in real time through fuzzy rules [9]. By comparing it with the traditional PID controller, the performance of the adaptive fuzzy PID controller in terms of dynamic response speed and stability will be evaluated [10, 11]. The expected research results will provide an effective control strategy for complex systems with frequent changes in dynamic characteristics and provide new ideas and methods for research in the field of adaptive control.

II. ADAPTIVE FUZZY PID CONTROLLERS

Taking a numerical model as the control object, the transfer function of the controlled object is [1,2,5,7-10].

$$G = \frac{20}{0.04s^2 + 6s + 1} \tag{1}$$

2.1 Adopt Traditional PID Control

This study first uses the traditional PID control method to control the controlled object G and then uses Matlab Simulink for simulation. The design block diagram is shown in Figure 1, and then a set of appropriate PID parameters is adjusted by the trial-and-error method, in which the input is the unit step signal, kp=100; Ki=1.6; Kd=0.1, and the simulation curve is shown in Figure 2. It can be seen that the dynamic response curve of the system under this parameter is very good, the rise time is short, the response speed is fast, and the system can quickly reach the steady state without steady-state error, indicating that the PID parameters we set meet the controlled requirements.

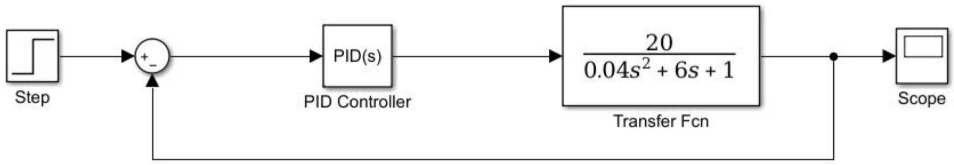

Fig. 1 Traditional PID Control Design Block Diagram of Controlled Object G

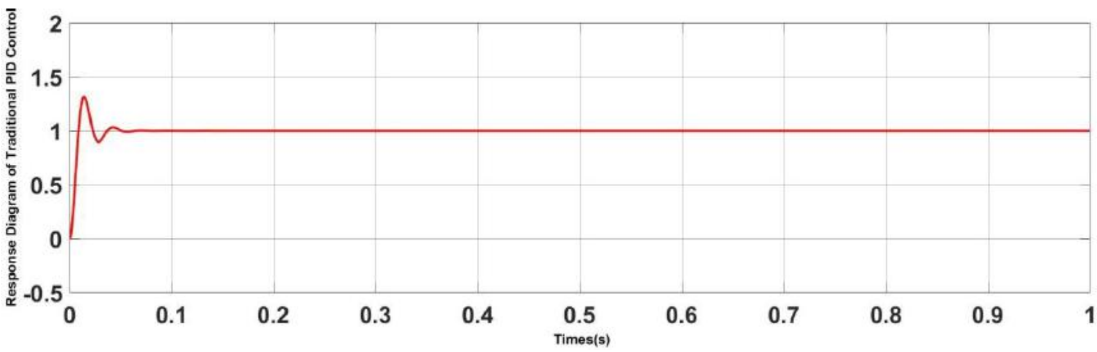

Fig. 2 Traditional PID Control Simulation Curve of Controlled Object G

The traditional PID control works well for the fixed-controlled system, but once the controlled object changes, the original PID parameters cannot meet the dynamic response requirements of the system. At this time, we must readjust the PID parameters, which is unrealistic in the actual control process. Therefore, this paper designs an adaptive fuzzy PID controller; that is, the fuzzy control method is used to adjust the three parameters (Kp、Ki and Kd) of the PID controller online. The simulation flow chart of fuzzy PID adaptive control is shown in Figure 3.

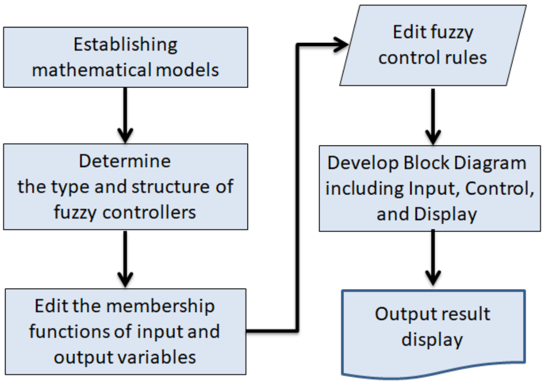

Fig. 3 Simulation Flow Chart of Fuzzy PID Adaptive Control

2.2 Adaptive Fuzzy PID Controller

In this design, a two-input (e，ec) and three-output (ΔKp，ΔKi，ΔKd)fuzzy controller is used. The error e and error change ec are used as the inputs of the fuzzy controller. The PID parameters are self-tuning according to e and ec at different times. The design block diagram is shown in Figure 4.

We define the system error e, error rate of change ec and the variation range of the three outputs(ΔKp，ΔKi，ΔKd) as the universe of discourse on the fuzzy set: (-6, -5, -4, -3, -2, -1,0,1,2,3,4,5,6), whose fuzzy subset is e，ec，ΔKp，ΔKi，ΔKd= NB，NM，NS，Z，PS，PM，PB and set e，ec，ΔKp，ΔKi，ΔKd follows the curve distribution of triangular membership function, from which the membership degree of each fuzzy subset can be obtained.

According to the membership evaluation table of each fuzzy subset and the fuzzy control model of each parameter, the fuzzy matrix table of PID parameters is designed using fuzzy synthetic reasoning, and the PID parameters are modified online. The values of three PID control parameters can be automatically adjusted according to the state of the controlled object. Under e and ec, the self-tuning requirements of the controlled process for parameters Kp, Ki and Kd shall meet the following laws:

(1) When | e | is large, the larger Kp and smaller Kd should be taken to speed up the system response;

(2) When | e | is medium, smaller Kp and appropriate Ki and Kd should be taken to make the system have a smaller overshoot;

(3) When | e | is small, larger Kp and Ki and appropriate Kd should be taken to avoid oscillation near the equilibrium point, so that the system has better steady-state performance.

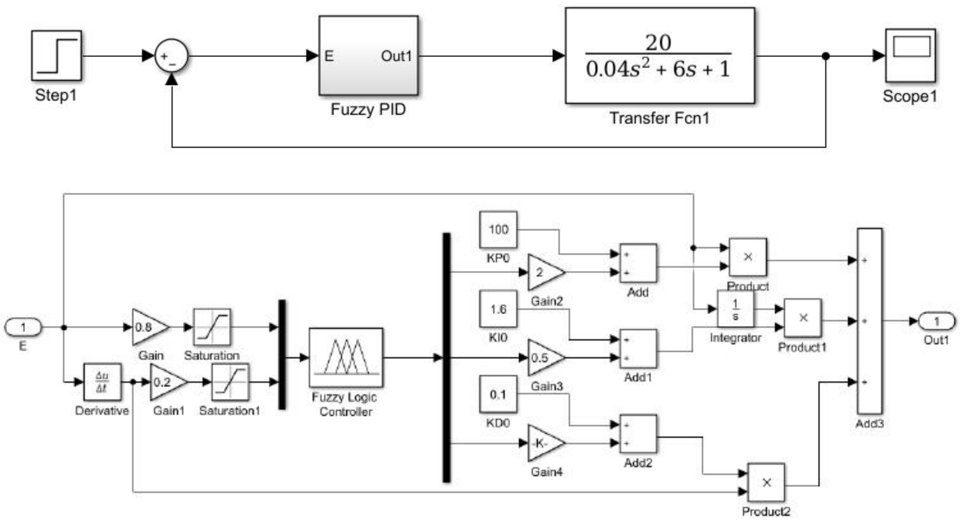

Fig. 4 System Design Block Diagram of Adaptive Fuzzy PID Controller

For this reason, in this design, we have given the fuzzy control table for the three parameters Kp, Ki and Kd, respectively, as shown in Table 1 to Table 3. After the fuzzy rule tables of Kp, Ki and Kd are established, the microcomputer measurement and control system automatically adjusts Kp, Ki and Kd online by processing the results of fuzzy logic rules, looking up tables, and calculating.

(1)Fuzzy Rule Table of Kp

Table 1 Fuzzy Rules of Kp

e \ ec	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PM	PM	PM	Z	Z
NM	PB	PB	PB	PB	PM	Z	Z
NS	PM	PM	PM	PS	Z	PS	PS
Z	PM	PM	PS	Z	NS	NS	NM
PS	PS	PS	Z	PS	NM	NM	NM
PM	PS	Z	NS	NM	NM	PB	NB
PB	Z	Z	NM	NM	NM	NB	NB

(2) Fuzzy Rule Table of Ki

Table 2 Fuzzy Rules of Ki

e \ ec	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NM	NM	NS	Z	Z
NM	NB	NB	NM	NS	NS	Z	Z
NS	NB	NM	NS	NS	Z	PS	PS
Z	NM	NM	NS	Z	PS	PM	PM
PS	NM	NS	Z	NS	PS	PM	PB
PM	Z	Z	PS	NM	NM	PS	PB
PB	Z	Z	PS	PM	PM	PB	PB

(3) Fuzzy Rule Table of Kd

Table 3 Fuzzy Rules of Kd

e \ ec	NB	NM	NS	Z	PS	PM	PB
NB	PS	NS	NB	NB	NB	NM	PS

NM	PS	NS	NB	NM	NM	NS	Z
NS	Z	NS	NM	NS	NS	NS	Z
Z	Z	NS	NS	NS	NS	NS	Z
PS	Z	Z	Z	Z	Z	Z	Z
PM	Z	PS	PS	PS	PS	PS	PB
PB	PB	PM	PM	PM	PS	PS	PB

III. FUZZY CONTROLLER DESIGNS

3.1 Determine the Type and Structure of Fuzzy Controller

Type the command fuzzy in the Matlab command window to enter the fuzzy logic editing window of the FIS editor. The Mamdanis (min-max) decision-making method is generally used for fuzzy decision-making, and the centroid method is generally used for solving fuzzy problems. Select the [Add Input] and [Add Output] options under [Edit] in turn to determine the structure of the fuzzy controller as two inputs and three outputs, and determine the names of input and output variables.

3.2 Edit Membership Functions of Input and Output Variables

Double-click an input or output icon in the editor window to open the membership function editing window; select [Add MFS] under [Edit] to select the number of membership functions as 7 (NB, NM, NS, Z, PS, PM, PB); select the icon of the variable to be edited; determine the range of the current variable quantization level as [-6, 6], and then determine the type of membership function as a triangle. The parameters of the membership function of each fuzzy language value can be adjusted. The adjustment method is: select the membership function in the [Membership Function Editor] window, drag the function with the left key at the specified position, and finally mark the fuzzy language value of the corresponding fuzzy subset for the membership function of each variable, as shown in Figure 4. After all membership functions are marked, close the membership function editing window. The editing process for the membership functions of each input and output variable is the same.

3.3 Editing Fuzzy Control Rules

Double-click the fuzzy control rule icon in the FIS window, or select the [View] drop-down menu [Edit rules] option to open the rule editing window. As long as you select their language variables in the [if, and (or) and then] selection boxes, and then click [Add rules] below the window, the rule will be written into the rule box. Write the fuzzy rule table shown in Figure 5 into the rule box in turn and close the window. At this point, the fuzzy controller is edited, and the file is saved. The file type is *.fis.

Return to the command window of Matlab, enter Simulink, enter the Simulink environment, and then drag the fuzzy logic controller function module to the model in the fuzzy logic toolbox module library of Simulink, double-click the fuzzy logic controller module, and enter the file name of the *.fis file created above in parameters. Finally, return to the command window of Matlab and use the run command to see the model of the designed fuzzy controller.

IV. COMPARISONS OF SIMULATION RESULTS

The obtained system simulation curve is shown in Figure 5. It can be seen from the simulation diagram that when the fuzzy controller is added to the system, because the fuzzy controller can modify the three parameters of PID (Kp、Ki、Kd) online according to the system error e and error change rate ec, the dynamic response curve of the system we obtained is relatively good and the rising speed is fast (it can be seen from Figure 5 that the time for the traditional PID control to reach the peak for the first time is close to 0.2S; while the time for the fuzzy PID control is close to 0.1s), There is basically no overshoot, which shows that the introduction of fuzzy controller in the traditional PID control can really make the system reach the steady state faster.

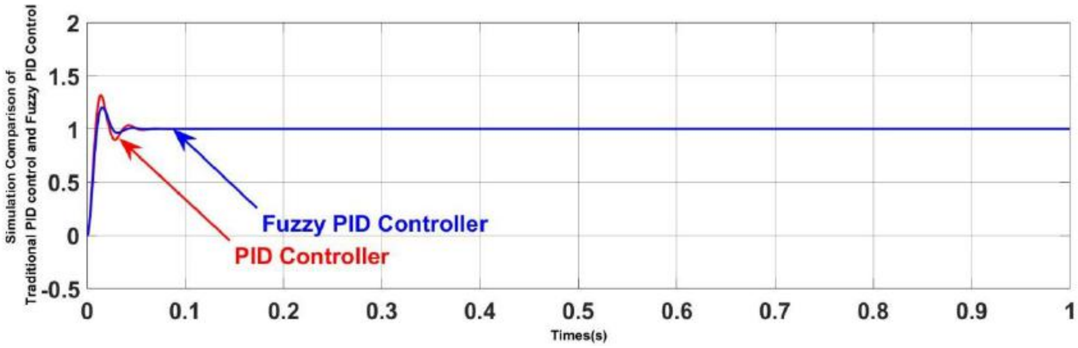

Fig. 5 Simulation Comparison between Traditional PID Control and Fuzzy PID Control of Controlled Object G

V. CONCLUSIONS

Through the numerical simulation experiment in this study, we comprehensively evaluated the control strategy based on a fuzzy PID adaptive controller. Compared with the traditional PID controller, the adaptive controller based on fuzzy PID has made significant improvements in dynamic response speed and stability. Especially in the face of a complex and fast-changing control system, its performance is particularly outstanding. The fuzzy PID adaptive controller can adjust the parameters of the PID controller in real time through the fuzzy reasoning mechanism so that it can adapt to the changing dynamic characteristics of the system. This makes it widely applicable in practical engineering applications. The introduction of the fuzzy reasoning module makes the parameter adjustment of the controller more intelligent and adaptive, reduces the dependence on empirical parameter adjustment, and improves the stability and performance of the control system.

This study provides an effective control strategy for the field of adaptive control and shows excellent performance in engineering practice. However, further experimental verification and engineering applications are needed to verify its applicability in different fields and to explore more optimization schemes to improve its performance.

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