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Study of fuzzy PID control based on vehicle seat detection system

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***Abstract*— The detection of vehicle seat Strength and fatigue is closely related to the quality of the car and the safety of the passengers, which requires high accuracy including short response time, little overshoot, few oscillations and small steady-state error. The conventional PID controller can not satisfy the requirement of high accuracy because of its fixed parameters. In view of the poor performance in setting parameters of conventional PID controller, this paper designed a fuzzy PID controller and established the rules of fuzzy control and membership function. Finally this paper conducted MATLAB simulation and experimental verification, whose results of simulation and experiment show that: The fuzzy PID controller has high control precision, the characteristics of high control speed and strong adaptability. It realizes the on-line adjustment of PID control parameters and makes sure that the controlled object have good dynamic and static characteristics.**

Keywords-fuzzy PID controller; fuzzy rules; MATLAB simulation

I. INTRODUCTION

In the vehicle seat testing process, it is essential to control the value of force loaded on the seat. And this paper adopts the electric servo system to control the force. Due to the disturbances of widespread existence of friction and backlash and the mechanical deformation caused by load asymmetry, the electrical servo system has strong nonlinear, which brings great difficulties for the control system [1].

In actual control system, conventional PID control has the advantages of simplicity, practicability, good robustness and high reliability. But there exists many problems including the fixed parameters system, poor adaptability to the operating conditions, overshoot, and poor performance in nonlinear system. And it is difficult to establish mathematical model in the practical application [2]. Fuzzy control system is a computer intelligent control system based on fuzzy theory, fuzzy language variable and fuzzy logic reasoning. As there is no integral part in fuzzy system, it is difficult to eliminate steady-state error. And there is a little oscillation at the equilibrium point when the classification of variables is not too much. However the conventional PID controller can make up the defect due to an integral part in its system.

In the test of vehicle seat strength and fatigue, the force value loaded on the seat is required for high control accuracy and small overshoot quantity. Therefore this study proposes a idea of fuzzy PID controller based on analysis of PID controller and fuzzy controller.

II. DESIGN OF FUZZY PID CONTROLLER

A. Comparisons between PID controller and fuzzy PID controller

When the structure and parameters of the controlled object can not be fully grasped or the precise mathematical model is not existed, it is the most convenient to use PID control technology. The set of parameters is decided according to the characteristics of process control, which is the most important part of the PID controller. Its structure is shown in Fig. 1.

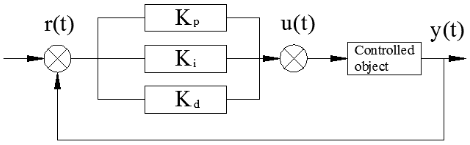

Figure 1. PID controller

u(t) -Output of the controller; Kp, Ki, Kd -Proportional function, Integral function, Differential function

Fuzzy PID controller optimizes the coefficients of the ratio, integral, differential of PID control according to certain rules of fuzzy logic algorithm, in order to achieve a better control effect [3]. The structure of fuzzy PID controller is shown in Fig. 2.

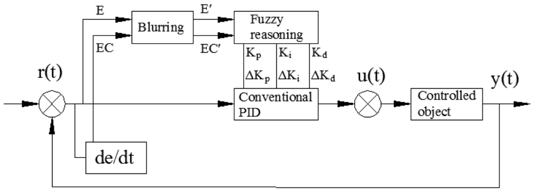

Figure 2. Fuzzy PID controller

r(t) - The set value; EC-Error rate of change; EC′ -Fuzzy quantity of error change rate; E-Error; E′ -Fuzzy quantity of error; Kp- Proportional function; Ki- Integral function; Kd- Differential function; de/dt- Error rate of change; y(t) - Adjusted quantity.

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Kp, Ki and Kd need to be continuously adjusted online in the nonlinear system. So it is necessary to control the 3 parameters fuzzily. Fuzzy PID controller detects E and EC continuously and reasons based on the fuzzy rules. Then fuzzy PID controller adjusts the coefficients of the ratio, integral and differential in real time to meet the requirements of the different E and EC of controller. The fuzzy PID can achieve good dynamic and static characteristics of system by finding out the fuzzy relationship between three parameters of PID and E and EC .

B. Position control of vehicle seat testing electric servo system

1) The constitution of the electric servo system for the vehicle seat detection

The electric servo system is mainly composed of electric cylinder, force sensor, servo driver, motion controller, IPC and so on. Force sensor mainly detects the practical force value loaded on the seat, which is a key component of the force closed-loop control system. Electric cylinder is mainly to provide power for the strength and fatigue test of vehicle seat. Servo driver mainly ensure the accurate position control of electric cylinder. IPC mainly executes the servo control algorithms and outputs the value of servo driver real-time. And they communicate with cable connection between IPC and servo driver to ensure stable tracking and signal receiving. And the system adopts cylinder servo cylinder and driver of Panasonic. IPC control has great advantages in the processing speed and real-time control compared with the traditional single-chip microcomputer control.

2) The mathematical model of the electric servo control system

The system of strength and fatigue testing for vehicle seat adopts fuzzy PID controller, which is a force closed-loop control system of electric servo. The principle of the control system is shown in Fig. 3.

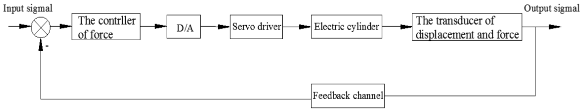

Figure 3. Principle diagram of electric-servo force closed-loop control system

The transfer function of the mathematical model of the system is:

$$G(s) = \frac{25.6}{s(6.6\times10^{-2}s^3+13.2s^2+5.07s+0.161)} \quad (1)$$

3) Design of fuzzy PID controller

a) Principle of rule-making [4]

- When |E| is too large, it means that the absolute value of the error is too large. A large Kp and a small Kd should be set in order to improve the response rapidity of the system and prevent too large instantaneous |EC|. The integration part should be restricted to avoid a large overshoot, so Ki should be taken for 0.
- When |E| is in the middle-size, a small Kp should be taken in order to prevent a large overshoot. In this case, the value of Kd has a great influence on the response of the system and an appropriate Ki should be set.
- When a small |E| emerges, a large Kp and a large Ki should be taken in order to keep the system in good stability. And a right Kd should be set in order to improve the anti-jamming performance of the system and avoid the oscillation of the system in the vicinity of the set value. The value of Kd is decided by the value of |EC|: When the |E| is large, a small Kd should be taken; When the |EC| is small, a large Kd should be taken; When the |EC| is under normal circumstances, Kd should be taken at medium size.

b) Rules table setting

According to the above parameters tuning, the corresponding parameter adjustment rules can be listed with the discriminant principle of "If E is Ai and if EC is Bi, then ΔKp, ΔKi an ΔKd are Ci", which is based on the technical knowledge and the practical experience of engineers [5]. The rules are shown in table 1-3.

TABLE I. FUZZY RULE TABLE OF KP

E ***EC***	NB	NM	NS	ZR	PS	PM	PB
NB	PB	PB	PM	PM	PS	ZR	ZR
NM	PB	PB	PM	PS	ZR	ZR	ZR
NS	PB	PM	PM	PS	ZR	NS	NM
ZR	PM	PM	PS	ZR	NS	NM	NB
PS	PM	PM	PS	PS	ZR	NS	NM
PM	PM	PS	ZR	ZR	NS	NM	NB
PB	PS	ZR	ZR	ZR	NM	NB	NB

TABLE II. FUZZY RULE TABLE OF KI

E ***EC***	NB	NM	NS	ZR	PS	PM	PB
NB	ZR	ZR	ZR	ZR	ZR	ZR	ZR
NM	NB	NB	NM	NS	NS	ZR	ZR
NS	NB	NM	NS	NS	ZR	PS	PS
ZR	NM	NM	PS	ZR	PS	PS	ZM
PS	NM	NS	ZR	PS	PS	PM	PM
PM	ZR	ZR	PS	NM	PM	PM	PB
PB	PS	ZR	ZR	ZR	NM	NB	NB

TABLE III. FUZZY RULE TABLE OF KD

E ***EC***	NB	NM	NS	ZR	PS	PM	PB
NB	PS	PS	NS	NM	NM	NS	NS
NM	PM	PS	NB	NM	NM	NS	ZR
NS	PS	PS	NS	NS	NS	ZR	ZR
ZR	PS	PS	ZR	ZR	ZR	PS	PS
PS	ZR	ZR	ZR	ZR	ZR	ZR	ZR
PM	PM	PS	PS	PS	PM	PM	PB
PB	PB	PM	PS	PM	PM	PS	PB

After the bases of fuzzy rules for three PID parameters are set up, the parameters can be adjusted automatically according to the fuzzy theory. The variation ranges of the system error E and the rate of error change EC are defined as the domain of fuzzy theory. Due to the high sensitivity of the trigonometric function, it is suitable for online adjustment of fuzzy control. Thus trigonometric functions is chosen for the control system, whose domain is {-6, -5, -4, -3, -2, -1, 0, 2, 3, 4, 5, 6}. And each value has the same width of the range. Because the control mode is required for high sensitivity near the equilibrium point, triangle with equal distance is adopted. The assignment tables of E, EC, Kp, Ki and Kd are shown in Table 4.

TABLE IV. DEVIATION E, EC, KP, KI, KD, MEMBERSHIP FUNCTION

	-6	-5	-4	-3	-2	-1	1	2	3	4	5	6
PB	0	0	0	0	0	0	0	0	0	0	0.5	1
PM	0	0	0	0	0	0	0	0	1	0.5	1	0
PS	0	0	0	0	0	0	1	0.5	1	0	0	0
ZR	0	0	0	0	0	1	1	0	0	0	0	0
NS	0	0	0	0	0.5	1	0	0	0	0	0	0
NM	0	0	0.5	1	0.5	0	0	0	0	0	0	0
NB	0.5	1	0.5	0	0	0	0	0	0	0	0	0

III. SIMULATION OF FUZZY PID CONTROL SYSTEM BASED ON MATALAB

In this chapter, a simulation model of fuzzy PID system is established in the Simulink windows, as shown in Fig. 4. The fuzzy inference value that is read by fuzzy PID.fis is used as the input of the engineering parameter. And the fuzzy controller is designed as the component part of the fuzzy system to participate in the simulation process [6-7].

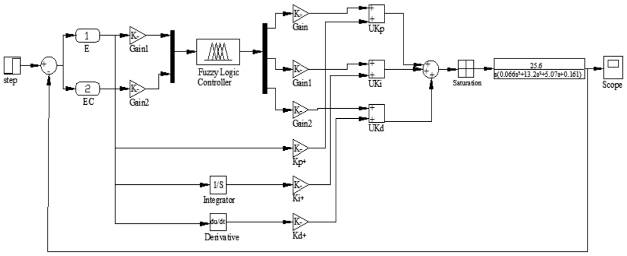

Figure 4. The simulation model of fuzzy PID system

The Unit-step Response Curves of PID control system and fuzzy PID control system are shown in the Fig. 5. We can see from the picture that: the stabilizing time of PID control is 4.7s and there are 0.05 overshoot, a little oscillation before stability and small stabilization error in the system. However the stabilizing time of fuzzy PID control is 3.8s and there is none of overshoot and stabilization error in the system. Plainly, the fuzzy PID controller has better performance than conventional PID controller for responding to unit-step signal.

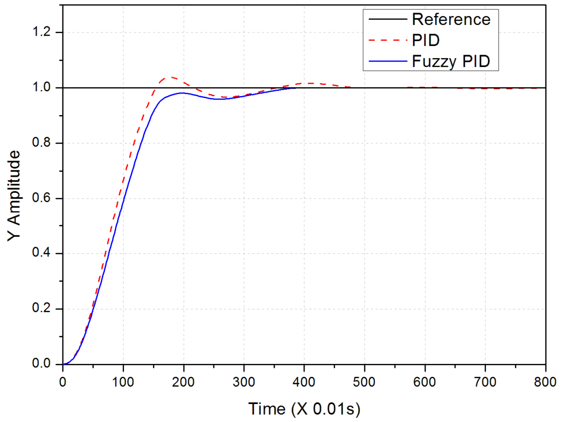

Figure 5. Unit-step Response Curves of PID control and fuzzy PID control system

The square-wave response curves of PID control system and fuzzy PID control system are shown in the Fig. 6. The square wave applied in the simulation has an amplitude of 1 and a period of 4. We can see from the curve: It lags 0.28s in PID system, more than 0.15 s in the the fuzzy PID system. From the 2 simulations, it can be seen that the tracking performance of fuzzy PID is significantly better than that of conventional PID.

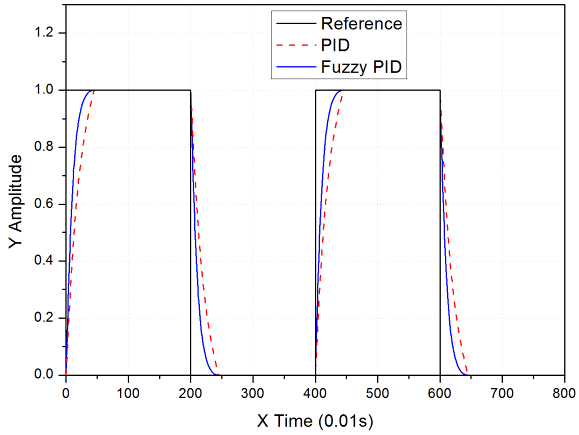

Figure 6. Square-wave response curves of PID control and fuzzy PID control system

IV. THE EXPERIMENTS

This chapter analyzes and compares the actual performance of PID controller and fuzzy PID controller through two groups of tests. Besides, we can verify the rationality and reliability of fuzzy PID controller and the correctness of the results for MATLAB simulations by the results of experiments. The two groups of tests are static load strength test and durability test based on vehicle seat. And we will record the experimental data in real time in order to analyze the stability time, overshoot, oscillation and steady-state error of the control system.

A. Static load strength test

The 450N is loaded on the surface of seat by the PID control and fuzzy PID control, and the 30s data is recorded in figure 7. From the curves of Fig. 7, we can see that: it takes 12s for the fuzzy PID controller to reach at the specified force value and keep steady state, less than the 16s of PID controller. And compared with the 21N of overshoot, a little oscillation and a small amount of steady-state error of the PID system, there are none overshoot, none oscillation and less steady-state error in the fuzzy PID system.

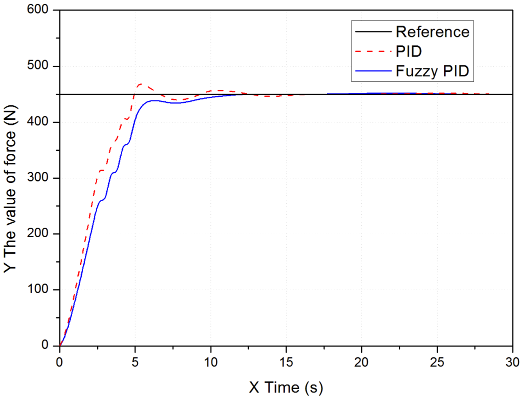

Figure 7. The curves of static load strength test

B. Seat durability test

According to the standard, the ±200N are loaded on the cushion height regulator of the seat for 10000 times, whose frequency is 1HZ. The data recorded is shown in Fig. 8.

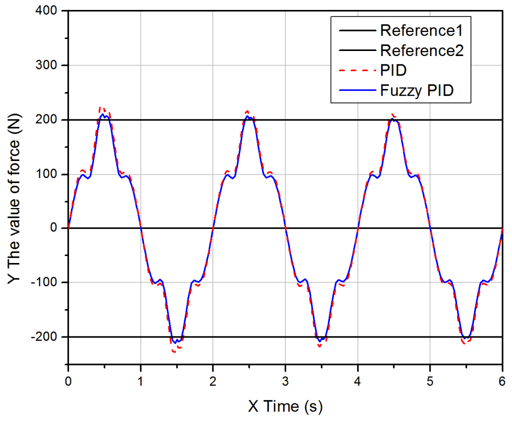

Figure 8. The curves of seat durability test

From the curves of Fig. 8, we can see that: the maximal overshoot is 18N in fuzzy PID control system, more than 10N in conventional PID control system. And compared with PID control system, the fuzzy PID control system has less oscillation and steady-state error.

As shown in the two groups of experiments, the fuzzy PID controller has better performance than conventional PID controller, which is coincident with the conclusion of MATLAB simulation. Thus, it is a good choice to apply fuzzy PID in vehicle seat detection system.

V. CONCLUSION

In this paper, the detection system of vehicle seat is in a real-time changing environment, so the system parameters will change with the change of the environment. But the conventional control strategy of fixed parameters can not meet the requirements. Therefore this paper designed a fuzzy PID controller for the electrical servo system of vehicle seat testing, which combines fuzzy control with conventional PID control. And this paper established the fuzzy control rules and membership function.

In order to verify the performance of the controllers, we did two groups of simulations of fuzzy PID controller and conventional PID controller in MATLAB. This paper emulated the two groups of controllers by unit-step signal and square-wave signal separately. The results of MATLAB simulations show that the fuzzy PID system has a smaller overshoot, less response time and less steady-state errors than the conventional PID system.

Finally, this paper designed two groups of experiments to detect the static load strength and the durability of vehicle seat. As shown in results of the experiments, the fuzzy PID system has a smaller overshoot, less response time, less oscillation and less steady-state error than the conventional PID system, which coincides the results of simulations. And the fuzzy PID system has a better performance than conventional PID control system, which solves the errors caused by the nonlinear of electric servo systems for vehicle seat testing.

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