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Simulation study of automotive electronics mechanical braking system based on self-tuning fuzzy PID control

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Abstract. On the basis of the analysis of vehicle longitudinal dynamic control system, the control problem of longitudinal automatic tracking based on two vehicles is discussed. The second order model of two-car following motion is established and the logic switching rule of acceleration/braking is designed. The three parameters of PID are adjusted by parameter self-tuning fuzzy PID control to control the variation range of the error between the vertical relative distance and vertical relative velocity of the controlled vehicle and the navigating vehicle to achieve the purpose of longitudinal control of the vehicle. The sufficient conditions for the stability of fuzzy PID control system are obtained by using the small gain theorem. The simulation results show that this method can reduce the overshoot of the system compared with the general fuzzy control, and enhance the dynamic anti-jamming ability. It has certain robustness and can solve the contradiction between the fastness and small overshoot.

Key words. Vehicle, kinetic control, longitudinal control, parameter self-tuning, fuzzy PID.

1. Introduction

The vehicle anti-lock braking control system (for short ABS) is a kind of active safety device, which can automatically adjust the wheel braking torque in an electronic control way according to the motion state of the vehicle in the braking process so as to achieve the purpose of preventing wheel locking. Nowadays, active safety of vehicle has become a hot research focus in the automotive field. As an active safety part of vehicle, the vehicle longitudinal dynamic control system consists of upper control system and lower control system [1–3]. The lower control system of vehicle longitudinal dynamics transfers the output of the upper control system to the controlled vehicle system to achieve the desired acceleration / deceleration. Its control model includes the braking system model, the engine model, the drive system model and the vehicle movement model four parts [4].

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The lower control system combined with the upper control system of the vehicle longitudinal dynamics to constitute the vehicle longitudinal dynamics control system. It is a complex nonlinear system, its actual characteristics is difficult to accurately describe with the linear model [5]. The parameter self-tuning fuzzy PID control method is used to control the longitudinal dynamic system of the vehicle. The real-time and effectiveness of the control system are studied in order to realize and improve the control performance of the vehicle longitudinal dynamic system.

2. Literature review

From the initial development point of view, the first application of the electronic mechanical braking is on the aircraft, and then slowly transforms into the vehicle. It is still in the applied research and improvement stage of the automotive field. Applied research in the car was first proposed by the Bosch Company in the 20th century 90 years. Bosch introduced a research project of "Brake 2000". The goal of the project is to study a braking system with faster response and significant braking effect. The electronic sensor braking system is the world's first set of fully-controlled braking system in the birth of this request. The system was first loaded in the high-end Mercedes-Benz SL500. At present, Bosch, Siemens and other companies have made some research results, but only in the experimental stage, and there is no mass production. In 2004, Australia's PBR International Limited announced that developed the first wired vehicle. Haldex Company in Sweden vigorously promoted the wire-controlled braking technology, but also launched its own electronic mechanical braking system. The significant results of the research and application of the fuzzy theory are focus on the United States, Japan and Europe and other countries and regions [6]. On the basis of the fuzzy ABS controller, Georg E. Mauer et al. introduced a slip rate predictor, which can be used to infer the discreet value of the slip rate due to the system lagging based on the measured current slip rate and braking torque. And the corresponding control rules are selected to identify the current pavement behavior by real-time judgment of the relationship between the slip rate and the braking torque. The simulation results on the single-wheel model show good control effect and can adapt to different changes of road surface, and it is not sensitive to external disturbance, and improves the robustness [5–7]. C. Jun combines various model-based control methods such as PID controller, sliding-mode controller and fuzzy controller, and it proves that the combination of controllers and improves the adaptability of different pavement by comparing with PID controller, and achieved better control effect. Mark Akey designed the ABS fuzzy controller, which uses three fuzzy control sets and seven logic variables. Its working principle is that the first two control sets are based on the measured wheel acceleration, the extremum of the angular acceleration, the vehicle speed, the status value of the solenoid valve and the current value to determine the current anti-lock phase and solenoid valve state. The third control set is based on this, and then according to the cycle and the brake pressure to determine the amount of regulation of the final pressure. The simulation results achieve the desired purpose, but the controlled quantity to be measured is too much control, the control is complex and the cost is much.

The research on the application of fuzzy theory in our country is relatively late, but it develops rapidly. In recent years, many domestic universities and automotive research institutions have done a lot of theoretical and experimental research in the fuzzy control technology, and laid a foundation for the development of fuzzy control [7]. On the basis of the simplified automobile model, Guokonghui, a famous scholar, designed ABS fuzzy controller and adaptive fuzzy controller to make the vehicle achieve better control under the variable operating conditions, and overcome the shortcomings of control singleness. Li Jun, Yu Fan, Zhang Jian-wu, et al. Put forward the control strategy of road surface recognition during vehicle steering braking. This method can calculate the optimal target slip rate in real-time according to the road surface attachment condition and vehicle motion state, and the vehicle's braking and lateral stability has been greatly improved by adopting the corresponding control strategy. Chen Jiong, Wang Hui-yi, Song Jian designed a fuzzy controller based on slip rate and deceleration, and simulated on a degree of freedom vehicle model, which proved that the controller was more adaptive than the logic threshold method.

From the research status quo at home and abroad, although the fuzzy control exhibits a great development, there are still some shortcomings of fuzzy control, and the establishment and analysis of fuzzy control system is still in the initial stage, the stability theory is not mature. Secondly, the modeling of fuzzy systems, the establishment of fuzzy rules, and the fuzzy reasoning methods have not been well resolved. Therefore, it needs further study and discussion in theory or in the application [8].

3. Research contents and methods

3.1. The longitudinal relative distance model of vehicles

The control quality of longitudinal relative distance between vehicles is an important index to evaluate the active safety of the vehicle. The control parameter is the longitudinal relative distance between vehicles [9]. Considering the dynamic response characteristics of the control system, in order to improve the precision of the model, the change rate of the longitudinal relative distance between vehicles is taken as the other parameter of the control system, and the second order model of two-car following motion is established. The role of the switch logic control system of engine throttle/brake master cylinder is to determine the switch of the engine throttle / brake master cylinder, and transfer the desired acceleration/subtraction value to the lower control system of the vehicle longitudinal dynamics. The one-dimensional model of relative longitudinal error of vehicles is

$$\delta'_{\mathrm{d}} = (x_{\mathrm{h}} - x) - L - H\,, \tag{1}$$

where H is the desired value of the longitudinal relative distance between vehicles. Symbol L denotes the length of the vehicle, x_{h} and x, respectively represents the vertical coordinate of the tail bumper of the navigation vehicle and controlled vehicle, and δ'_d is the longitudinal relative distance error between vehicles. The one-dimensional control model is simple in structure and easy to control, but under the actual longitudinal driving conditions, the longitudinal relative distance error between vehicles is related to the longitudinal displacement rate of the controlled vehicle. Considering the influence of the controlled vehicle speed on the accuracy of the model, Swaroop et al. proposed a two-dimensional model of the relative distance between vehicles

$$\delta_{\mathrm{d}} = (x_{\mathrm{h}} - x) - L - H - \lambda v\,, \tag{2}$$

where δ_{d} is the relative longitudinal distance error between vehicles, λ is the compensation time of the controlled vehicle converging to δ'_{d}. and v is the speed of controlled vehicle.

3.2. Relative longitudinal velocity model between vehicles

The relative error of longitudinal relative velocity between vehicles is

$$\delta_v = v_{\mathrm{h}} - v\,, \tag{3}$$

where δ_v is the relative longitudinal velocity error between vehicles and v_{h} is the speed of the navigation vehicle.

3.3. Second order model of two-car following motion

The longitudinal relative distance two-dimension control and the relative velocity control model are adopted to establish the second order longitudinal relative distance control model between vehicles.

$$\delta_{\mathrm{d}} = (x_{\mathrm{h}} - x) - L - H - \lambda v\,,$$

$$\delta_v = v_{\mathrm{h}} - v \tag{4}$$

and the state space equation of the model is given as:

$$X = AX + Bu + \varGamma w = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix} X + \begin{bmatrix} -\lambda \\ -1 \end{bmatrix} u + \begin{bmatrix} 0 \\ 1 \end{bmatrix} w\,, \tag{5}$$

where X is the state vector of the control system, $X^{\mathrm{T}} = [x_1, x_2] = \delta d, \delta v$, u is the control variable of control system (controlled vehicle acceleration/deceleration a), w is the disturbance variable of the control system (navigation vehicle acceleration/deceleration ah). The second-order model contains the longitudinal displacement, velocity and acceleration/deceleration information of the navigation vehicle and the controlled vehicle, which can reflect the real-time and dynamic characteristics of the longitudinal automatic tracking control system of the vehicle team [10]. The control system is a two-input single-output control system, the input variable is the longitudinal relative distance error between vehicles and the relative speed error, and the output variable is the expected controlled vehicle acceleration/deceleration.

4. Results and simulated analysis

4.1. Parameter self-tuning fuzzy PID controller

Parameter self-tuning fuzzy PID control is a kind of fuzzy compound control. In order to meet the requirement of the self-tuning of PID parameters at different error e and error change rate ec, PID parameters are modified online by using fuzzy control rules. The basic idea of parameter self-tuning fuzzy PID control is that the fuzzy relationship between three PID parameters and error e and error change rate ec is found out firstly, the e and ec are tested constantly in the running, and then three parameters are modified online based on fuzzy control theory to meet the different requirements of different e and ec on the control parameters, and to achieve the purposes of desired control.

The self-tuning requirements for the parameters K_{P}, K_{I} and K_{D} at different e and ec can be summarized as the following rules:

1) When $|e|$ is large, larger K_{P} and smaller K_{D} should be taken (to make the system response faster) and $K_{\mathrm{I}} = 0$ (the integral effect is removed to avoid a large overshoot).

2) When $|e|$ is medium, a smaller K_{P} (to make the system response has a smaller overshoot), appropriate K_{P} and K_{D} (especially the value of K_{D} has a greater impact on the response of the system) should be taken. When $|e|$ is small, larger K_{P} and K_{I} should be taken (to make the system have better steady-state performance) and K_{D} should be appropriate to avoid oscillation near the equilibrium point. The absolute values of error $|e|$ fuzzy and the error rate of change $|e|$ fuzzy are taken as the input language variables. For fuzzy input quantities, the combination of $|e|$ and $|ec|$ states can be set based on the design of the above rules, and the corresponding memberships can be calculated.

4.2. Selection and simulation of controller parameters

The fuzzification quantization factor of the input variables e and ec and the defuzzification scale factor of the output variables P, I and D (denoted by R) are selected: $Ke = 7.2$, $Kec = 8$,$RP = 0.6$, $RI = 1.3$, $RD = 1.0$. In different states, the setting value is obtained by the conventional PID parameter tuning method

$$K'_{\mathrm{P1}} = 1,\ K'_{\mathrm{I1}} = 0,\ K'_{\mathrm{D1}} = 0.00\,,$$

$$K'_{\mathrm{P2}} = 2,\ K'_{\mathrm{I2}} = 0,\ K'_{\mathrm{D2}} = 1.25\,,$$

$$K'_{\mathrm{P3}} = 3,\ K'_{\mathrm{I3}} = 0,\ K'_{\mathrm{D3}} = 2.50\,,$$

$$K'_{\mathrm{P4}} = 4,\ K'_{\mathrm{I4}} = 0,\ K'_{\mathrm{D4}} = 3.75\,,$$

$$K'_{\mathrm{P5}} = 5,\ K'_{\mathrm{I5}} = 2,\ K'_{\mathrm{D4}} = 5.00\,,$$

The MATLAB/Simulink platform is used for simulation control research, and the control block diagram is shown in Fig. 1 .

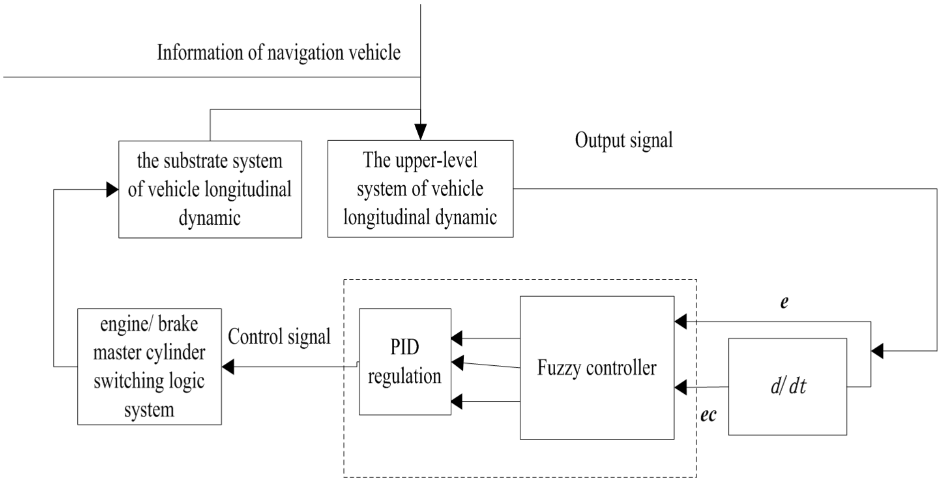

Fig. 1. The longitudinal dynamic fuzzy PID control system of automobile

Figures 2–5 are the simulation results of parameters self-tuning fuzzy PID control system of vehicle longitudinal dynamic.

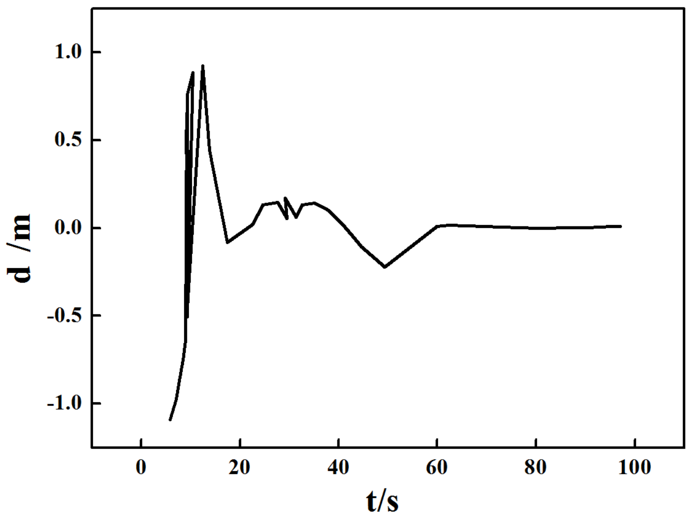

Fig. 2. Longitudinal relative distance errors of vehicles

Figures 2 and 3 show that when the navigation vehicle is in the variable acceleration/deceleration mode, the controlled vehicle is controlled by the parameters of self-tuning fuzzy PID, the change range of the longitudinal relative distance error between the navigation vehicle and the controlled vehicle is –1–1 m, which is

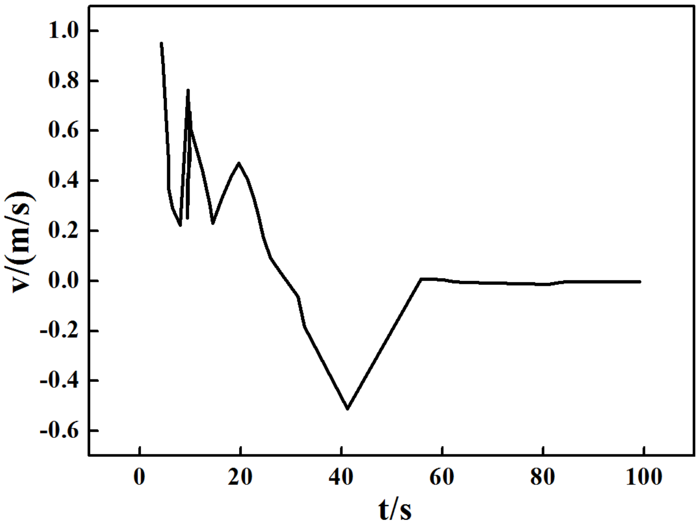

Fig. 3. Longitudinal relative velocity errors of vehicles

smaller than the distance error 1.4 m achieved by using single fuzzy control. While the change range of the longitudinal relative velocity error is only –0.6–1 m/s, which is smaller than velocity error 1 m/s achieved by using single fuzzy control, and the change is gentle and finally converges to zero, thus realizing that the controlled vehicle can automatically track the navigation vehicle, and the robustness is better than that using the fuzzy control.

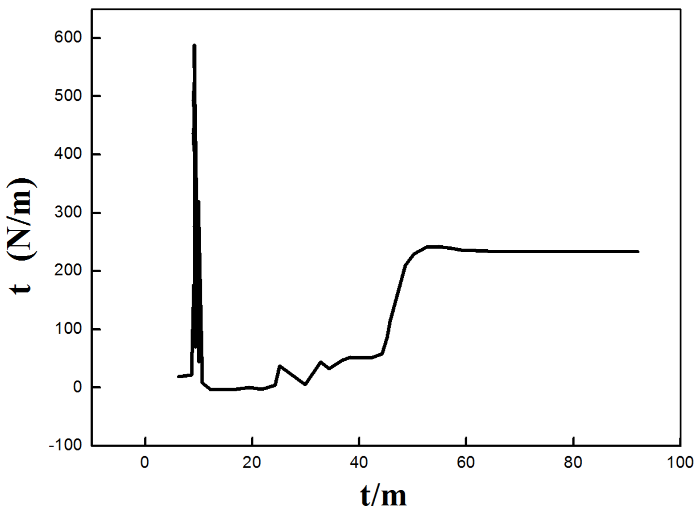

Fig. 4. Retarding torque

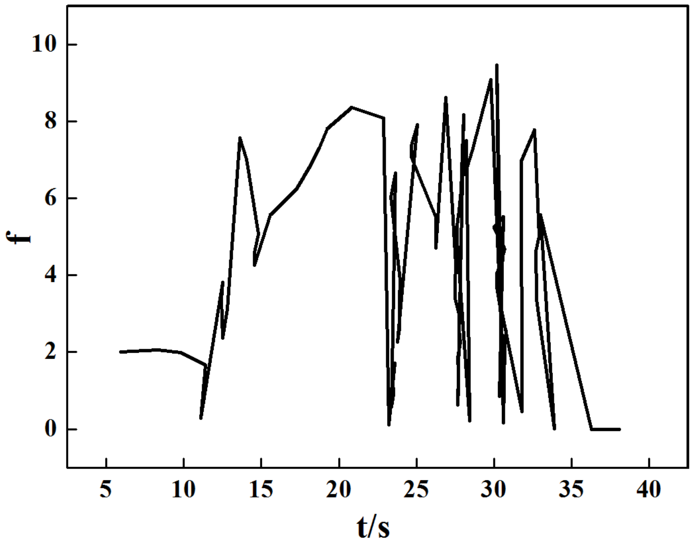

Fig. 5. Throttle percentage angle

Figures 4 and 5 are the braking torque t of the controlled vehicle and the throttle percentage angle f response. When the angle of the controlled vehicle throttle percentage is greater than zero, the car accelerates, and the brake torque associated with the brake is zero. Otherwise, when the angle of throttle percentage is less than zero, the car decelerates, and the brake torque is greater than zero. It can be seen that the simulation curve with parameter self-tuning fuzzy PID control accord with this logic, and it can transit smoothly during most of the time, but at the same time, the frequent switching of the dynamic torque and throttle percentage angle happen because of the frequent alternation between accelerator acceleration and brake deceleration between 20 s and 35 s.

5. Conclusion

Through the above analysis, we can see that the longitudinal dynamic system of the automobile and the parameter self-tuning fuzzy PID control can achieve the automatic control of the safe distance of the two vehicles. Because it uses the fuzzy control to express the advantages of irregular events and learns the tuning function of PID control, so compared with the single fuzzy control, it can reduce the overshoot volume, and also enhance the dynamic anti-jamming ability and improve the robustness, which solves the contradiction between the fastness and the small overshoot. However, this method has a problem that the switching of the braking torque and the throttle percentage angle is frequent due to the frequent alternation of the acceleration of the accelerator and the deceleration of the brake, which needs further improvement.

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