Vehicle ACC Control Based on Fuzzy PID

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Abstract: ACC (Adaptive Cruise Control) is a crucial technology to control the automatic driving of a vehicle, which can automatically adjust the driving status of the vehicle according to the driving status of the vehicle in front so that the vehicle always keeps a safe distance from the vehicle in front, which can primarily relieve the driver's driving pressure and avoid tailgating. The research is of great significance to the realization of intelligent driving of vehicles. In this paper, the fuzzy PID control method is used to study the vehicle ACC system. Firstly, the basic concept and key components of the ACC system are explained, the vehicle longitudinal dynamics model is established, and the primary ranges of kp, ki and kd parameters are determined through simulation; based on this, the fuzzy PID control algorithm of vehicle ACC is designed considering three different driving conditions of fixed speed and following cruise mode. The fuzzy PID control algorithm of the vehicle ACC system is designed and established. The joint simulation model of MATLAB is used to simulate the vehicle ACC system under three different driving conditions. The simulation results show that the vehicle ACC system designed in this paper ensures the safety and stability of following the vehicle while providing the vehicle's ride's comfort.

Keywords: Intelligent Assisted Driving, Adaptive Cruise Control, Fuzzy PID Control Algorithm, Joint Simulation, Fixed Speed and Follow Cruise

Introduction

The rapid increase in cars has brought significant challenges to the smooth flow of traffic and driving safety (Li & Jia, 2017). Modern science and technology development has led to a higher and higher degree of automation (Sheng & Gao, 2019). Advanced driver assistance systems that sense with advanced sensors and control the vehicle to perform a series of corresponding

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operations according to the vehicle's driving environment are gradually becoming the standard configuration of vehicles (Qin et al., 2021). Vehicle adaptive cruise (ACC, Adaptive Cruise Control) It is against this background that the Cruise Control system came into being. During the driving process of the vehicle, the ACC system senses the distance of the obstacle ahead relative to the vehicle according to the distance sensor installed at the front of the vehicle, and the speed sensor collects the vehicle speed signal simultaneously (Chen et al., 2017; Lihan et al., 2020). When the distance between the host vehicle and the vehicle ahead is less than or greater than the safe distance, the ACC system controls the driving speed by coordinating with the braking system and the engine control unit so that the vehicle and the vehicle ahead always maintain a safe distance, and realize working modes such as cruise control, avoid rear-end collisions, and improve road traffic efficiency. As shown in Figure 1, the automotive ACC system is divided into four parts: an information perception unit, electronic control unit, an execution unit and a human-computer interaction interface (Liu, 2020).

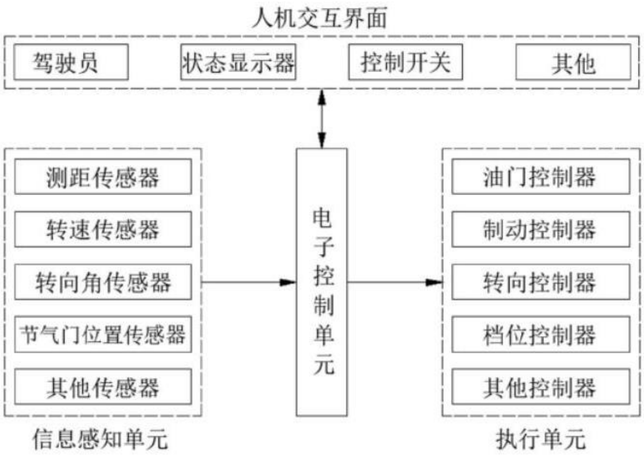

Figure 1 Consists of the ACC System

When the driving vehicle starts the ACC system, the ranging sensor installed in the front of the vehicle will continuously scan the road conditions ahead, and the speed sensor will also obtain the speed signal of the vehicle at this time. It will automatically enter the adaptive cruise mode. Suppose the distance between the vehicle ahead and the vehicle is greater or less than the set safe distance. In that case, the ACC system will calculate a relatively safe distance according to the vehicle speed and output acceleration control signals to the lower layer for execution. The device can adjust the vehicle's speed to ensure that the vehicle and the vehicle ahead always maintain a safe driving distance. When no vehicle or other obstacle is on, the ACC system will switch to cruise control mode. The system will automatically control the accelerator pedal according to a speed set by the driver in advance, and the vehicle speed collected by the vehicle speed sensor to adjust the vehicle speed so that the vehicle always keeps running at the set speed stably. The figure below shows the working principle of the ACC system.

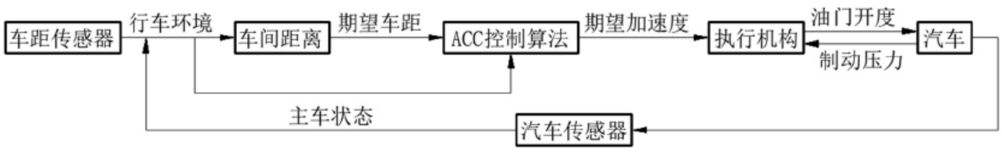

Figure 2 The Working Principle of ACC System of Car

Development Status of Adaptive Cruise Technology

Currently, the research on ACC uses various control methods, such as PID control, model predictive control, linear quadratic optimal control, fuzzy control, neural network control and fuzzy PID control (Mohtavipour et al., 2017). The current research progress introduces the architecture and working principle of the ACC system, summarizes the research status of ACC, and points out the future development trend. Literature designed different control algorithms for the ACC system, using predictive model control to optimize multi-objective control, using adaptive cruise control algorithm to achieve multi-objective control, comprehensively considering the driver's expected output, vehicle following Factors such as safety and the physical limitations of the vehicle itself achieve the best matching of the ACC controller's working modes and a smooth transition between different ways. Considering the vehicle driving situation on the road with a low adhesion coefficient, the road adhesion coefficient is estimated by the least square method to determine the limit constraint conditions when the model predictive control is solved. The nonlinear model predictive control algorithm considering the fuel consumption rate of the engine and the efficiency of the motor is comprehensively considered, and the nonlinear longitudinal dynamics model of the hybrid electric vehicle is established. Reference designed a vehicle ACC platform based on fuzzy control and compared it with the PID control scheme; the simulation results show that the fuzzy control effect is better. In addition, there are strategies such as hierarchical control, parameterization of key characteristics, and fuzzy control algorithms for adaptive cost functions. The above solutions generally have good feedback under specific operating conditions. Still, when faced with complex road conditions in real situations, the road conditions faced by the vehicle are summarized into seven categories, and the fuzzy PID control method is used to study the problem. First, the PID method is robust and suitable for various control fields (Chamraz & Balogh, 2018). Second, the fuzzy control summarizes the driver's rich driving experience and can adjust the PID control parameters (Anand & Ohol, 2022; Aniculaesei et al., 2018).

ACC System Working Mode

The road conditions the car is driving are usually complex and diverse. To cope with different driving conditions, the ACC system is generally divided into two working modes: cruise control and the following cruise mentioned above. It can be divided into acceleration control, deceleration control, start control and stop control.

(1) Cruise control When there are no vehicles or other obstacles in front of the vehicle, the vehicle will drive at a constant speed at a speed pre-set by the driver.

(2) The following control mode is divided into four cases: acceleration control, deceleration control, start control and stop control.

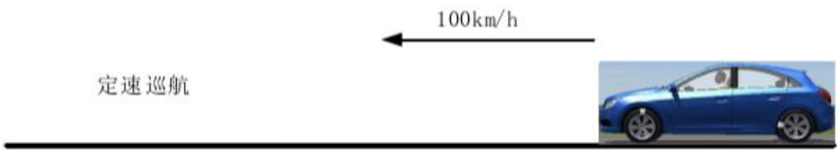

Figure 3 Fixed Speed Cruise Diagram

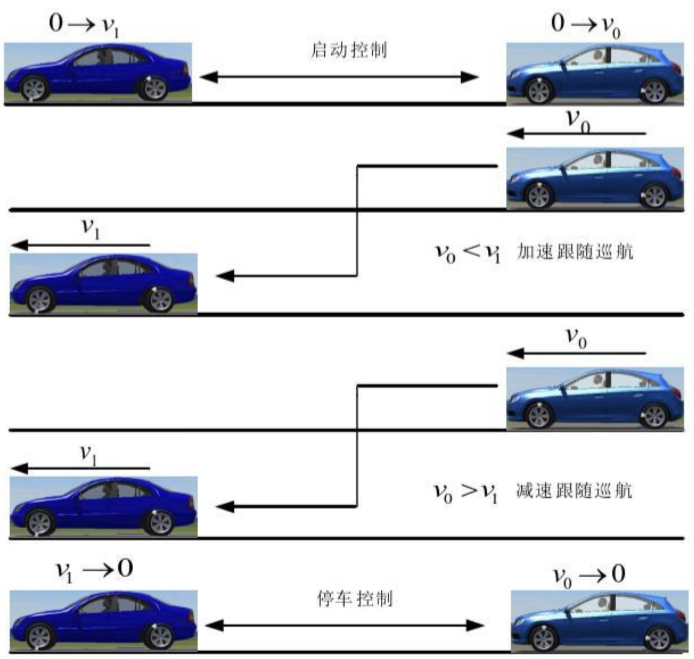

Figure 4 Follow Cruise Schematic

Vehicle Modelling Based on Cars

Based on the above-mentioned adaptive cruise, there are mainly two working modes: constant speed and the following cruise. Cruise control is to control the speed of the longitudinal movement of the vehicle to reach a pre-set cruising speed. In contrast, the next cruise means that the vehicle needs to control the vehicle's direction according to the vehicle's motion state in front and maintain a stable and safe distance between the vehicle and the vehicle in front. To avoid rear-end collisions, cruise control and follow cruise control the longitudinal movement of the vehicle. The mechanisms that control the longitudinal motion of the vehicle are the vehicle's power system and braking system. Vehicle power system mainly includes an engine, torque converter and automatic transmission. Vehicle braking system control precisely controls the pressure of the brake cylinder to generate braking force and act on the wheels for braking. The adaptive cruise control system designed in this paper adopts layered control. The upper layer controller calculates the desired acceleration required by the vehicle according to the motion state of the vehicle, and the lower layer control converts the expected acceleration into the throttle valve that the actuator of the model vehicle should apply.

This paper uses Carsim software to establish longitudinal vehicle dynamics. The vehicle inverse dynamics model needs to control the driving and braking actuators of the vehicle according to the expected acceleration calculated by the upper controller. It is a calculation module.

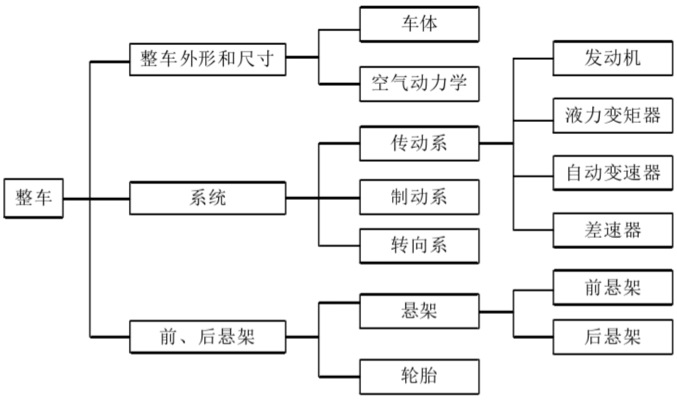

Figure 5 Vehicle Dynamics Model Structure

The simulation experiment in this paper uses the C-Class Hatchback2017 model of Carsim software, and the relevant parameters are shown in the following table.

Table 1 Vehicle-Related Parameters

Vehicle Parameters	**Symbol**	**Numerical Value**	**Unit**
Vehicle Quality	M	1412	Kg
Centre of Gravity to Front Axle	L_1	1015	Mm
Centre of Gravity to Rear Axle	L_2	1895	Mm
Main Reduction Ratio	R_m	4.1	-
Air Density	ρ	1.206	-
Adhesion Coefficient	ϕ	0.85	-

Concrete Model

Engine Model

The selected engine model parameters refer to Audi A6L 2.0T automobile engine; select the 125KW engine in the software, and the parameter settings are shown in the following figure:

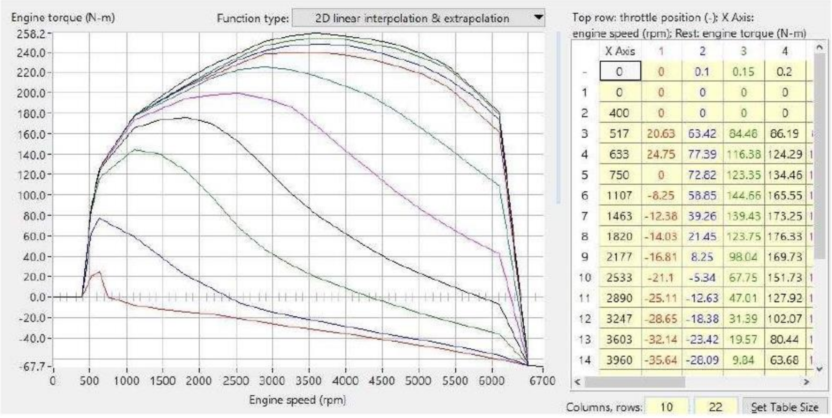

Figure 6 Engine Parameter Setting

Torque Converter Model

The torque converter parameter settings are shown in Figure 7.

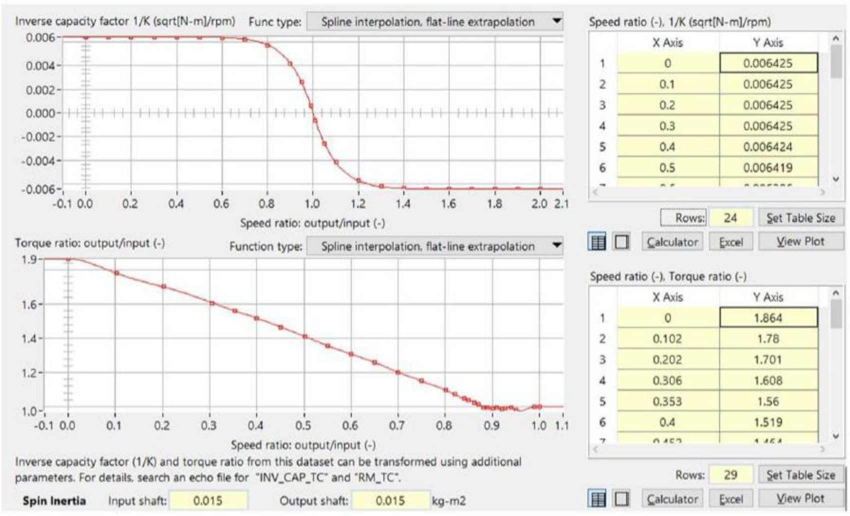

Figure 7 Torque Converter Parameter Petting

Automatic Transmission Model

The model vehicle automatic transmission used in this paper is a 6-speed transmission, of which the direct gear is 4. Figure 8 shows the automatic transmission parameters.

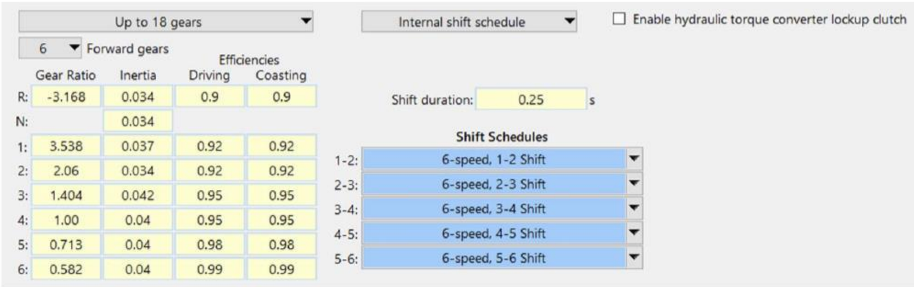

Figure 8 Automatic Transmission Parameter Setting

Finally, according to the existing data, MATLAB software establishes the vehicle inverse, longitudinal dynamics model. The inverse longitudinal dynamics model shows the relationship between expected acceleration, throttle opening, and braking pressure.

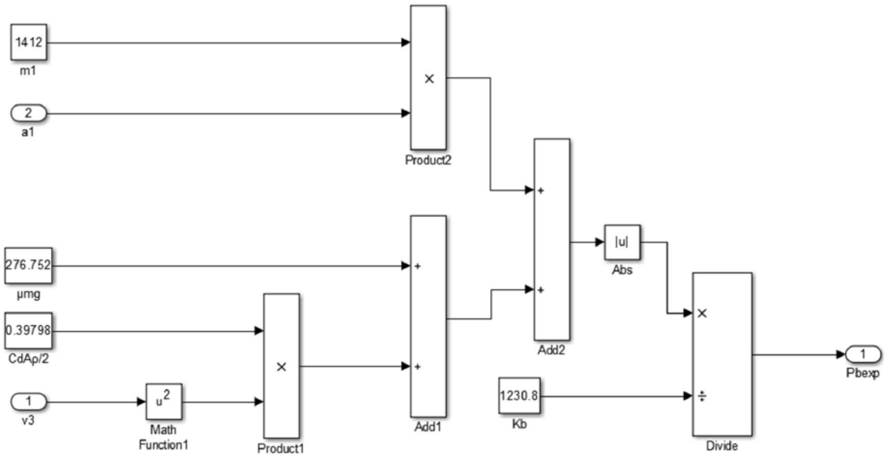

Figure 9 Expected Brake Pressure Calculation Model

Research Method

The drive-brake switching algorithm is designed, and the simulation model of the drive-brake control switching and safety clearance strategy is built (Li et al., 2022). The fuzzy PID control method is used to design the vehicle adaptive cruise control algorithm based on the vehicle longitudinal dynamics model (Ambroziak & Chojecki, 2023). Two cruise control algorithms are designed for different working conditions: cruise control algorithm at fixed speed and cruise control algorithm following and two algorithms are built—simulation model (Sheng et al., 2019; Suwoyo et al., 2021).

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Theoretical Basis of Fuzzy PID Algorithm

PID is a control law obtained by proportional, integral and derivative deviation, namely, Equation 1:

$$u(t) = k_p\left(\left(e(t) + \frac{1}{T_i}\int_0^t e(t)dt + T_d\frac{de(t)}{dt}\right)\right) \quad (1)$$

In the formula, $kpe(t)$ is the proportional control term, kp is called the proportional coefficient; is the integral control term, Ti is the integral time constant; is the Derivative control term, Td is the derivative time constant (Shi, 2020). The PID control block diagram is shown in Figure 10.

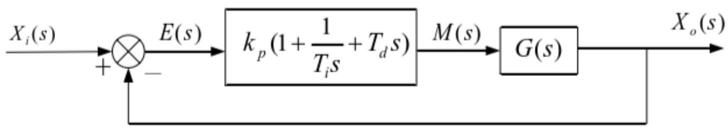

Figure 10 PID Control Block Diagram

The PID controller is mainly used in the series correction link. The function of the PID controller is as follows:

(1) The proportional link can speed up the system's response speed, and increasing kp can reduce the steady-state error of the system. Still, an excessively large kp will worsen the system's dynamic quality, cause system oscillation, and deteriorate the dynamic performance and stability of the system.

(2) The function of the integral coefficient k; reduces the system's steady-state error. The larger k; precision. The proportional control term plus the integral control term can eliminate the system's steady-state error, but the system's dynamic process will slow down. If the integral control is too strong, the overshoot of the system will increase, making the system unstable.

(3) The function of the differential coefficient ka is to predict the deviation change in advance, suppress the overshoot caused by kp and ki in advance, speed up the response speed of the system, reduce the overshoot and oscillation, and help to improve the dynamic performance of the system. But too large ka will make the system control process break in advance, thus prolonging the time of system adjustment. Fuzzy PID control is a control method that combines fuzzy control and PID control. In PID control, because the three PID parameters selected by different designers are different, and the three parameters are obtained mainly by field heuristics, PID control is often not optimal, but a "sub-optimal" controller that meets

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specific index requirements, and the fixation of three parameters also limits the all-around performance of PID control. To make up for this deficiency, it has been found that better control effects can be obtained by designing the three PID parameters to be variable and able to change following the response adaptively. The basic principle of fuzzy PID control is to use the theory and method of fuzzy mathematics to formulate fuzzy control rules and store these rules, control effect evaluation indicators, and PID control initial parameters in the computer knowledge base, adjust the parameters of PID control to achieve the best control effect (Suwoyo et al., 2018). Therefore, this paper adopts the fuzzy PID control method to study the problem of vehicle adaptive cruise, the principle of fuzzy PID control is shown in Figure 11.

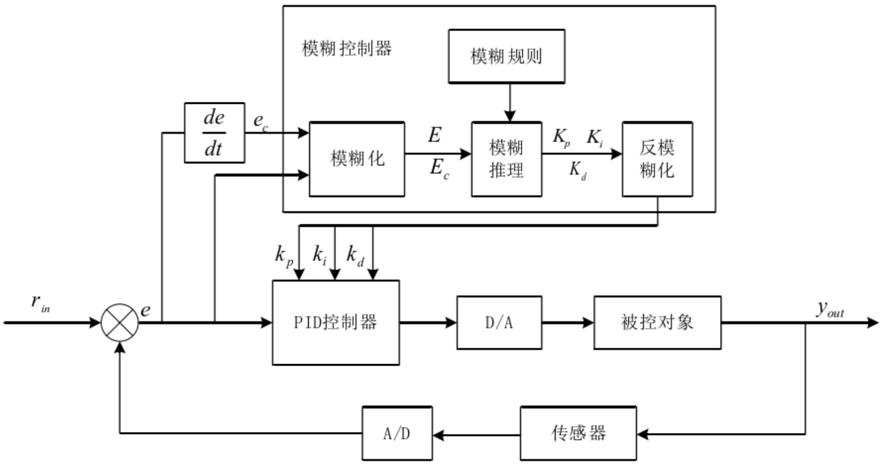

Figure 11 Fuzzy PID Control Structure Diagram

Algorithm Design of Cruise Control

The primary purpose of cruise control is to control the vehicle to maintain its speed. The set speed does not change. In the fuzzy PID control algorithm, the input of the fuzzy controller is the difference between the target speed and the actual speed and the rate of change of the speed difference, the output is the three parameters $kp1$, $ki1$, and $ka1$ of the PID controller, and the input of the PID controller is the target speed and the actual speed. The difference in speed, the output is the desired acceleration of the vehicle (Rout et al., 2016; Suwoyo et al., 2020).

Formulation of Fuzzy Rules for Cruise Control

Cruise control is divided into two situations: acceleration to cruise speed and deceleration to cruise speed. The input of the fuzzy control in the cruise control fuzzy PID controller is the deviation E1 between the cruise speed and the actual speed and the change rate E of the deviation; the output is the three parameters $Kp1$, $Ki1$, $Ka1$ of PID control. The strength of proportional, integral and differential effects in each control stage is determined according to different deviations and deviation change rates. In formulating fuzzy rules, the dynamic error

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and the overshoot must be considered comprehensively (Adriansyah et al., 2019). Among them, the overshoot affects the vehicle's comfort, which means that the acceleration applied by the vehicle cannot be too significant (Wu et al., 2019).

When the absolute value of the speed deviation E1 is significant, it is necessary to quickly reduce the deviation to make the vehicle reach cruising speed as soon as possible. At this time, the adjustment range should be increased to increase the vehicle speed, and the values of $Kp1$ and Ki1 should be increased. The adjustment will affect the driving stability and ride comfort of the vehicle. The increase of the parameters $Kp1$ and $Ki1$ should be determined according to the deviation change rate Ec. Value.

When the absolute value of the speed deviation E1 is generally significant, to reduce the steady-state error of the control system to reach the set cruise speed as soon as possible, in the case that the output does not oscillate, increase $Kp1$, according to the deviation change rate E. To suppress the control strength of $Kp1$ and reduce the overshoot of the system at the same time, to ensure the comfort of riding, Ka1 should be appropriately increased.

If the absolute value of the speed deviation E1 is small, the actual speed of the vehicle is not much different from the cruising speed. At this time, it is necessary to continue to reduce the steady-state error while avoiding a significant overshoot that affects ride comfort and vehicle stability. To improve the sex, the size of $Kp1$ and K;1 should be kept moderate, and Ka1 should be appropriately increased. When the absolute value of the speed deviation E1 and the deviation change rate Ec tend to 0, the vehicle should drive at a constant speed. For a certain steady-state error, $Kp1$, $Ki1$ should be appropriately reduced, and $Kd1$ should be increased.

Cruise Control Fuzzy PID Controller

The fuzzy PID control module for cruise control is built in MATLAB/Simulink, as shown in Figure 12. The input of the fuzzy controller is the speed deviation and the rate of change of the variation, and the output is the parameters $Kp1$, $Ki1$, $Ka1$ of the PID controller. The PID controller the input is the deviation between the actual speed and the target speed. The variation and the controller's three parameters $kp1.ki1$ and $ka1$ are summed through proportional, integral and differential operations, and the output is the expected acceleration of the vehicle.

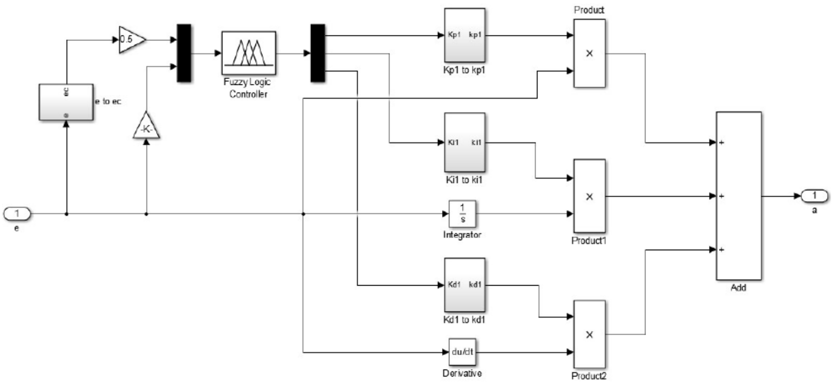

Figure 12 Fuzzy PID Control Module for Fixed Speed Cruise

Algorithm Design of Following Cruise Control

Formulation of Fuzzy Rules for Following Cruise

The following cruise control is divided into five situations: start following, acceleration and deceleration following, the preceding vehicle cutting into the vehicle's lane, the prior vehicle cutting out of the vehicle's route, and parking tracks. Safe distance. The input of the fuzzy controller in the following cruise fuzzy PID control is the deviation Ez of the distance between the two vehicles and the safety distance and the relative speed V of the vehicle and the preceding vehicle, and the three parameters $Kp2$, $Ki2$ and $Ka2$ of the PID control are output.

Suppose the absolute value of the deviation E2 is significant. In that case, this situation usually occurs when the vehicle in front accelerates and decelerates, and the vehicle in front cuts into the vehicle's lane. At this time, the actual distance between the two vehicles is quite different from the safety distance. At this time, priority should be given to driving safety and fast following, and the deviation needs to be reduced as soon as possible. $Kp2$ and $Ki2$ should be appropriately increased according to the relative speed V of the two vehicles. To avoid adjusting the early braking to affect the driving stability of the vehicle, appropriate reduction of Small $Kd2$.

Suppose the absolute value of the deviation E2 is too large. In that case, this situation mainly occurs following the acceleration and deceleration of the preceding vehicle and when the prior vehicle cuts into the vehicle's lane in front. The ride comfort should be appropriately considered under the premise of driving safety. To quickly reduce the deviation, According to the relative speed V of the two vehicles, $Kp2$ and $Ki2$ should be appropriately increased. At the same time, to quickly adjust the overshoot of the desired acceleration to avoid affecting the ride comfort and increase the driving stability of the vehicle, Ka2 should be appropriately increased.

Suppose the absolute value of the deviation E2 is small. This situation usually occurs when starting to follow, following the acceleration and deceleration of the preceding vehicle, and

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stopping to observe. The distance between the two vehicles is close to the safety distance. To control the overshoot and improve the anti-interference ability of the control system, $Kp2$ should be appropriately reduced according to the relative speed V of the two vehicles, and $Ki2$ and $Ka2$ should be increased.

Suppose the absolute value of the deviation E tends to be 0. In that case, this situation may occur when starting to follow, following the acceleration and deceleration of the preceding vehicle, when the prior vehicle cuts into the vehicle's lane and stops and follows. The distance between the two vehicles is approximately equal to the safety distance. The distance from the vehicle in front should be kept constant. To suppress the overshoot in advance to ensure the comfort of riding, $Kd2$ should be appropriately increased, and $Kp2$ and $Ki2$ should be appropriately increased according to the relative speed Vr of the two vehicles to achieve stability following the vehicle in front the goal (Adriansyah et al., 2021).

In the condition that the preceding vehicle cuts out of the own vehicle's lane when the primary vehicle has not cut out of the own vehicle's route, the own vehicle is in the following mode of following the preceding vehicle's acceleration and deceleration conditions, the three parameters of PID control and the absolute value of the deviation E2 and the two The relationship of the relative speed V of the vehicle should follow the above rules. After the current vehicle cuts out of the vehicle's lane, there is no obstacle in front of the vehicle. At this time, the vehicle enters cruise control mode. The relationship between the three parameters of PID control, the absolute value of the deviation Ez and the relative speed of the two vehicles V, should follow the cruise control mode Fuzzy rules in control (Asere et al., 2015). The following fuzzy control rules are formulated based on the above analysis, as shown in Figure 13.

PID V_r / E_2	NB	NM	NS	ZO	PS	PM	PB
NB	(PB,NS,PS)	(PB,NS,PS)	(PM,ZO,ZO)	(PM,PS,ZO)	(PS,PS,NS)	(PS,PM,NS)	(ZO,PM,NM)
NM	(PM,NM,NS)	(PM,NM,NS)	(PS,NS,ZO)	(PS,NS,ZO)	(ZO,ZO,PS)	(NS,ZO,PS)	(NM,PS,PM)
NS	(PS,NS,ZO)	(PS,NS,ZO)	(ZO,ZO,PS)	(ZO,PS,PS)	(NS,PS,PM)	(NM,PM,PM)	(NB,PM,PB)
ZO	(ZO,NS,NM)	(ZO,NS,NM)	(NS,NM,NS)	(NS,NM,ZO)	(NM,NM,ZO)	(NM,NM,PS)	(NB,NB,PM)
PS	(PS,NS,ZO)	(PS,NS,ZO)	(ZO,ZO,PS)	(ZO,PS,PS)	(NS,PS,PM)	(NM,PM,PM)	(NB,PM,PB)
PM	(PM,NM,NS)	(PM,NM,NS)	(PS,NS,ZO)	(PS,NS,ZO)	(ZO,ZO,PS)	(NS,ZO,PS)	(NM,PS,PM)
PB	(PB,NS,PS)	(PB,NS,PS)	(PM,ZO,ZO)	(PM,PS,ZO)	(PS,PS,NS)	(PS,PM,NS)	(ZO,PM,NM)

Figure 13 Fuzzy Rules for Following Cruise Control

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Follow Cruise Fuzzy PID Controller

The fixed-speed cruise fuzzy PID control model is built in MATLAB/Simulink, as shown in Figure 14. The input of the fuzzy controller is the speed deviation and the rate of change of the variation, and the output is the fuzzy parameter values $Kp2$, $Ki2$, $Ka2$ of the PID controller. The input of the controller is the deviation between the actual and target speed, and the output is the expected acceleration (Wang et al., 2023).

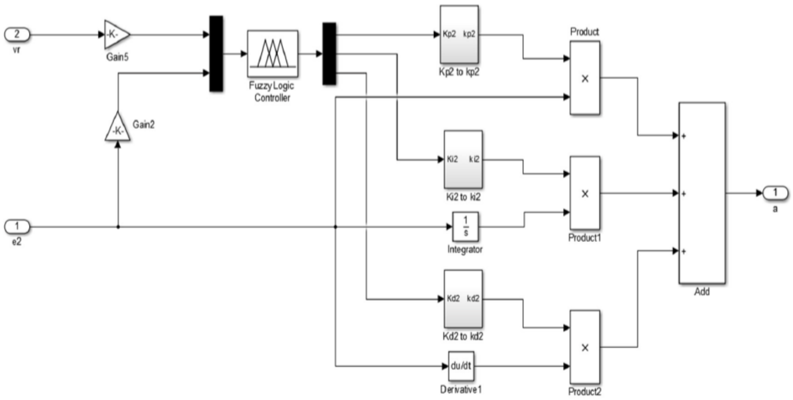

Figure 14 Fuzzy PID Control Model for follow-the-cruise

Result and Discussion

Simulation system design

The two cruise control algorithms are integrated into the vehicle ACC control algorithm through the FC/CC Switch logic switching module. The MATLAB co-simulation module for vehicle ACC control is built, as shown in Figure 15. The input of the vehicle model in Carsim is the output of the vehicle ACC control algorithm, and the result is the input of the vehicle ACC control algorithm. The joint simulation forms a closed-loop feedback control, which controls the model vehicle to realize the adaptive cruise function. The module Safe Distance integrates the vehicle safety distance algorithm. The input value is the acceleration of the vehicle, the speed of the vehicle, and the relative speed between the vehicle and the vehicle in front, and the output value is the safety distance between the vehicle and the vehicle in front.

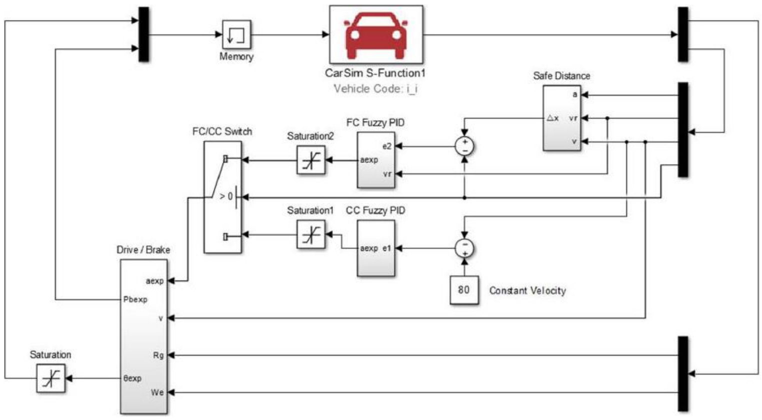

Figure 15 Adaptive Cruise Fuzzy PID Joint Simulation Model

The fuzzy PID control algorithm of cruise control is integrated into the CCFuzzyPID module. The input is the deviation between the cruise speed and the actual speed of the vehicle, and the output is the expected acceleration of the vehicle. The following cruise fuzzy PID control algorithm is integrated into the FCFuzzyPID module. The input of the module is the deviation between the actual distance and the safe distance between the two vehicles and the relative speed of the front and rear vehicles, and the output is the expected acceleration of the vehicle. According to the riding comfort evaluation index, when the absolute value of the acceleration/deceleration of the vehicle is less than 3 m/s2, people feel relatively comfortable riding in the car, so the expected acceleration output by the two cruise control algorithms is determined by Saturation1, and The Saturation2 module is limited to make the acceleration and deceleration of the vehicle within the range of 3m/s2~3m/s2 to ensure the comfort of the vehicle. The module Drive/Brake integrates the vehicle inverse engine model, the inverse braking system model and the drive-brake switching model. The input of the Drive/Brake module is the expected acceleration, speed, gear ratio and engine speed of the vehicle, and the output is the vehicle. The throttle opening degree or vehicle braking pressure, the expected throttle opening degree is in the range of 0~1, which is limited by the Saturation module. The FC/CC Switch module switches the cruise control mode and the following cruise mode. When there is no obstacle in front of the vehicle, the feedback signal value of the ranging radar installed on the vehicle is -1, according to the selection of the FC/CC Switch module. Condition ">0", the module will select the lower output to realize the vehicle cruise control. When the radar detects an obstacle in front of the vehicle, the radar will give feedback on the distance of the obstacle. The obstacle distance is a positive value, so FC/ The CC Switch module will select the output on the road to realize the vehicle following cruise control, thereby achieving the vehicle adaptive cruise control. When the vehicle is in constant speed cruise mode, the difference between the set cruise speed and the actual speed of the vehicle is input into the CCFuzzyPID module. The CC Fuzzy PID module calculates the expected acceleration of the vehicle, and converts the expected acceleration into the vehicle's expected throttle through the

Drive/Brake module. The opening degree or desired brake pressure is output to the vehicle model to control the vehicle to realize the cruise control function. When the vehicle is in the following cruise mode, the expected safe distance calculated by the safe distance calculation module Safe Distance and the actual distance between the two vehicles are calculated and then input to the FC Fuzzy PID control module. The deviation between the deviation and the relative speed of the vehicle and the vehicle in front, calculate the expected acceleration of the output vehicle, convert the expected acceleration into the vehicle's expected throttle opening or expected brake pressure through the Drive/Brake module to the vehicle model, and control the vehicle to achieve follow cruise Function.

Research on Cruise Control

The cruise control simulation is divided into two working conditions, namely acceleration and deceleration of the vehicle to the specified cruising speed. The specific simulation conditions are as follows.

Simulation of Acceleration Conditions

Set the vehicle's initial speed to 50Km/h and the target cruising speed to 100km/h. Carry out a cruise simulation of the vehicle at a constant rate. The obtained speed and acceleration curves are shown in Figure 16.

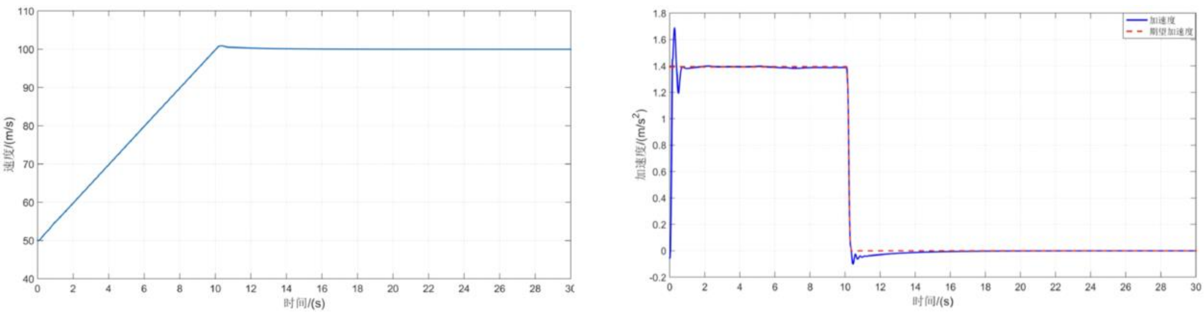

Figure 16 Vehicle Speed Change Curve (Left) and Vehicle Acceleration Variation Curve (Right)

It can be seen from Figures 22 and 23 that the speed of the vehicle is 50km/h at 0s, and it starts to accelerate from 0s, and after 10s, the speed increases from 50km/h to 100.6km/h, and then quickly falls back to 100km/h. The acceleration process After completion, the vehicle continues to drive at a speed of 100 km/h. The vehicle's acceleration increases from 0 to 1.69 m/s2 at the moment of acceleration. After experiencing a small fluctuation, the acceleration remains unchanged at 1.39 m/s2 until the end of the acceleration process, and the acceleration quickly drops to -0.1 m/s2, and then returns to 0 m /s2 and remains unchanged, the acceleration change corresponds to the speed change trend, and is consistent with the expected acceleration curve. During the whole process, the speed change is relatively stable. Although the acceleration fluctuates, the amplitude is small. The maximum peak value of the

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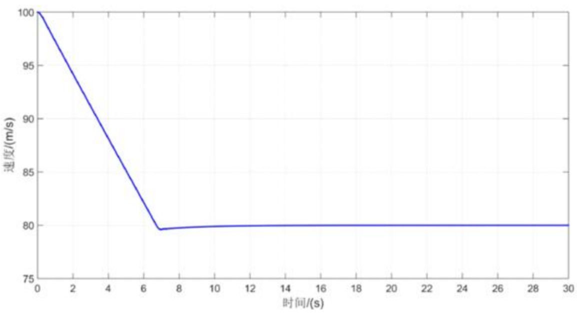
acceleration is 1.69 m/s2, and the minimum peak value is -0.1m/s2, so the driver's driving comfort is also guaranteed.

Simulation of Deceleration Conditions

Set the initial speed of the vehicle as 100km/h and the target cruising speed as 80km/h, and simulate and analyse the vehicle. The curve of vehicle speed and acceleration obtained under this condition is shown in Figure 17.



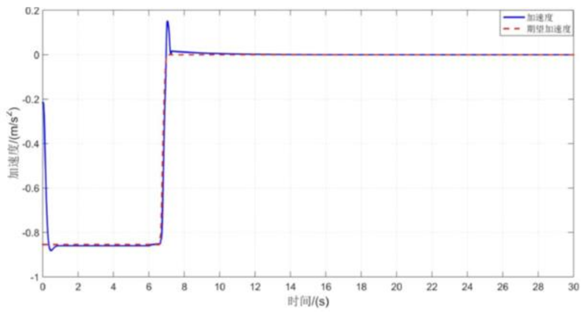


Figure 17 Vehicle Speed Change Curve (Left) and Vehicle Acceleration Variation Curve (Right)

It can be seen from Figures 24 and 25 that the vehicle starts to decelerate from 0s, the deceleration process lasts for 6.7s, and the vehicle speed decreases from 100km/h to a minimum of 79.6km/h, after which the vehicle speed slightly recovers to 80km/h and remains stable at 80km/h. h Do a uniform linear motion. The vehicle's acceleration decreased from 0 to -0.88m/s2 at the moment of deceleration and then slightly recovered to -0.86 m/s2 and remained unchanged to 6.7s. During this process, the vehicle continued to decelerate. After 6.7s, the acceleration began to pick up, and at 7s, the acceleration rose to the highest point of 0.15m/s2, and then gradually decreased to 0m/s2, and remained unchanged. The acceleration variation trend corresponds to the velocity variation trend and fits well with the expected acceleration variation. During the whole process, the vehicle's acceleration is not lower than -1m/s2, which ensures the vehicle's comfort.

Follow-Up Cruise Research

The following cruise simulation mainly considers the acceleration and deceleration of the following target vehicle. At this time, the vehicle's initial speed is set to be 30km/h. From 0s, the vehicle follows the motion state of the target vehicle and automatically adjusts the motion state of the vehicle to follow the target vehicle. The simulation time is in the 70s, and the simulation conditions are shown in Figure 18. Figure 19 shows the motion of the target vehicle in the Carsim software.

Figure 18 Follow the Cruise Simulation Working Conditions

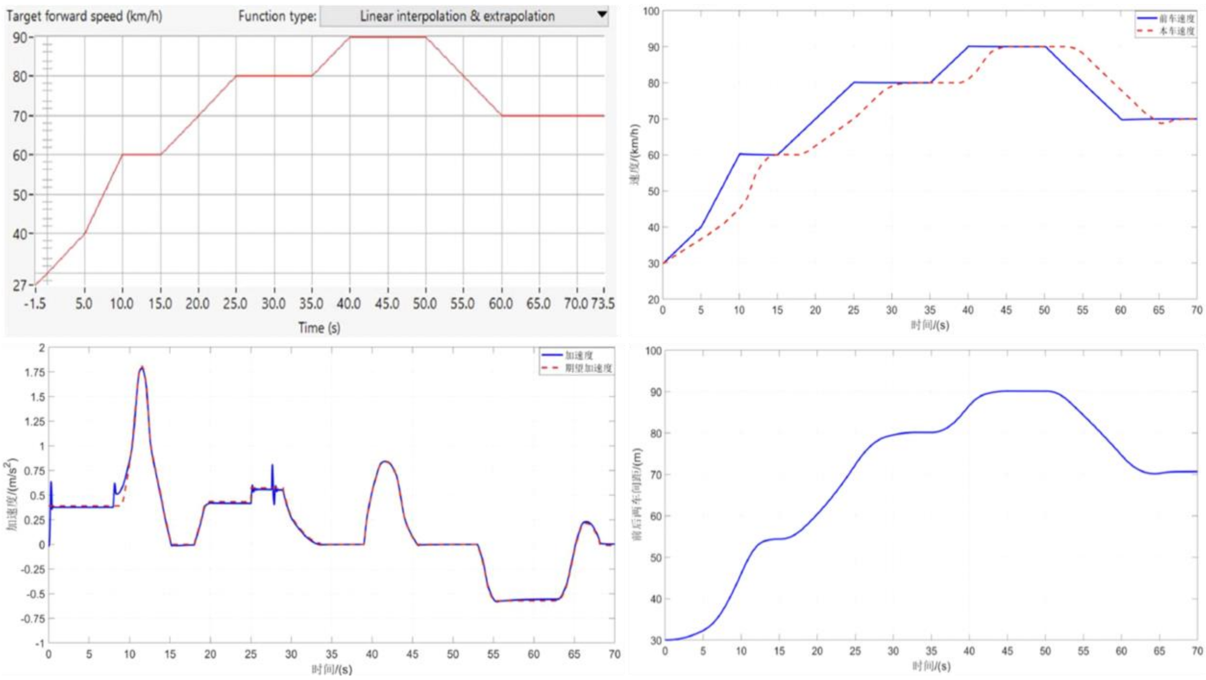


Figure 19 Target Vehicle Speed Variation Curve (Upper Left); Speed Change Curve of Two Cars (Upper Right); Speed Change Curve of Two Cars (Lower Left); and Variation Curve of Acceleration and Desired Acceleration of This Vehicle (Lower Right)

Figure 19 (Upper Left) shows the speed change of the preceding vehicle. During the simulation time of the 70s, the primary vehicle's speed increased from 30km/h to 90km/h in three stages, then decelerated from 90km/h to 70km/h, and finally reached 70km/h. The speed of h is a uniform linear motion. Figure 19 (Upper Right, Lower Left and Lower Right) shows that after the preceding vehicle's speed is adjusted, the vehicle also begins to adjust its speed and changes according to the primary vehicle's speed. The changing trend of the vehicle's speed and the speed of the preceding vehicle are consistent. The rate of the vehicle in front reaches 90km/h within 45s, and it comes 90km/h 5s later than the vehicle in front. During this time, the speed of the vehicle changes relatively gently. After the vehicle in front decelerates from 90km/h, the vehicle also follows the vehicle in front. Although there are fluctuations in the deceleration process, the amplitude is small. Finally, the vehicle stably follows the vehicle in front to move in a straight line at a uniform speed. The vehicle's positive and negative acceleration corresponds to the rate's changing trend. The changing direction of the vehicle and expected acceleration are consistent. Although there are fluctuations in the process, the

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amplitude is not significant. The duration is concise, indicating that the ACC control. The maximum peak value of the vehicle's acceleration is 1.786m/s2. The minimum peak value is -0.581m/s2, indicating that the passengers feel more comfortable in the acceleration and deceleration of the vehicle. During the process, the distance between the vehicle and the preceding vehicle increases or decreases with the vehicle's speed. It can be maintained stably, indicating that the ACC controller controls the vehicle with good followability.

Given the situation that the vehicle in front often cuts into the lane when passing the ramp, let the vehicle drive on the road at a speed of 80km/h, and the vehicle in the next lane cut into the route of the vehicle at a rate of 80km/h from 30m ahead on 5s. The car first decelerates, then accelerates, and finally follows the vehicle in front at a safe distance and moves in a straight line at a constant speed. The simulation time is 35s, and the change curves of the speed of the two vehicles, the change curves of the acceleration and the expected acceleration of the vehicle, and the change curves of the distance between the two vehicles are shown in Figure 20.

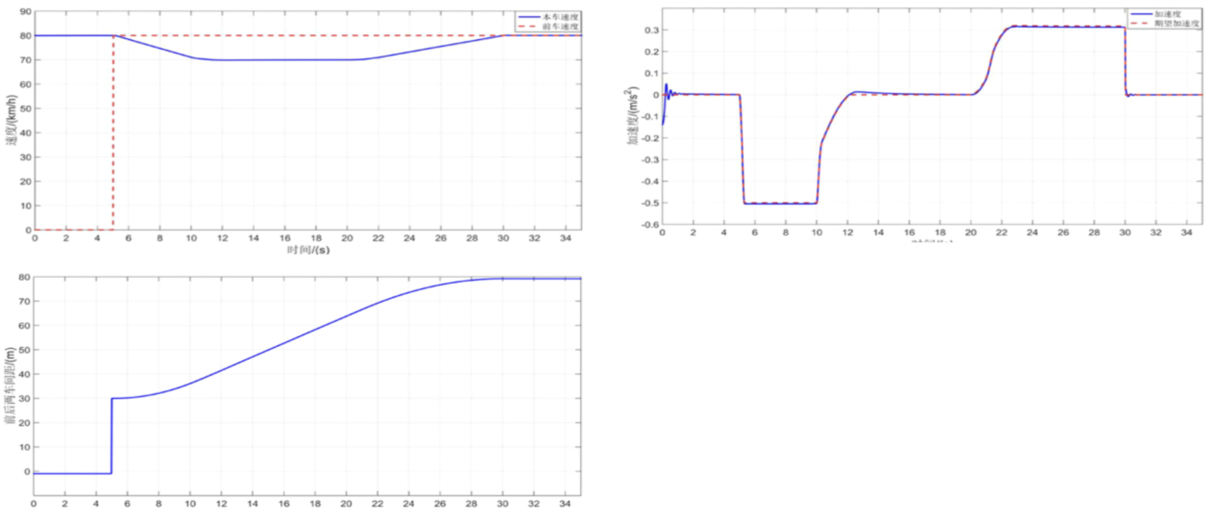

Figure 20 Two-Vehicle Speed Change Curve (Upper Left); Own Vehicle Acceleration and Desired Acceleration (Upper Right); and Change Curve of Distance Between Front and Rear Two Cars (Lower Left)

It can be seen from Figure 20 that there is no vehicle in front of the vehicle at the beginning, and the value returned by the ranging radar is -1. After the vehicle travels at a speed of 80km/h for 5s, the vehicle radar detects that the front vehicle cuts into the lane at 30m ahead, and the vehicle immediately decelerates. The speed decreases to 70km/h at 11.3s. After driving at a constant rate of 9.6s, the vehicle accelerates. At 30.06s, the vehicle accelerates to 80km/h. The car's speed is the same, and finally, the two vehicles move together at a constant speed in a straight line at the same speed. During this process, the distance between the car and the car in front increases. When the rate of the two vehicles is the same, the distance between the car and the car in front is 79.19m; keep this spacing the same. The positive and negative acceleration of the vehicle reflects the changing trend of the speed. The acceleration is consistent with the expected acceleration curve. Although there are fluctuations in the middle, it is small, and the duration is short. The acceleration and expected acceleration curves indicate that the controller has good followability. The maximum peak value of acceleration is 0.31m/s, and the minimum peak value is -0.5m/s, so the driver's riding experience will be more comfortable.

Conclusions

In this paper, the fuzzy PID control theory is used to study the longitudinal driving ACC system of the vehicle, mainly including the research on domestic and foreign adaptive cruise technology research and the explanation and analysis of its advantages and disadvantages. Models of vehicle engine, torque converter and automatic transmission are established in Carsim software to participate in the simulation. A fuzzy PID control algorithm is designed and tested under three working conditions, and good feedback is obtained.

References

Adriansyah, A., Ihsanto, E., Gunardi, Y., Suwoyo, H., Andika, J., & Shamsudin, A. U. (2021, 20-21 Oct. 2021). Design a Simulation Tools for Goal Seeking Behavior of a Mobile Robot. 2021 International Conference on Computer System, Information Technology, and Electrical Engineering (COSITE),

Adriansyah, A., Suwoyo, H., Tian, Y., & Deng, C. (2019). Improving the Wall-Following Robot Performance using PID-PSO Controller. *Jurnal Teknologi, 81*(3).

Ambroziak, A., & Chojecki, A. (2023). The PID controller optimisation module using Fuzzy Self-Tuning PSO for Air Handling Unit in continuous operation. *Engineering Applications of Artificial Intelligence, 117*. https://doi.org/10.1016/j.engappai.2022.105485

Anand, S., & Ohol, S. S. (2022). Modelling and simulation of adaptive cruise control and overtake assist system. *Materials Today: Proceedings*. https://doi.org/10.1016/j.matpr.2022.09.330

Aniculaesei, A., Howar, F., Denecke, P., & Rausch, A. (2018, 20-20 March 2018). Automated generation of requirements-based test cases for an adaptive cruise control system. 2018 IEEE Workshop on Validation, Analysis and Evolution of Software Tests (VST),

Asere, H., Lei, C., & Jia, R. (2015, 9-12 Oct. 2015). Cruise Control Design Using Fuzzy Logic Controller. 2015 IEEE International Conference on Systems, Man, and Cybernetics,

Chamraz, S., & Balogh, R. (2018, 31 Jan.-3 Feb. 2018). Two approaches to the adaptive cruise control (ACC) design. 2018 Cybernetics & Informatics (K&I),

Chen, Z., Hu, X., Li, Y., & Zhang, Z. (2017, 18-20 July 2017). Speed control system design of automatic parking based on fuzzy-PID control. 2017 IEEE International Conference on Information and Automation (ICIA),

Li, F., Li, Y., Yan, C., Ma, C., Liu, C., & Suo, Q. (2022, 4-6 March 2022). Swing Speed Control Strategy of Fuzzy PID Roadheader Based on PSO-BP Algorithm. 2022 IEEE 6th Information Technology and Mechatronics Engineering Conference (ITOEC), Li, L., & Jia, D. (2017, 21-23 July 2017). Research on Air Conditioning System of Subway Station Based on Fuzzy PID Control. 2017 4th International Conference on Information Science and Control Engineering (ICISCE),

Lihan, S., Jie, M., & Baoqing, Y. (2020, 22-24 Aug. 2020). Fuzzy PID Design of Vehicle Attitude Control Systems. 2020 Chinese Control And Decision Conference (CCDC),

Liu, Y. (2020, 4-6 Dec. 2020). Human-Computer Interface Design Based on Design Psychology. 2020 International Conference on Intelligent Computing and Human-Computer Interaction (ICHCI),

Mohtavipour, S. M., Jafari, H., & Shahhoseini, H. S. (2017, 22-22 Dec. 2017). A novel design for adaptive cruise control based on extended reference model. 2017 IEEE 4th International Conference on Knowledge-Based Engineering and Innovation (KBEI),

Qin, X., Nian, X., & Gao, W. (2021, 24-26 Nov. 2021). Research and Design of Single Phase Inverter Based on Fuzzy PID Control. 2021 IEEE/ACIS 22nd International Conference on Software Engineering, Artificial Intelligence, Networking and Parallel/Distributed Computing (SNPD),

Rout, M. K., Sain, D., Swain, S. K., & Mishra, S. K. (2016, 3-5 March 2016). PID controller design for cruise control system using genetic algorithm. 2016 International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT),

Sheng, G., & Gao, G. (2019, 3-5 June 2019). Research on the Attitude Control of Civil Quad-Rotor UAV Based on Fuzzy PID Control. 2019 Chinese Control And Decision Conference (CCDC),

Sheng, N., Chen, X., Ge, H., & Li, D. (2019, 22-24 Nov. 2019). Optimal Interval Type 2 Fuzzy PID Controller and its Application in Inverted Pendulum System. 2019 IEEE 2nd International Conference on Automation, Electronics and Electrical Engineering (AUTEEE),

Shi, J. Z. (2020). A Fractional Order General Type-2 Fuzzy PID Controller Design Algorithm. *IEEE Access, 8*, 52151-52172. https://doi.org/10.1109/ACCESS.2020.2980686

Suwoyo, H., Tian, Y., Deng, C., & Adriansyah, A. (2018). Improving a wall-following robot performance with a PID-genetic algorithm controller. 2018 5th International Conference on Electrical Engineering, Computer Science and Informatics (EECSI),

Suwoyo, H., Tian, Y., & Hajar, M. H. I. (2020). Enhancing the Performance of the Wall-Following Robot Based on FLC-GA.

Suwoyo, H., Tian, Y., Wang, W., Li, L., Adriansyah, A., Xi, F., & Yuan, G. (2021). Maximum likelihood estimation-assisted ASVSF through state covariance-based 2D SLAM algorithm. *TELKOMNIKA (Telecommunication Computing Electronics and Control), 19*(1), 327-338.

Wang, Y., Zhang, Y., Zhang, C., Zhou, J., Hu, D., Yi, F., Fan, Z., & Zeng, T. (2023). Genetic algorithm-based fuzzy optimization of energy management strategy for fuel cell vehicles considering driving cycles recognition. *Energy, 263*. https://doi.org/10.1016/j.energy.2022.126112

Wu, L., Cheng, Q., Zhou, H., Han, C., Liu, L., & Sun, D. (2019, 22-24 Nov. 2019). Fuzzy Cruise Control for Connected Vehicles Based on Vehicle Networking. 2019 Chinese Automation Congress (CAC),