Research on Dynamic Simulation of Vehicle ACC Based on Active Disturbance Rejection Control Technology

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Abstract. To improve the robustness and safety of the vehicle's adaptive cruise control system, this paper designs an active disturbance rejection controller (ACC_ADRC) with strong robustness. The upper controller is based on the active disturbance rejection control algorithm, obtains the expected acceleration of the vehicle according to the relative speed and relative distance of the preceding vehicle. The lower controller is based on PI control, according to the expected acceleration, it realizes the adaptive cruise control of the vehicle by controlling the throttle opening and the pressure of the master cylinder. Finally, based on the ADAS HIL simulation platform, the controller of this research and a mass production controller (ACC_MP) were simulated and verified. The simulation results show that compared with the ACC_MP controller, the ACC_ADRC controller has stronger robustness and reduces the overshoot of speed, acceleration and distance, and effectively improves the comfort and safety of the vehicle.

Keywords: Adaptive cruise control system; Robustness; Active disturbance rejection control.

1. Introduction

The automobile adaptive cruise control system (ACC) reduces the operating burden of the driver by controlling the distance and relative speed between the vehicle and the target vehicle in front, and improves the comfort and safety of the vehicle[1-3]. Therefore, the ACC control algorithm largely determines the overall control effect. In the design of the ACC controller, John Jairo Martinez[4] proposed a vehicle longitudinal motion control method based on reference model. Although the comfort and safety in this research is well, but the reference model has poor accuracy, the control system is more complicated and the real-time control is poor. Wu[5] proposed the adaptive cruise control of the optimal active braking control algorithm. Based on the problem of active braking and system lag, this paper design a vehicle dynamics model, a vehicle reverse longitudinal dynamics model and an active hydraulic braking system model, verified by simulation. It improves ride comfort and driving safety. Xiaohan Li[6] proposed an ACC fuzzy control strategy based on the driver's operating experience. The control strategy responds quickly, but the speed stability is not good at the early stage of the following mode in low-speed conditions. Wei Zheng[7] designed an ACC PID control strategy algorithm, which has fast response and small overshoot, but the control effect is not ideal under the complicated working conditions of the follow control mode. Dezhao Zhang[8] based on the rolling time domain predictive control theory and vehicle dynamics theory, proposed a vehicle adaptive cruise control system for turns driving, which realized the comprehensive optimization control of the longitudinal tracking and lateral stability of the ACC, but the control system’s stability is poor during the following process.
Due to the complex driving conditions, it has strong nonlinearity and uncertainty, the require of the robustness about the control algorithm is higher, and its influencing factors mainly come from the “internal disturbance” of the vehicle (internal parameters of vehicle system modeling are not determine) and "external disturbances" (such as sudden changes in road friction, road gradient changes)[9-11]. Traditional nonlinear system processing methods can hardly meet the accuracy, stability and rapidity requirements of ACC systems. The active disturbance rejection control (ADRC) algorithm does not depend on the system model, it can estimate and compensate various internal and external disturbances of the system in real time. Combined with a special nonlinear feedback structure, it can achieve good control quality [12-15]. Xiaomei Yao and Guoping Yao[17][18] have shown that the second-order ADRC can effectively control existing first-order to third-order objects, and it is equally effective in controlling linear and nonlinear objects. The second-order ADRC has strong robustness, and can better solve the problems of nonlinearity, time-varying, internal disturbance and rough external disturbance control in the ACC control process.

In order to improve the comprehensive performance of the automotive ACC system under different working conditions, this paper adopts the second-order active disturbance rejection control algorithm to design the ACC controller, and conducts joint simulations under multiple working conditions. The results show that: ACC based on active disturbance rejection control has strong anti-interference ability, effectively deal with various complex situations in the driving process, has stronger robustness, reduces the overshoot of speed, acceleration and vehicle distance, and effectively improves the comfort and driving safety of the vehicle adaptive cruise control system.

2. Overall Design of Automobile Adaptive Cruise Control System

The overall structure of the automobile ACC system is shown in Figure 1. The automobile ACC system adopts a hierarchical control structure, which is composed of a sensor module, an upper controller, a lower controller and a self-car model. The sensor module obtains information such as the relative speed and relative distance to the vehicle in front, and outputs it to the upper controller. The upper controller includes cruise control mode and following mode. Both cruise control mode and following mode adopt ADRC control. The upper controller outputs the desired acceleration to the lower controller, the lower controller realizes acceleration correction through PI control, and converts it into control variables such as throttle opening or brake master cylinder pressure, updates the vehicle dynamics model state, and realizes adaptive cruise control features.

![Figure 1. The overall structure of the automobile adaptive cruise control system.](image)

3. ACC System Algorithm Analysis

3.1. Analysis of ACC upper Controller

As shown in Figure 2, the upper ACC controller is mainly composed of mode switching logic, safety distance algorithm, distance control algorithm and speed control algorithm. When the sensor does not detect a vehicle in front, the desired acceleration is output through the speed control algorithm, and the car starts the cruise control mode. When the sensor detects that there is a target vehicle ahead, the relative speed and relative distance of the two vehicles are input into the desired distance algorithm and the distance control algorithm, and output the expected acceleration, the car enters the following mode.
3.1.1. Desired distance algorithm analysis. The desired safety distance is equal to the sum of the relative speed of the two vehicles and the speed of the vehicle, and then multiplied by the expected time interval, and finally compared with the minimum expected safe distance, whichever is the maximum value to ensure driving safety. The calculation formula of the desired distance algorithm is:

\[
Desire.distance = \max \left\{ (Target.dv + Car.v) \times t_h, ACC.DistMin \right\}
\]  

Among them, \(Desire.distance\) is the desired safe distance, \(Target.dv\) is the relative speed of the two vehicles, \(Car.v\) is the speed of the vehicle, \(t_h\) is the desired time interval, and \(ACC.DistMin\) is the minimum safe distance.

3.1.2. Algorithm analysis of cruise control mode. The structure of the cruise control mode is shown in Figure 3. When the vehicle ahead is not detected within the detection range of the vehicle sensor, or the distance between the vehicle ahead and the vehicle is larger than the response distance, the vehicle travels at the set cruise speed. In the research of this paper, the cruise control algorithm of ADRC is constructed. The desired vehicle speed \((Desire.speed)\) and the vehicle speed \((Car.v)\) are used as the input of the ADRC controller, and output the expected acceleration. The acceleration expression in the cruise control mode is:

\[
ax = \frac{Desire.speed - Car.v}{kv}
\]

Among them, \(ax\) is the desired acceleration, \(Desire.speed\) is the desired speed, \(Car.v\) is the actual speed of the car and \(kv\) is the speed gain coefficient.

3.1.3 Analysis of Following Mode Algorithm. The structure of the following mode is shown in Figure 4. When the vehicle sensor detects that there is a vehicle ahead, and the distance between the two vehicles is within the reaction range and is decreasing, the following mode is activated. The following mode is controlled by ADRC. The acceleration expression in following mode is:
In the formula, $ax$ is the desired acceleration, $Target.ds$ is the relative distance between the two vehicles, $Desire.distance$ is the desired safety distance, $kd$, $kv$ are the distance gain coefficients and speed gain coefficients, and $Target.dv$ is the relative speed of the two vehicles.

![Figure 4. Following mode structure.](image)

3.2. Analysis of ACC Lower Controller

The lower controller structure is shown in Figure 5. The vehicle inverse longitudinal dynamics model of the ACC lower-level controller is composed of drive/brake switching logic and PI controller. The PI controller is used to realize acceleration correction, and the drive/brake switching logic ensures the smoothness of switching. The vehicle’s reverse longitudinal dynamics model converts the desired acceleration of the upper controller into throttle opening or braking pressure, and inputs it into CarMaker's vehicle dynamics model, so that the vehicle can track the desired acceleration and realize the adaptive cruise function. The lower controller expression is:

$$
\begin{align*}
\Delta ax &= \text{Desire}.ax - \text{Car}.ax \\
x &= \Delta ax \cdot k_p + \Delta ax \cdot k_v
\end{align*}
$$

If $0 \leq x \leq 1$, then output to the throttle opening, if $-1 < x < 0$, then output to the brake pressure. Among them, $\Delta ax$ is the difference between expected acceleration and actual acceleration, $x$ is the PI control output, $k_p$, $k_v$ are the gain coefficients of PI control respectively.

![Figure 5. Lower controller structure.](image)

4. Simulation Experiment and Analysis

In order to verify the effect of the algorithm, a hardware-in-the-loop (HIL) test system with CarMaker software setting scene and Micro AutoBox running control algorithm was constructed. The ACC_ADRC controller and ACC_MP controller were used for multi-condition testing. Four operating conditions are set for simulation: cruise control operating conditions, constant speed driving conditions of the preceding vehicle, acceleration operating conditions of the preceding vehicle with sudden changes in road friction, and emergency braking operating conditions of the preceding vehicle. ADAS HIL test platform is shown in Figure 6.
4.1. Cruise Control Conditions
There is no target vehicle ahead, the initial speed of the vehicle is 16.67 m/s (60 km/h), and the set target speed is 27.78 m/s (100 km/h). The simulation result is shown in Figure 7.

It can be seen from Figure 7(a)(b) that under the cruise control condition, the vehicle accelerates from 60 km/h to 100 km/h, the acceleration time of the ACC_ADRC controller is 8.02 s, the speed overshoot is about 0.10%, and the acceleration overshoot is about 0.12%, and the acceleration time of the ACC_MP controller is 10.1 s, the speed overshoot is about 1.46%, and the acceleration overshoot is about 9.95%. In contrast, the ACC_ADRC controller has faster speed following control, smaller deviation from the expected tracking value, and a maximum acceleration of 1.4 m/s², which meets national standards and has better riding comfort and vehicle driving safety.

4.2. Constant Speed Driving Conditions of the Preceding Vehicle
The initial speed of the vehicle is 27.78 m/s (100 km/h), and the vehicle in front travels at a constant speed of 22.22 m/s (80 km/h). The simulation results are shown in Figure 8.

It can be seen from Figure 8(a)(b)(c) that under the constant speed driving condition of the preceding vehicle, the vehicle accelerates from 100 km/h to 80 km/h, the distance from the vehicle to the vehicle in front decreases, and the vehicle smoothly decelerates to a stop at a distance of 100 m. The ACC_ADRC controller shows better performance in terms of distance, speed, and acceleration deviation, meeting national standards and ensuring better riding comfort and vehicle driving safety.
It can be seen from Figure 8(a) that when encountering a low-speed vehicle ahead, both the ACC_ADRC controller and the ACC_MP controller can control the vehicle to decelerate and follow the preceding vehicle, but when ACC_MP decelerates and follows the preceding vehicle, its speed control appears overshoot, the maximum overshoot is about -4.55%, and the maximum speed overshoot of ACC_ADRC is 0.13%. From Figure 8(b), it can be seen that the acceleration jitter of the ACC_MP controller is large during the deceleration following process, while the ACC_ADRC controller can track the expected value changes steadily. From Figure 8(c), it can be seen that the ACC_MP controller has overshoot during the vehicle distance control process, and its maximum overshoot is about -19.88%, while the ACC_ADRC controller has the maximum vehicle distance overshoot, the amount is 0.14%.

Therefore, compared with the ACC_MP controller, the ACC_ADRC controller has a better control effect on speed, acceleration and vehicle distance, can better track its expected value, and has better robustness.

4.3. Accelerating Driving Conditions of the Preceding Vehicle with Sudden Changes in Road Friction
Within t=0-50s, the vehicle will follow the preceding vehicle at a constant speed at 22.22m/s (80km/h). At t=20s, there will be a 50m long frictional sudden change road. Within t=50-120s, the vehicle in front accelerates to 33.33m/s (120km/h), the expected speed of the vehicle is 27.78m/s (100km/h). The simulation result is shown in Figure 9.

It can be seen from Figure 9(a)(b)(c) that when t=20s passing through the road with sudden change in friction of the road surface, there is a large deviation between the speed control and the distance control of the ACC_MP controller, and the maximum speed overshoot is about 1.68%, the maximum overshoot of the vehicle distance is about 6.74%, the acceleration control has oscillations, and the number of oscillations is about 22, while the speed overshoot of the ACC_ADRC controller is about 0.12%, the number of acceleration oscillations is 0, and the vehicle distance overshoots is about 0.11%. Therefore, compared with the ACC_MP controller, the ACC_ADRC controller has better anti-interference ability and stability, and its speed, acceleration and vehicle distance tracking performance is better.

At t=50s, when the vehicle in front accelerates, both the ACC_ADRC controller and the ACC_MP controller can control the vehicle to accelerate and follow the car according to the desired trajectory, but the ACC_ADRC controller has better speed, acceleration and excepted value of distance track, and has better robustness.

4.4. Emergency Braking Driving Conditions of the Preceding Vehicle
The vehicle follows the vehicle in front at an initial speed of 25m/s (90km/h) at a constant speed. At t=10s, the vehicle in front suddenly starts emergency braking. At t=20s, the speed of the vehicle in front is 0m/s. The simulation results are shown in the figure 9.
It can be seen from Figure 10(a) that after the vehicle in front performs emergency braking, both the ACC_ADRC controller and the ACC_MP controller can perform follow-up braking. The ACC_ADRC controller takes 14.13s from braking to parking, and the ACC_MP controller takes 18.16s; From Figure 10(b), it can be seen that the maximum braking deceleration of the ACC_ADRC controller during braking is -2.6m/s², which conforms to the national standard (the maximum braking deceleration is not greater than 3.0m/s²), It has better ride comfort and driving safety. It can be seen from Figure 10(c) that the parking distance of the ACC_ADRC controller is 13.47m, and the parking distance of the ACC_MP controller is 2.10m.

Therefore, compared with the ACC_MP controller, the ACC_ADRC controller can react more quickly and accurately, following the brakes of the preceding vehicle to park, and its parking distance is larger, which has better riding comfort and driving safety.

5. Conclusion

This paper constructs an active disturbance rejection control based automobile adaptive cruise control hierarchical controller. The upper controller is based on the active disturbance rejection control algorithm according to the relative speed and relative displacement of the vehicle in front, obtains the desired acceleration of the vehicle. The lower controller is based on PI control, according to the expected acceleration of the upper controller, it realizes the adaptive cruise control of the vehicle by controlling the throttle opening and the pressure of the master cylinder. The simulation results show that the ACC_ADRC controller designed in this paper has stronger robustness, reduces the overshoot of speed, acceleration and vehicle distance, and can be effective under conditions such as sudden changes in road adhesion coefficient and emergency braking of the preceding vehicle. It responds to various complex situations in the driving process of the car, has strong anti-interference ability, and effectively improves the safety, comfort and adaptability of the vehicle's adaptive cruise control system.

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