Stratified Control Strategy of Vehicle Longitudinal Active Collision Avoidance

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Abstract. In order to improve the safety and real-time performance of vehicle longitudinal active collision avoidance, a layered collision avoidance control method based on warning value, standard collision time safety model TTC and fuzzy PID is proposed in this paper. Based on the collision time safety model, the upper controller obtains the braking deceleration of the vehicle according to the relative speed and relative displacement of the obstacle in front. The lower controller is based on fuzzy PID, according to the brake deceleration speed of the upper vehicle, by controlling the pressure of the brake master cylinder of the vehicle, the control of vehicle speed is realized. Finally, using the CarSim/Simulink co-simulation platform, and taking the straight-line working condition as an example, the collision avoidance effect of the controlled vehicle under different speeds was simulated and verified. The results show that the upper controller can afford the appropriate speed of collision avoidance and deceleration according to the reference information, and the lower controller can adjust the brake deceleration speed according to the fuzzy PID, so as to realize the vehicle braking pressure, meet the requirements of longitudinal active collision avoidance.

1. Introduction

With the development of automobile intelligence, the longitudinal active collision avoidance system of vehicles has become an advanced active safety technology, which is of great significance to solve traffic safety problems such as rear-end collisions. Therefore, the research on longitudinal collision avoidance systems has received extensive attention [1]. MILANES V et al[2] introduced the THW model of the longitudinal collision avoidance system to solve the rear-end collision caused by the sudden braking of the preceding vehicle. HAN J et al[3] obtained the collision time TTC more accurately by fusing the lane line information with the vehicle motion information collected by the monocular camera, which reduced the generation of false alarms, and compared with the latest collision avoidance technology, improved automobile longitudinal collision avoidance system. Li Lin et al[4] constructed a hazard level estimation model based on the driver’s behavior in real traffic conditions, and proposed a collision avoidance control strategy for the autonomous emergency braking system based on Prescan, which effectively avoided collisions or reduced the degree of collisions. Seungwuk Moon et al[5] proposed an adaptive cruise control strategy, using a confusion matrix to adjust adaptive cruise parameters. This control algorithm greatly improves the driver’s naturalness and severe braking under normal driving conditions. Wei Yang et al.[6] established an automatic emergency pedestrian system AEB-P layered collision avoidance system based on a fuzzy neural network upper controller and a PID-based lower controller for pedestrians. This hierarchical control strategy flexibly allocates early warning and braking time according to the actual working
conditions. The above studies have established early warning models and braking control strategies to solve the safety and practicability of the longitudinal active collision avoidance system. However, the classification of danger level is too complicated and the training of neural network is too time-consuming, which affects the real-time performance of automatic emergency braking, and reduces the robustness of collision avoidance effecting. Therefore, this paper proposes a time safety model TTC based on the early warning index δ and a hierarchical controller based on fuzzy PID to simplify the danger level, improve the sensitivity of obstacle detection and the real-time performance of the longitudinal collision avoidance system.

2. Overall structure of longitudinal collision avoidance

In order to improve the real-time performance of the longitudinal collision avoidance control system and simplify the danger level warning, a hierarchical control system for longitudinal active collision avoidance is proposed. As shown in Figure 1, the upper-level controller determines the ideal vehicle braking deceleration based on the relative displacement, relative speed and vehicle own speed between the target vehicle and the obstacle, and through the TTC algorithm of the time safety model based on the warning index δ. The lower-level controller is based on fuzzy PID and realizes the control of braking force by following the desired braking deceleration.

![Figure 1. Overall structure of longitudinal collision avoidance.](image)

2.1. Upper controller design

2.1.1. Standard Time Security Model TTC. TTC refers to the time required for two vehicles to collide, also known as the collision avoidance algorithm[7]. When defining the dangerous braking distance, the TTC braking distance is used in the algorithmic logic. If the TTC is less than all the delay time and the driver does not respond to the collision warning, the system should automatically brake at this time [8]. The standard TTC model is shown in Equ.1:

\[
TTC = \frac{D}{v_{rel}}
\]  

Where, \(D\) -the relative distance between the vehicle and the obstacle, \(v_{rel}\) -the relative speed of the vehicle and the obstacle.

2.1.2 Warning value \(\delta\) and standard TTC model. The calculation function of early warning index δ proposed by Jiang Lijun [9] is Equ.2:

\[
\delta = \frac{d - d_{br}}{d_w - d_{br}}
\]  

Where, \(d_{br} = v_1 \cdot T_{delay} + f(\mu) \cdot \frac{(2v_0 - v_1)b_1}{2a_{max}}\), \(d_w = d_{br} + v_0 \cdot T_{br, min}\)
Combining equations (1), (2), (3), the braking deceleration value expected by the upper controller is eq u (4):

\[ a_{\text{ref}} = W_1 \cdot a_1(\delta) + W_2 \cdot a_2(TTC) \]  

(4)

Where, the definition of each parameter is shown in Table 1:

| Parameter | Definition |
|-----------|------------|
| \(d\)    | The distance between the vehicle and the obstacle |
| \(d_w\)  | Braking critical distance |
| \(d_u\)  | Warning critical distance |
| \(T_{\text{delay}}\) | System delay time |
| \(f(\mu)\) | Road adhesion coefficient |
| \(a_{\text{max}}\) | Maximum braking deceleration |
| \(T_{k,\text{min}}\) | Minimum vehicle time |
| \(W_1, W_2\) | Weights |
| \(a_1\) | related parameters with \(\delta\) |
| \(a_2\) | related parameters with TTC |
| \(v_0\) | Vehicle speed |
| \(v_1\) | Obstacle speed |
| \(\delta\) | Warning value |

2.1.3. Warning value \(\delta\) and standard TTC model. The simulink model of TTC with the warning value \(\delta\) is constructed by Equ 5, as shown in Figure 2. Where, \(T_{\text{delay}} = 0.2s\), \(f(\mu) = 0.5\), \(a_{\text{max}} = 2g\), \(T_{k,\text{min}} = 2m\), \(W_1 = 0.6\), \(W_2 = 0.4\).

Figure 2. The simulink model of TTC with warning value \(\delta\)

2.2. Lower controller system

2.2.1. Lower controller design. The lower-level controller uses fuzzy PID [10] for control. The deviation between the expected braking deceleration \(a_{\text{ref}}\) and the actual braking deceleration \(a_0\) output from the upper-level fuzzy PID controller and the deviation change rate \(e\) are used as input, and the output parameter is the system of the vehicle. Move the master cylinder pressure IMP_PCON_BK. The fuzzy reasoning process includes 2 input variables \(e\) and \(e\), and 3 output variables proportional coefficient, the integral coefficient and the differential coefficient. The structure of the fuzzy PID controller is shown in Figure 3:
Figure 3. Fuzzy PID controller structure

(1) Fuzzifying of precise quantity
The input values $e$ and $e\dot{c}$ are both fuzzified by the range [-1,1], and the fuzzified range of the output values is [-15,15].

(2) Determining fuzzy subset
The fuzzy input and output variables are: NB (negative big), NM (negative middle), NS (negative small), ZO (zero), PS (positive small), PM (positive middle), PB (positive big), that is, the fuzzy subset is \{positive big, positive middle, positive small, zero, negative small, negative middle, negative big\}.

(3) Selecting membership function
The fuzzying variables $e$ and $ec$ and $K_p$, $K_i$, $K_d$ are all obey to the Gaussian distribution.

(4) Formulating fuzzy rules
As shown in Tab.2, Tab.3 and Tab.4 applying "if $e$ and $ec$ then $K_p$, $K_i$, $K_d$" to describe the rules, 50 fuzzy rules are gotten.

| Table 2. Fuzzy Rules of $K_p$ |
|-----------------------------|
| $e$ | NB | NM | NS | O | PS | PM | PB |
| $K_p$ | NB | NB | NM | NM | NS | O | O |
| $ec$ | NB | NB | NM | NM | NS | O | O |
| $K_p$ | NS | NB | NM | NS | O | PS | PS |
| $ec$ | NS | NB | NM | NS | O | PS | PS |
| $K_p$ | O | NM | NM | NS | O | PS | PM |
| $ec$ | O | NM | NM | NS | O | PS | PM |
| $K_p$ | PS | NM | NS | O | PS | PM | PB |
| $ec$ | PS | NM | NS | O | PS | PM | PB |
| $K_p$ | PM | O | O | PS | PS | PM | PB |
| $ec$ | PM | O | O | PS | PS | PM | PB |
| $K_p$ | PB | O | O | PS | PM | PM | PB |
| $ec$ | PB | O | O | PS | PM | PM | PB |

| Table 3. Fuzzy rules of $K_i$ |
|-----------------------------|
| $e$ | NB | NM | NS | O | PS | PM | PB |
| $K_i$ | NB | NB | PB | PB | PM | PM | PS |
| $ec$ | NB | PB | PB | PM | PM | PS | O |
| $K_i$ | NM | PB | PB | PM | PM | PS | O |
| $ec$ | NM | PB | PB | PM | PM | PS | O |
| $K_i$ | NS | NM | NS | O | PS | PS | PM |
| $ec$ | NS | PM | PM | PS | PS | O | NS |
| $K_i$ | O | PM | PM | PS | PS | O | NS |
| $ec$ | O | PM | PM | PS | PS | O | NS |
| $K_i$ | NS | PS | PS | O | NS | NS | NM |
| $ec$ | NS | PS | PS | O | NS | NS | NM |
| $K_i$ | O | PM | PM | PS | PS | O | NS |
| $ec$ | O | PM | PM | PS | PS | O | NS |
| $K_i$ | PB | O | O | PS | PS | PM | PB |
| $ec$ | PB | O | O | PS | PS | PM | PB |
| $K_i$ | PB | O | O | PS | PS | PM | PB |
| $ec$ | PB | O | O | PS | PS | PM | PB |
Table 4. Fuzzy rules of $K_d$

| $e$ | NB | NM | NS | O | PS | PM | PB |
|-----|----|----|----|---|----|----|----|
| $K_d$ | NB | PS | NS | NB | NB | NM | PS |
| ec | NM | PS | NS | NM | NM | NM | NS | O |
| | NS | O | NS | PM | NM | NS | NS | O |
| | O | O | NS | PM | NM | NS | NS | O |
| | PS | O | O | O | O | O | O | O |
| | PM | PB | NS | PS | PS | PS | PS | PB |
| | PB | PB | PM | PM | PM | PS | PS | PB |

Based on the "mamadani" fuzzy rule, the output of $K_p, K_i, K_d$ are shown in Fig.4, Fig. 5 and Fig.6.

Figure 4. Output surface for $K_p$

Figure 5. Output surface for $Ki$
2.2.2. Lower controller based on Matlab/Simulink

The lower-level controller takes the deviation $e$ between the expected deceleration $a_{ref}$ and the actual deceleration $a_0$ as input, and uses the fuzzy PID method to adjust the calculation and output the master cylinder pressure IMP_PCON_BK in a timely manner. The Simulink model of the lower-level controller established by fuzzy PID is shown in Fig7:

![Figure 7. Simulink model of the lower controller](image)

3. Co-simulation analysis of hierarchical collision avoidance control system

3.1. Build CarSim vehicle model

Use CarSim software to establish a vehicle model of a certain C-class car. Some vehicle parameter is shown in Tab 5. The vehicle model includes seven subsystems: transmission system, powertrain, steering system, braking system, suspension system, aerodynamics, tires, and car body[11].

| Serial Number | Parameter                        | Definition       |
|---------------|----------------------------------|------------------|
| 1             | vehicle weight                   | 1270kg           |
| 2             | Vehicle length                   | 4.170m           |
| 3             | Vehicle width                    | 1.916m           |
| 4             | Vehicle height                   | 1.610m           |
| 5             | Centroid position coordinates    | (-1.250, 0, 1.450)|
| 6             | Suspension spring stiffness      | 35000N/m         |
| 7             | Sensor position coordinates      | (4, 0, 0.5)      |
| 9             | The maximum sensing range of the sensor | 60m              |

3.2. Build a joint simulation platform

CarSim/Simulink is used to establish a co-simulation. According to the established time the safety model TTC is built based on the early warning value $\delta$ and the fuzzy PID longitudinal hierarchical collision avoidance controller, the model input variable is the relative speed V0-V1 of the vehicle and
the obstacle, the vehicle. The relative distance \(d\) from the obstacle, the vehicle speed \(V_x\), and the output variable are the brake master cylinder pressure \(\text{IMP}_\text{CON}_\text{BK}\) of the vehicle, as shown in Figure 8.

![Figure 8. Co-simulation of longitudinal layered collision avoidance controller](image)

### 3.3. Co-simulation analysis

In order to verify the effectiveness of the longitudinal collision avoidance controller, the road adhesion coefficient \(\mu=0.85\) was selected in the simulation, the vehicle speed was 40km/h and 65km/h, the simulation time was 30s, and the distance between the obstacle and the main vehicle was 60m. At the same time, a front long-distance sensor is installed on the main vehicle, located near the rear-view mirror, with an observation distance of 60m. Observe the three evaluation indicators of the driving trajectory, the yaw rate and the lateral acceleration when the obstacle is at a standstill and at a constant speed of 20km/h, as shown in Figure 9 (a), (b), (c) and Figure 10 (a), (b), (c) show:

![Figure 9](image)

(a) Longitudinal speed

![Figure 10](image)

(b) Distance to obstacles
From Figure 9 (a), (b), (c), it can be seen that due to the relatively high relative speed of the two vehicles, when a static obstacle appears in front of the main vehicle, the main vehicle will perform the emergency braking at a deceleration of -0.7g. When it is 3s, the speed of the main vehicle drops to 0, and the relative displacement with the obstacle is 5m at this time, avoiding the collision with the obstacle.

Compared with the results of the automatic emergency braking system AEB under the C-NCAP standard of the Chinese New Car Evaluation Regulations, the braking deceleration response time has been reduced by 0.2s, and the duration of the main vehicle braking has been reduced by 1s. The detection of stationary obstacles is more sensitive, which realizes the emergency braking of front stationary obstacles within the range of long-distance sensors.
4. Conclusion
(1) A longitudinal layered collision avoidance controller is established by CarSim/Simulink joint simulation. The upper controller makes decisions based on the relative displacement, relative speed and speed of the host vehicle and obstacles brake deceleration. The lower controller adjusts the braking deceleration based on the fuzzy PID, which realizes the effective control of the brake master cylinder pressure, and achieves the longitudinal active collision avoidance effect of the vehicle at high speed under high adhesion roads, which verifies the effectiveness of the controller.
(2) Based on the early-warning value $\delta$ and the standard collision time safety model TTC, the braking deceleration is decided, which simplifies the hazard level, shortens the time needed for obstacle detection, and speeds up the real-time performance of the controller.
(3) The longitudinal stratified collision avoidance controller achieves a good avoidance through braking. However, due to the simplification of the control strategy, the effect of longitudinal collision avoidance under the complex conditions of the obstacle is poor. In the future, under the complex working conditions, it is possible to appropriately divide the hazard levels, while ensuring real-time performance to achieve the effect of longitudinal collision avoidance. At the same time, the longitudinal and lateral coupling collision avoidance control of vehicles, which will be considered to realize the integrated planning of collision avoidance path and speed.

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