A Model Based on Hierarchical Safety Distance Algorithm for ACC Control Mode Switching Strategy

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***Abstract*—Intelligent vehicle has the trend for multiple ADAS system combined with each other, the traditional ACC generally with cruise control mode, accelerate control mode, stable follow control mode, decelerate control mode, emergency brake collision avoidance control mode, no combination of FCW and AEB function. This paper proposes a ACC system combined with FCW and AEB function, this system based on electric vehicle. Firstly, the system through safety distance model and dangerous condition judgment model to calculate the coefficient of safety level, then combining vehicle sensing information through control mode switching strategy to choose cruise control mode, accelerate control mode, stable follow control mode, decelerate control mode, emergency brake collision avoidance control mode. So as to realize acceleration, cruise, early warning and braking functions smooth switching.**

Keywords-radar; camera; ACC control; hierarchical safe distance algorithm

I. The ACC System Basic Architecture Baesd on Electric Vehicle

For the reason of ACC system is composed of multiple subsystems,so the BUS structure of the system is very important.Only by adopting effective bus structure,these subsystens could connected together to complete the periodic and reliability function of ACC system.Compared to the traditional fuel vehicles, Electric car use motor drive system to provide torque and their chassis generally adopt a VCU for integrated control.This paper put forward a BUS communication architecture of ACC system to the four-wheel independent drive electric vehicle.

Sensors (for example Radar,cameras and so on)of the ACC system are mainly used to identify cars in front of the vehicle , on the one hand, they through BUS read the vehicle information such as speed and horizontal pendulum to effectively identify the goal car;on the other hand ,they take effectively target information(such as distance,speed,azimuth and target species)to VCU through the BUS for subsequent information fusion,target selection processing.

Access transmission gear signal is not used as the ACC actuator system, but in order to get current transmission forces and torques to control the drive torque.

Electronic control unit is used to run the ACC to calculate the corresponding acceleration.The acceleration and deceleration signal via bus transmission subsystem to the driving system and braking system, which is converted to control signal.On the other hand, the ACC system needs from these related subsystems get vehicle state information and data. Such as the vehicle speed, acceleration,motor torque and yaw velocity.

To achieve the ACC controller required deceleration, only with motor drag to reduce the motor speed is not enough, also need to active braking by hydraulic system. There are two kinds of brake controller, based on electric motor power active braking controller and active braking controller based on hydraulic braking unit.

ACC system requires intervention on the drive system , in order to change the setting of the vehicle acceleration and torque. Internal combustion automotive engine control have electronic accelerator pedal EGAS. Electronically controlled gasoline engine ME7 and electronically controlled diesel engine EDC to change vehicle acceleration and engine speed. The electric vehicle directly through control of motor to increase or decrease torque.

Display components and control components are connected by CAN Bus. The ACC system need driver intention information(setting vehicle speed, select system time interval)and bring information to driver(such as radar whether or not identify effective target).

Vehicle data transmission using CAN, FlexRay and LIN BUS. Vehicle network connected each subsystem together, in addition to access to other instruments or functions. What's more, besides the way of data transmission, but also provides network signal communication protocol.

In this paper, the basic structure of the ACC system as shown in the figure below.

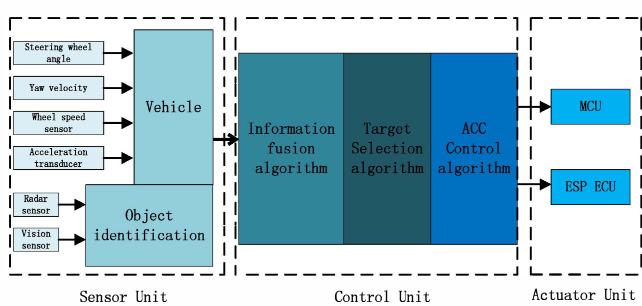

Figure 1. Basic structure of the ACC system

II. The Hierarchical Safety Distance Model

Vehicle longitudinal active collision avoidance control method based on the space between vehicle as control object, through real-time monitoring the car speed, the target speed, real-time distance and other information. To calculate the safety distance from the vehicle to target vehicle at current condition, then through the actual real-time distance and safety distance calculate the safety factor to the danger zone to determine current dangerous situation of vehicle. Finally by the control system make corresponding measures to ensure the vehicle safety driving condition.

There are three kinds of traditional safety distance models: the safety distance model based on the headway, the safety distance model based on the braking process and the safety distance model based on the driver model. These three safety distance models can be counted as classic safe distance models. Now the safety distance models are based on these three safety distance models. Most of the safety distance models cut brake process of the vehicle and target vehicle movement to segment and safety distance formula in the original subdivided into a number of different safety distance formula. Although this method targeted have very big enhancement when calculating the safety distance, but it adds to complexity of the safe distance model. For active collision avoidance in vehicle longitudinal control method, the requirement of time is occupied the main position, only the system involved in time as possible and simplify control system to a certain extent, to improve control precision of the vehicle longitudinal active collision avoidance control method and the practical commercial value. Some safety distance models specific numerical data use the experimental data, the experimental data can only adopt the method of individual on behalf of all, such data do not have all the responses to the driver's driving characteristics, driver's driving characteristics of attacking compared to driver's driving characteristics of conservative have very big difference, the corresponding safety distance model nature also has certain differences.

Based on the braking process:

$$S_0 = v_c \times t_d + \frac{v_c^2}{2a_{\max}} + d_0 \tag{1}$$

Based on the headway:

$$S_0 = v_c \times t_h + d_0 \tag{2}$$

Based on the driver aim model:
Static target:

$$S_0 = v_c \times t_g + \frac{v_c^2}{2a_{\max}} \tag{3}$$

Uniform or accelerated motion target:

$$S_0 = -v_{rel} \times t_g + v_c \times t_{hw} \tag{4}$$

Slow movement target:

$$S_0 = -v_{rel} \times t_g + 0.75t_g^2 + v_c \times t_{hw} \tag{5}$$

Among them:

S_0 —Safe distance;

v_c, v_{rel} —Default of velocity, The relative velocity;

d_0 —The distance to the target vehicle after the vehicle static;

t_d, t_h, t_g, t_{hw} —The driver reaction time, Headway time, The driver prediction time, Driver's subjective feeling can tolerate the minimum interval in the headway;

The safety distance model based on the braking process main problem is using the model to calculate safe distance results too big, can ensure the safety of vehicle, but too much space between vehicle leading to traffic flow decreased. The safety distance model based on the headway main problem is that when the vehicle velocity have large difference to calculate the safety distance is small, can achieve good traffic flow state, but too small distance cannot guarantee the safety of the traffic safety problems in the process, easy to cause the vehicle collision accident. The safety distance model based on the driver aim model main problem is requires consideration of a driver's characteristic and the driver's driving mode, for the vast and complex driver team, it's hard to make a model includes all of the driver's driving characteristics, only by setting up a safe distance model parameters from part of the experimental data, taking the methods of part on behalf of all.

Although classical safety distance model has some disadvantages, but the applicability of the classical safety distance model is relatively strong, do not need to study and segmentation of vehicle driving state, what's more, model simplify a lot compare to other safety distance model, which reduces the running time of the control system, improve the real-time performance of system. Because the safety distance model based on the braking process vehicle spacing is too large, the safety distance model based on the headway vehicle spacing is too small, so when bulid the safety distance model can integrated the advantages of these two models to complementary.

In this paper, the adaptive cruise system, approach and stable control mode is in a relatively safe state, so adopt the safety distance model based on the headway to calculate the threshold to trigger. Deceleration and emergency brake mode at a dangerous condition, so adopt the safety distance model based on the braking process to calculate the threshold to trigger. The safety distance model based on the headway vehicle spacing is too small, can guarantee larger acceleration in approach control mode and small headway space between front vehicle in stable control mode, what's more, the two mode increased road traffic flow and improved the efficiency of the road. The safety distance model based on the braking process vehicle spacing is too large, can ensure the vehicle braking system early intervention braking operation in deceleration and emergency brake control mode at a dangerous condition, so as to ensure the driving safety of vehicle.

The approach and stability safety distance control model:

$$S_0 = v_c t_h + d_2 \tag{6}$$

The safety distance model in deceleration and emergency brake control mode:

$$S_0 = v_c \times t_d + \frac{v_c^2 - v_2^2}{2a_{\max}} + d_1 \tag{7}$$

Among them:

S_0 —Safe distance;

v_c, v_2 —Default of velocity, Target vehicle velocity;

$a_{\max}$ —Maximum braking deceleration;

d_1, d_2 —The distance with target vehicle when stopping;

t_d, t_h —The driver reaction time, Headway;

III. DANGEROUS CONDITION ASSESSMENT MODEL

Safety distance model have established, then need to judge the safety condition of the vehicle, whether vehicle driving at current situation there will be a risk of collision. Against dangerous condition judgment in the process of the vehicle driving, many research scholars at home and abroad have a lot of research, have a plenty of deceleration as the judgment standard, have a plenty of time as the judgement standard (such as collision time TTC, it's reciprocal of 1/TTC as a risk factor for safety distance classification, determine the current state of dangerrous) and standard of judgment on the distance(According to the size of the actual space compared with the corresponding safety distance as a result, judge the risk of vehicle).

Existing dangerous situation judgment method mainly by time and distance, the dangerous situation judgment method based on the division of time take the rest of the time remaining of collision as a dangerous condition evaluation index, through comparing the actual residual time and safety time to ensure the safety of the vehicle state. The dangerous situation judgment method based on the division of distance according to the division of main formula of the safe distance, through headway and safety distance each interval comparision, determine the current vehicle's safety interval, judge the vehicle's safety state. In this paper, a judgment method of safety coefficient have been proposed, belongs to the judgment method based on distance, through the study of the division of safety distance formula, through calculating the headway distance and safety distance ratio falls at a local safe distance formula and safe distance foemula of interval, combining with the current speed on the local information to determine the safety status of the vehicle.

Safety factor as a dangerous situation on the basis of direct judgment method in the process of system operation, through real-time monitoring the size of the safety coefficient calculation, determine the safety factor and the dangerous interval relations, judge vehicle current security situation, take timely measures to avoid collision. Safety factor is defined as:

$$\varepsilon = \frac{S_0}{D} \times \sigma v \tag{8}$$

Among them:

ε —Safety factor;

S_0 —Safe distance;

D, σ, v —Headway, Velocity coefficient, Default of speed;

In the process of driving, as the change of the speed of the vehicle, the space and the safe distance between the target vehicle also will to change, so the safety factor is a variable. Under normal driving shape, safety coefficient is equal to zero, the current distance from vehicle to target vehicle is greater than the current state of safety distance, vehicle running in a safe condition.

When the safety coefficient is equal to zero, the vehicle is in a state of safety, vehicle longitudinal active collision avoidance control methods do not take any slowdown measures, keep monitoring the status.

When the safety coefficient is equal to 1, the vehicle in general danger condition, the driver without any reduction measures, vehicle longitudinal active collision avoidance control device will automaticaly take closed throttle and small braking deceleration of the measures, and keep monitoring, ensure the safety of the vehicle driving;

When the safety coefficient is equal to 2, the vehicle in a dangerous situation, the driver did not take reasonable reduction measures in time, the vehicle longitudinal active collision avoidance control device will automatically close the throttle, take maximum braking intensity and keep monitoring to ensure the security of the vehicle.

IV. CONTROL MODE SWITCHING LOGIC AND CONTROL METHODS

Adaptive cruise control in the task of each function is independent of each other, so under any control cycle, adaptive cruise control only under a certain control functions. Adaptive cruise control mode including: cruise control mode, accelerate control mode, stable follow control mode, decelerate control mode, emergency brake collision avoidance control mode.

Cruise control mode generally adopts PID control and fuzzy PID control to control. Accelerated following models and deceleration collision avoidance is generally based on the square of the velocity difference between target vehicle divided by the headway to get the desired acceleration, in order to achieve a smooth control effect, generally introduce a threshold h, to solve the problem of frequent switching. Stable follow control mode usually adopts linear quadratic optimal control algorithm, this method has high accuracy, rapid response, good stability and so on. Emergency brake collision avoidance mode generally give the execution unit one of the biggest brake pressure, make the vehicle speed at a distance of 0.

Control mode switching logic according to the set of cruising speed, default of speed, headway, the target speed, actual distance and whether there is a valid target determine safe level to select the appropriate working mode. The overall structure as shown in the figure below:

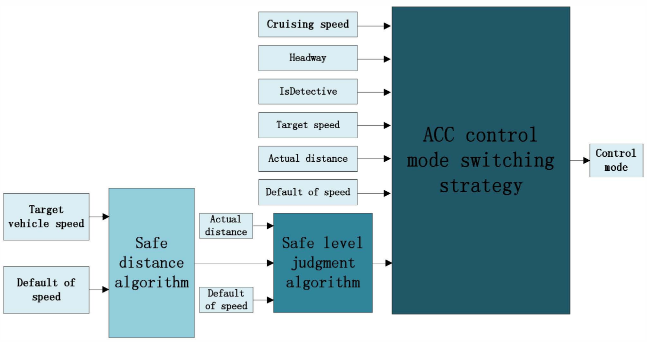

Figure 2. Control mode switching logic overall structure

When the vehicle in front of the no target vehicle, the vehicle is in a state of cruise control. The current party in a target vehicle and target speed is less than the default of the speed, actual distance is greater than safe distance of headway safety distance model calculated, when that [(V_target<=V_host)&&(D>(V_target*Tp+Min_distance)) &&(IsDetective==1)], control mode switch to accelerate control mode. The current party in a target vehicle and target speed is less than the default of the speed, through the safety distance model based on the braking process to calculate safe distance, then with the actual distance to get ratio, in combination with the speed information to calculate the safety factor is equal to 1, when that [(V_target<=V_host)&&(safe_out==1)&&(IsDetective==1)], control mode switch to decelerate control mode. The current party in a target vehicle and target vehicle speed is less than the default of the speed, through the safety distance model based on the braking process to calculate safe distance, then with the actual distance to get ratio, in combination with the speed information to calculate the safety factor is equal to 2, [(V_target<=V_host)&&(safe_out==2)&&(IsDetective==1)], control mode switch to emergency brake collision avoidance control mode. The current party in a target vehicle and target speed is less than the default of the speed of 2m/s, or the safety distance model based on the headway computation of safety distance and the actual distance is less than 0.5m/s, when that [(D-(V_target*Tp+Min_distance))<0.5],[(V_host-V_target)<2], control mode switch to stable follow control mode.

V. THE SIMULATION

Control mode switching logic according to the set of cruising speed, default of speed, headway, the target speed, actual distance and whether there is a valid target determine safe level to select the appropriate working mode. The simulation model as shown in the figure below:

Figure 3. Control mode switching logic overall structure

Adaptive cruise control in the task of each function is independent of each other, so under any control cycle, adaptive cruise control only under a certain control functions. Adaptive cruise control mode including: cruise control mode, accelerate control mode, stable follow control mode, decelerate control mode, emergency brake collision avoidance control mode. The system simulation model as shown in the figure below:

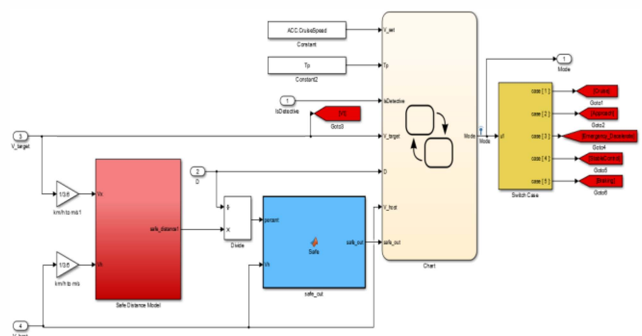

Figure 4. The system simulation model

Simulation experiment divided into five groups, the selection of variables is: whether there is a valid target, the local velocity, a target vehicle speed, the setted cruising speed, dangerous distance, headway, the safe distance, the system get these variables to determine safety coefficiency of grade, then to judge the control mode. The experimental simulation results shown in the table below:

TABLE I. THE EXPERIMENTAL SIMULATION RESULTS

Test	IsDetective	V_host	V_target	V_set	Min_distance	Tp	D	safe_out	Mode
1	0	20	0	20	3	1.5	0	0	1
2	1	30	20	20	3	1.5	40	0	2
3	1	30	20	20	3	1.5	30	1	3
4	1	30	20	20	3	1.5	20	2	5
5	1	22	20	20	3	1.5	33	0	4

VI. CONCLUSION AND THE APPLICATION

In this paper, the ACC control mode switching strategy for hierarchical safety distance model have been come up, considering the ACC work control mode, cruise control mode, accelerate control mode, stable follow control mode, decelerate control mode, emergency brake collision avoidance control mode can smoothly switch between each other. Through the safety distance model and dangerous condition judgment model to calculate the coefficient of safety level, to provide sufficient information for ACC control mode switching strategies, the simulation results shows that this method can well realize working mode switching.

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