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Longitudinal Control Strategy of Collision Avoidance Warning System for Intelligent Vehicle Considering Drivers and Environmental Factors

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Abstract—**The collision avoidance warning system, as an intelligent assistance driving technology, provides the driver a safety and comfortable driving experience, by transferring early warning signals to avoid collision while detecting potential danger. In view of the shortcomings of traditional safety distance models, this paper focuses on the driver style and environmental factors to establish novel models of warning distance, dangerous distance and expectation safety distance. The fuzzy control was used to analyze the relationship among driver style, environmental factors and vehicle velocity variable with the safety distance. Based on the relative distance and speed, a sliding mode variable structure control method was employed to get desired acceleration for the upper controller, and and a PID method was applied to design the lower controller. The tracking effectiveness of the controller was verified by numerical analyses. The simulating results show that the proposed system， which can enable the rear vehicle to follow the speed change of the front vehicle to remain the expectation safety distance, and to keep the running state safety.**

I. INTRODUCTION

According to the data of the National Bureau of Statistics of China, there were 129,000 traffic accidents and 42,000 deaths in 2015, which resulted in a great loss of life and property of the people [1, 2]. There are many factors contributing to traffic accidents, such as weather conditions, unreasonable vehicle distance and driver behaviors. Among them, driver factor is considered to be the main cause of the accidents. Additionally, vehicle safety distance is one of the most important indexes of traffic safety [3]. Consequently, it is necessary to establish a reasonable safety distance model, which can improve traffic efficiency and avoid collision to reduce traffic accidents. The vehicle collision avoidance system relates to the field of active safety technology, which has provided more comfortable and safer driving experience for drivers. The system detects the actual distance and relative speed between host vehicle and front vehicle, and makes early audio alarm to alert drivers of potential hazards. Therefore, the reasonable safety distance is a guarantee for the reliable work of the system. However, consideration of drivers and environmental factors has been scant in the existing vehicle safety distance model.

Many researchers have made research on safety distance and collision avoidance system. The safety distance calculation is an important technology in collision warning system. Y. L. Chen presented a novel algorithm for safety braking distance calculating between two driving cars [4]. However, the effects of the surrounding environment were ignored, although drivers' behaviors were considered. B. Wang analyzed the main influence factors affecting expectation safety distance in the actual car-following using one-way analysis of variance [5]. Besides, other safety distance models were proposed and adopt to judge the safety condition of the vehicle [6, 7]. About the control strategy research, some researchers applied fuzzy-based control to avoid collisions [8, 9, 10]. Moreover, in order to increase vehicle stability performance, cooperation of braking and active steering has also been applied by many researchers [11].

The safety distance is one of the references for drivers to judge whether the vehicle distance is safe. Considering driver factors and environmental factors, this paper focuses on vehicle safety distance models including warning distance, dangerous distance and expectation safety distance, based on fuzzy control. The new model could reflect the drivers' operating characteristics under different traffic conditions, and the flexibility and adaptability under different environment. Furthermore, the longitudinal control strategy is also one of the widely researched topics. The sliding mode control and PID control method were employed to get desired acceleration and control acceleration. Then, the collision warning system was established by using Simulink and CarSim co-simulation platform. The simulation results showed that the control system had good tracking performance and anti-collision effectiveness.

This paper is organized as follows. In Section II, a new algorithm of vehicle safety distance is comprehensively introduced. Section III describes the establishment of longitudinal control system. Section IV verifies the performance of the control system using simulations. Finally, conclusions are presented in Section V.

II. METHODOLOGY

The function of anti-collision warning system is to control the speed and maintain the safety distance, and at the same

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time, the system has to achieve high efficiency and save energy. For those purposes, this section establishes safety distance model, considering the driver style and environmental factors.

A. Traditional warning and dangerous distance model

Reasonable vehicle safety distance model can improve the traffic efficiency. At present, the main models are fixed distance model, time headway model, and driver estimation model. The parameters of each model are generally selected according to the experience, without considering the driver factors, road conditions, weather conditions, and other factors. The accuracy is difficult to guarantee. Combined with the vehicle kinematics and dynamics theory, when the front vehicle decelerates, the existing traditional safety distance model based on the braking process is as follows [12]:

$$D_{warn} = v_1(t_1 + t_2) + \frac{V_{rel}t_3}{2} + \frac{V_{rel}(v_1 + v_2)}{2a_m} + d_0 \qquad (1)$$

$$D_{danger} = v_1 t_2 + \frac{V_{rel}t_3}{2} + \frac{V_{rel}(v_1 + v_2)}{2a_m} + d_0 \qquad (2)$$

where D_{warn} is the warning distance, which is used to alarm, D_{danger} is the dangerous distance, it is automatic braking distance, V_{rel} is the relative velocity, v_1 is the velocity of the rear car, v_2 is the velocity of the front car, and t_i (i =1, 2, 3) is the reaction time of driver, braking coordination time, braking force growth time, respectively. For reducing the computational complexity, it takes t_2=0.3s, t_3=0.2s. a_m is the maximum braking deceleration of the ground, d_0 is the safety parking distance between two cars, and the empirical value usually is 5m.

B. Driver style and environmental factors

The reaction time of drivers is relevant to such factors as driving style, weather, velocity, continuous driving time, gender, age, and driving age. It is normally set between 0.3-1.5 s [12].

In this paper, there are three main factors including the driving style, weather conditions, and velocity related to the reaction time of the driver. Since these influencing factors impact on the safety distance with complexity and fuzziness, it is difficult to establish mathematical model. The fuzzy control is adopted to establish the fuzzy estimation model of driver's reaction time.

a) Driver style: According to psychological characteristics, it can be classified into aggressive, ripe and conservative. The fuzzy set is {aggressive, ripe, conservative}, and the domain scope is [1, 1.5].

b) Weather condition: The weather influences the psychological state and the load degree of the driver. It has a high visibility under the sunny weather. The driver has a small psychological load and an easy state, and reaction time is short. On the contrary, the driver has a low excitability and a long reaction time in the raining day. The visibility is low in fog and snow weather, which increases the driving uncertainty, and driver's attention is more concentrated. Therefore, weather differences can cause changes in braking time under emergency situation. The fuzzy set is {snow, fog, rain, sun}, and the domain scope is [0, 1].

c) Velocity: The drivers' degree of tension and attention are different at different speed. When the velocity is higher, the braking reaction time is shorter. The fuzzy set is {low, middle low, high, middle high, very high}, and the domain scope is [0, 120].

Road surface friction coefficient: which defined as ψ， It decides the maximum deceleration of the ground [14]. On the dry asphalt or concrete pavement, which belongs to good adhesion road, ψ=0.8, it takes $a_m = \psi$ *g=8m/s^2. On the wet asphalt pavement, ψ=0.5, it takes a_m = 5 m/s^2. On the snow pavement, ψ=0.2, it takes a_m = 2 m/s^2. In summary, as the output variable, the fuzzy set of the driver reaction time is {slow, middle, fast}, and the domain scope is [0.3, 1.5]. Its membership function is a triangle membership function.

C. Expectation safety distance based on driver and environmental factors

In the stable traffic flow condition, the expectation safety distance means the safety car-following distance, which can satisfy the driver's subjective expectation under certain road condition and velocity. Because of the difference of driver style and road condition, the fuzzy control is applied to establish the mathematical model, according to experience and reference documents. Considering the driver's age, experience and character differently, we can obtain the optimized INTELSIM expectation safety distance model is as follows:

$$D_{des} = v_1 * f_{(Driver)} * t_0 + d_0 \qquad (3)$$

Note that, t_0 is the time headway, and $f_{(Driver)}$ is the option coefficient of the driver style. The selection of $f_{(Driver)}$ is as follows:

$$f_{(Driver)} = \begin{cases} 1, aggresive \\ 1.25, ripe \\ 1.5, conservative \end{cases} \qquad (4)$$

The selection of $f_{(Driver)}$ depends on the driver's self-perception. For example, an unskilled novice driver can choose to drive in a conservative style.

About the selection of the time headway, in the stable traffic flow, the driver will predict driving tendency according to relative speed and relative distance, then follow the front car with the appropriate time headway. Sometimes, the time headway may be lower than the driver's reaction time.

In order to enable the vehicle maintain the desired safety distance, the fuzzy set of the relative distance is {very small, small, middle, big, very big}, as the fuzzy input variable, the domain scope is [0,100]. The other input variable, the vehicle speed, uses previous fuzzy settings. The fuzzy set of time headway is {very small, small, middle, big, very big}, as the fuzzy output variable, the domain scope is [0, 3].

The Mamdani reasoning method and the center of gravity method were used to make the inverse model gelatinization. Then the result can be obtained by fuzzy toolbox of MATLAB.

The improved safety distance model considers the difference of driver style and environment condition factors.

TABLE I. COMPARISON OF THE IMPROVED AND TRADITIONAL WARNING & DANGEROUS DISTANCE

Weather	Road Condition	Driver Style	Rear car velocity 60 km/h		Rear car velocity 100 km/h	
			Improved Warn/Danger distance (m)	*Traditional Warn/Danger Distance (m)*	*Improved Warn/Danger distance (m)*	*Traditional Warn/Danger distance (m)*
Sun	Dry bitumen 0.8	Aggressive	40.05/11.75	46.22/12.14	86.12/38.75	94.38/41.22
		Ripe	42.05/11.86		90.36/41.42	
		Conservative	44.35/12.7		94.39/44.41	
	Gravel road 0.5	Aggressive	45.95/11.69	52.12/12.79	102.5/44.65	110.8/47.12
		Ripe	46.89/12.52		104.1/47.15	
		Conservative	48.51/13.35		106.3/50.32	
Rain	Wet bitumen 0.6	Aggressive	48.51/11.69	56.84/13.32	124.7/44.64	123.9/51.85
		Ripe	50.6813.04		127.6/51.88	
		Conservative	53.98/13.35		129.7/53.32	
Fog	Dry bitumen 0.8	Aggressive	46.71/11.03	46.22/12.14	95.21/38.75	94.38/41.22
		Ripe	48.32/11.86		97.56/41.42	
		Conservative	49.89/12.7		99.43/44.41	
Snow	Ice 0.2		100.1/19.1	94.36/18.04	242.8/97.76	233.7/94.36

Assuming that the front car is stationary, the rear car approaches the front car with the speed of 60km/h and 100km/h, separately. The results are shown in TABLE 1. From the results, it is seen that the improved safety distance model changes with the different parameters. Under the same road condition and different drive styles, the safety distance is different. Under the same driver style and different road condition or weather, the safety distance is different, too. It is indicated that the proposed model has a good dynamic adaptability.

III. SIMULATION

The longitudinal control module of the collision avoidance system mainly includes safety distance model, inverse dynamics model, vehicle dynamics model and layered controller model.

A. Longitudinal dynamics model and control architecture

The dynamics simulation software CarSim can be used to simulate the vehicle longitudinal dynamics model. The rear vehicle model is the D level SUV with the engine power 250 KW, and the front vehicle is minivan with the engine power 270 KW.

In the vehicle anti-collision warning system, the upper level controller decides the desired acceleration based on relative distance and relative velocity. The lower level controller decides the desired throttle value or brake pressure [10, 11, 13]. Some researchers have developed the lower level controller, which determines control input variables by using inverse dynamics model. The hierarchical control structure is shown in Fig. 1. The maximum and minimum accelerations are limited in 0.25 g and -0.5 g.

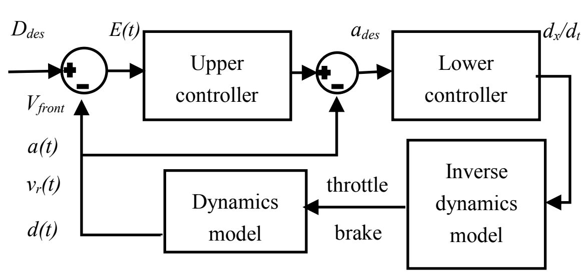

Figure 1. Longitudinal control pattern structure diagram.

B. Establishment of inverse dynamics model

a) Calculation of the desired throttle: By simulating in CarSim software, the opening value of throttle under a certain speed and acceleration can be obtained. It should be inputted into 2-Lookup Table in Simulink.

b) Calculation of the braking pressure: In the vehicle longitudinal dynamics system, the vertical force balance equation along the longitudinal direction is as follow, during the braking process.

$$ma_{des} = F_t - F_{bdes} - \Sigma F(v) \tag{5}$$

The driving force is zero, $\sum F\ (v)$ is the sum of resistance. Only the air resistance and rolling resistance are considered, without considering the climbing resistance. Under the condition of not exceeding the maximum braking force, the desired braking pressure has an approximate linear relation with the desired braking force.

$$F_{bdes} = K_b \bullet P_{des} \tag{6}$$

K_b is the ratio of the braking force to the brake pressure in the brake line. In CarSim software, it is shown as follows:

$$K_b = \frac{T_{bf} + T_{br}}{rP_b} \tag{7}$$

T_{bf} and T_{br} correspond to the brake torque of front wheels and rear wheels. Here r denotes the rolling radius of tire and P_b presents the braking pressure. Joint up:

$$P_{des} = \frac{(-a_{des} - \frac{1}{2} C_d A \rho \upsilon^2 - mgf)}{K_b} \tag{8}$$

c) Determination of the acceleration/deceleration switching curve: The frequent switching between acceleration/braking during the vehicle cruising will damage the engine and transmission system. To prevent this, it's necessary to draw the acceleration/deceleration switching curve. The car model is set up by using the CarSim software. The initial speed is 200km/h, the throttle value is zero, the braking force is zero, and the friction coefficient is 0.85, until the car auto stop. The relationship switching curve of velocity and acceleration is drawn. As the blue line shown in Fig. 2, the floating buffer area lies between the black and red line (the upper and lower threshold line), which ranges from -0.2 to 0.2.

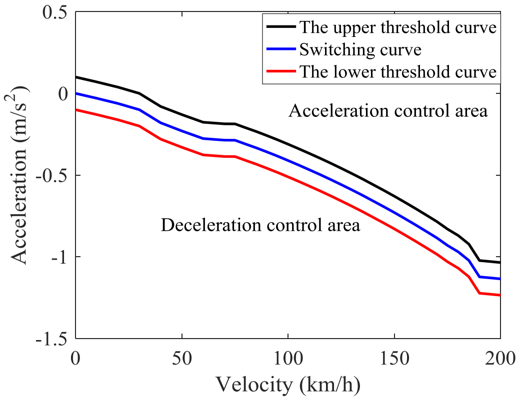

Figure 2. Acceleration and deceleration switching curves.

C. Layered controller design

The upper controller is mainly used to determine the desired acceleration at present, according to the relative distance, relative speed and actual acceleration. Sliding mode control is a kind of nonlinear control strategy of variable structure control system. It has good characteristics that the system structure changes with time. The control characteristics can make the state of the system moving along the sliding mode, called switching surface, and switch the control input on this surface. The sliding mode is independent of the parameter and disturbance of the system, and the robustness is better.

The distance error and speed error are defined as follows:

$$e(t) = D_{fact}(t) - D_{des}(t) \tag{9}$$

$$\dot{e}(t) = v_2 - v_1 \tag{10}$$

Sliding surface is defined as follows:

$$S = \dot{e} + \lambda_1 e + \lambda_2 \int_0^t e dt \tag{11}$$

Where λ_1, λ_2 are sliding surface gain and strictly positive, satisfied the Hurwitz condition. After derivation:

$$\dot{S} = a_2 - a_1 + \lambda_1 \dot{e} + \lambda_2 e \tag{12}$$

Using the law of exponential convergence:

$$\dot{S} = -b \operatorname{sgn} s - ks \qquad b > 0, k > 0 \tag{13}$$

The constant b represents the rate of the moving point moving towards to the sliding surface. If the constant b is small, the approaching speed is slow. If the constant b is large, it will cause great jitter when the moving point reaches the sliding surface. The desired acceleration is as follows:

$$a_{des} = a_1 = a_2 + \lambda_1 \dot{e} + \lambda_2 e + b \operatorname{sgn}(S) \tag{14}$$

After the differential calculation of the Lyapunov function, the results are obtained:

$$\dot{V} = \left(\frac{1}{2} S^2\right)' = S\dot{S} = -S\beta \operatorname{sgn}(S) = -|S|\beta \tag{15}$$

By the Lyapunov stability criterion for β>0, To arbitrarily, $t \in (0, +\infty)$, $\hat{V}$<0, the control system is stable.

As the conventional control method, PID can determine the control coefficient by experience and trial independent of the mathematical model. Therefore, the lower controller is verified based on the PID method, as shown in Fig. 3. Different method application will affect the performance of controller, so it's meaningful to contrast PID performance with the others'. The model-matched robust controller, as shown in Fig. 4, is employed to do the comparison and analysis based on the literature [10].

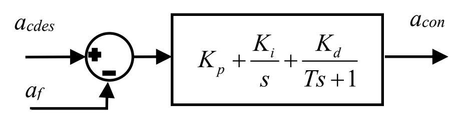

Figure 3. PID control.

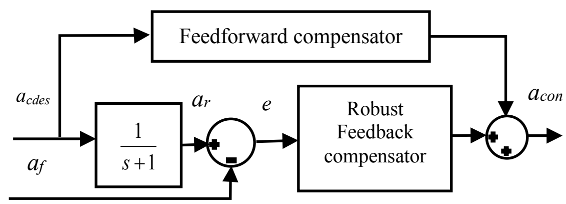

Figure 4. Model-matched robust control.

IV. RESULTS

The vehicle dynamics module is imported from CarSim, and the upper and lower controller module input the desired variable to the vehicle dynamics model. The safety distance module considers the driver style and environmental factors。

The vehicle simulation environment parameters are analyzed on the assumption that the road is dry asphalt pavement, the weather is a sunny day, and the driver style option is the ripe driving style.

Simulation result 1: The front car's speed is 60km/h, the rear car's speed is 70km/h, and the initial distance is 40m. The simulation result of velocity is shown in Fig. 5. The results indicate that the rear car cruise with the front car in a proper velocity. When the lower controller is PID, the rear vehicle speed represented by the red dash dot can track the front vehicle speed represented by the black line 6 seconds later. Under the control of the model matched robust control, due to the large influence of the acceleration fluctuation, the speed is unstable, as is shown by the blue line.

The simulation result of distance is shown in Fig. 6. Based on the PID lower controller, it shows that the actual distance represented by the black curve is gradually close to the desired safety distance represented by the red dash dot, from the initial 40m to 32m. The desired safety distance follows the front car speed and is larger than the warning distance of 22m represented by the blue dash dot and 10m of the dangerous vehicle distance represented by the carmine line. The running state is safety without triggering alarm.

The acceleration curve based on PID is shown in Fig. 7. The red dash dot represents the actual acceleration, and it has a quick response to the desired acceleration represented by the black line, with fast reaction speed and good dynamic characteristics. Although the maximum error is 0.5m/s^2 at the beginning, it will gradually become stable when the rear vehicle tracks the front car's speed. The desired and actual acceleration have a steady static error range [-0.1, 0.1] m/s^2.

The acceleration curve based on the model-matched robust controller is shown in Fig. 8. The reaction of actual acceleration represented by the green dash dot lags behind, and there is large error between the desired acceleration represented by the black line. Because this controller relies on accurate vehicle model The maximum error is large, more than 1m/s^2. When the velocity keeps stable, the steady error of acceleration approaches zero nearly. It means that the control precision is high. Therefore, when the error is large, the speed can be controlled by PID, and the accuracy can be emphasized.

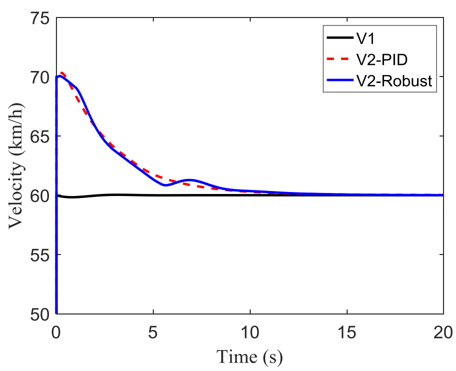

Figure 5. Velocity curve based on PID and robust controller.

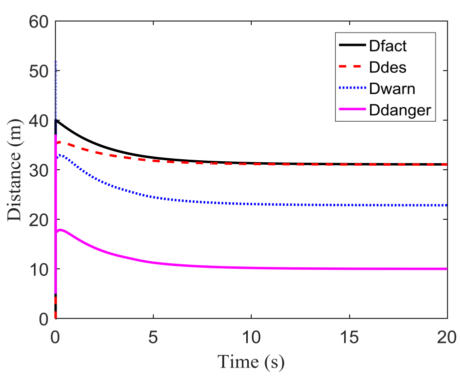

Figure 6. Distance curve based on PID in lower-level controller.

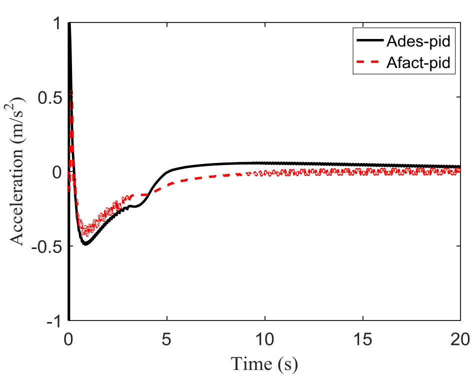

Figure 7. Acceleration curve based on PID controller.

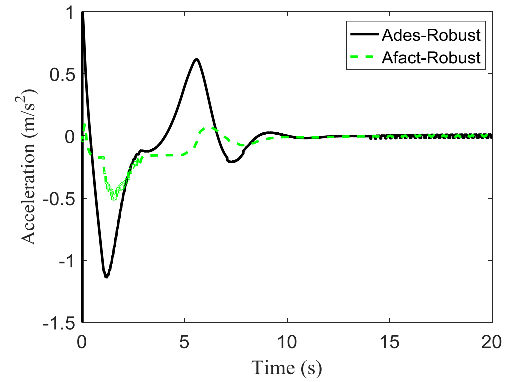

Figure 8. Acceleration curve based on robust controller.

Since the front car's driving condition is uncertain, such working condition as acceleration, deceleration and constant speed of the front vehicle are considered in this part.

Simulation result 2: The front car's speed is consumed to fluctuate from 30km/h to 90 km/h, and the initial vehicle distance is set to 30 meters. The simulation result of the velocity is shown in Fig. 9. The black line represents the front vehicle speed change, the initial speed of the front car is 60km/h. The rear car can keep up with the speed of the front car in 5s, and follow the leading vehicle speed. The tracking result is shown as the red line.

The simulation result of the distance curve is shown in Fig. 10, the PID controller is adopted. During the driving process, the actual distance represented by black line tracks the desired safety distance represented by the blue line. In the beginning, early warning happens because of the high initial speed and small distance. After the tracking speed is stable, the actual distance is greater than the early warning distance represented by green line and dangerous distance represented by red line. The running state is safety without triggering alarm.

The simulation result of the acceleration curve is shown in Fig. 11, the maximum acceleration occurs at the beginning of tracking, most of the value of the actual acceleration represented by red line changes in the range of -0.3 to 1 m/s^2, which fits human comfort requirements. And the error between the actual and desired acceleration represented by black line ranges from -0.08 to 0.08.

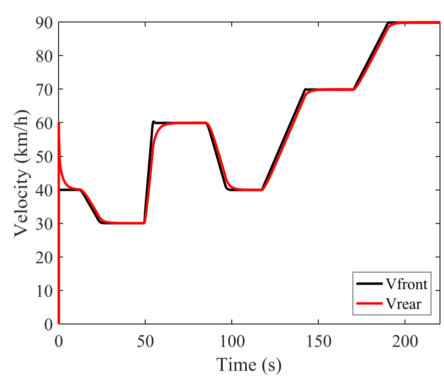

Figure 9. Velocity curve based on PID in lower-level controller.

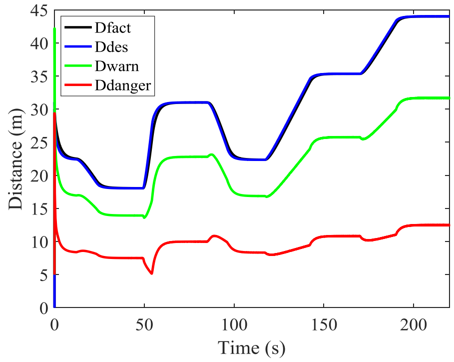

Figure 10. Distance curve based on PID in lower-level controller.

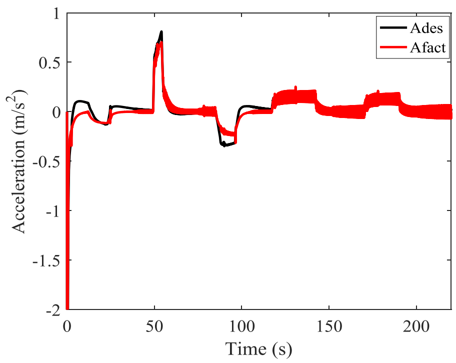

Figure 11. Acceleration curve based on PID in lower-level controller.

V. CONCLUSIONS

A new safety distance model was proposed in order to adapt the change of traffic condition and driver style, and the collision avoidance warning system combined with the longitudinal dynamics model was established. The main contents are concluded as follows:

(1) The improved safety distance model was established by considering the driver style (aggressive, ripe, conservative), weather conditions (snow, fog, rain, sun), and vehicle speed variable. The driver's reaction time and time headway were obtained by using the fuzzy control method. Besides, the friction condition of pavement was considered. The new models were able to adapt to the changes of environment, and meet driver's expectation.

(2) Based on the relative distance, speed and acceleration, the upper level controller employed sliding mode control to obtain the desired acceleration. The lower level controller employed PID controller to get the desired throttle value and brake pressure based on the inverse dynamics model. Simulation results show that the rear car can follow the front car within the range of expectation safety distance. And the actual distance was greater than warning and dangerous distance. The results indicated that our designed controller achieved effective tracking performance，and reflected the driver's characteristics.

With respect to the establishment of safety distance model, the influencing factors are numerous and coupled with each other. About the topics for the further research, driver car-following experiments will be designed to verify whether the expectation distance meets the driver's car following habits. More vehicle evaluation and tests of the proposed control strategy will be performed. It also gives a reference to future energy vehicle safety control and assistance driving technology.

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