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Simulation of Automotive Anti-Collision System using Matlab

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ABSTRACT:

The traffic accident is a major hazard in modern society. Automotive anti-collision system is an advanced security technology based on intelligent transportation system. Researchers worldwide have carried out relevant studies which are helpful to improve the road traffic safety and reduce the rate of traffic accident. In this paper, first functions of each part of the system are modelled to form the model of the whole part. According to the characteristics of automotive dynamics system and the characteristics of actuator structure, dynamics model of automatic anti-collision system are developed to simulate the complex process of the vehicle mobility. Some functions of the developed system are verified by simulation using Matlab. The system shows good control on the vehicle speed and safety stopping distance.

KEYWORDS:

Automotive anti-collision system; Model; Simulation; Matlab

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1. Introduction

With the development of China's economy, more and more families start to own cars. The traffic also became intensive. Due to the increase of traffic accident, technologies about vehicle safety have attracted more attention. Because of the uncertainty and complexity of vehicle driving environment, the automotive anti-collision system is required to perceive the changes in the external environment and make early alarm and prevention of the risk [1]-[3]. Researches on the automotive anti-collision system first originated from the developed countries such as Germany, the United States and Japan. Later, Japan in making plan of future vehicle development, also explicitly puts the development of more complex intelligent vehicle and driving safety supporting system as one of the key technologies in traffic safety. Toyota Motor Corporation has developed the active prevention security system.

The domestic researches in anti-collision system a China were started a little late. Ying and Ke [4] have discussed the system and chip based automotive anti-collision system on the basis of the understanding principles of range and velocity measurement. They proposed an automotive anti-collision system which applies SOC and ultra wideband wireless location technology. Xinghua and Yida [5] studied the power control of intelligent automotive anti-collision system. They designed the hardware circuit of the power control module. Based on feedback linearization inverter control algorithm and with the idea of bidirectional flow compensation, different brake pressures were used in the electromagnetic valves of each wheel control, thereby improved the power control algorithm of the intelligent automotive anti-collision system. Xinyu [6] designed and analyzed the DSP system on the basis of combining DSP technology and modern high speed circuit design technology which can be used to implement the pre-warning function of automotive anti-collision system. The anti-collision system can also be applied to other fields, such as coal industry [7], airport [8] [9] and locomotive [10]. This paper presents the establishment of new automotive anti-collision motion model. On the basis of vehicle dynamics and control theory, the functioning of automotive anti-collision system is studied. At last, the system is verified by simulation using the MATLAB software.

2. Automotive anti-collision model

In this paper the motion models for the side and non-side anti-collisions are established. Two-dimensional Cartesian coordinate system is established as the car moving in the positive direction of Y-axis. The angle between the line connecting the target point and origin of coordinate and the positive direction of Y-axis is called the azimuth angle. If the target is at right of Y-axis, it is positive; if the target is at left of Y-axis, it is negative. The angle that the axis of vehicle moving direction passing by is called relative angle θ. It is positive at clockwise direction and negative at counter clockwise direction. The physical quantities azimuth angle α and relative angle θ used in this paper are explained as follows:

$$0 \le |\alpha| \le 180 \text{ and } 0 \le |\theta| \le 180$$

2.1. Non-side anti-collision model

The non-side collisions are shown in Fig. 1. For the non-side anti-collision, it is known that:

$$\{D / L \le \sin|\alpha| \le 1 \quad \textit{and} \quad 0 \le |\theta| \le 180 - |\alpha|$$

Suppose that the target B is in the second quadrant and is regarded as a particle, vehicle A and vehicle B speed up and collide at O after time as shown in Fig. 2. From kinematics, the following motions are established,

$$\begin{cases} S_{BO} = v_B T + \frac{1}{2} a_B T^2 \\ S_{AO} = v_A T + \frac{1}{2} a_A T^2 \\ \frac{L}{\sin|\theta|} = \frac{S_{BO}}{\sin|\alpha|} = \frac{S_{AO}}{\sin(|\theta| + |\alpha|)} \end{cases}$$

Then, the following equations can be obtained:

$$S_{BO} = \frac{v_B a_A - v_A a_B}{a_A^2}\left(-v_A \pm \sqrt{v_A^2 + \frac{2a_A L \sin(|\theta| + |\alpha|)}{\sin|\theta|}}\right) + \frac{L a_B \sin(|\theta| + |\alpha|)}{a_A \sin|\theta|}$$

$$T = \frac{1}{a_A}\left(-v_A \pm \sqrt{v_A^2 + \frac{2a_A L \sin(|\theta| + |\alpha|)}{\sin|\theta|}}\right)$$

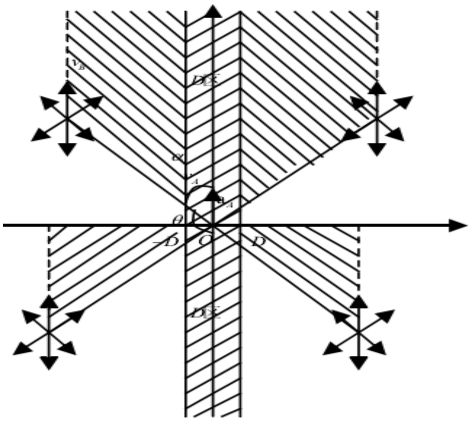

Fig. 1: Anti-collision zone in different directions

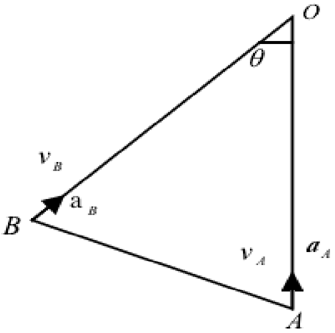

Fig. 2: Collision trajectory model with single target

2.2. Side anti-collision model

From Fig. 1, for side anti-collision, it is known that:

$$\begin{cases} 0 \le \sin|\alpha| < \frac{D}{L} \\ 0 \le |\theta| \le 180 \end{cases}$$

Motions of the target at any directions can be decomposed into motions at X-axis and Y-axis. There is no target in X-axis at L=0. Dividing the targets at D area into two areas with X-axis as the boundary and for $v_B = 0$ and $|\alpha| < 90$, the following can be arrived,

$$v_A T + \frac{1}{2} a_A T^2 = L\cos|\alpha|$$

$$T = \frac{-v_A \pm \sqrt{v_A^2 + 2a_A L\cos|\alpha|}}{a_A}$$

When $a_A = 0$, $T = L\cos|\alpha| / v_A$.

2.3. Vehicle longitudinal dynamics model

From the relationship between corresponding torque and transfer speed of vehicle dynamics model, the vehicle longitudinal dynamics model can be obtained as follows:

$$\begin{cases} \frac{f_e(\omega_e, \alpha) - (T_p + 0.3\dot{T}_p)}{0.11} = \dot{\omega}_e + 0.3\ddot{\omega}_e \\ T_p = 15.786\left(\frac{vR_g}{r_r \omega_e}\right) = \omega_e^2 \\ T_t = K_{tc}\left(\frac{vR_m R_g}{r_r \omega_e}\right)\omega_e^2 \tau\left(\frac{vR_m R_g}{r_r \omega_e}\right) = 249.189\tau R_g^2 v^2 \\ 15.154T_0 - 1185P_b - 245 = 1296v + 0.665v^2 \end{cases}$$

The above equation takes the throttle opening α and a brake pressure P_b as the input to output the vehicle speed and acceleration. This equation contains five states (engine speed ω_e, pump wheel torque T_p of hydraulic torque converter, the torque converter turbine torque T_t of hydraulic torque converter, torque and transmission ratio R_g of automatic transmission and vehicle speed v).

2.4. Vehicle inverse longitudinal dynamics model

The implementation of automotive automatic anti-collision system needs to use the vehicle inverse longitudinal dynamics model. The input of inverse longitudinal dynamics model is the expected acceleration with the output being the expected throttle opening and braking pressure. Its structure is shown in Fig. 3. After switching the control of engine torsion output and control of brake torque, the expected throttle opening can be calculated according to the requirements of the expected acceleration. During this process, calculation of expected engine torsion and inverse engine models are needed. Expected acceleration is represented as $\dot{v}_{des}$, and the vehicle motion equation is expressed as:

$$M\dot{v}_{des} = F_d - F_b - F_f(v)$$

Where F_d represents the driving force on the vehicle produced by the engine driving acting on the road. F_b represents the braking force on the vehicle produced by braking effect acting on the road; represents rolling resistance, $F_f(v)$ wind resistance, engine dragging backward resistance, and other various resistances. According to part of the above algorithm, the expected engine torque T_{des} is given by,

$$T_{des} = \frac{M\dot{v}_{des} + F_f(v)}{k_d} = \frac{1250\dot{v}_{des} + 245 + 0.665v^2}{k_d}$$

Based on the expected engine torque and engine speed, the expected throttle opening can be obtained by the inverse engine model:

$$\alpha_{des} = f_{ie}(T_{des}, \omega_e)$$

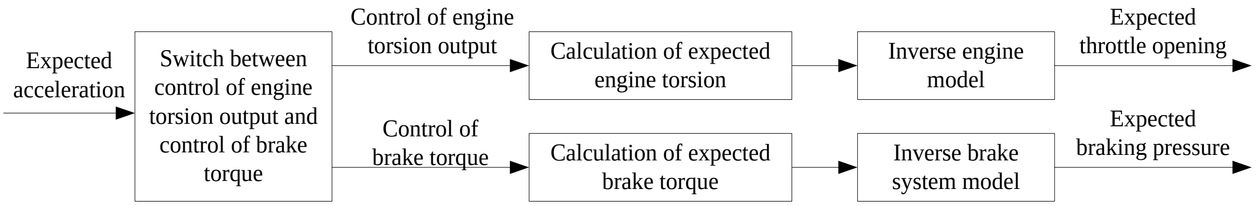

Fig. 3: Vehicle inverse longitudinal dynamics model

After switching control of engine torsion output and control of brake torque, the expected brake pressure can be calculated according to the requirements of the expected acceleration. During this process, calculation of expected brake torque and inverse brake system model are needed. The expected brake pressure is given by,

$$P_{des} = \frac{M\dot{v}_{des} + F_f(v)}{k_{pf}} = \frac{1250\dot{v}_{des} + 245 + 0.665v^2}{1185}$$

2.5. Brake actuator model

The electric motor raises the pressure of brake fluid through oil pump and stored it in the accumulator. The brake actuator controller through the PWM controlling signal controls the opening and closing of the pressure raising valve and pressure reducing valve. When pressure raising valve opens and pressure reducing valve closes, pressure oil in the accumulator flow into the brake pipe through the ABS device, increasing the brake pressure and resulting in brake effect. When pressure reducing valve opens and pressure raising valve closes, pressure oil in the brake pipe flow back to the oil box, reducing the brake pressure and weakening and eliminating the brake effect. The brake actuator controller realized the expected brake pressure through reasonable control of pressure reducing valve and pressure raising valve. According to the characteristics of the hydraulic systems, take a first-order inertia system model as brake actuator model that contains the controller as follows,

$$P_{des} = t_p\dot{P}_b + P_b$$

In the equation above, P_{des} refers to the expected brake pressure; P_b refers to the actual brake pressure of brake actuator; t_p refers to constant of the first-order inertia system which according to the experimental data is 0.1. The brake actuator model is:

$$P_{des} = 0.1\dot{P}_b + P_b$$

2.6. Dynamics model of anti-collision system

Combining the vehicle longitudinal dynamics model and vehicle inverse longitudinal dynamics model by controlling the executer model to obtain the automotive anti-collision system dynamics model which takes the expected acceleration as inputs and the speed and acceleration of a vehicle as outputs as follows,

$$\frac{f_e(\omega_e, \alpha) - \left(T_p + 0.3\dot{T}_p\right)}{0.11} = \dot{\omega}_e + 0.3\ddot{\omega}_e$$

$$T_p = K_{tc}\left(\frac{vR_mR_g}{r_r\omega_e}\right)\omega_e^2 = 15.786K_{tc}\left(\frac{vR_g}{r_r\omega_e}\right)\omega_e^2$$

$$T_t = K_{tc}\left(\frac{vR_mR_g}{r_r\omega_e}\right)\omega_e^2\tau\left(\frac{vR_mR_g}{r_r\omega_e}\right) = 249.189\tau R_g^2v^2$$

$$15.154T_0 - 1185P_b - 245 = 1296v + 0.665v^2$$

$$T_{des} = \frac{M\dot{v}_{des} + F_f(v)}{k_d} = \frac{1250\dot{v}_{des} + 245 + 0.665v^2}{k_d}$$

$$\alpha_{des} = f_{ie}(T_{des}, \omega_e)$$

$$P_{des} = \frac{M\dot{v}_{des} + F_f(v)}{k_{pf}} = \frac{1250\dot{v}_{des} + 245 + 0.665v^2}{1185}$$

$$\alpha_{des} = 0.01\ddot{\alpha} + 0.1\dot{\alpha} + \alpha$$

$$P_{des} = 0.1\dot{P}_b + P_b$$

3. System simulation

Matlab Simulink is used to simulate the function of controller in the developed automotive anti-collision system, mainly the aspects of vehicle speed and safe distance. A collision vehicle is assumed to be rapidly approaching the self vehicle at a speed of 50km/h vehicle from 50m distance. At this time, the speed of self vehicle is considered as 80km/h. The vehicle speed and safe distance are controlled by the Simulink controller. The response diagram of speed and time is shown in Fig. 4. The response diagram of distance and time is shown in Fig. 5. For this considered cases, the safety distance is 33.6m. As the speed of self vehicle is significantly higher than that of the front vehicle, the two vehicles are approaching gradually. When the actual distance is less than the safe distance (about 2s), throttle executer of automotive automatic anti-collision system controls the vehicle speed and the speed of vehicle begins to be reduced, making the actual distance maintained beyond the safe distance. The speed of self vehicle ultimately tends to be 50km/h (i.e. front vehicle speed).

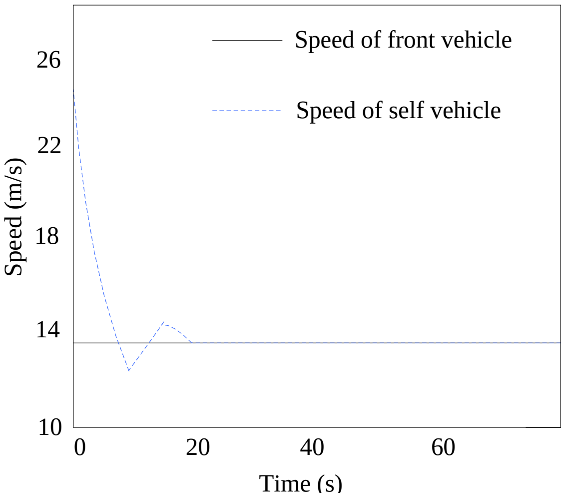

Fig. 4: Response diagram of speed and time

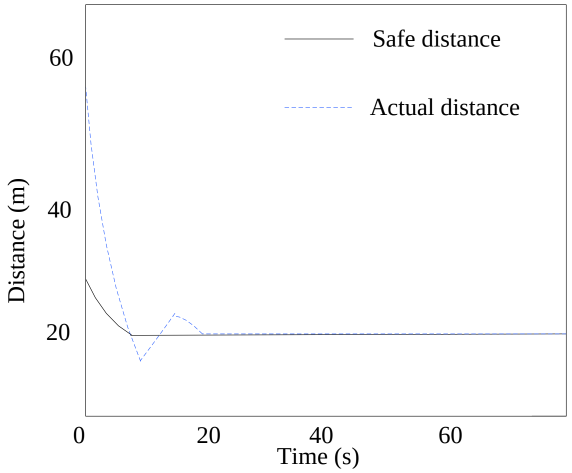

Fig. 5: Response diagram of distance and time

When the self vehicle is running at 65km/h speed and suddenly a vehicle runs in front of the self vehicle from the other lane at 72km/h speed, the response diagrams of speed & time and distance & time are shown in Fig. 6 and Fig. 7 respectively.

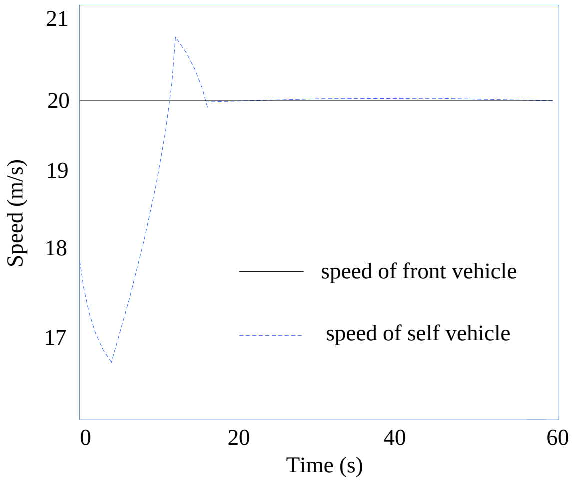

Fig. 6: Response diagram of speed & time

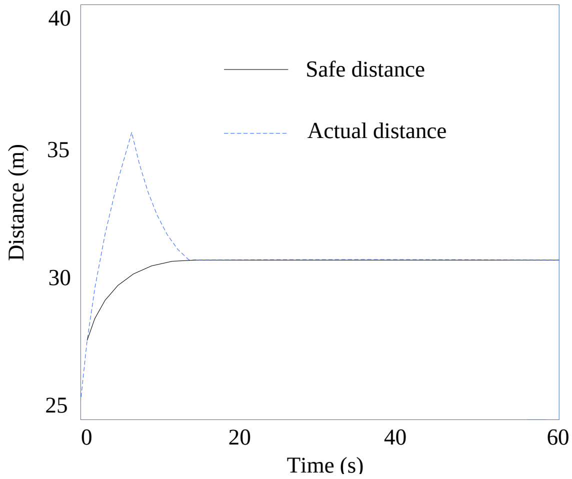

Fig. 7: Response diagram of distance & time

4. Conclusions

In this paper, new automotive anti-collision system models were developed and then simulated using Matlab Simulink. The developed automotive anti-collision dynamics system model can accurately simulate the dynamics of the actual system for a given control parameters of vehicle. Using the designed upper and lower controllers, the safe distance and vehicle speed as obtained by Matlab Simulink kept the vehicle in a safe distance, preventing the occurrence of rear-end collision. Further work involves the consideration of whole system function instead of part of the vehicle system model.

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