Design of advanced emergency braking system based on vehicle-road cooperation

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ABSTRACT

In this paper, a technical solution for the integration of vehicle-road cooperation and advanced emergency braking system is proposed. Firstly, the problems existing in the practical application of the system are analyzed, and the application scenarios are summarized by multi-level screening method. According to the different functional requirements of application scenarios, the overall system architecture and control strategy algorithm are put forward.

Keywords: AEBS, V2X, Control Strategy, System design.

1. INTRODUCTION

AEBS is internationally recognized as the most effective and realistic active safety technology to reduce the occurrence of crashes and reduce the fatality rate. [1] Europe, Japan, United States and China are developing relevant standards and regulations to promote the application of AEBS on all vehicle types. The Insurance Institute for Highway Safety (IIHS) estimates that AEB could prevent roughly 28,000 crashes and 12,000 injuries by 2025. However, there are still many aspects of AEBS technology that need to be improved, for example, in bad weather and special road sections the system does not work properly leading to failure or withdrawal, which seriously affects the expected safety effect of the system. Vehicle-Road cooperation technology can provide a high-precision and highly reliable way to obtain road and vehicle information for AEBS systems. [2]This paper proposes a design scheme of advanced emergency braking system applying vehicle-road cooperation technology, with the goal of improving the accuracy of target recognition and the accuracy of kinds and decisions of the system in complex traffic environment.

2. APPLICATION SCENARIO RESEARCH

The application scenario mainly adopts the research method of multi-layer filtering and screening, and the filtering guidelines mainly include three layers, the first layer is the accident risk guideline layer, which aims to screen out all scenarios of collision prevention and control needs; the second layer is the safety protection guideline layer, which aims to screen out scenarios where AEBS cannot be effectively prevented and controlled at present; the third layer is the technology adaptation guideline, which aims to screen out AEBS failure scenarios that can be obviously optimized and enhanced by using V2X, and the multi-layer filtering and screening process of the application scenario as shown in Figure1.

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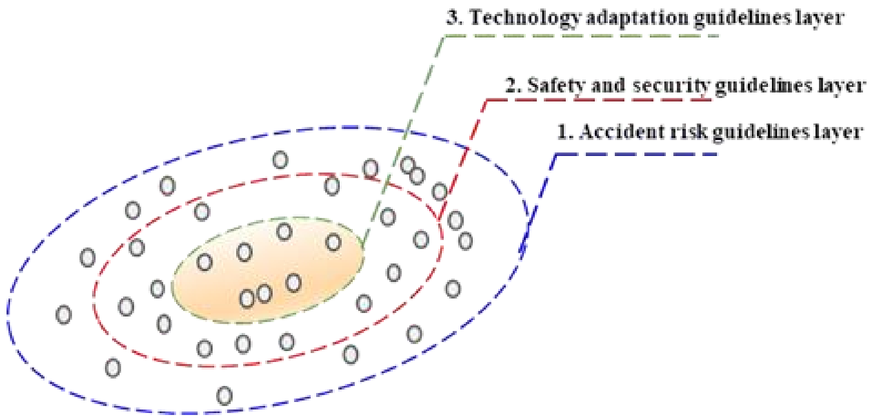

Fig.1 Multi-layer filtering and screening process of the application scenario

In the first accident risk guideline layer, the characteristics of traffic accidents in China are further analyzed based on the statistical data of the Annual Report on Road Traffic Accident Statistics, and collisions are classified in three dimensions: "casualties", "property damage" and "road type", and the current high-risk collision scenarios are summarized. [3]

In the second safety prevention and control guideline layer, the current collision prevention and control system (AEBS) failure scenarios are summarized by the six-layer functional decomposition method, [4] removing the set of scenarios that have been effectively solved in the high-risk accident scenarios in the first guideline layer, and retaining the set of scenarios that cannot be effectively prevented and controlled by AEBS in the high-risk collision scenarios.

In the third technology adaptation criterion layer, the expert research method was used to select the scenarios from three dimensions of technical maturity, safety necessity and implementation cycle of vehicle-road cooperation. The scenarios assembled in the second layer were staged and converged, and the scenarios with *higher* technical maturity and stronger necessity were finally adopted as the application scenarios of V2X-AEBS.

It is found that V2X-AEBS application scenarios mainly focus on the optimization and enhancement of the perception and decision-making stages of the system, and at this stage, the two scenarios are mainly classified as "Road" and "Environment"， The V2X-AEBS segmentation scenario design is shown in Figure 2.

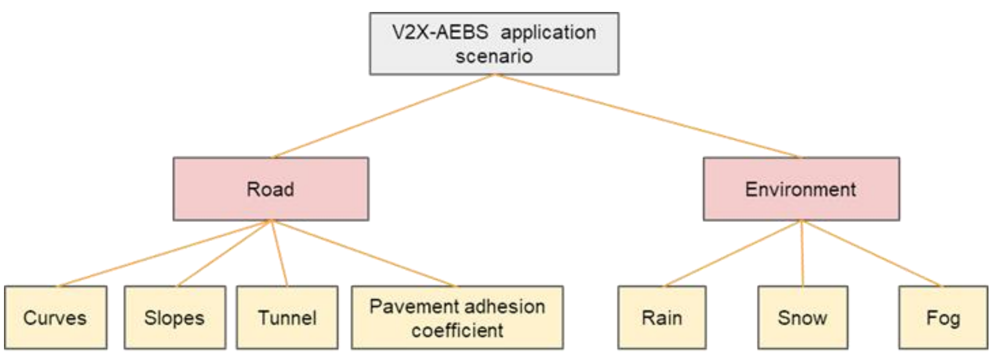

Fig.2 V2X-AEBS segmentation scenario

3. GENERAL SYSTEM ARCHITECTURE DESIGN

V2X-AEBS mainly consists of two parts: vehicle-side and road-side. The vehicle-side part mainly includes camera and radar as well as AEBS control unit, and OBU; the road-side mainly includes Converged sensing devices and RSU, The roadside and vehicle-side communication is compatible with both LTE-V/DSRC, [5]and the vehicle-side sensors and control unit and OBU communicate via CAN bus. The system architecture is shown in Figure 3.

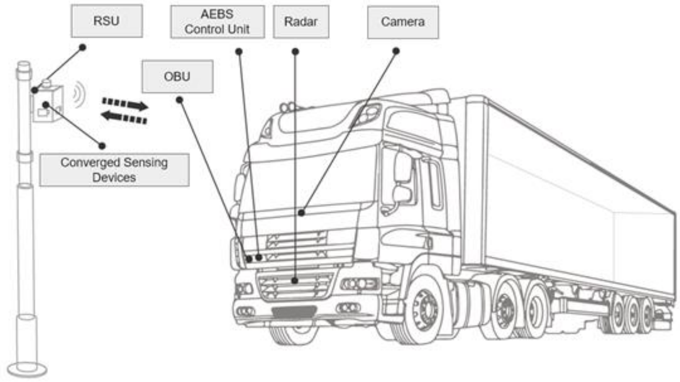

Fig.3 V2X-AEBS architecture schematic

The V2X-AEBS works by the following steps:

Step 1: The RSU senses to obtain the information of the collision risk target and the road attachment information, and also sends it in the form of broadcast in combination with the weather information in the area.

Step 2: OBU determines the danger status by fusing its own high precision positioning as well as the received RSU information and its own sensor information.

Step 3: Determine the existence of a collision state by first warning the driver through vision and hearing.

Step 4: the vehicle is dynamically optimized by vehicle road information for vehicle speed and emergency brake trigger moment control algorithm.

Step 5: the driver is still not taking control measures such as braking or steering after the warning, the vehicle in accordance with the threshold value calculated in the fourth step, the vehicle braking control to help the vehicle to avoid collisions.

4. CONTROL STRATEGY ALGORITHM DESIGN

4.1 Advanced emergency braking model selection

From the perspective of the composition of the advanced emergency braking system, the technical difficulties of the current control strategy research are focused on the identification and screening of dangerous targets, the algorithm model and the stability of the system, etc. The existing control strategies include: based on the safe distance model, based on the safe time model, based on the driver's subjective feeling model, etc. [6] [7]

The model based on collision time distance has the advantages of adjustable control and easy calibration widely used in the AEBS control algorithm for all kinds of vehicles, but because the object of this paper requires precise adjustment of vehicle control parameters, the model based on safety distance is selected as the target model, and because there are many kinds of safety models, this paper does not fixly select one as the research object, and only optimizes the variable parameters in it.

4.2 Slope road braking control optimization

The distance-based safety model in triggering all levels of warning and braking mainly relies on the comparison with the relative distance D between the self vehicle and the collision risk and the braking control trigger distance threshold, so the accuracy of the braking control trigger distance threshold is the key to the distance-based safety model braking control collision avoidance. [8]However, under the actual operating conditions of vehicles, there are often complex and variable road conditions and meteorological conditions, so the distance-based safety model control parameters need to be optimized and calculated for various scenarios.

V2X-AEBS can obtain the collision risk localization, road adhesion coefficient, road slope and other parameters of the road section ahead through the roadside fusion sensing equipment, and broadcast to other vehicles in the road section through the base station. V2X-AEBS slope scenario design is shown in Figure 4.

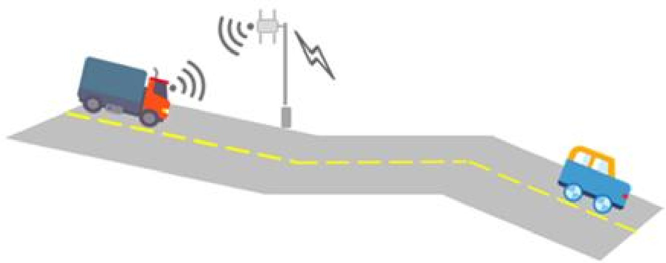

Fig.4 V2X-AEBS slope road scenario design

The ultimate braking deceleration rate that can be triggered by the vehicle during the change of slope and the change of road surface adhesion coefficient also changes, the specific relationship is shown below:

$$a_{d-\max} = \begin{cases} \mu g \cos\alpha - g\sin\alpha \\ \mu g \cos\alpha + g\sin\alpha \end{cases} \tag{1}$$

where $a_{d-\max}$ denotes the triggerable ultimate braking deceleration, μ denotes the road surface adhesion coefficient, and α denotes the road surface slope. [9]

4.3 Curve road braking control optimization

Compared with straight road driving, the actual relative position relationship between self-vehicle and collision risk points changes. On the one hand, it is necessary to recalculate the relative distance between the two vehicles, and on the other hand, it is necessary to judge whether the collision risk is in this lane. The curve road scenario is shown in Figure 5.

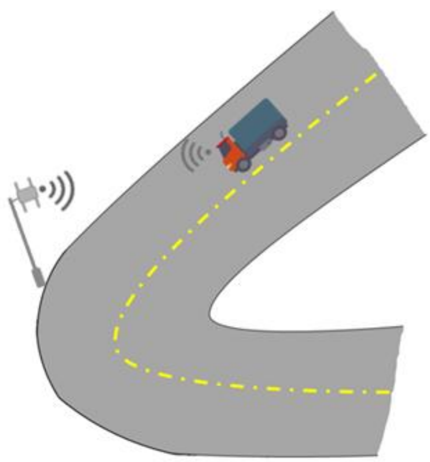

Fig.5 V2X-AEBS curve road scenario design

The curvature radius of the curve is R , The width of single lane is W , The current position coordinates of the self-vehicle is (X_1, Y_1), heading angle is β_1 , The position of the previous historical track is (X_1, Y_1) , previous historical heading angle is β_1' ,Collision risk location is (X_2, Y_2) .[10]

The calculation steps of collision risk and self-vehicle lane determination are as follows
Step 1:Combined with the radius of curvature R, the center coordinate (X_0, Y_0) .is calculated.

$$\begin{cases} R = \sqrt[2]{(X_1 - X_0)^2 + (Y_1 - Y_0)^2} \\ R = \sqrt[2]{(X_1' - X_0)^2 + (Y_1' - Y_0)^2} \end{cases} \tag{2}$$

Step 2: Calculate the position of curvature radius of collision risk.

$$R' = \sqrt[2]{(X_2 - X_0)^2 + (Y_2 - Y_0)^2} \tag{3}$$

Step 3: Determine whether the collision risk is in the same lane.

If $|R' - R| \geq W$, Then collision risk and self-vehicle are in different lanes. If $|R' - R| \leq W$, Then collision risk and self-vehicle are in same lane.

The calculation steps of path distance between self-vehicle and collision risk are as follows:

Step 1: Calculate the straight line distance between two coordinate positions

$$D = \sqrt[2]{(X_2 - X_1)^2 + (Y_2 - Y_1)^2} \tag{4}$$

Step 2: Calculate the central angle of two risk points

$$\theta = 2\sin^{-1}\frac{2D}{R} \tag{5}$$

Step 3: Calculate the actual relative distance between two risk points

$$\triangle D = \frac{\theta}{180^{\circ}}\pi R \tag{6}$$

4.4 Tunnel road braking control optimization

The particularity of tunnel structure and the complexity of tunnel system make the tunnel become the high incidence of traffic accidents, and the consequences of accidents are often very serious, so the importance of tunnel operation safety can be seen. There are great differences in sight conditions and ventilation inside and outside the tunnel, and the special driving environment has a greater impact on traffic safety, so the operation safety of the tunnel has always been the focus and difficulty of safety management. According to the tunnel structure, it can be divided into entrance transition section, tunnel internal section and exit transition section. According to the current research at home and abroad, the tunnel internal accident frequency is the highest, followed by the tunnel entrance, and the tunnel exit transition section has fewer accidents. Therefore, this part of the study needs to be divided according to the characteristics of the tunnel structure. The schematic diagram of each section of the tunnel is shown in Figure 6.

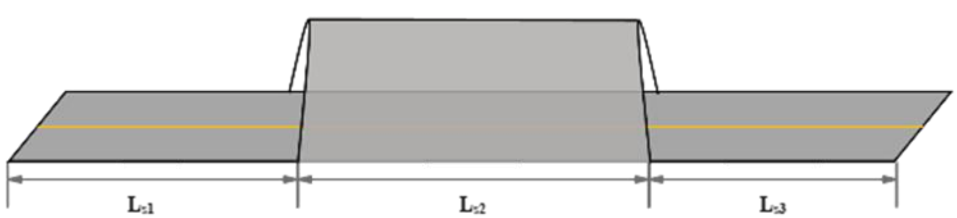

Fig.6 Schematic diagram of emergency braking control model based on TTC

At present, there are two key problems in the application of AEBS in tunnel collision prevention and control, one is that the AEBS vision sensor fails due to the "black hole" and "white hole" effect at the transition section of the tunnel entrance and exit due to the sudden change of illumination; the other is that the millimeter wave radar echo is affected by the characteristics of the closed structure and metal structure inside the tunnel;

The prevention and control solutions for tunnel collision accidents mainly have the following two pain points: firstly, if the collision risk in the tunnel is perceived by roadside perception, the problem of self-vehicle positioning in the tunnel can not be effectively solved at present, resulting in that the self-vehicle can not carry out effective braking control according to information such as collision location; Second, lidar can become a perception supplementary scheme for vehicles besides cameras and radars, and has been widely used in intelligent network passenger cars, but it is limited by cost, easy pollution and other issues, and can not be put into practical application in operating vehicles.

At present, the traditional prevention and control technology of expressway tunnel section in China mainly includes a series of active safety measures, such as visual transformation of tunnel entrance and exit, lighting design, special marking application and so on. The lighting of the tunnel is designed in sections:

"Entrance section LS1" adopts the combination of lighting intelligent control and entrance section illumination sensor to adjust the illumination of tunnel entrance section, eliminate the "black hole" phenomenon when the driver just enters the tunnel, and improve the visual comfort of the driver entering the tunnel;

"Middle section LS2", a mode of combining illumination control with a transition section illumination sensor and a visibility detector is adopted to stabilize the illumination in the tunnel and simultaneously reduce the influence of visibility reduction caused by automobile exhaust gas in the tunnel;

"Exit section LS3" adopts the combination of lighting control, middle section illumination sensor and exit tunnel illumination sensor to realize the smooth transition of brightness inside and outside the tunnel, eliminate the dazzling effect caused by strong light outside the tunnel in the daytime and the "black hole effect" caused by low brightness at the exit of the tunnel at night.

Based on the optimization model of emergency braking control considering road geometric alignment and road adhesion coefficient, and referring to the related research results of driver reaction time in tunnel section, it is found that driver reaction time is highly linearly related to its related influencing factors. The reaction time of drivers in the tunnel entrance transition section, the tunnel interior section and the exit transition section is about 0.6 s, 0.1 s and 0.4 s longer than that in the ordinary section, respectively. The reaction time of the driver in each section of the tunnel in good weather and rainy and foggy weather. In rainy days, according to the different rainfall intensity, the driver's visibility is different, which eventually leads to the different reaction time of the driver in different visibility. According to the relevant research, the reaction time in rainy days with visibility of 50 ~ 200 m, 200 ~ 500 m and 500 ~ 1 000 m is about 1. 2 s, 0.8 s and 0. 4 s longer than that in good weather, Therefore, according to the different visibility in rainy days, the reaction time of drivers in the transition section of tunnel entrance and exit should be corrected. [11]

In addition to the above optimization, the safe distance between two vehicles can also be used to measure and calculate in the tunnel with sensors installed in the tunnel for distance measurement. When the minimum driving distance of the vehicle is less than the distance calculated by the algorithm, the driver will be warned and the vehicle will be braked.

5. CONCLUSION

According to the optimization algorithm of vehicle-road information interaction design strategy, the emergency braking of vehicles can be controlled and adjusted according to different road geometric linearity, road adhesion and collision risk. The research results provide a new idea of using V2X technology to assist AEBS to improve the technical level of collision protection in bad weather and complex road conditions. In the future, actual road scenes and test vehicles will be selected to verify the control algorithm proposed in this paper.

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