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A Real-time Warning Model of Vehicle-person Collision Risk based on Minimum Safe Distance

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Abstract

A real-time warning model of vehicle-person collision risk based on minimum safe distance is a technology to protect the safety of pedestrians in traffic in the network connection environment. Based on the minimum safe distance theory, this paper proposed a real-time warning model of human-vehicle collision risk with dynamic coefficients.Firstly, a real-time warning model of human-vehicle collision risk was constructed. Secondly, a accident model of pedestrian with headphones was established. In this stage, typical models were selected to analyze the collision characteristics, based on which the appropriate human-vehicle distance algorithm was summarize and thus the margin of safe distance in different scenarios was determined. Finally, the warning effect of the model was calculated in the term of braking distances under different speeds, sections and road adhesion coefficients, and compared with the braking distances without the intervention of the warning system. The results showed that the model not only has high accuracy, but can effectively warn drivers and pedestrians so as to reduce the accident rate.

Keywords

Traffic Information Engineering and Control; Vehicle-Person Conflict; Safe Distance; Intelligent Warning; Network Connection Environment.

1. Introduction

With the continuous development of the economy and society and the advancement of science and technology, the automobile industry has developed rapidly, and the number of motor vehicles has increased rapidly. While cars bring convenience to the people, the frequent occurrence of road traffic accidents also threatens the lives of pedestrians. In traffic, pedestrians are the most vulnerable group. When pedestrians cross the road or walk on the side of the road, It is easy to collide or collide with vehicles on the road, resulting in injury or even death.

At present, there are many researches on pedestrian safety at home and abroad. Liu Yinen of South China University of Technology [1] studied the pedestrian target recognition in the scene of crossing the street which took the behavior of pedestrians wearing headsets as the research object, and based on the YOLOv3-Max network. After that, the Adaboost algorithm and SVM classification algorithm are applied to identify the behavior of pedestrians wearing headsets, and to issue early warnings to drivers in time.Peripheral visual environment compensation measures for pedestrians with bowed heads to walk safely[2],written by Liu Shuang from Harbin Institute of Technology,put forward the idea of improving the compensation measures of peripheral visual environment, and divided the walking space with potential safety hazards into three categories according to the characteristics of visual behavior: Vision-guided, vision-traversing, and vision-hybrid. According to different types of spaces, corresponding visual compensation measures are proposed to provide reference for the

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construction of walking safety environment in similar scenarios.Vehicle Forward Collision Warning Algorithm [3]written by Chang'an University Jiang Siyang , forward collision warning algorithm is divided into safety time logic algorithm and safe distance logic algorithm according to the type of warning threshold, and also summarizes and introduces the automatic adjustment of warning threshold. method of adaptation. During the driving process of the vehicle, the forward collision warning system can transmit a warning signal to the driver, and then the driver will act according to the warning signal, thereby reducing the possibility of a rear-end collision.Wang et al. [4] proposed a forward collision warning algorithm that can adjust the warning threshold in real time according to the driver's behavior changes, which can better match the driver's behavior fluctuations and individual differences under long-term driving conditions, so as to achieve Reduce the false positive rate of the system.

The above research has certain shortcomings. Liu Yian's research system needs to establish a huge database for pedestrian capture, whose data acquisition capabilities are limited and inaccurate. It only warns the driver, and cannot give full play to the role of pedestrians and vehicles in active avoidance under certain road conditions .Liu Shuang’s research uses peripheral visual environment compensation measures to protect pedestrian safety, which is more dangerous for pedestrians in the scene of human-vehicle interaction. In this situation, the safety of pedestrians cannot be effectively protected. Jiang Siyang's research on safety distance is aimed at the collision between vehicles, and does not specifically focus on pedestrian safety.

In view of this, this paper proposes a research on a real-time warning model of pedestrian-vehicle collision risk based on the minimum safe distance, which can not only realize real-time interaction of pedestrian and motor vehicle information, but also make up for some gaps in the current vehicle-road collaboration research for pedestrians. It has strong practical significance and application value to fully realize the effective coordination of people and vehicles, and remind drivers and pedestrians when it is judged that there is danger.

2. Construction of Early Warning System Model

The real-time early warning model of human-vehicle collision risk proposed in this paper is shown in Fig.1, which is based on the minimum safe distance. First, the pedestrian terminal obtains the coordinate position information and weather condition information through GPS of the mobile phone and transmits them to the receiving terminal of vehicle networking through WIFI. Then, the obtained pedestrian information and real-time uploaded information such as speed, acceleration, adhesion coefficient, mass of the vehicle, the fastest braking time of the brakes, the shortest braking distance, etc. are broadcast and transmitted to vehicles within a certain distance range from pedestrians through vehicle networking. Finally, vehicles make collision danger judgment according to the received information that has been broadcast and shared. When the distance between the pedestrian and the vehicle is less than the safe distance, the two-way warning is implemented for both the pedestrian and the vehicle.

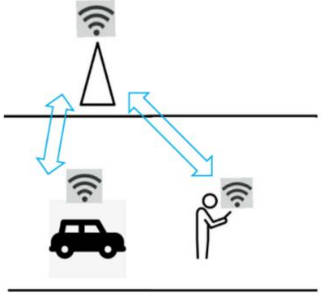

Fig.1 Early Warning System Model

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The flow chart which depicts how the system work is presented in Fig.2. First of all, the connected vehicle receives continuous images of the surrounding environment at a certain frequency within a certain time interval which can form the movement trajectory of pedestrians, so that the pedestrian's travel direction can be predicted. Data including the navigation route of the vehicle and the predicted trajectory of the pedestrian are compared with the characteristics of each collision accident model from the model database of the system, and according to the similarity of the calibration, the collision warning judgment model is selected. If the similarity is less than the minimum matching similarity, the system will select the accident model with the highest similarity to the current scene as the corresponding accident model.

After the accident model is successfully matched, the corresponding collision risk coefficient and the characteristics of the person-vehicle trajectory are utilized as the basis for the subsequent selection of models to calculate the actual distance and the safe distance between the person and the vehicle. The safety distance algorithm in the system produces the safety distance results according to the accident model acquired in real-time, vehicle speed, and road adhesion coefficient, then compared with the actual distance between people and vehicles. When the safety distance is smaller than the actual distance, an early warning is issued.

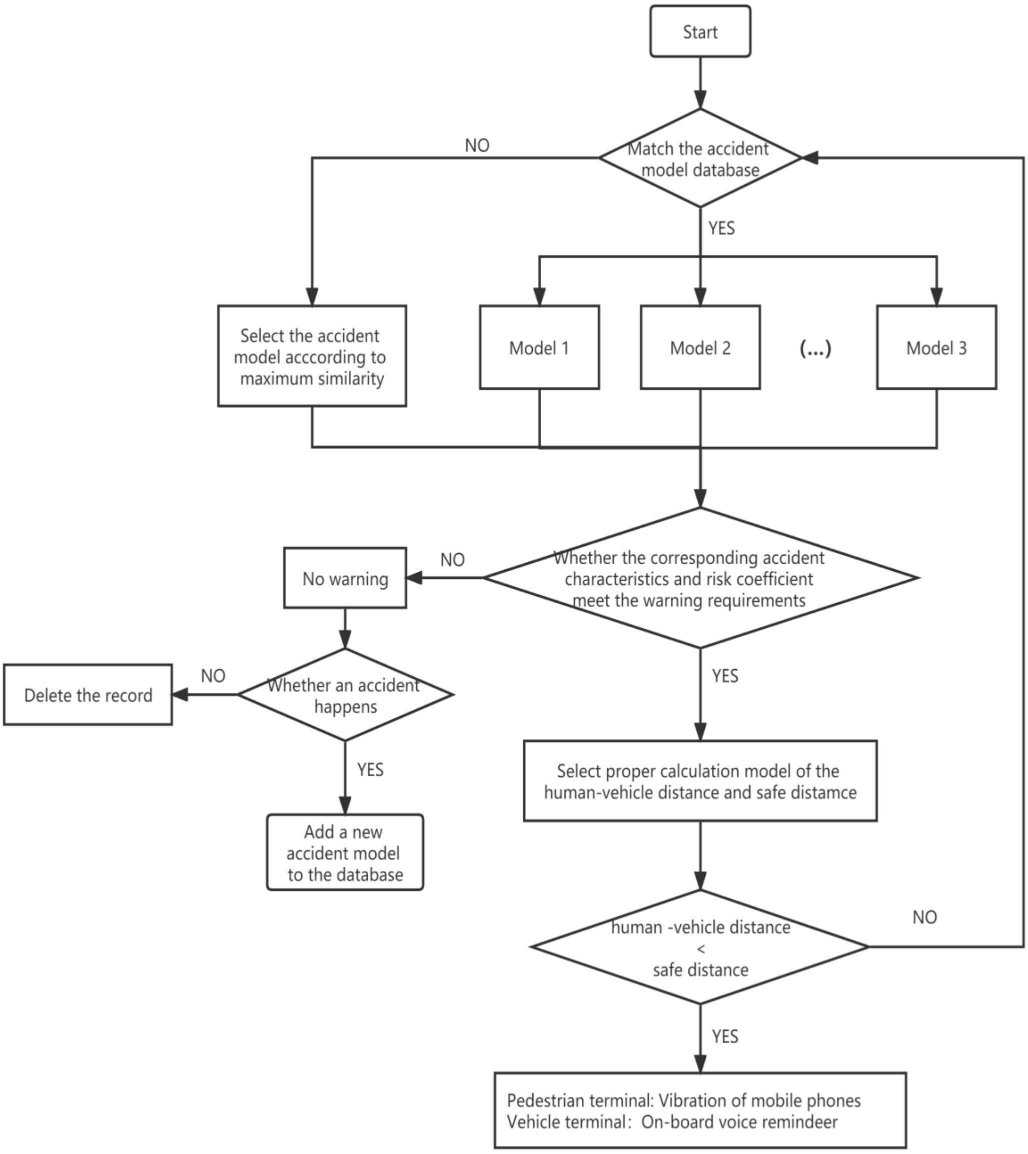

Fig. 2 Early Warning System Workflow

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3. Collision Warning Judgment Model

Human vehicle collision is one of the most serious traffic accidents. Many domestic and foreign scholars have conducted in-depth and extensive research on the collision distance and put forward many valuable methods. For example, the rear braking distance through the vehicle [5], which refers to the distance between the vehicle from the collision point to its final stop position; it can also be realized by means of trace [6-7] to reproduce the accident.However, in real accidents, many traces cannot be accurately measured.

The types of traffic accidents due to pedestrian travel are mainly concentrated in the following specific situations: In the process of normal driving, sudden turning, vehicle starting and temporary parking on urban roads, the hearing of pedestrians is blocked due to wearing headphones, resulting in the failure to hear the sound of drivers honking in time. Therefore, the vehicle is prone to collision with the pedestrians in front of it. In the urban intersection section, when pedestrians cross the intersection, there is a risk of collision with the vehicles in the traffic flow perpendicular to their travel direction. In the traffic flow in this direction, the vehicles in the straight and right turn directions are in danger of collision with pedestrians. In the mixed lane section of the campus, the proportion of pedestrians in the campus is high, the pedestrian density on the road is large, so it is difficult for vehicles to pass and it is easy to collide with pedestrians. A large number of accident models can be established through induction and sorting, and this paper mainly selects several representative models, as shown in Fig. 3 below, and makes a specific analysis on the collision models in the case of vehicle linear motion model and curve motion model. Circles represent pedestrians, rectangles represent vehicles, and arrows represent the direction of speed.

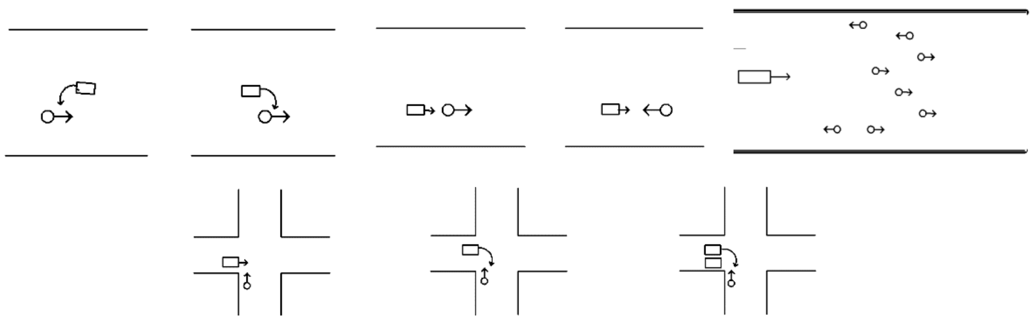

Fig. 3 traffic accident model

3.1 Section Headings

3.1.1 Actual Distance Model Between Man and Vehicle

The relative distance between people and vehicles is an important basis to determine whether they will collide. Accurate distance model can reduce the false reports of early warning system.When predicting the conflict risk, a two-dimensional right-hand coordinate system is established with the pedestrian as the origin and the forward direction as the positive direction of the X-axis.Convert the vehicle position coordinate information obtained based on the Internet of vehicles into the relative coordinates under the coordinate system.Below α is the included angle between the driving direction of the vehicle and the connecting line between the person and the vehicle position.The full load mass is 3600kg, the wheelbase L = 2.8, the full load is the distance from the center of mass to the rear circumference b = 0.8m, the height of the center of mass hg = 0.8m, the ground braking force of the front wheel reaches the adhesion, and the ground braking force of the rear wheel is only half of that of the front wheel. The relative distance between people and vehicles under the above eight typical scenes is studied in detail.

Euclidean distance model [5] is the most commonly used distance model. This model simplifies the two research objects into a circle. The X direction is along the road direction, the Y direction is perpendicular to the road direction, the circle represents people and the rectangle represents vehicles.In the application of the model, the Euclidean distance between the centers of two circles needs to be obtained first, and then judged.If the Euclidean distance is less than or equal to the sum of the radii of the two circles, that is, the two circles overlap or tangent, indicating that the two collide; otherwise, it means safety.

The form of Euclidean distance is simple and the calculation efficiency is high. It is reasonable to describe pedestrians as circles with safe walking radius, but it is conservative to define vehicles as circles.The shape of the vehicle is closer to a rectangle. After defining it as a circle, many situations that are not collision are also considered that collisions have occurred.On this basis, the vehicle is defined as a rectangle. During the operation of the algorithm, the position coordinates around the vehicle are obtained based on the network environment, and the position coordinates closest to the pedestrian are used to calculate the person vehicle distance.

linear motion model:

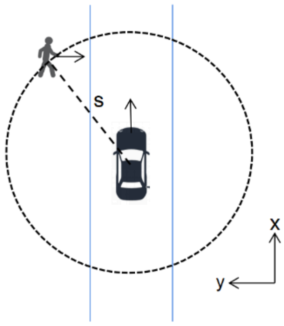

Fig. 4 model I

It is assumed that the vehicle maintains its current speed during movement. Determine the pedestrian's intention of moving direction based on the information obtained from the Internet environment. When the pedestrian is on the left of the vehicle and the vector angle between the moving direction and the vehicle and its moving direction is not within (- 180 °, - 90 °), as shown in Fig. 4, the system does not give early warning.If within this range, i.e. between the opposite movement of the pedestrian and the vehicle and the vertical movement, it conforms to the early warning model.Where (x1,y1), (x2,y2) are respectively pedestrian coordinates, and the coordinates of the point with the shortest distance between the vehicle and the pedestrian. The pedestrian vehicle distance is calculated by the following formula:

$$X = \sqrt{(x1-x2)^2+(y1-y2)^2} . \tag{1}$$

curve motion model:

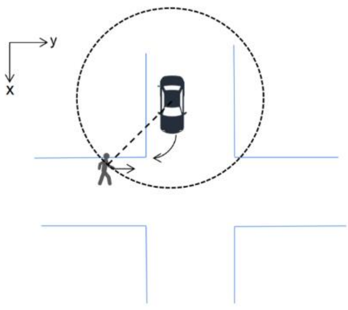

Fig. 5 model II

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Assuming that the vehicle maintains the current acceleration and the steering wheel speed is constant, the pedestrian goes straight, the vehicle is in a right turn, the pedestrian is on the right side of the vehicle, and the vector angle between the moving direction and the vehicle and its moving direction is not within the range of (90 °, 180 °), as shown in Fig. 5, the system does not carry out early warning; If within this range, i.e. between the opposite movement of the pedestrian and the vehicle and the vertical movement, it conforms to the early warning model. Where (x1, y1) is the pedestrian coordinate, and the pedestrian vehicle distance is calculated by the following formula:

$$x_1^{\ 2} + y_1^{\ 2} = s^2 \tag{2}$$

$$s = v_0 t + \frac{1}{2}\frac{du}{dt}t^2 \tag{3}$$

$$ds = \sqrt{1 + y^2} \tag{4}$$

3.2 Safe Distance

At present, scholars at home and abroad have conducted in-depth research on the safe distance model, and mainly proposed the following four classic safety models: fixed safety distance model [6], safety distance model based on braking [7], safety distance model based on headway distance [8], safety distance model based on driver preview [9]. Among them, the fixed safety distance model which always maintains a fixed inter-vehicle distance during the following car is not able to adapt to the complex and changeable road environment nowadays, while the braking-based safety distance model is established on the premise of assumption that the preceding car brakes and its following distance is often too large and goes against the smooth flow of road traffic. Besides, the safety model based on the headway does not take the influence that the motion state of the preceding vehicle has on the inter-vehicle distance into account, which does not conform to the driver's actual following characteristics. Although the subjective characteristics of drivers are considered in the driver's preview safety distance model, the established model tends to fail to accurately reflect the actual driving situation due to insufficient reference samples. In response to the above problems, Chinese and foreign scholars have made different researches and discussions.

The specific calculation process of the safety distance D is as follows:

$$D = \frac{\delta_1}{3.6}v_0 + \frac{v_0^{\ 2}}{25.92\frac{du}{dt}} + \frac{\delta_2 v_0}{3.6} + \delta_3 \tag{5}$$

In the model, δ_1 is the acting time of the brake and is taken as 0.2s. δ_2 is the parameter affected by the communication delay and the coordination time of the brake, and its value is 0.24s. δ_3 is the safety margin, which is jointly affected by the road section and the speed of the vehicle.

The braking deceleration $\frac{du}{dt}$ is derived as follows:

According to the selected vehicle type, ignoring the rolling resistance couple, air resistance and inertia moment of the rotating mass when the vehicle decelerates, according to the force analysis of the vehicle when it brakes on a level road, it can be obtained as:

$$Fz_1 = \frac{1}{L}(Gb + mh_g \frac{du}{dt}) \tag{6}$$

$$Fz_2 = \frac{1}{L}(Ga - mh_g \frac{du}{dt}) \tag{7}$$

And the braking deceleration formula of the car is:

$$\begin{aligned} \frac{du}{dt} &= \frac{1.5\varphi Gb}{L - 1.5\varphi h_g} \\ &= \frac{16.17\varphi}{2.8 - 1.2\varphi} \end{aligned} \tag{8}$$

Pedestrian motion is highly uncertain, which makes it difficult to avoid invalid early warning. In order to establish a kinematic model that conforms to the actual pedestrian motion characteristics, we shoot around the vehicle through vehicle networking and obtained continuous images to predict the uncertain motion of pedestrians. The warning function of the system can be realized by calculating and comparing the distance between the pedestrian and the vehicle and the safety distance through the above method. The following part will verify the accuracy of the above method.

4. Verification and Result Analysis

Since the main scenes of pedestrian traffic accidents are urban roads, campuses and campuses, and the vehicle speed is not high, the speed range used in the verification data in this paper is 15 ~ 70km / h; There will be sunny weather and ice and snow weather in cities, and the roads are basically good asphalt pavement, so the range of road adhesion coefficient is 0.1 ~ 0.9.Verify the safety distance under different speeds and road adhesion coefficients, braking distance under early warning state, braking distance under non early warning state, braking distance margin under early warning state and braking distance margin under non early warning state by controlling variables. Two groups of checking data and curves are obtained through the formula.

In ensuring road adhesion coefficient φ= 09 unchanged and the same section model is selected,Set 12 vehicle speeds within the speed range of 15 ~ 70km / h,Calculate the braking distance in the warning state and the braking distance in the non warning state within this range through the formula. According to the results of braking tests conducted on 48 cars equipped with vacuum booster on dry and good roads from 1993 to 1998 in "autocar ",andThe braking distance curve is fitted according to the principle of least square method.The formula obtained by fitting is verified and calculated,As shown in icon 1, the specific formula is as follows:

$$\begin{aligned} s_1 &= 0.0034v_0 + 0.00451{v_0}^2 \\ s_2 &= \frac{0.24}{3.6}v_0 + 0.0034v_0 + 0.00451{v_0}^2 \end{aligned} \tag{9}$$

When other conditions remain unchanged, verify the safety distance under different road adhesion coefficients, braking distance under early warning state, braking distance under non early warning state, braking distance allowance under early warning state and braking distance allowance under non early warning state.In order to ensure data reliability and safety, two calculation formulas of braking distance will be adopted in this paper. The calculation results are shown in Table 2,Through fitting formula, the curve is shown in Figure 1 and Figure 2. The specific calculation formula is as follows:

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$$v_t = v_0 - \frac{du}{dt}t$$
$$s_1 = v_0 t - \frac{1}{2}\frac{du}{dt}t^2$$
$$s_2 = s_1 + \frac{0.24}{3.6}v_0 \qquad (10)$$

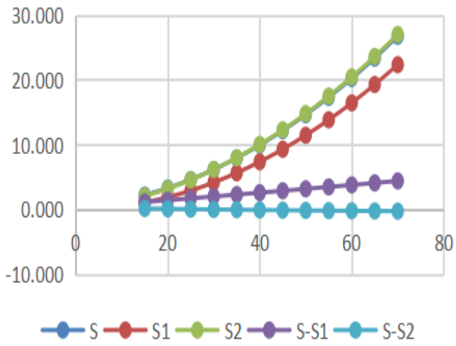

Fig. 6 Braking distance comparison I

Table 1. comparison of braking distance

V0 / S	15	20	25	30	35	40
S	2.201	3.291	4.609	6.154	7.928	9.930
S1	1.066	1.872	2.904	4.161	5.644	7.352
S2	2.066	3.205	4.570	6.161	7.977	10.019
S-S1	1.135	1.419	1.705	1.993	2.284	2.578
S-S2	0.135	0.085	0.038	-0.007	-0.049	-0.089
V0 / S	45	50	55	60	65	70
S	12.160	14.617	17.303	20.217	23.359	26.729
S1	9.286	11.445	13.830	16.440	19.276	22.337
S2	12.286	14.778	17.496	20.440	23.609	27.004
S-S1	2.874	3.172	3.474	3.777	4.083	4.392
S-S2	-0.126	-0.161	-0.193	-0.223	-0.250	-0.275

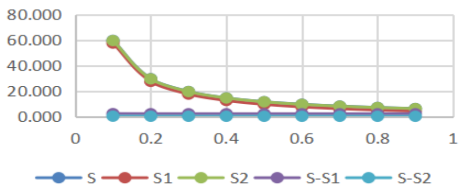

Fig. 7 Braking distance comparison II

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Table 2. comparison of braking distance

V0 / S	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
S	6.154	6.989	8.063	9.494	11.498	14.504	19.515	29.536	59.598
S1	4.096	4.930	6.001	7.430	9.431	12.431	17.433	27.435	57.442
S2	6.096	6.930	8.001	9.430	11.431	14.431	19.433	29.435	59.442
S-S1	2.058	2.059	2.061	2.064	2.067	2.073	20.433	2.101	2.157
S-S2	0.058	0.059	0.061	0.064	0.067	0.073	21.433	0.101	0.157

V0 in Table 1 represents the vehicle speed when the vehicle detects that the distance between people and vehicles is less than the safe distance; S stands for safety distance; S1 represents the braking distance in the early warning state; S2 represents the braking distance under non warning state; S-S1 represents the distance between the vehicle and the pedestrian after the braking process in the early warning state. The value of s-S1 is positive, which means that the vehicle brakes in time after the early warning to avoid collision with pedestrians. The value of s-S1 is negative, which means that the vehicle fails to brake in time after the early warning to avoid collision with pedestrians; S-s2 represents the distance between the vehicle and the pedestrian at the end of the braking process in the non warning state.

In Figure 1, s-s1-v0 curve can be seen from the image. When other conditions remain unchanged, the distance between the vehicle and the pedestrian is positive after the end of the braking process in the early warning state, so it increases with the increase of speed. After the early warning, the vehicle can brake in time to avoid collision with pedestrians, and the curve shows an increasing trend, indicating that the set safety distance is relatively conservative in the case of high risk of high speed.S-s2 -- V0 curve although the distance between the vehicle and the pedestrian is positive or negative after the end of the braking process in the early warning state, with the increase of speed, the braking distance increases, and the accident risk of human vehicle collision gradually increases. When the speed reaches 30km / h, the braking distance of the vehicle will probably exceed the safe distance, resulting in accidents.In Figure 2, in both braking States, the braking distance decreases with the increase of vehicle speed, but it is always positive, so collision with pedestrians can be avoided.The braking distance margin in the early warning state is 2m more on average than that in the non early warning state. Therefore, the early warning system can be obtained from the curve chart, which can effectively reduce the accident rate.

5. Conclusion

(1) In this paper, a real-time early warning model of human vehicle collision risk based on the minimum safe distance is proposed. Using the vehicle networking communication technology, the continuous image of the vehicle's surrounding environment is used to predict the pedestrian's travel intention and build a more accurate collision model to reduce the ineffective early warning to a great extent; The road adhesion coefficient is introduced into the vehicle early warning and anti-collision model, and it is used as an important basis for early warning and anti-collision judgment and execution logic.

(2)Select the vehicle linear motion model and curve motion model for specific analysis, and get the actual distance algorithm of people and vehicles under different models; Select a specific vehicle model for safety distance analysis, so that the model established in the database is more in line with the actual situation, so as to make the early warning system more accurate.

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(3) The verification results show that the average positive alarm rate of the vehicle active early warning and collision avoidance model based on the real-time early warning model of human vehicle collision risk based on the minimum safety distance is high; In the emergency braking test condition, the collision can be avoided successfully, and the shortest relative distance between the two vehicles is mostly kept within the range of 1.35 ~ 4.92 m, which can fully protect the safety of pedestrians. Compared with the comparison model, it has better safety and stability under test conditions.

(4) In the future research work, more complex early warning and collision avoidance problems in practice will be considered, such as driver driving habits, driving status, etc; At the same time, further improve the accuracy and real-time of pedestrian intention recognition model to make it more suitable for the real driving environment.

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