A Temporal-spatial Collision Warning Method at Non-signalized Intersection

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Abstract

For the complexity of accidents occurred at the intersections, a temporal-spatial collision warning method was proposed. On the basis of vehicle’s passing time of the conflict zone, the algorithm calculated probability of accident was established. Due to the deficiencies of considering time coordinate only, spatial coefficient which represented the relationship between actual distance and safety braking distance was used to correct the algorithm. A two-way and two-lane intersection was taken as an example. The drivers were divided into three categories: normal, negative and positive. Finally, special warning method was used to remind different kinds of drivers to avoid accidents. The results illustrated that the system should warn the negative drivers earlier and a delay warning measure should be taken for positive drivers.

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Keywords: traffic safety; collision warning; temporal-spatial; thresholds

1. Introduction

In recent years, as China’s car ownership increases, the traffic problem is getting worse. The traffic accident is the main source of casualties and property damage. Accidents occurred at the intersection is complex; it takes a large proportion of the total traffic accidents. According to statistics, in China, intersection accidents accounted for about 30% of the total number of accidents, the number was 36% in United States, 43% in Europe and 42.2% in Japan separately. The driver must deal with complicated information in the intersection, including changes in lights, vehicles in other direction, bicycles and pedestrians. In China, there is plenty of mixed traffic; it increased the

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complexity of the intersection. Therefore, it is important to analyze the traffic accidents at intersections for preventing accidents, reducing losses and improving traffic safety.

There are plenty of researches about how to improve traffic safety in intersections. Hafner et al [1] leveraged vehicle-to-vehicle(V2V) communication technology to implement computationally efficient decentralized algorithms for two-vehicle cooperative collision avoidance at intersections. Sepulcre [2] presented a cooperative communications testing platform implemented to evaluate the operation and effectiveness of cooperative active safety applications under challenging driving and communications conditions. Because the high traffic accident rate at intersection, Wang Yunpeng [3] presented a vehicle trajectory collision warning system based on Vehicle Infrastructure Integration(VII) system for improving the traffic safety. After analyzed the system function, physical and logical framework of the system had been designed in detail, and vehicle collision could be detected in real time by the collision detection algorithm. Tan and Huang [4] explored the engineering feasibility of a future-trajectory-prediction-based cooperative Collision Warning System when vehicles were equipped with a relatively simple differential GPS unit and relatively basic motion sensors. The research focused two issues: providing an engineering argument of possible functional architectures of systems and presenting a plausible example of the proposed future-trajectory-based design. Zhang [5] proposed a new threat assessment measure, time-to-last-second-braking, and its advantages over previous measures were discussed. The measure was in agreement with human natural judgment of the urgency and severity of threats. A collision avoidance system provided a warning when the probability of an inadequate overtaking gap exceeded a threshold. Two thresholds, distributed signal detection theoretic(DSDT) model and signal detection theoretic(SDT)model were tested. The results supported the conclusion that DSDT model was a useful, quantitative tool that should be used by warning designers [6].

Internet of vehicles offers new opportunities to the problem, in the system, vehicle information is collected, and the servers analyze the data and provide service to the vehicles. It is of great significance to improve traffic safety, reduce traffic congestion and future energy conservation. With the development of wireless technology, communication capability greatly enhanced the real-time performance of system. Based on the analysis of conflict on the road intersection, time region of vehicle gone through the conflict zone was taken as a priority measure and distance as a correction coefficient, a temporal-spatial dynamics collision warning method at intersection was proposed.

This paper is organized as follows: Risk assess method is presented in section 2 and the warning strategy is introduced in section 3. Section 4 is conclusion.

2. Methodology

2.1. Vehicle model

For the analysis of traffic conflict at road intersections, the vehicle generally was regarded as the particle, rectangular, round or oval. Miller and Huang [7] proposed a cooperative collision warning system, the vehicle was considered as particle, the vehicle's position, speed, heading and other information were used to calculate the potential conflict position in the future, as shown in Fig.1.

If vehicles kept the current state of motion, the accident would occur in point \((x+, y+))\). \(x+, y+\) were calculated as follows:

\[
x_1 = \frac{(y_2 - y_1) - (x_1 \tan \theta_2 - x_1 \tan \theta_1)}{\tan \theta_1 - \tan \theta_2} \tag{1}
\]

\[
y_1 = \frac{(x_2 - x_1) - (y_1 \cot \theta_2 - y_1 \cot \theta_1)}{\cot \theta_1 - \cot \theta_2} \tag{2}
\]

Huang et al [8] considered vehicles as particles, the Closest Point of Approach was used to calculate the relative distance between the two vehicles when they crossed the intersection, as a basis for judging if the vehicles were
safety. And the vehicles were considered as circle model to calculate the distance between vehicles, time to collision of vehicles were analysis, and a conflict resolution algorithm was proposed [9].

In real traffic environment, if the vehicles were considered as particles, there were large errors when calculated distance in conflict detection. Closest point of approach method was usually used in navigation for vessels, based on the positions and speeds of surrounding ships, the method determined whether the vessels were in danger. The ship is tiny for the ocean, so its size is negligible. On the other hand, there are not typical intersections in the ocean, so it is necessary to determine the position by the azimuth, heading and velocity vector. The vehicle could be considered as circle model had three reasons. First, there were errors by the particles method; second, calculation was complex by the rectangular method and third is because there are security zone for the vehicles in the process of moving.

The rectangle method was used. On one hand, compared with the particle method, the calculations were more accurate, it was possible to describe the relative relationship between the vehicles more clearly. On the other hand, from the point of warning, more precise calculation was needed, and if the result was that vehicles stopped in the critical position, the real traffic accidents were avoided.

2. Time basis

For the one-dimensional transportation, which means that vehicles traveling in the same direction, such as car-following or lane-changing, the relationship between the vehicles could be described by the relative distance and velocity; and for two-dimensional transportation, like the intersection, the direction, steering and other factors of vehicles influenced the traffic safety, therefore, a more realistic safety indicator was needed to represent the degree of danger. A typical two-way two-lane intersection was used as example. As shown in Fig. 2.

The dark area is the conflict zone. Vehicle A travelled from west to east, vehicle B travelled from south to north. The collision problem is a binary issue. If the vehicles were recognized as particles, when the two particles move to a certain point at the same time, there was a conflict between the particles. If the vehicles were considered as rectangles, the vehicle will collide in the conflict area in several ways.

1) Two vehicles arrived at the conflict area almost simultaneously, as shown in Fig. 3 (a), the front right point of vehicle A and front left point of vehicle B contacted in the conflict area, the two vehicles collided.

2) Vehicle A entered the conflict zone firstly, before it leave the zone, vehicle B arrived in the zone, side collision occurred between the vehicles. As shown in Fig. 3 (b).
3) Vehicle B entered the conflict zone firstly, the same as vehicle A, side collision occurred between the vehicles. As shown in Fig. 3 (c).

For vehicle A,

\[ t_{A1} = \frac{d_A}{V_A} \]  \hspace{1cm} (3)

\[ t_{A2} = \frac{d_A + K_B + L_A}{V_A} \]  \hspace{1cm} (4)

Where, \( t_{A1}, t_{A2} \) were times of reaching and leaving the zone of vehicle A separately; \( d_A \) was the distance between vehicle A and edge of the zone, \( K_B \) was the width of vehicle B, \( L_A \) is the length of vehicle A.

Similarly for vehicle B:
$$t_{b1} = \frac{d_B}{V_B}$$

(5)

$$t_{b2} = \frac{d_B + K_A + L_B}{V_B}$$

(6)

2.3. Space basis

In process of vehicle braking, deceleration changes as shown in Fig.4.

Where,

1) \([0, t1]\), the reaction time of the driver, referred to the time from the driver recognized the unusual to brake started to work, including the perception-reaction time, referred to the time from driver recognized the abnormal to his foot was off the accelerator pedal; the perception-action time, referred to the time driver moved his foot from accelerator pedal to the brake pedal; pedal’s idle running time. In this phase, the brake didn’t work; vehicle didn’t decelerate and kept the constant speed.

2) \([t1, t2]\), referred to the time brake started to work. The driver operated the brake pedal, the vehicle began to decelerate, deceleration increased from 0 to the driver’s expectation. In this phase, the deceleration was changing.

3) \([t2, t3]\), the brake work as driver’s expectation, the vehicle kept a constant deceleration.

4) \([t3, t4]\), the time driver relaxed brake. The deceleration decreased from constant value to 0. Therefore, braking distance is calculated as follows:

$$d = vt_i + \int_{t1}^{t4} adt$$

(7)

Because work time of brake is very short, the second phase was classified into the constant speed phase. In addition, vehicles stopped finally, so the end speed was 0. \(t_i\) represented the reaction time of driver, it is from 0 to t2. Simplified braking distance is calculated as:

$$d = vt_i + \frac{v^2}{2a}$$

(8)
3. Analysis

When there was a conflict, if the vehicle should be alarmed was analysis. Three assumptions were made:
1) Vehicles could avoid the collision through decelerating or stop only.
2) The intersection was non-signal intersection.
3) Both vehicles travelled straight with constant speed, and they could collect information in the cooperative system of vehicles.

3.1. Safety indicator

Based on time that vehicles passed the intersection, if arriving time of a vehicle was between the arriving time and leaving time of the other vehicle, they would collide in the conflict zone in the future. Vehicle A was used for example, \( p(A) \) was the collision probability.

\[
p(A) = 100\%, t_{A1} \in [t_{B1}, t_{B2}] 
\]

(9)

The thresholds were arriving time and leaving time of vehicle B, determined by the \( K_A, v_B \) and \( L_B \).

When \( t_{A1} \notin [t_{B1}, t_{B2}] \), the more closer arriving time of vehicle A was to the thresholds, the larger the probability of collision was, so

\[
\begin{align*}
p(A) &= \frac{t_{B1} - t_{A1}}{t_{B2}} , t_{A1} < t_{B1} \\
p(A) &= \frac{t_{A1} - t_{B1}}{t_{A1}} , t_{A1} > t_{B1}
\end{align*}
\]

(10)

However, the time basis ignored the level of emergency of probability of collision. It could be reflected by the distance between the vehicle and the conflict zone. The braking distance of vehicle was influenced by the reaction time of drivers, deceleration and other factors. According to the assumptions, when distance between the vehicle and conflict zone less than the safety braking distance, if the vehicle brake with maximum deceleration, the collision couldn’t be avoided. So, the coefficient \( \beta \) was introduced to represent the level of emergency of collision probability.

\[
\beta = \begin{cases} 
1 - \left(\frac{d_A - d_{AS}}{d_A}\right)^{t_d}, & d_A > d_{AS} \\
1, & d_A \leq d_{AS}
\end{cases} 
\]

(11)

\[
d_{AS} = v_0t_d + \frac{v_0^2}{2a_{max}}
\]

(12)

\( d_A \) was the distance between the vehicle and conflict zone, \( d_{AS} \) was the safety braking distance, \( t_d \) was the reaction time of drivers and \( a_{max} \) was the max deceleration of the vehicle. In reality, the normal range of the reaction time of drivers was 0.4-1s, when the driver was shocked, it may exceed 1s. The emergency deceleration of the vehicle was 7.5-8m/s², the normal range was 1.5-4m/s². Fig.5 and fig.6 showed the factors’ influence to the coefficient.

As fig.5 shown, curves from left to right represented the influence of speeds from 20km/s to 100km/h. As the distance decreased, the level of emergency increased. For the same distance, the larger the speed was, the larger the collision probability was.

As fig.6 shown, curves from left to right represented the influence of reaction time from 0.3 to 1s. As the distance decreased, the level of emergency increased. For the same distance, the larger the reaction time was, the larger the collision probability was.
3.2. Warning method

Based on characteristics of the drivers and probability mentioned above, special warning method should be presented for different drivers. The drivers could be divided into three categories:

Normal: For this type of driver, the degree of risk changed with distance uniformly. The relationship was shown as dotted line in Fig.7 and Fig.8. As distance decreased, uniform warning method was used to remind the drivers to avoid the conflict. $d_1$ and $d_2$ represent safety and dangerous thresholds separately.

![Fig. 5. Coefficient influenced by speed.](image)

![Fig. 6. Coefficient influenced by reaction time.](image)
Negative: The bad driving habits, poor driving skills, and other conditions were recognized as negative characteristics of drivers. When the driver met the emergency scenario, they couldn’t do the right reaction in time, it was the main source of the accident. Therefore, for this type of drivers, early warning approach was used to remind drivers, which is based on the uniform warning method, warning would be earlier or be strengthen. Relationship between the degree of risk and distance was shown in Fig. 7. At the same distance, degree of risk is greater than it in normal conditions.

![Fig.7. Warning to negative drivers.](image)

Positive: good driving habits, high driving skills, and quick response, etc. were regarded as positive drivers. They could do a quick response in emergency scenario. Therefore, in order to ensure driving safety, improving traffic efficiency, delay warning method was used to remind drivers, which on the basis of uniform warning method, warning lately or reducing the warning strength. Relationship between the degree of risk and distance was shown in Fig. 8. At the same distance, degree of risk is less than it in normal conditions.

![Fig.8. Warning to positive drivers.](image)
4. Conclusion

Based on the analysis of the characteristics of conflicts occurred at road intersections and simplified vehicle model, a temporal-spatial warning method was proposed. First, time region of vehicle gone through the conflict zone were calculated, it was used to judge whether the accidents occurred; the coefficient based on the relationship between the safety braking distance and actual distance were considered as correction to the algorithm. The drivers were divided into three categories: normal, negative and positive. According to the features of different drivers, a special warning method was used, that for negative drivers, the system should warn the drivers earlier and a delay warning measure should be taken for positive drivers. However, for simplicity, a lot of assumptions such as constant speed and constant deceleration, the vehicle must slow down or stop to avoid accidents, so more research is needed in the future.

Reference