Collision Risk Assessment Considering Relevant Factors of Crossing Path Crash Scenarios

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Abstract

To evaluate collision risk when passing through the non-priority side of unsignalized intersections, and consider measures to avoid collisions, we proposed a method consisting an index that evaluates the risk based on the visibility of intersection and vehicle condition, and scenarios describing how the vehicle and collision object encounter at the intersection. As a result of investigating driving behavior data with the proposed method, it was clarified that the proposed method was effective to show whether certain driving supports can avoid collisions or not.

I. Introduction

Although the number of fatalities due to traffic accidents in Japan is decreasing, 3,694 people die in traffic accidents annually [1]. The most common crash type in Japan is rear-end crash and the second common is crossing path crash. Automatic emergency braking (AEB), which are becoming popular in recent years, may not be effective because collision objects may rush out from places where they are not visible. Therefore, countermeasures for crossing path crashes are required. Among the places where crossing path collisions occur, many of them are at unsignalized intersections. From this, in this paper, we focus on the crossing path collision when passing through the non-priority side of an unsignalized intersection.

As a previous study concerning the prevention of crossing path crashes at unsignalized intersections, Seo et al. proposed a warning system using vehicle-to-vehicle (V2V) communication technology [2]. Their system warned a driver when there was a vehicle equipped with a V2V communication terminal approaching the intersection from the side. This system is effective at intersections where the visibility is limited because the system can detect and warn the driver about approaching vehicles that are not visible. However, this system is most effective when all the related vehicles are equipped with V2V communication equipment. Kojima et al. proposed a system that displays the situation inside blind spots of an intersection and provides visual aid information to the driver [3]. This system provides the driver with information which cannot be acquired visually such as vehicles present inside the blind spots by shooting the blind spot with cameras and showing the images on displays. To realize this system, it is required to install cameras and displays in the intersection environment with a cost. The above two methods to support the driver to prevent crossing path crashes are thought to be effective when these technologies are widely spread, but it takes much time. Therefore, we need an approach to develop driver assistance systems which are effective without information from other vehicles of infrastructure but using the information acquired by the ego-vehicle.

Raksincharoensak et al. [4] developed a risk prediction driving support system to prevent pedestrian collisions at unsignalized intersections. In this research, they modeled the risk prediction driving mechanism of an expert driver and applied the driving support system based on the model to an unsignalized crossing. As a result, the constructed model was able to reproduce the driving behavior of an expert driver. In addition, it was confirmed that the hazard-anticipation-driving system designed based on the model can reproduce the same driving behavior of an expert driver in an actual vehicle. Furthermore, when the designed system was applied to a near-miss scenario with a pedestrian, it was confirmed that collision with the pedestrian at the unsignalized intersection can be prevented. In this study, the driving behavior of an expert driver was modeled, however, it is not feasible to model the behavior of an expert driver in various intersection geometry, traffic environment, and vehicle state. Therefore, it is meaningful to develop a collision risk assessment method that considers these factors.
Therefore, the purpose of this study is to propose a method that can evaluate the collision risk when driving through the non-priority side of unsignalized intersections, and consider measures to reduce collision risk with the evaluated risk. To achieve the purpose, we first proposed an index that quantitatively evaluates collision risk based on the visibility obtained from intersection’s geometry and vehicle condition (position and speed), and “Collision Mode” which describes the collision scenario between an intersection approaching vehicle and crossing objects at blind intersections. And then, we applied the risk index and Collision Mode to driving behavior data and considered driving support methods to reduce collision risk by simulating the change in vehicle behavior following driving support, such as increase and decrease in deceleration when a crossing object is found.

II. Method

A. Collision risk index \( S_d \)

\( S_d \) is an index that indicates the probability of a vehicle approaching an intersection to collide with an object traveling on the crossing road based on the intersection’s environment elements and the vehicle’s state. In concrete, \( S_d \) indicates the probability of a collision between the vehicle and a collision object when the driver finds the collision object and starts decelerating after a certain idle running time in the situation shown in Fig.1. \( S_d \) is defined as equation (1) where \( X \) denotes the distance between the vehicle and the object’s traveling area, \( y \) denotes the viewable distance, \( V_{ego} \) denotes the speed of ego vehicle, \( V_{crs} \) denotes the speed of collision object, \( T_r \) denotes the idle running time, and \( \beta \) denotes the braking deceleration for collision avoidance after finding the collision object. \( G(X, y, V_{ego}, V_{crs}, T_r, \beta) \) included in equation (1) is a collision judging function which is defined as equation (2). \( p_p(V_{crs}, \mu, \sigma) \) included in equation (1) is a probability density function of the collision object’s speed. According to the work of Takata [5], the probability density function of the collision object’s speed follows a normal distribution of mean \( \mu \) and standard deviation \( \sigma \). Therefore, we defined \( p_p(V_{crs}, \mu, \sigma) \) as equation (3).

\[
S_d = \int_{\mu^{\text{upper}}}^{\mu^{\text{lower}}} G(X, y, V_{ego}, V_{crs}, T_r, \beta) p_p(V_{crs}, \mu, \sigma) dV_{crs}
\]  

(1)

\[
G(X, y, V_{ego}, V_{crs}, T_r, \beta) = \begin{cases} 
1 & \text{(Collision)} \\
0 & \text{(No collision)} 
\end{cases}
\]  

(2)

\[
p_p(V_{crs}, \mu, \sigma) = \frac{1}{\sqrt{2\pi}\sigma^2} \exp\left(-\frac{(V_{crs}-\mu)^2}{2\sigma^2}\right)
\]  

(3)

Fig. 1: Situation where the vehicle finds the collision object

This index has two preconditions. One is that “finding the collision object” means that the object is geometrically visible from the vehicle. And the other is that the speed of collision objects are constant and do not decelerate or stop even if the vehicle is visible and nearby. Under the above conditions, the index \( S_d \) has the following features:

- Collision risk values can be compared between the intersections of different shapes because the visibility of the intersection is reflected in the index.
- Collision risk values can be compared between drivers with different speed profiles because the position and speed of the ego vehicle are reflected in the index.

Table 1 shows the constant parameters used in this paper. The mean reaction time of drivers in their 60s (0.83 s) measured in the study of Makishita and Matsunaga [6] was adopted for \( T_r \). A deceleration value (0.4 G) used to analyze near-miss incidents [7] was adopted for \( \beta \). Three types of collision objects (Pedestrian, Bicycle, and Car) were assumed and the mean and standard deviation of each type’s speed were set respectively.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_r$</td>
<td>Idle running time [s]</td>
<td>0.83</td>
</tr>
<tr>
<td>$\beta$</td>
<td>Braking deceleration [G]</td>
<td>0.4</td>
</tr>
<tr>
<td>$\mu$</td>
<td>Mean speed of collision object [km/h]</td>
<td>4</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>Standard deviation of speed of collision object [km/h]</td>
<td>1</td>
</tr>
</tbody>
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### B. Collision Mode

Although the value of the risk index can express the degree of collision risk, it is necessary to investigate measures to reduce the collision risk and verify their effects to avoid collisions. Hence, we classified collision scenarios between the vehicle and collision object into 3 types, and classified passing scenario without collision between them into 3 types and defined them as “Collision Mode”. Fig. 2 shows the description of the 6 modes.

The 3 types of collision scenarios between the vehicle and collision object correspond to Mode 1, 2 and 3. It is to be noted that in Mode 3, the occurrence of collision is calculated under the assumption that the vehicle decelerates at constant deceleration until it stops after finding the object. However, in an actual environment, drivers may judge that they will not collide if they pass the intersection first, and therefore they may not decelerate and Mode 3 may not occur.

The 3 types of passing scenarios through an intersection without collision correspond to Mode 4, 5 and 6. Mode 4 is a case where the collision object passes the intersection after the vehicle. Mode 5 is a case where the vehicle passes the intersection after the collision object. For this mode, it includes the case where the vehicle stops inside the intersection. Mode 6 is a case where the vehicle stops before entering the intersection.

![Fig. 2: Description of Collision Mode](image)

### C. Driving behavior data

Driving data of 31 older drivers (ME1-ME31) and 2 driving instructors (MP1, MP2) driving through a set course in the residential area of Tokyo were collected with a data recorder unit. Participants were explained about the nature of the experiment before driving and informed consent was obtained from each participant before driving. This data collection was done with the approval of the ethics committee of The University of Tokyo. Among the whole data, we used the driving behavior passing through the non-priority side of an unsignalized intersection. This intersection had a stop sign and the road which the drivers drove was a one-way road. Fig. 3 shows the appearance of the intersection.

![Fig. 3: Appearance of unsignalized intersection](image)
III. Results

A. Example of $S_d$ and Collision Mode (ME7)

Fig. 4 shows the $S_d$ and Collision Mode against collision objects traveling from the left, vehicle speed of driver ME7 and the viewable distance of each collision object. The horizontal axis is the vehicle position relative to the intersection, and the origin is the point where the driver’s viewpoint overlaps the stop line. The top-left graph shows the $S_d$ of each object in different colors. The right three graphs show the proportion of Collision Mode against pedestrians, bicycles, and cars traveling from the left. The vertical axis indicates the probability of encountering each Collision Mode, and the sum of the probability to collide (Modes 1 to 3) is equivalent to the $S_d$ value. The two graphs from the bottom on the left side each show the vehicle speed and viewable distance. The two black lines parallel to the vertical axis are, from the left, the position where the vehicle front end overlaps the stop line, and the position where the vehicle front end reaches the entrance of intersection.

Although ME7 did not decelerate near the stop line, he accelerated after stopping near the intersection entrance. $S_d$ of pedestrian and bicycle increased as it approached the intersection, and decreased to 0 at a stroke by decelerating. But it increased to 1 immediately after entering the intersection. $S_d$ of cars was 0 before and during the approach to the intersection. In terms of Collision Mode against bicycles as an example, the probability of Mode 2 (Yellow) and Mode 5 (Cyan) at position -2.1 m was approximately 0.6 and 0.4 respectively. This indicates that the Collision Mode against bicycles which the driver finds at position -2.1 m and the probability of the modes are approximately 60 % for Mode 2 and 40 % for Mode 5. Using $S_d$ and Collision Mode makes it possible to interpret the possibility and scenarios of collision with objects while the vehicle approaches the intersection.

B. Driving support 1: Increasing deceleration when a crossing object is found

Fig. 5 shows the vehicle speed of driver ME22 passing through the intersection, Fig. 6 shows the viewable distance of bicycles from the left, and Fig. 7 shows the Collision Mode of bicycles from the left. For bicycles found near position 0 m, collisions can often be avoided in Mode 6. However, there was a high possibility of Mode 2 with bicycles found near position -1.2 m. Fig. 8 shows the Collision Mode of bicycles when the deceleration was increased to 0.8 G with driving support. Different from when the deceleration was 0.4 G, collisions between bicycles found near position -1.2 m are avoided in Mode 6. In this case, it is suggested that the vehicle was able to stop before entering the intersection by increasing the deceleration, and this leads to the avoidance of collisions with bicycles.

C. Driving support 2: Decreasing deceleration when a crossing object is found

Fig. 9 shows the vehicle speed of driver ME27 passing through the intersection, Fig. 10 shows the viewable distance of pedestrians from the left, and Fig. 11 shows the Collision Mode of pedestrians from the left. For pedestrians found before position -1.7 m, the vehicle collides with the pedestrians in Mode 3. In addition, for pedestrians found in the position range between -1.6 m and -1.1 m, the vehicle avoided collision with them in Mode 4. However, there were cases where the vehicle collided in Mode 1 as well. Fig. 12 shows the Collision Mode of pedestrians when the deceleration was decreased to 0.1 G with driving support. Compared to the result when the deceleration was 0.4 G, the possibility of avoiding collisions with pedestrians found before position -1.7 m was higher, and there was almost
no possibility of colliding with pedestrians found in-between position -1.6 m and -1.1 m in Mode 1. In this case, the results indicate that the speed when entering the intersection was high, and it was more effective for the vehicle to pass through the intersection with small deceleration rather than applying sudden braking with larger deceleration.

In the case of driver ME27, collisions with pedestrians were be avoided by reducing the deceleration. However, from the results described in Fig. 13 and 14, collisions with bicycles and cars were not avoided when the deceleration was smaller. Moreover, the damage due to the collision was assumed to be larger because the vehicle speed was relatively higher. This happens because driver ME27 passed through the non-priority side of the intersection without decelerating as shown in Fig. 9. Therefore, it is required to decelerate and stop and make safety checks before entering the intersection when driving the non-priority side of an unsignalized intersection.

From the results shown above, the scenarios of collisions that would likely to occur in real driving behavior data were clarified using the proposed risk assessment method ($S_d$ and Collision Mode). Moreover, the effectiveness of specific driving support (increase and decrease in deceleration) to avoid collisions was assessable using the method. However, it needs to be noted that certain support may have a positive effect on one collision object and have a negative effect on another object at the same time. Therefore, the investigation of measures to avoid collision needs to be done considering the objects that may exist in the intersection.
IV. Discussion

To assess the safeness of driving behavior with the proposed method, we investigated Collision Mode, and behavior of driving instructors. Fig. 15 shows the vehicle speed of instructor MP2 and Fig. 16 shows the viewable distance of each collision object. MP2 stopped and checked for safety at two different points, the stop line and the entrance of intersection. Fig. 17 shows the Collision Mode of MP2. Although collisions were often avoided in Mode 6, there was still a possibility of colliding with bicycles from the left in Mode 2 around position 0 m. Hence, it is even difficult for driving instructors, who take safety into consideration while driving, to reduce collision risk against bicycles to zero. To compensate for this risk, the instructor placed her foot on the brake pedal so that she can press the pedal immediately, and she was making frequent checks to the sides to find objects as soon as possible when entering the intersection. In addition, she slowly put out the vehicle’s front end when entering the intersection to show other traffic participants that she is going to enter the intersection and promote others to decelerate for her. From the above, it is difficult to reduce collision risk against bicycles to zero at unsignalized intersections, and the vehicle needs to enter the intersection in a way that it can guide deceleration of crossing objects to compensate for the collision risk.

V. Conclusion

We proposed a collision risk method at unsignalized intersections that consists of collision risk index $S_d$ and Collision Mode, and considered how to reduce collision risk of real driving data. As a result, the method was effective to show that both increase and decrease in deceleration after finding a collision object can avoid collisions. In addition, the analysis of instructor’s driving using the method made clear that it is difficult to make the collision risk against bicycles to zero at unsignalized intersections, and it is suggested that the vehicle needs to enter the intersections while guiding the crossing object’s deceleration to compensate for the collision risk.

References