Study on Cooperative Intersection Collision Detection System Based on Vehicle-to-Vehicle Communication

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Abstract. A conventional intersection collision detection system based on vehicle-to-infrastructure (V2I) communication has performance limitations owing to the real-time limitations and the cost of installing the infrastructure. In this study, to overcome these problems, a cooperative intersection collision detection system based on vehicle-to-vehicle communication was proposed. An algorithm was developed to estimate the degree of risk at the intersection using the time-to-intersection (TTI) value. Furthermore, the proposed algorithm was verified by applying it to a real collision detection system, which demonstrated the potential of the proposed cooperative intersection collision detection system in relation to the ideal TTI value. Based on the results of this study, the proposed cooperative intersection collision detection system will solve the inaccuracy of the conventional system based on V2I communication.

Keywords: Urban Intersection, V2V, Collision Detection System, PreScan

1 Introduction

The number of traffic accidents is greatly increasing around the world with the increase in the number of cars. According to the statistics for the United States of America and Japan, about half of all traffic accidents occur at intersections [1, 2]. This high accident rate at intersections is the result of the blind zones formed by objects or buildings located at the corners of intersections. Recently, a cooperative safety system, which combines vehicle-to-vehicle (V2V) communication and vehicle-to-infrastructure (V2I) communication, has been developed in the information technology field and is being implemented to solve problems such as the blind zones at intersections [3].

Previous studies have used sensors installed on road surfaces to transmit information about dangerous situations to drivers or radar sensors installed on traffic lights at intersections to sense vehicles in blind zones and transmit this information to

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drivers [4, 5]. However, these intersection collision detection systems using V2I communication require the installation of multiple sensors on road surfaces, and their real-time capability is inferior to that of V2V communication. Therefore, an intersection collision detection system using V2V communication is required. Thus, this paper proposes an intersection collision detection system that applies V2V communication.

2 System design

The cooperative intersection collision detection system proposed in this paper uses V2V communication. First, the relative distance (RD) and relative angle (RA) to a target vehicle are calculated by combining the information from the ego vehicle and surrounding vehicles provided by their vehicle monitoring systems through the V2V communication [6].

In this paper, the degree of risk is determined by using the time-to-intersection (TTI), the intersection collision risk index, after calculating the distances from the ego and target vehicles to an intersection, as shown in Fig. 1. Here, the TTI is the time required for a car to enter an intersection, as calculated using formula (1).

\[
TTI_n (s) = \frac{\text{Intersection distance}_n}{\text{Target vehicle speed}_n}
\]  

(1)

Moreover, using RD and RA, the distances from the ego and target vehicles to the intersection can be calculated using formulas (2) and (3), respectively.

The degree of collision risk at an intersection can be determined through the change in \( TTI_{ego} \) when the absolute value of the difference between the \( TTI_{ego} \) for the ego vehicle and \( TTI_n \) for a target vehicle is less than or equal to \( TTI_{Threshold} \), as shown in formula (4). Here, \( n \) is the id of the target vehicle.

\[
\text{Intersection distance}_i = \text{target vehicle speed}_i \times \text{relative distance} \times \text{relative angle}
\]

\[
\text{Relative distance} = \sqrt{\text{distance}_n - \text{distance}_i}
\]

\[
\text{Relative angle} = \arctan\left(\frac{\text{intersection distance}}{\text{relative distance}}\right)
\]

\[
\text{Intersection collision risk index} = \begin{cases} 
0 & \text{if } |TTI_{ego} - TTI_n| > TTI_{Threshold} \\
1 & \text{otherwise}
\end{cases}
\]

Fig. 1. Calculation principle for determining distances to intersection using RA and RD
Intersection distance

\[ r_{Ego} = RD_1 \cdot \cos(\theta_{Ego}) \]  

\[ r_{n} = RD_n \cdot \sin(\theta_{n}) \]  

\[ |TTI_{Ego} - TTI_n| \leq TTI_{Threshold} \]  

3 Simulation and results

To verify the applicability of the intersection collision detection system proposed in this paper, a scenario was used wherein a blind zone at an intersection prevented the drivers of the ego and target vehicles from seeing each other.

The proposed system was verified through a comparison of the ideal TTI and the TTI calculated by the proposed intersection collision detection system based on V2V communication. Here, the ideal TTI was produced by measuring the distances of the ego and target vehicles to an intersection after installing radar sensors at the collision point of the intersection. Fig. 2(a) and (b) shows the TTI\(_{ego}\) and TTI\(_{1}\) calculated by the proposed system and the ideal TTI\(_{ego}\) and TTI\(_{1}\), respectively. Fig. 2(c) shows the TTI\(_{ego}\) and TTI\(_{1}\) error rates.

The results show that the calculated and ideal TTI values over the whole simulation range were relatively similar, with TTI\(_{ego}\) and TTI\(_{1}\) average error rates of 12.32% and 9.22%, respectively. Furthermore, the TTI error rate results of Fig. 2(c) show that the error rate greatly increases at an imminent collision point. This occurred because the ideal TTI value is very small when a collision is imminent.

![Fig. 2. TTI of proposed system vs. Ideal TTI: (a) ego vehicle, (b) Target vehicle 1, (c) Error rate of ego vehicle and target vehicle](image)
4 Conclusion

This paper proposed an intersection collision detection system based on V2V communication. The degree of risk was determined by using the TTI, the intersection collision risk index, after calculating the distances from the ego and target vehicles to an intersection using RD and RA, which were calculated by combining the information from the ego and surrounding vehicles provided through the V2V communication. The error rate of the proposed system, compared to the ideal TTI, was about 10.77%, which verified that the system determined a comparatively accurate degree of risk. Thus, it was verified that the cost of installing a separate communication infrastructure could be reduced by determining a dangerous situation at an intersection using only V2V communication.

In future studies, research will be conducted to determine the degree of collision risk at intersections with various shapes in addition to right-angle intersections.

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