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Cooperative Intersection Collision - Warning System Based on Vehicle-to-Vehicle Communication

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Abstract

Intersection-collision warning systems use vehicle-to-infrastructure communication to avoid accidents at urban intersections. However, they are costly because additional roadside infrastructure must be installed, and they suffer from problems related to real-time information delivery. In this paper, an intersection-collision warning system based on vehicle-to-vehicle communication is proposed in order to solve such problems. The distance to the intersection is computed to evaluate the risk that the host vehicle will collide at the intersection, and a time-to-intersection index is computed to establish the risk of a collision. The proposed system was verified through simulations, confirming its potential as a new intersection-collision warning system based on vehicle-to-vehicle communication.

Keywords: Intersection Collision Warning, V2V, V2I, Urban Intersection

1 Introduction

As the number of vehicles increases globally, the number of car accidents increases proportionally. According to the available statistical data concerning vehicle accidents in USA and Japan, approximately 50% of car accidents occur at intersections [1,2]. A high percentage of car accidents occur at intersections owing to blind areas resulting from high-rise buildings in urban areas. In order to address these problematic blind areas at intersections, connected safety-communication systems are being introduced [3,4]. Typical connected safety-communication systems are either vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I) and research is on-going to develop these systems [5,6]. One previously researched method to address the blind areas at intersections proposed the installation of sensors on the road surface to detect dangerous situations and notify drivers when they exist [7]. Another researched method proposed installing radar sensors on traffic lights at intersections to detect other vehicles and notify drivers of dangerous situations [8]. However, such collision-warning systems are based on V2I communication and require the installation of sensors on the road surface. Moreover, they lack the real-time capability available with V2V communication. Therefore, intersection-collision warning systems based on V2V communication are sought. In order to overcome current limitations, this paper proposes an intersection-collision warning system based on V2V communication.

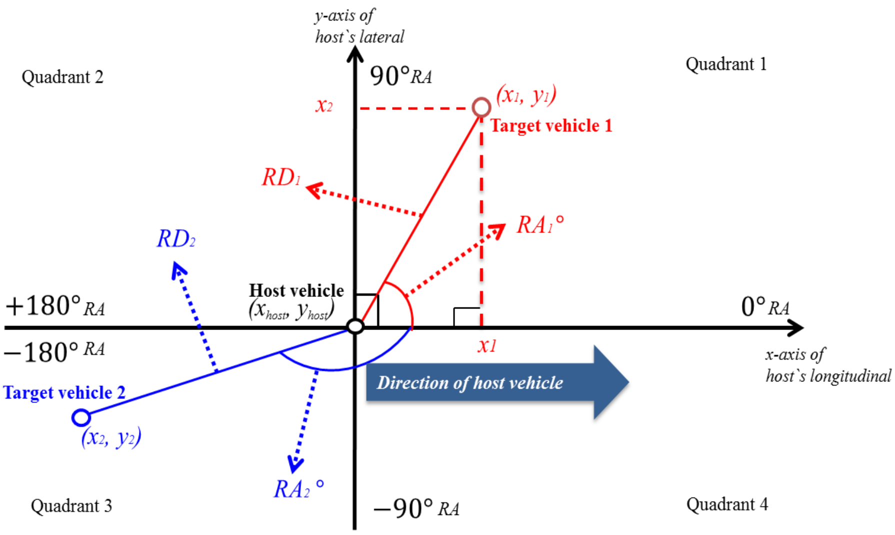


Fig. 1 RD and RA from the surrounding-vehicle observer system

2 Cooperative Intersection-collision Warning System

The intersection-collision warning system proposed in this paper is a system that addresses the dangers posed by blind areas and applies V2V communication with the ultimate aim of reducing vehicle collisions. As shown on Fig. 1, surrounding-vehicle observer systems integrate the target vehicle's data received from V2V communication with the host vehicle's data, and compute the relative distance (RD) and the relative angle (RA) to the target vehicle [9]. However, the computed RD to a target vehicle is a linear RD and does not consider the scenario illustrated in Fig. 2. For this reason, our proposal computes the distance to intersection from the host vehicle and the target vehicle using the RD and RA from the surrounding-vehicle observer server, as shown on Fig. 3. The proposed method then evaluates the degree of risk using a time-to-intersection (TTI) index to establish the risk of a collision at the intersection. The TTI measures the time required for a vehicle to enter the intersection. The TTI for the host vehicle and the target vehicle is calculated using Equations (1) and (2), respectively. A small TTI value implies that the risk is high.

$$TTI_{host}\ (\mathrm{s}) = \frac{Intersection\ \ distance_{host}}{Host\ vehicle\ \ speed_{host}} \tag{1}$$

$$TTI_{n}\ (\mathrm{s}) = \frac{Intersection\ \ distance_{n}}{Host\ vehicle\ \ speed_{n}} \tag{2}$$

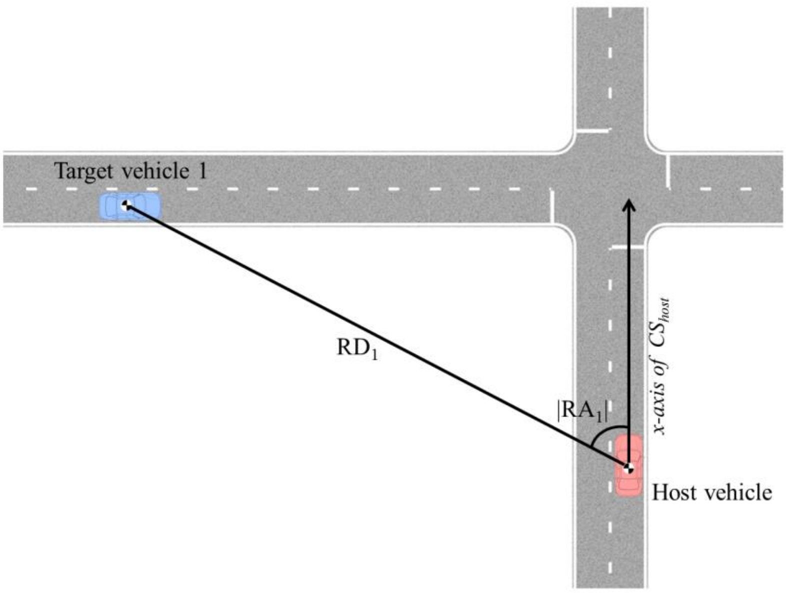


Fig. 2 RD and RA at the intersection

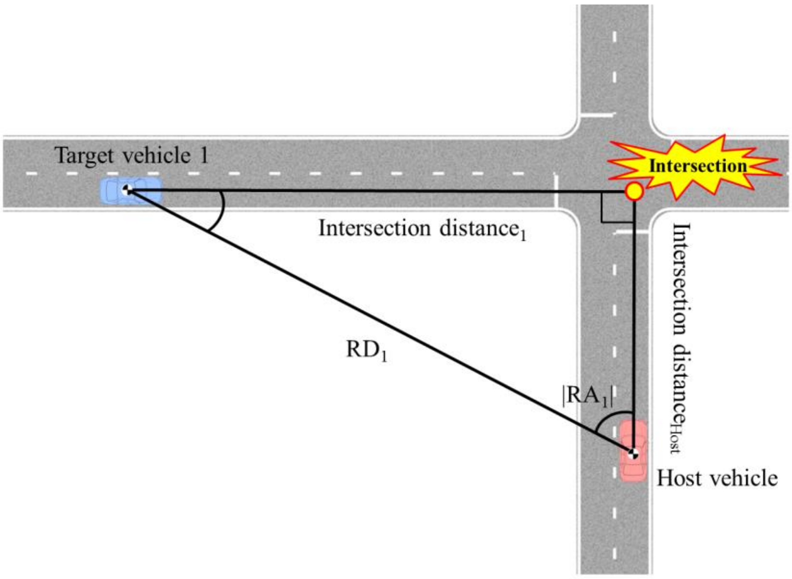


Fig. 3 Computing the distance to the intersection

The distance between the host vehicle and the intersection and the distance between the target vehicle and the intersection is calculated using Equations (3) and (4), respectively. The intersection-collision warning system is designed to evaluate the degree of risk with varying TTI_{host} values when the absolute value of difference between the TTI_{host} of the host vehicle and the TTI_n of the target vehicle is less than a certain threshold, $TTI_{threshold}$, as formulated in Equation (5). Here, “n” refers to the target vehicle.

$$Intersection\ distance_{host} = RD_n \cdot \cos(|RA_n|) \tag{3}$$

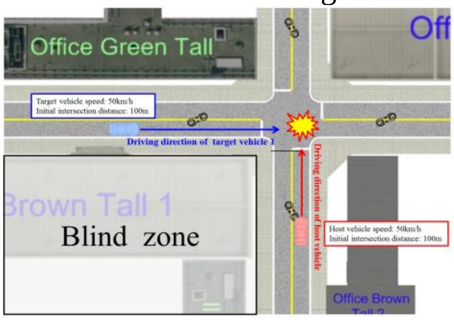
$$Intersection\ distance_n = RD_n \cdot \sin(|RA_n|) \tag{4}$$

$$|TTI_{host} - TTI_n| \le TTI_{threshold} \tag{5}$$

3 Simulation and results

3.1 Simulation scenario

In order to verify the intersection-collision warning system proposed in this paper, an urban intersection scenario was developed as shown in Fig. 4(a). The driver of the host vehicle will find it difficult to see the target vehicle approaching the intersection because of high-rise buildings (i.e., the blind zone), as depicted in

(a) 

(b) 

Fig. 4 Simulation scenario: (a) Urban intersection, (b) Host vehicle from the driver's point of view

Fig. 4(b). A scenario was imagined such that the drivers of both the host and target vehicles are not aware that another vehicle is approaching the intersection, owing to the blind zone, leading to a collision at the intersection. The GPS system used in this simulation accurately establishes the position within an error range of 50 cm.

3.2 Simulation results

First, the system was verified through a comparative analysis between intersection distances and the ideal intersection distance computed using the proposed V2V communication based on the collision-warning system. The ideal intersection distance was computed by installing a radar sensor at the intersection collision point to measure the distances from the host vehicle and the target vehicle to the intersection. Figs. 5(a) and 5(b) respectively represent the resulting intersection distance and the ideal intersection distance computed using the proposed system. Based on the results in Fig. 5, the intersection distance and the ideal intersection distance computed using the proposed system within the entire simulation area had an average error rate of 12.07% and 9.62%, respectively. This indicates that the intersection distance was estimated with relative accuracy against ideal intersection distance. Thus, the feasibility of the intersection-collision system based on the V2V communication was confirmed. Fig. 6 represents various warning flags for the intersection-collision warning system based on the TTI. Warning flags with varying TTIs are represented in Table 1 [10]. The results from Fig. 6 reveal that the degree of risk increases as the host vehicle approaches the intersection-collision point and that the warning flag adequately evaluates the degree of risk.

Table 1 Intersection warning flag

Degree of Risk	Low	Medium	High
TTI [s]	≤2.7	≤1.7	≤0.8
Flag	1	2	3

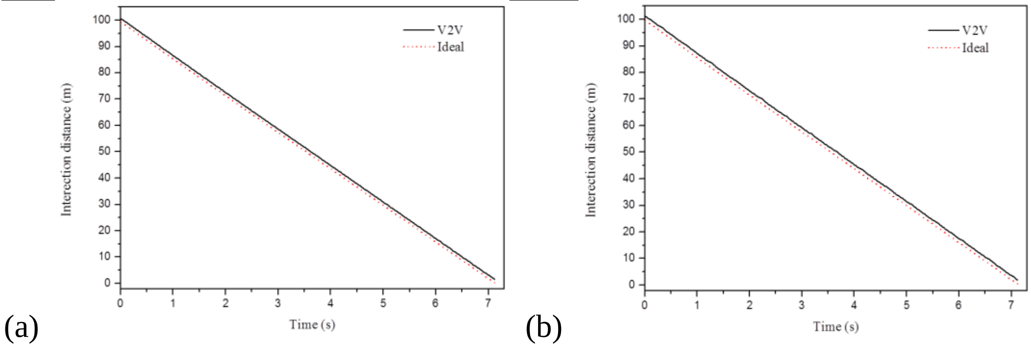


Fig. 5 Intersection distance of proposed system vs. Ideal intersection distance: (a) Host vehicle, (b) Target vehicle

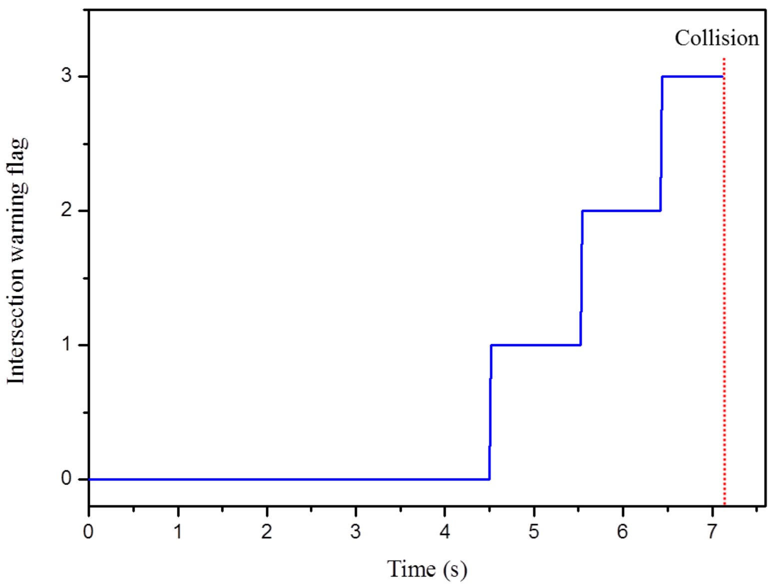


Fig. 6 Intersection warning flag

4 Conclusion

In this paper, an intersection-collision warning system based on V2V communication was proposed. First, RA and RD were computed using data from the target and host vehicles received from the V2V communication. After computing the distance of the host and target vehicles to the intersection, the TTI was used to evaluate the degree of risk. The intersection distance value from the proposed system had an error rate of 10.85% when compared with the ideal intersection distance value, and hence, we could confirm that the intersection distance was computed relatively accurately against ideal intersection distance. Moreover, the intersection-collision warning system based on the TTI reliably issued warnings of a dangerous situation to the drivers throughout the entire area. Hence, we confirmed the feasibility of using the V2V-based collision-warning system to avoid vehicle accidents at intersections. In future research, systems that are proposed for a real collision-avoidance system shall be applied to the proposed method, and systems proposed for real vehicle-communication environments will be verified.

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