Study on Collision Risk during V2V-based Lane Changes using Minimum Collision Avoidance Distance

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Abstract. This paper proposes a system to determine the minimum collision avoidance distance with vehicles in other lanes during lane change when vehicle-to-vehicle (V2V) communication is established between the host vehicle and the vehicle ahead. Existing collision avoidance systems have the limitations that blind spots exist because they employ sensor-based recognition and that the moving time in the lateral direction should be calculated in advance before the collision risk distance is calculated. To resolve these problems, V2V communication and minimum collision avoidance distance (CAD) method were adopted in this study. To verify the minimum CAD for lane change, the relative velocity and the time required for lateral direction movement were calculated and reflected in the simulation scenarios. The collision risk during a lane change was then calculated using the relative velocity and CAD.

Keywords: V2V (Vehicle to vehicle), CAS(Collision avoidance system), ADAS(Advanced driver assistant system)

1 Introduction

In recent years, the advanced driver assistance system (ADAS) has been actively studied to reduce collisions among vehicles. Examples of typical active safety systems are FCW (forward collision warning), RCW (rear-end collision warning), AEB (autonomous emergency braking), LKAS (lane keeping assist system), LDWS (lane departure warning system), and BSD (blind spot detection) [1][2][3]. These systems can help avoid collisions through vehicle control in dangerous situations. It is important to execute appropriate control strategies after determining risks correctly in dangerous situations. If risk determination is incorrect, accidents may occur. The method to determine the risks may vary depending on the applied system. Collision risk determination methods using neural networks [4] and using the minimum safety spacing (MSS) method [5] have been investigated. However, the above studies were limited by the sensor detection range because risks were determined using sensors.
Furthermore, studies on collision risk determination using the MSS method had a limitation that the moving time in the lateral direction had to be calculated in advance. In recent years, V2V (vehicle to vehicle) and V2I (vehicle to infra) communication-based collision risk determination approaches are being explored [6]. Thus, it is necessary to study risk determination to overcome the above-mentioned problems such as limitations of sensor detection range and moving time calculation in the lateral direction. In this paper, a method of collision risk determination based on the minimum collision avoidance distance (CAD) during lane change in a V2V environment is proposed.

### 2 Determination of collision risk during lane change

We determined the collision risks between host and target vehicles when the host vehicle changed its lane. Fig. 1 shows a flow chart of the process. CAD was calculated using the relative distance and velocity and also using the moving time of the host vehicle in the lateral direction via locations of the host and target vehicles as obtained through V2V communication. The calculated relative distance and CAD were compared. If the relative distance was larger than the CAD, collision could be avoided during lane change. If the relative distance was smaller than CAD, collision could occur during lane change.

**Fig. 1.** Flow chart of collision risk determination.

Eq. (1) shows the relative distance between the host and target vehicles over time. $S_r(0)$ is the relative distance between host and target vehicles at $t_{adj}$. To avoid collision, $S_r(t)$ should always be larger than 0. The maximum CAD value represents the minimum value of Eq. (1). Eq. (2) shows the minimum CAD. The maximum value out of the calculated results over time is the minimum CAD.

Fig. 2 shows the geometric method to calculate $t_c$. Through Eq. (3), the time to move to the place where collision with another vehicle can occur can be calculated.

$$S_r(t) = S_r(0) - CAD > 0, \ \forall t \in [t_c + t_{adj}, T]$$

$$Cd = \min_{t \in [t_c, T]} \max_{t \in [t_c, T]} \left[ S_r(t) - 0 \right]$$

$$t_c = \sqrt{\left( \frac{S_r(0) - CAD}{a_h} \right)^2 + \left( \frac{S_r(0) - CAD}{v_h} \right)^2}$$

$$Sr(t) = Sr(0) - CAD > 0, \ \forall t \in [t_c + t_{adj}, T]$$
3 Simulation and results

3.1 Simulation scenario

The collision risk when the host and target vehicles run at a constant velocity using V2V communication was analyzed according to the relative distance and CAD calculation values. A change rate of 2–10 km/h was applied to the relative velocity between the host and target vehicles. The target vehicle velocity was set higher than the host vehicle velocity. In addition, the road width was set as 3.5 m in accordance with the road design regulations in Korea, and $t_{lat}$ was set as 5 s [5]. Simulations were conducted while changing the host vehicle velocity according to the suggested relative velocity conditions.

3.2 Simulation results

For the scenario defined in Section 3.1, the obtained collision risk determination simulation results were verified with regard the minimum CAD.

Fig. 3 shows the change in the relative distance according to the relative velocity between the two vehicles. The arrow in the figure indicates the minimum CAD. As shown in the figure, the larger the relative velocity between the two vehicles, the larger was the change in the relative distance. Furthermore, if the relative distance between the host and target vehicles was larger than the minimum CAD, the host vehicle could safely change its lane to the lane of the target vehicle.

Fig. 4 shows the collision risk according to the relative velocity between the host and target vehicles. As shown in the figure, the larger the relative velocity between

$$CAD = (V_m - V_{ld})(t_c + t_{adj}), \quad V_m < V_{ld}, \quad \forall t \in [t_c + t_{adj}, T]$$

(2)

$$t_c = \frac{s}{H}t_{lat}$$

(3)

Fig. 2. Calculation of $t_c$ through a geometric method.
the two vehicles, the smaller was the minimum collision avoidance distance, and therefore, the time of risk decreased. When the relative velocity was 10 km/h, the change in the relative distance was large so that the distance became larger than the minimum CAD at approximately 0.3 s. Thus, after 0.3 s, the risk became 0. When the relative velocity was 2 km/h, the change in relative distance was so small that the distance became larger than the minimum CAD at approximately 8.6 s. Thus, after 8.6 s, the risk became 0.

Fig. 3. Changes in relative distance according to the relative velocity.

Fig. 4. Collision risks according to the relative velocity.
4 Conclusion

In this study, collision risks were determined through the minimum CAD for V2V-based lane changes. Lane change risks were determined according to the minimum CAD, which varied with the relative velocity between the host and target vehicles. Since existing lane change risk determination systems are sensor-based, they have the limitation that they cannot recognize target vehicles if the target vehicles are located in the blind spot. In contrast, the proposed collision risk determination system exhibited no blind spot because it was based on V2V communication, which can overcome the performance limitations of the existing risk determination systems. Simulations were conducted to verify whether the proposed system can determine collision risks with target vehicles correctly for various relative velocities. Through the simulations, we verified the usability of the proposed collision risk determination system.

In the future research, we plan to study minimum collision risk determination by considering acceleration.

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