Advanced Science and Technology Letters
Vol.86 (Ubiquitous Science and Engineering 2015), pp.20-25
http://dx.doi.org/10.14257/astl.2015.86.05

Braking Performance Improvement Method for V2V Communication-Based Autonomous Emergency Braking at Intersections

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Abstract. In this study, a control method is proposed for improving the braking performance of an autonomous emergency braking (AEB) system by reflecting various friction conditions of the driving road surface on the basis of vehicle-to-vehicle (V2V) communication. Because the conventional AEB system's control logic is set on the basis of the friction factor of a certain road, various road conditions are not reflected. To improve the braking and collision performance according to changes in road surface friction, a new method of control logic that reflects friction force changes is introduced. In addition, the concept of time to collision (TTC) at an intersection is applied to analyze the braking and collision characteristics of the vehicle's AEB system. With the new control method that applies friction force changes during driving, it is confirmed that the braking and collision performances are improved compared to the conventional method.

Keywords: V2V (Vehicle to vehicle), AEB (Autonomous emergency braking), TTC (Time to collision), Road Surface condition

1 Introduction

With the increasing interest in vehicle safety and implementation of relevant legislation underway, adoption of systems that can improve the convenience and safety of the driver is increasing. A representative example is the autonomous emergency braking (AEB) system. In the past, AEB systems detected obstacles by using radar and image sensors [1].

An obstacle detection sensor attached to a vehicle can detect an obstacle only directly in front of it because of the physical hindrance of surrounding vehicles. Particularly, the risk of traffic accidents due to blind zones is high at intersections, where vehicles approach from multiple directions, because of the limitation of the obstacle detection sensor [2]. To solve this problem, vehicle-to-infrastructure (V2I) and vehicle-to–vehicle (V2V) communication methods were introduced to vehicle AEB systems [3][4].

ISSN: 2287-1233 ASTL

To evaluate the completeness of a vehicle AEB system, an objective evaluation procedure is necessary, and usually the Euro NCAP AEB evaluation procedure is followed. The control logic determines the braking and collision characteristics of V2V-based vehicle AEB systems. The conventionally performed AEB control method is carried out by mainly reflecting a uniform road condition. In other words, the braking and collision control logic of a vehicle AEB reflects only the dry asphalt condition [5]. When only a certain road condition is reflected, braking and collision performance becomes limited because frequently changing road conditions cannot be satisfied [6]. Furthermore, in existing studies, AEB system evaluations were conducted under a particular road state condition. Because such a research field suggests an evaluation method from the AEB system aspect, AEB performance improvements are limited [7].

Therefore, in this study, a control method that can improve AEB performance is proposed by considering road surface friction state on the basis of a V2V communication environment at intersections. The usefulness of the new control method is analyzed by carrying out a comparison with a conventional system, which does not consider the variable road surface friction conditions.

2 AEB System Control Method

The AEB system proposed in this paper consists of a part that calculates time to collision (TTC) at intersections and a part that calculates braking time point, for effective braking according to road surface conditions.

As shown in Eq. (1), the operation starting time of the proposed AEB system is the moment when the vehicle's collision risk TTC_{Host} becomes smaller than the braking time ($TTC_{propose}$) according to the road surface condition.

$$TTC_{Host} < TTC_{propose}\ (Full\ braking) \tag{1}$$

In this paper, the collision risk calculation method of the previous study was used [8]. In the V2V communication environment, TTC was calculated using the distance to a collision position of a host vehicle and target vehicle and each vehicle's speed, as shown in Eq. (2).

$$TTC_{Host} = \frac{\text{Intersection distance}}{V_{Host}} \tag{2}$$

The braking time ($TTC_{propose}$) according to road surface condition can be calculated through the speed and the distance to a stop, as shown in Eq. (3). Using the maximum deceleration (a_μ), the braking distance (S_μ) and time (T_μ) to a stop can be obtained with Eq. (4).

$$TTC_{propose} = \frac{S_\mu}{V_{Host}} \tag{3}$$

$$S_{\mu} = \frac{V_{Host} \times T_{\mu}}{2}, T_{\mu} = \frac{V_{Host}}{a_{\mu}}, a_{\mu} = \mu \times g \tag{4}$$

3 Simulation and Results

3.1 Simulation Scenario

In this paper, to verify the proposed AEB system, the simulation was configured as shown in Fig. 1. The driver of the host vehicle cannot see the other vehicle approaching from a different direction because of the blind zone due to a building. Consequently, a collision of the host vehicle and target vehicle occurs at the intersection.

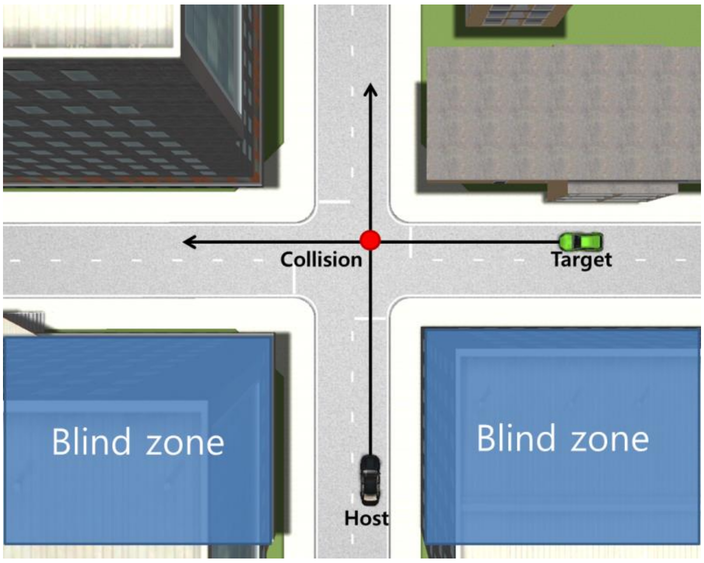

Fig. 1. Simulation configuration

As shown in Table 1, the vehicle speed was set to 40 km/h and 60 km/h, which are representative cases based on the Euro NCAP AEB Test scenarios. Road surface conditions were set to dry asphalt ($\mu = 0.85$), wet asphalt ($\mu = 0.60$), and snow asphalt ($\mu = 0.30$). For the conventional AEB system, a test was conducted under the dry asphalt condition only. On the other hand, to compare the relative performance of the proposed and conventional AEB systems, the occurrence/avoidance of collision was compared by applying them to the dry asphalt as well as additional road surface conditions, i.e., wet asphalt and snow asphalt. Accordingly, the simulation was carried out by changing the road surface condition according to the given vehicle speeds.

Table 1. Simulation scenario.

AEB Scenario	Speed [km/h]	Road Surface Condition	Friction Factor (μ)
City	40	Dry asphalt	0.85
Inter-Urban	60	Wet asphalt	0.60
		Snow asphalt	0.30

3.2 Simulation Results

Table 2 shows the simulation results indicating whether a collision occurred between the vehicles according to the speeds and friction factors provided in Table 1. The conventional AEB system avoided collision with the vehicle entering the intersection for dry asphalt and 40 km/h, and for wet asphalt; but collisions occurred in all other conditions. However, it was confirmed that the proposed AEB system avoided the collision in all speeds and road surface conditions provided in the simulation scenario. Through this result, the usefulness of the proposed AEB system control algorithm was confirmed

. **Table 2.** Collision/avoidance according to speed and friction factor.

AEB system	Road condition / Speed [km/h]	Dry asphalt $\mu = 0.85$	Wet asphalt $\mu = 0.60$	Snow asphalt $\mu = 0.30$
Conventional	40	Avoided	Collided	Collided
	60	Avoided	Collided	Collided
Proposed	40	Avoided	Avoided	Avoided
	60	Avoided	Avoided	Avoided

As a representative condition that can show the usefulness of the proposed AEB system, a case of snow asphalt and a case where the vehicle speed is 40 km/h were selected. Fig. 2 shows the change of TTC, which is collision risk according to time, and the results for the conventional AEB system and the proposed AEB system were comparatively analyzed. To safely avoid a collision between vehicles on the snow asphalt, which has lower road friction than the dry asphalt road surface, the AEB system requires a longer braking time than on dry asphalt. Because the conventional AEB system does not take the road surface condition into consideration, the collision risk is 1.6 s in the snow asphalt road condition, and the braking permission time is confirmed to be the same as that of the dry asphalt road condition. As a result, it was confirmed that a collision occurred at 9.6 s with the conventional AEB system. However, it was confirmed through Fig. 2 that the collision was avoided with the proposed AEB system because the full braking power was confirmed at the collision risk of 1.89 s, which was faster than the full braking permission time of the conventional system.

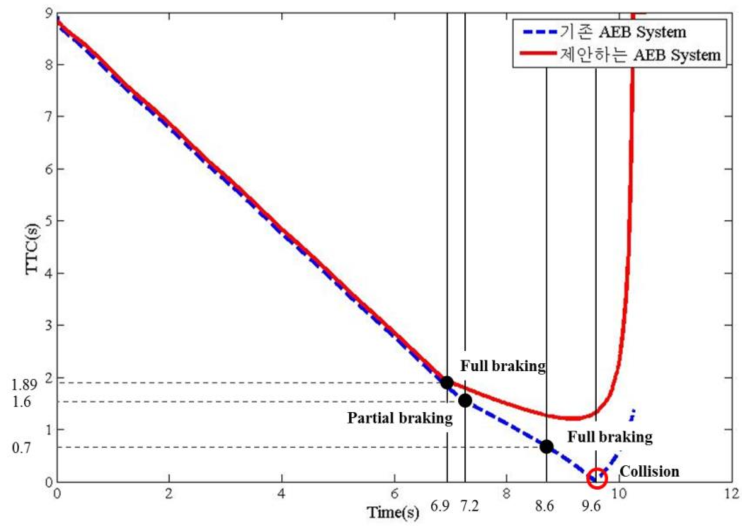

Fig. 2. TTC changes at road and speed conditions (snow asphalt: μ = 0.3; v: 40 [km/h]).

4 Conclusion

In this paper, a control method was proposed that can improve the AEB performance by considering various road surface conditions on the basis of a V2V communication environment at an intersection.

The conventional AEB allowed a partial brake and full brake through collision risk at an intersection by using the location and speed information of the self-vehicle and surrounding vehicles on the basis of V2V communication. Because the braking permission time of the conventional AEB system is set on the basis of dry asphalt, it is fixed at 1.6 s and 0.7 s although the road surface condition changes. As a result, collisions occurred on the wet asphalt and snow asphalt. Therefore, there was a limitation in the AEB system's collision performance because the braking permission time did not consider the road surface conditions.

In contrast, the proposed AEB system permits full braking by deriving a braking permission time after calculating the collision risk at an intersection considering the road surface conditions. The simulation confirmed that the vehicle in which the proposed AEB system algorithm was applied avoided collisions in all given scenario condition environments. Through this outcome, it was confirmed that the brake and collision performance were improved with the proposed AEB system compared to the conventional system.

As follow-up studies, research will be carried out on a method for estimating road friction factor and on a collision detection system for various types of intersections.

Acknowledgments. This research was supported by the MSIP (Ministry of Science, ICT and Future Planning), Korea, under the C-ITRC(Convergence Information Technology Research Center) (IITP-2015-H8601-15-1005) supervised by the IITP(Institute for Information & communications Technology Promotion)

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