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AEB System for a Curved Road Considering V2V-based Road Surface Conditions

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Abstract. In this study, a brake intervention time algorithm of an ego vehicle is proposed to consider various road surface conditions when driving, through vehicle to vehicle (V2V) communication with a front vehicle in a curved road. Conventional autonomous emergency braking (AEB) systems have a consistent brake intervention time regardless of road surface conditions. To avoid a collision with a vehicle in front, a control method is introduced, in which the brake intervention time changes according to the road surface conditions. To verify the brake intervention time according to various road friction factors, the simulation scenario reflected the vehicle velocity and road curvature radius. The control method, which changed the brake intervention time according to the road surface conditions, had better collision-avoidance performance than the conventional AEB system control method.

Keywords: V2V (Vehicle to vehicle), AEB (Autonomous emergency braking), TTC (Time to collision), Curve road, Road friction

1 Introduction

According to a report of the U.S. National highway traffic safety administration (NHTSA), approximately 80% of traffic accidents were due to driver mistakes [1]. In addition, according to statistical data of the Road Traffic Authority in South Korea, the accident rate on flat curved roads in 2011–2013 was approximately 58% [2]. To reduce driver-caused accidents, studies are actively carried out for advanced driver assistance systems (ADAS). Among various types of ADAS, the autonomous emergency braking (AEB) system avoids collisions with a vehicle in front. The sensor-based AEB system has a limited detection range [3]. Recently, to overcome this limitation, studies have been conducted on AEB systems based on communication schemes such as vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) [4]. In addition, studies have been carried out on many road environments for AEB system applications [5]. At Euro NCAP, an AEB system test

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was carried out on a straight road considering the road surface conditions [6]. However, the conventional AEB system studies were carried out under certain road surface conditions. AEB systems designed for only certain road conditions have a limitation in brake performance when the road surface condition changes.

Therefore, a study is required for appropriate brake intervention time according to road conditions, because the braking distance changes with road surface condition. In this paper, an optimal AEB algorithm is proposed, which considers various road conditions when driving on a curved road in urban area under a V2V environment.

2 Proposed AEB System Control Method

The AEB system proposed in this paper is configured as shown in Fig. 1. The proposed AEB system permits full braking by deriving the brake intervention time according to road surface condition. To determine the brake intervention time, the collision risk (time-to-collision, or TTC) with a front vehicle was compared with the brake intervention time TTC_{thr} for avoiding a collision with the front vehicle. In other words, braking is permitted in an ego vehicle by determining an instant when the TTC value becomes smaller than TTC_{thr} value as a brake intervention time.

To determine the brake intervention time, the TTC and TTC_{thr} parameters are required. The two parameters can be obtained through Eq. (1) and (2). Eq. (1) calculates TTC by using the relative velocity and relative distance of the ego vehicle and the front vehicle. Through this, the time to collision of the ego vehicle and front vehicle can be confirmed.

$$\mathrm{TTC[s]} = \frac{\text{Relative distance}}{\text{Relative velocity}} \tag{1}$$

Eq. (2) calculates the brake intervention time TTC_{thr} through the relative velocity after obtaining the braking distance according to maximum deceleration by using the constant acceleration formula. To calculate the brake intervention time considering various road surface conditions, the maximum deceleration and braking distance have to be calculated considering the road conditions.

The maximum deceleration of the ego vehicle for stopping in various road surface conditions is calculated through Eq. (4). Through the maximum deceleration, the minimum collision distance can be obtained through Eq. (3) for avoidance of a collision with a front vehicle. TTC_{thr} can be calculated through Eq. (2) with the distance calculated through Eq. (3) and the relative velocity.

$$\mathrm{TTC_{thr}[s]} = \frac{\text{Stop distance}}{\text{Relative velocity}} \tag{2}$$

$$\text{Stop distance[m]} = \frac{(\text{Relative velocity})^2}{2 \times \text{Deceleration}} \tag{3}$$

$$\text{Deceleration}[\mathrm{m}/s^2] = \mu \times \mathrm{g} \tag{4}$$

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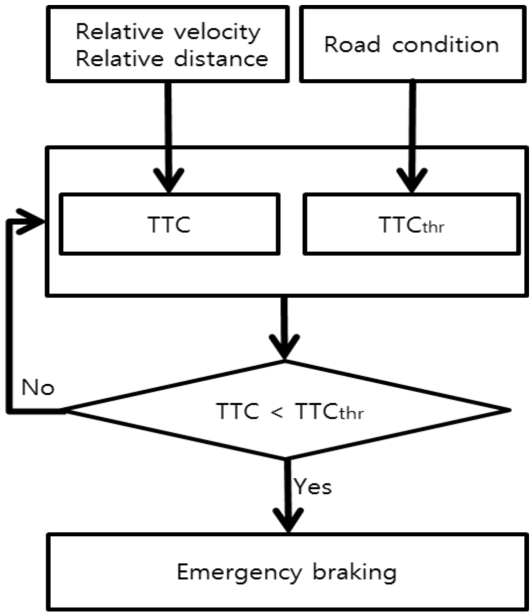

Fig. 1. AEB system flow chart

3 Simulation and results

The PreScan simulation tool was used for configuring the V2V communication environment of the host vehicle and target vehicle, and for modeling the driving environment. Because PreScan has a limitation in modeling a vehicle with a high degree of freedom and constructing a simulation environment of various road conditions, the limitation was supplemented through CarSim, which is a vehicle dynamics simulation tool. Using MATLAB/Simulink, the AEB system algorithm was implemented, and PreScan and CarSim were interfaced.

3.1 Simulation scenario

A scenario of a curved road environment was composed to compare the conventional AEB system and the AEB system considering road conditions. In the vehicle driving scenario, the AEB system of the ego vehicle was set to operate by recognizing a stationary vehicle in front on the basis of V2V communication. In addition, the road conditions were classified into various road conditions, including snow-covered road (μ = 0.3), wet road (μ = 0.5), and dry road (μ = 0.85). For the speed condition of the ego vehicle, 40 km/h, which is an urban area speed, was applied. For the road

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curvature radius, 70 m was applied. The simulations were carried out according to all given road surface conditions.

3.2 Simulation results

Through the scenario defined in Section 3.1, the simulation results of the proposed AEB system were confirmed.

Fig. 2(a) shows the performance analysis of the conventional AEB system. With respect to braking with the conventional AEB system, a partial braking is permitted at 1.6 [s] and full braking at 0.7 [s]. On the x-axis, which means simulation execution time, a partial braking was permitted at 12.1 [s] and full braking at 13.6 [s]. The collision with the front vehicle was avoided on dry road and wet road among the road conditions set up. However, the collision occurred with the front vehicle on the snow-covered road. Because the snow-covered road condition has a lower road surface friction factor than the dry road and wet road, it was confirmed that the conventional AEB system has a limitation in contributing to collision avoidance because these road surface conditions are not reflected.

Fig. 2(b) shows the performance analysis when the proposed AEB system was applied. The brake intervention time of Table 1 shows the time point derived through Eq. (2). It can be seen that as the road surface friction factor becomes lower, more braking distance is required and the brake intervention time becomes faster. In Fig. 2(b), it is confirmed that the full braking intervention time is 13.1 [s], 12.7 [s], and 11.9 [s] for dry road, wet road, and snow-covered road, respectively. Because the brake intervention time changes according to the road surface condition, the collision did not occur in all road surface conditions proposed in the simulation.

Table 1. Brake intervention time according to velocity and road surface condition

Road condition / Velocity[km/h]	Snow-covered Road (μ=0.3)	Wet Road (μ=0.5)	Dry Road (μ=0.85)
40	1.88[sec]	1.13[sec]	0.67[sec]

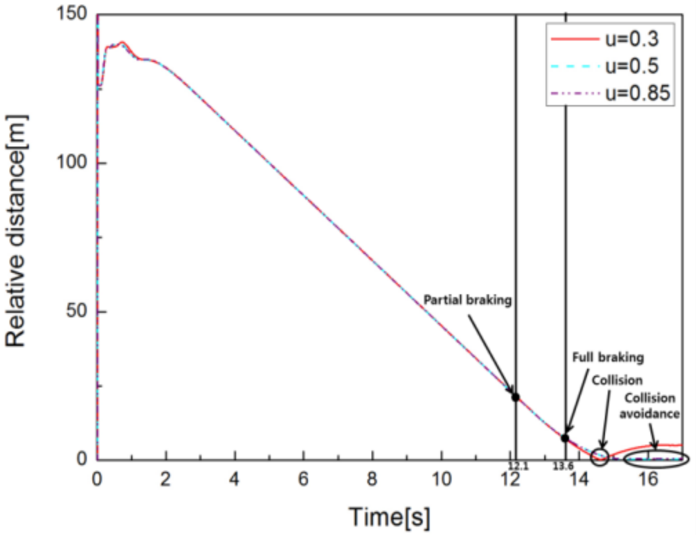

Fig. 2 (a). AEB system comparison according to relative distance (conventional AEB system).

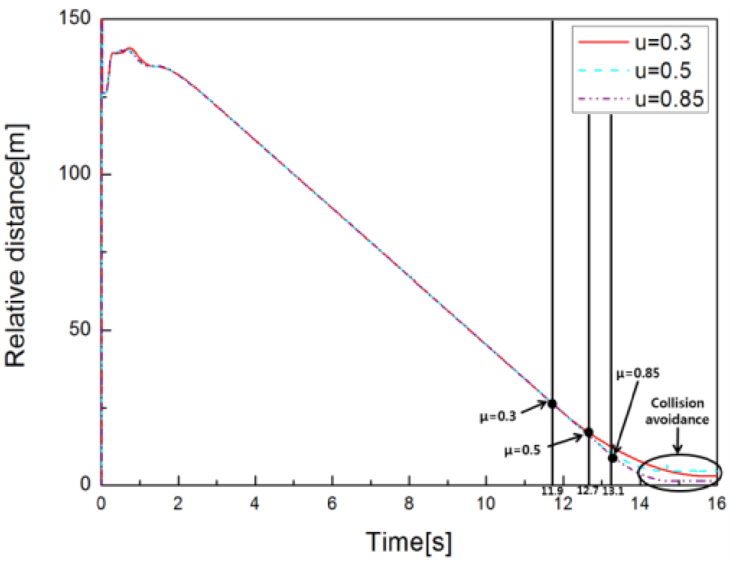

Fig. 2 (b). AEB system comparison according relative distance (proposed AEB system).

4 Conclusion

In this paper, an algorithm was proposed for brake intervention time considering road surface conditions on urban curved roads in a V2V environment. Braking was carried

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out by comparing the brake intervention time, which varies according to the road surface condition, with TTC. The conventional AEB system has a limitation in brake performance under various road surface conditions because the brake intervention time is consistent. On the other hand, the proposed AEB system can supplement the collision performance limitation of the conventional AEB system for various road surface conditions because the AEB system is controlled by varying the brake intervention time with road surface conditions. It was confirmed through the simulation that the proposed AEB system avoided a collision with a front vehicle under various road surface conditions of a curved road. Through this, the usefulness was confirmed for the proposed AEB system control algorithm.

In the future, a follow-up study will be carried out for the brake intervention time on a curved road considering a gradient in addition to the curved road on flat land.

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