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A Study and Analysis for Calculating the Brake-application Time of AEB Systems Considering the Gradient

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Abstract

In this study, a control algorithm is proposed to enhance the braking performance for an Autonomous Emergency Braking (AEB) system by improving the method for calculating the brake-application time when the vehicle is on an incline. The conventional AEB system in an algorithm-applied vehicle is limited because the gradient is not considered. With such systems, only a flat road environment is considered in terms of the road settings. To improve the braking performance on an incline, an AEB algorithm considering the road gradient is developed. A new calculation method for the brake-application time is proposed on the basis of the maximum deceleration that a vehicle can obtain on a road, and this is done by analyzing the force exerted on a vehicle that is on an incline. We confirmed that the AEB algorithm proposed in this paper improves the braking performance compared to the conventional AEB algorithm.

Keywords: *Autonomous Emergency Braking (AEB), Collision Avoidance, Time To Collision (TTC), Incline, Brake-application time*

1. Introduction

According to study by HEATCO, a research project funded by the European Union, approximately 250,000 European drivers and pedestrians were seriously injured by automobile accidents in 2012 [1]. To reduce such injuries, studies are being actively carried out on the Advanced Driving Assistance System (ADAS), with viable proposals such as the Autonomous Emergency Braking (AEB) system [2]. A sensor-based AEB system is an active safety system that applies braking by automatically determining risks [3]. It is shown that the AEB system reduces the collision accident rate by approximately 30% [4].

Studies on the conventional AEB algorithm have proposed methods for improving the brake-application time by estimating the road-surface conditions through dynamic vehicle analysis and for improving the Time-To-Collision (TTC) calculation at intersection and along curved road environments [5-8]. The conventional algorithm's performance was verified by referring to a test scenario from the European New Car Assessment Programme [9]. However, this test did not consider a vehicle on an incline [10]. Because the maximum deceleration for a vehicle on an incline is different from that on a flat surface, the conventional AEB algorithms do not always calculate the brake-application time accurately. Therefore, research is needed for an AEB system algorithm that avoids collisions by calculating the braking time accurately when the vehicle is on an inclined surface.

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In this paper, an AEB algorithm is proposed that can avoid a collision with the vehicle ahead of it. The proposed algorithm analyzes the braking performance in downhill high-risk environments. Through a simulation, the effectiveness of the proposed algorithm is demonstrated by comparing it with the conventional AEB system, which does not consider the gradient.

2. AEB System Considering a Gradient Environment

In this paper, the system performance of a conventional AEB system is enhanced by considering the influence of inclines on vehicle braking. In a previous study, the TTC risk index was defined as the ratio of relative distance and relative velocity, as shown in Eq. (1) [11]. The AEB system is operated by applying the brake when the risk index TTC is smaller than a certain value. The brake-application time calculated for a conventional AEB system is improved with an AEB algorithm that considers the effects of driving on an incline. As with the brake-application time in conventional studies, this study uses an AEB system installed on a Volvo. For this Volvo, full braking is applied when the TTC ≤ 0.9 s [12].

$$TTC = \frac{S_{rel}}{V_{rel}} \quad (1)$$

With this proposal, the brake-application time is modified by considering the road gradient, rather than calculated using a stipulated time, such as 0.9 s. Figure 1 provides a flowchart for the proposed AEB system considering a gradient. The proposed AEB system applies full braking when the TTC $\leq TTC_{min}$, by comparing the TTC collision-risk index and a new risk index that considers a gradient, TTC_{min}. Eq. (2) offers the equation for calculating TTC_{min}. In this equation, S_{min} is the minimum deceleration distance, calculated by Eq. (3). To calculate the minimum deceleration distance, the maximum deceleration a_{max} is calculated. Assuming a vehicle is decelerating at a constant rate, the maximum deceleration is calculated using Eq. (4). In this equation, when calculating a maximum deceleration a_{max}, a gradient for the driving environment is taken into consideration, and μ is the road-surface friction factor, assumed to be 1. When a vehicle is running, if Eq. (5) is satisfied, a collision can be avoided by applying full braking to the vehicle while simultaneously releasing the throttle.

$$TTC_{min} = \frac{S_{min}}{V_{rel}} \quad (2)$$

$$S_{min} = v_0 t + \frac{1}{2} a_{max} t^2 \quad (3)$$

$$a_{max} = -\mu\, cos(\theta)\, g + gsin(\theta) \quad (4)$$

$$TTC \leq TTC_{min} \quad (5)$$

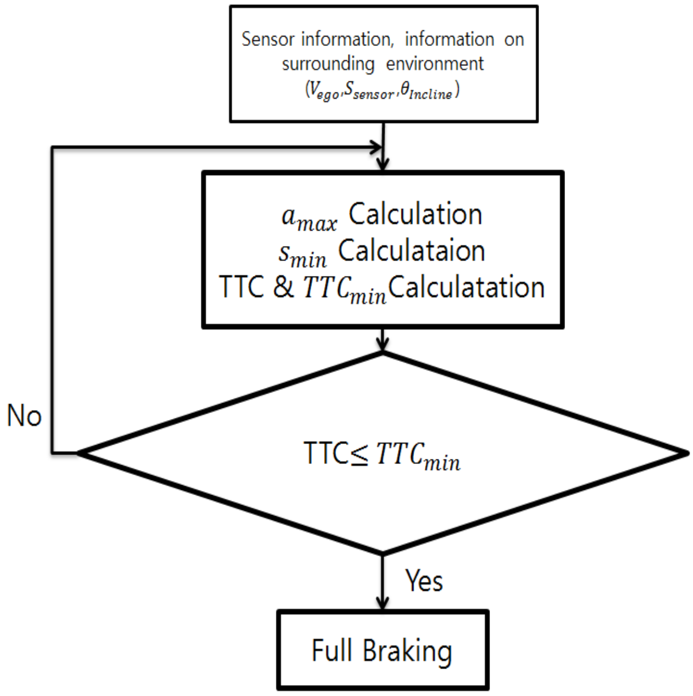

Figure 1. Flowchart for the AEB System Considering an Incline

3. Configuration of the Simulation Environment

Figure 2 provides a diagram for the configuration of the simulation environment for the proposed AEB system. PreScan was used for the basic settings of the sensors that recognize the surrounding environment, including nearby vehicles. The AEB system's control algorithm was implemented with MATLAB/Simulink, and the vehicle was controlled by implementing it with PreScan.

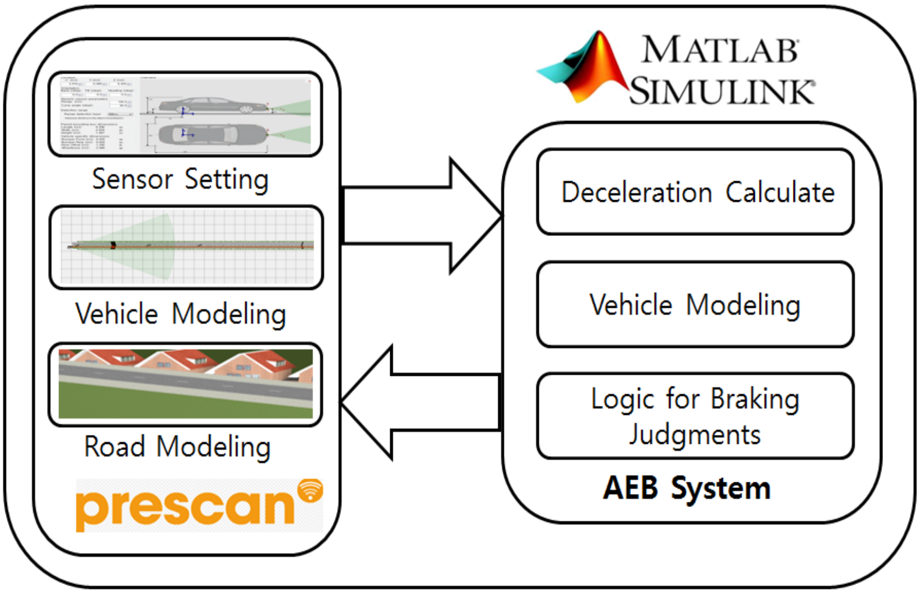

Figure 2. Configuration for the Simulation Environment

The simulation scenario was established, as shown in Figure 3 by applying the conditions shown in Table 1. A situation was designed such that the ego vehicle approaches a stationary vehicle ahead of it at a speed of 60 km/h on an incline. The speed of the vehicle was set by referencing the speed scenario for the AEB evaluation procedure with the ADAC group. Based on the safe longitudinal gradient specified by the South Korean Ministry of Land, Infrastructure and Transport, the gradients were set at 0%, 4%, 8%, 11%, 14%, and 17% [13].

Table 1. Settings for the Simulation Environment

Parameter	Value
Ego Vehicle Velocity [km/h]	60
Incline [%]	0, 4, 8, 11, 14, 17
Road-friction Coefficient	1

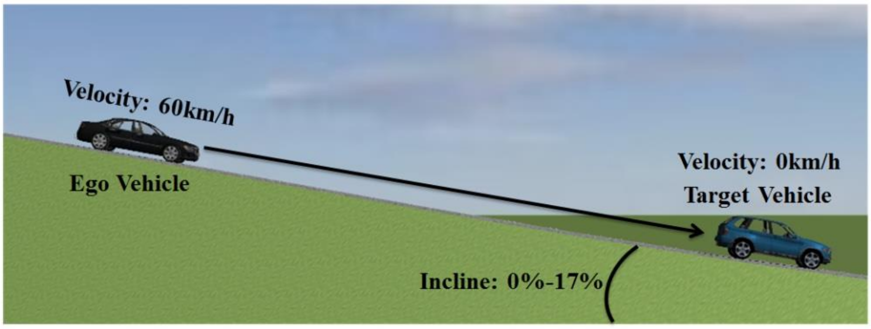

Figure 3. Model for the Road Environment

4. Simulation and Experiment Results

To verify the performance of the proposed AEB system that considers the effects of an inclined environment, the simulation results for the conventional AEB system were compared with those of the proposed AEB system. Tables 2 and 3 show the simulation results according to the gradient, with the vehicle speed conditions provided in Table 1. Table 2 shows the simulation results for the conventional AEB system, and Table 3 provides the simulation results for the proposed AEB algorithm. The "relative distance" in Tables 2 and 3 is the distance between the front bumper of the ego vehicle and the rear bumper of the stationary target vehicle. The "braking time" is the time at which the braking flag occurs after the simulation has started.

Table 2. Conventional AEB Simulation Results According To the Gradients

AEB System / Incline [%]	Basic AEB		Avoidance /Collision
	Relative Distance [m]	Braking Time [s]	
0	1.36	6.79	A
4	0.42	6.57	A
8	0	6.53	C
11	0	6.51	C
14	0	6.50	C
17	0	6.49	C

A: avoidance C: collision

Table 3. Proposed AEB Simulation Result According To the Gradients

AEB System / Incline [%]	Proposed AEB		Avoidance /Collision
	Relative Distance [m]	Braking Time [s]	
0	0.59	6.84	A
4	0.93	6.53	A
8	0.86	6.44	A
11	0.95	6.39	A
14	1.14	6.34	A
17	1.32	6.29	A

A: avoidance   C: collision

Table 2 shows the results from simulating a conventional AEB system-applied vehicle on a road where the gradients are 0%, 4%, 8%, 11%, 14%, and 17%. From these results, it is confirmed that the conventional AEB system-applied vehicle avoided a collision in an environment with gradients of 0% and 4%. However, the vehicle collided with the vehicle ahead on inclines of 8%, 11%, 14%, and 17%. Because the conventional AEB system does not consider the gradient in a driving environment, the change in maximum deceleration is unrecognized. Consequently, collisions occur because the conventional AEB system calculates the brake-application time by assuming that the road is flat.

Table 3 lists the results from simulating an AEB system-applied vehicle with the proposed algorithm on roads with gradients of 0%, 4%, 8%, 11%, 14%, and 17%. These results confirm that the AEB system-applied vehicle with the proposed algorithm avoided collisions in all gradient conditions. With the proposed AEB system, the brake-application times were calculated by considering the gradient and the maximum deceleration changes in the vehicle-driving environment. It was confirmed that the proposed AEB system improved the braking performance by overcoming this limitation in conventional AEB systems.

The results for the time at which the braking flag occurred are listed in Tables 2 and 3 and graphed in Figures 4 and 5.

Figure 4 shows the times at which flags occurred with the conventional AEB system-applied vehicle. In the figure, the conventional AEB system-applied vehicle applied braking at 6.79 s in a gradient environment of 0%, and at 6.52±0.03 s in a gradient environment of 4%–17%. It was confirmed that because the conventional AEB system does not consider the gradient, braking was applied at a similar time in road environments with 4%–17% gradients.

Figure 5 shows the times at which flags occurred with the proposed algorithm for an AEB system-applied vehicle. In the figure, the proposed algorithm applied braking at 6.79 s in a gradient environment of 0%, and at 6.41±0.12 s in a gradient environment of 4%–17%. Unlike with the conventional AEB system wherein the braking-application times were similar, the braking-application times with the proposed algorithm were calculated differently according to the change in gradient.

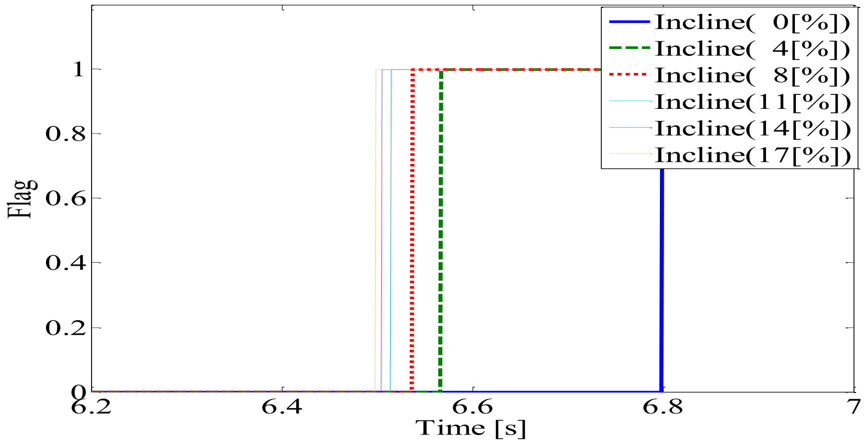

Figure 4. Flag Simulation Results for the Conventional AEB System

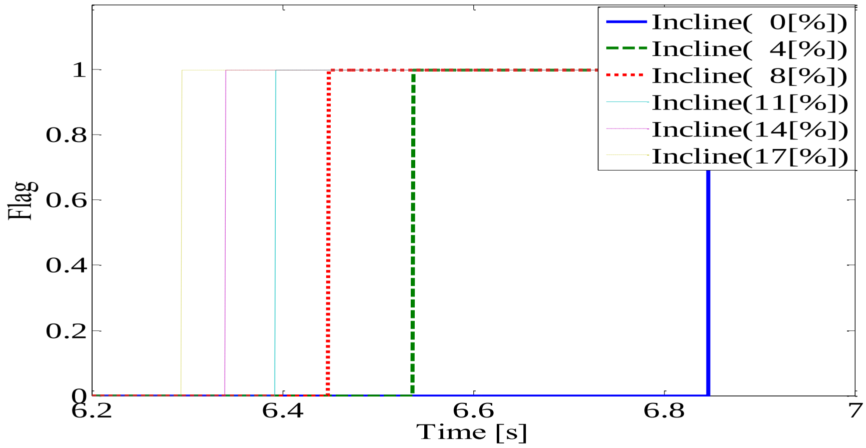

Figure 5. Flag Simulation Results for the Proposed AEB System

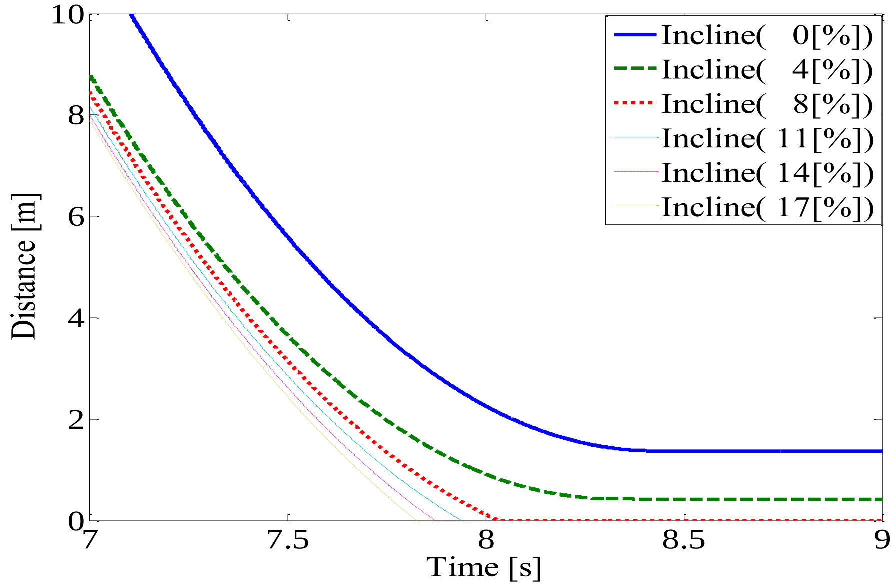

Figure 6. Relative Distance Simulation Results for the Conventional AEB System

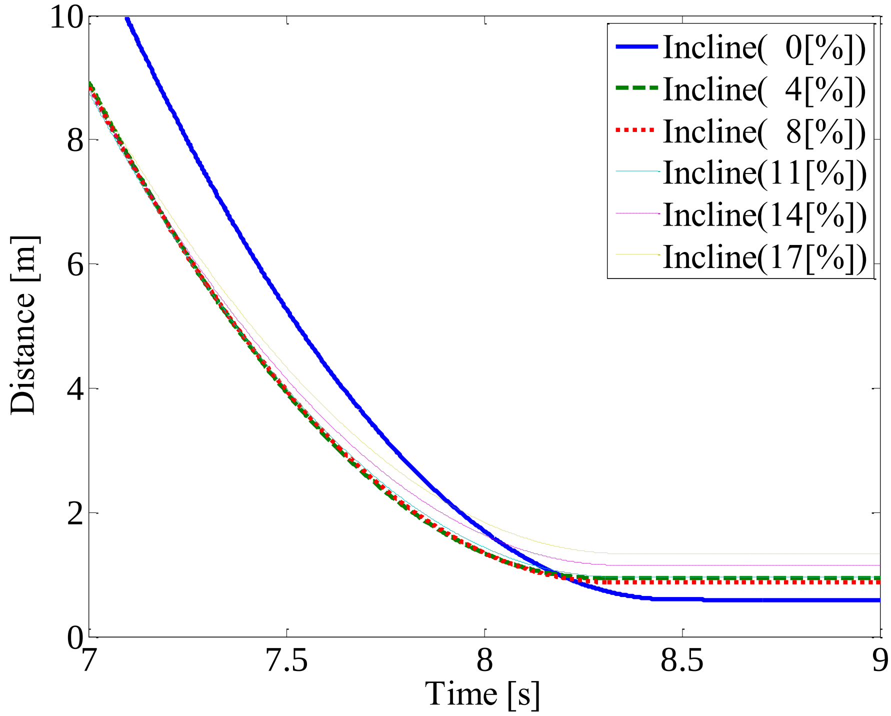

Figure 7. Relative Distance Simulation Results for the Proposed AEB System

The results for the relative distances shown in Tables 2 and 3 are graphed in Figures 6 and Figures 7. Figure 6 depicts the relative distances for a conventional AEB system-applied vehicle. In this figure, the conventional AEB system-applied vehicle avoided a collision with the vehicle ahead by stopping at a relative distance of 1.36 m in an environment with an inclination of 0% (i.e., on a flat surface). For an environment with a 4% gradient, a collision was avoided by stopping at a relative distance of 0.42 m. However, in the case of inclines of 8%–17%, it was confirmed that collisions occurred because the relative distance of the vehicles was 0 m.

Figure 7 depicts the relative distances of the proposed algorithm in an AEB system-applied vehicle. In this figure, the proposed algorithm avoided collisions in all gradient environments. The collisions were avoided because the relative distance with the front ahead changed from 0.59 m to 1.32 m, according to a gradient change of 0%–17%.

5. Conclusion

In this paper, an AEB algorithm was proposed. This algorithm enhances the brake-application time by considering the gradient. To verify the proposed AEB algorithm, it was compared with the conventional AEB system by changing the road gradient. Through simulations, a limitation in the conventional AEB system was confirmed. The conventional AEB system cannot accurately calculate the brake-application time when the vehicle is driven on an incline. The proposed AEB algorithm improved the brake-application time by considering the maximum deceleration for a vehicle in a gradient environment. The simulation results confirmed that the proposed AEB algorithm avoided collisions under all gradient conditions, thereby verifying that the proposed AEB algorithm's braking performance improved.

Future studies shall be carried out for the AEB system algorithm by considering more scenarios and road-surface conditions.

Acknowledgments

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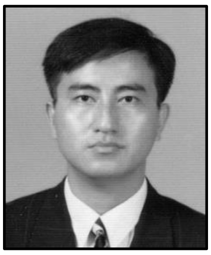

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