A NEW APPROACH TO FORWARD COLLISION AVOIDANCE

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ABSTRACT

Forward collision occurs most frequently and involves the largest number of fatalities among various types of collisions in traffic accidents. Active research has been carried out to develop systems to avoid or mitigate forward collision. These systems are effective in reducing the number and the severity of occupant injuries, however, there is still margin for improvement, especially for reducing jerk felt by the occupants while improving system performance. We propose a new approach to forward collision avoidance by integrating distance control and emergency braking according to likelihood of collision. We also use a low-cost camera vision sensor for detecting lanes and vehicles, and estimating collision risks. Evaluation of the proposed approach using our driving simulator showed the improvement in collision avoidance in terms of earlier system intervention, increased relative distance and reduced relative speed to a preceding car. Meanwhile, the reduced deceleration rate implied that vehicle occupants would feel jerk less during system intervention.

Keywords: forward collision avoidance, camera vision sensor, driving simulator, advanced driver assistance systems

INTRODUCTION

Various types of advanced driver assistance systems have become commercially available, helping drivers avoid or mitigate traffic accidents. These systems in general monitor driving environment and situations continuously, provide drivers with information and warning for convenience and safety, and take necessary actions to avoid possible crashes even without drivers' intervention.

Development of these systems requires careful and thorough evaluation of not only algorithms, but also user acceptance and adaptation. For this purpose, driving simulation provides an ideal environment by creating various driving situations that may not be possible with a real car in real

traffic for safety reasons and putting drivers in a simulation loop to evaluate objective performance and subjective feelings.

Among various types of collisions in traffic accidents, forward collision occurs most frequently and involves largest number of fatalities (Hanna and Widmann, 2008). Active research has been carried out to develop systems to avoid forward collision and, as a result, the representative systems such as PRE-SAFE Brake by Mercedez-Benz (Breuer et al., 2007) and City Safety by Volvo (Distner et al., 2009) have been introduced. These systems in general monitor roadways using sensors, warn drivers of possibility of collision, and apply braking to prevent or mitigate collision, if necessary.

A radar is the most common type of sensors used in collision avoidance systems, thanks to its high detection accuracy, robustness, and wide sensing capability, in spite of high cost (Bloecher et al., 2009). A low-cost camera vision sensor can also be applied to collision warning and avoidance because it can detect lanes, cars, and pedestrians in short range (Stein et al., 2010; Dagan et al., 2004).

Time-To-Collision (TTC) is normally used to determine timing of warning and intervention by these systems. For example, PRE-SAFE Brake warns a driver of possible collision around TTC of 2.6 seconds visually and acoustically, then applies braking up to 0.4G around TTC of 1.6 seconds, and finally applies full braking around TTC of 0.6 seconds (Bloecher et al., 2009).

Although these systems are effective in reducing the number and the severity of occupant injuries (Verma, 2010), there is margin for improvement, especially for reducing jerk felt by the occupants while improving system performance. This research thus aims to develop a more effective and efficient collision avoidance system utilizing a low-cost vision sensor. A driving simulator has been used to implement a camera vision system and evaluate the proposed collision avoidance system.

CAMERA VISION SYSTEM

Implementation on a driving simulator

In order to evaluate the proposed collision avoidance system in a safe and controlled driving simulation environment, we implemented a camera vision system on our driving simulator, as shown in Figure 1. We installed a low-cost CCD camera on the roof of the driving simulator cabin. We developed a lane and vehicle detection algorithm using an image processing module, Vision builder AI, integrated with Labview by National Instruments (Park, 2010).

The driving simulator, as shown in Figure 1, is equipped with (1) a 4 channel visual system that generates and displays photorealistic graphic images on segmented flat screens with front and rear field-of-view of 130x40 and 60x40 degrees, (2) a motion system that generates 3 degree-of-freedom motion (roll, pitch and heave) using unique combination of an AC servo motor and links installed at each wheel for fast response and low noise, (3) a 5.1 channel sound system that generates realistic driving sound and special effects, (4) a full-car cabin with realistic control loading and full instrumentation, and (5) driver status measuring equipment including an eye

tracking system and a physiological signal measuring unit. The simulator is operated by SCANeR II software in a distributed network of 8 personal computers.

(a) (b) (c)

Figure 1 Kookmin University driving simulator: (a) entire view, (b) a rear screen, and (c) a camera vision sensor

Lane Detection

Figure 2 shows the lane detection procedure. Once a gray level image is obtained by the CCD camera, a region of interest is selected for lane search. The Sobel edge detection algorithm is then used to detect edges of candidate lanes. The edges are processed to stand out by using a threshold value to separate bright pixels of lanes from dark pixels of roads. The Hough transform algorithm is then used to obtain straight lines from the detected edges. The inverse perspective transform is applied to determine position of the detected lanes on real roads based on the location of the lanes in the pixel coordinate system (Park, 2010). Figure 3 shows a sample of lane detection results.

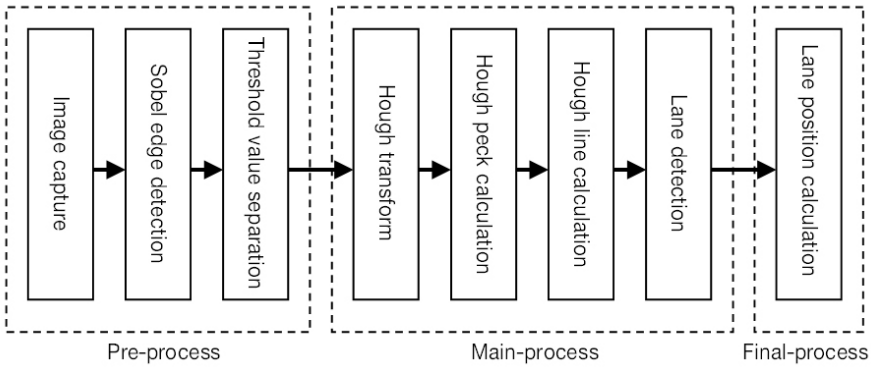
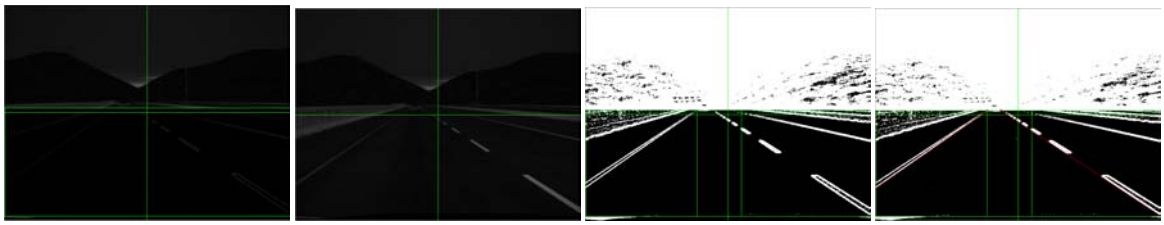


Figure 2 Lane detection procedure



(a) (b) (c) (d)

Figure 3 Lane detection result: (a) captured image, (b) Sobel edge detection, (c) threshold processing, and (d) detected lanes

Vehicle Detection

Vehicle detection algorithms use a variety of information including color, shadow, geometrical features, textures and vehicle lights to detect vehicles (Sun et el., 2006). We used shadow information. Figure 4 shows the vehicle detection procedure. Once a gray level image is captured, it is processed by a low pass filter for smoothing. Darker shadow areas are then separated from the background as candidate vehicle objects. Since these objects can contain non-vehicle objects, height and width information of the objects is used to filter out the non-vehicle objects. If a vehicle is detected as multiple objects due to particular distribution of shadows, information about their locations, sizes and relative distances is used to combine them. The inverse perspective transform is applied to determine position of the detected vehicles on real roads based on the location of the vehicles in the pixel coordinate system (Park, 2010). Figure 5 shows a sample of vehicle detection results.

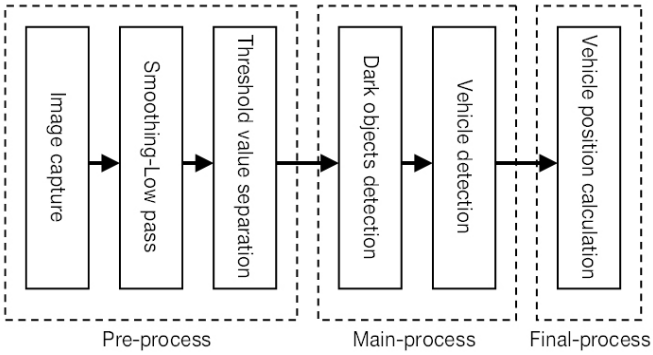
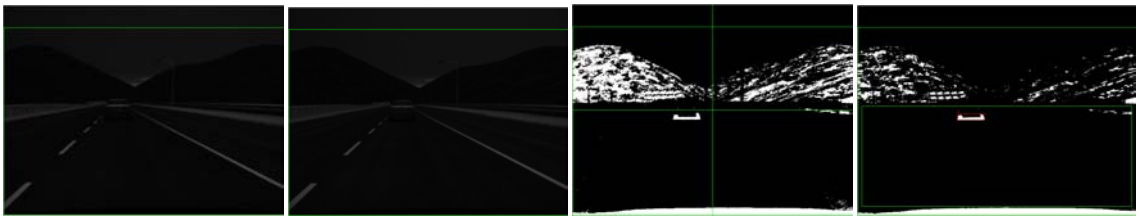


Figure 4 Vehicle detection procedure



(a) (b) (c) (d)

Figure 5 Vehicle detection result: (a) captured image, (b) low-pass filtering, (c) threshold processing, and (d) detected vehicle

ACTIVE FORWARD COLLISION AVOIDANCE

Our basic approach for forward collision avoidance is to integrate automatic distance control and emergency braking appropriately in order to reduce jerk felt by vehicle occupants while improving collision avoidance ability. If TTC is relatively large, distance control is executed to maintain safe distance and reduce possibility of collision. If TTC continues to become smaller, braking is applied accordingly to avoid or mitigate collision.

We introduce a safe distance concept, based on the critical warning distance proposed by Nakaoka (Nakaoka, 2008). The safe distance, D_s, is described by the following equation:

$$D_s = \frac{v^2}{2a} - \frac{(v - v_r)^2}{2(a - a_r)} + D_m \qquad (1)$$

where v is the host vehicle speed, v_r the speed difference between the host and the preceding vehicles, a_r the acceleration difference between the host and the preceding vehicles, and D_m safety margin distance when both vehicles stop.

The proposed collision avoidance system can respond in 4 ways, as illustrated in Figure 6: first, if the relative distance between the host and the preceding vehicle is larger than the safe distance in (1), no intervention is initiated. Second, if the relative distance becomes smaller than the safe distance and larger than TTC of 1.6 seconds, the proposed algorithm activates PI distance control, similar to adaptive cruise control, to reduce the host vehicle speed and maintain the safe distance. Figure 7 shows a block diagram of the distance control. Third, if the relative distance becomes smaller than TTC of 1.6 seconds and larger than TTC of 0.6 seconds, the system applies partial braking up to 0.4G. Finally, if the relative distance becomes smaller than TTC of 0.6 seconds, the system applies full braking.

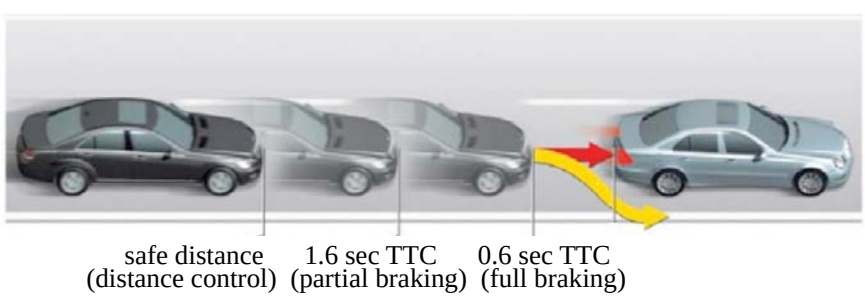


Figure 6 Proposed approach for active forward collision avoidance

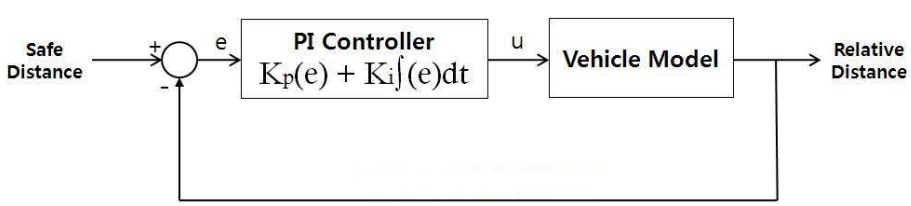


Figure 7 PI distance control block diagram

PERFORMANCE EVALUATION

Sudden Stop

The first evaluation scenario involves sudden braking by a preceding vehicle in the middle of driving. The host vehicle follows the preceding vehicle moving with the speed of 60 km/hr, and then the preceding vehicle suddenly applies full braking of 0.8G to make a stop.

The driving simulation results for the proposed avoidance system are compared with those of the representative conventional system, PRE-SAFE. Figure 8 shows that the distance between the host and the preceding vehicles when stopped for the proposed system is 4.1 m, meanwhile the distance for the conventional system is 1.0 m. This difference of 3.1 m clearly indicates larger margin for safety provided by the proposed system.

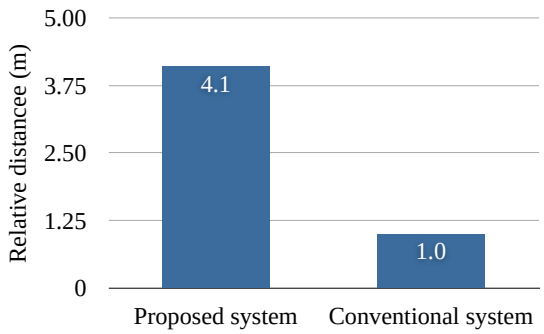


Figure 8 Distance between the host and the preceding vehicles for the proposed and the conventional systems

For timing of collision avoidance intervention, the proposed system intervenes 1.36 seconds earlier than the conventional system (Figure 9). This is because the proposed system starts to intervene earlier with distance control based on the safe distance criterion, followed by partial braking around TTC of 1.6 seconds, meanwhile the conventional system starts to intervene later with partial braking around TTC of 1.6 seconds.

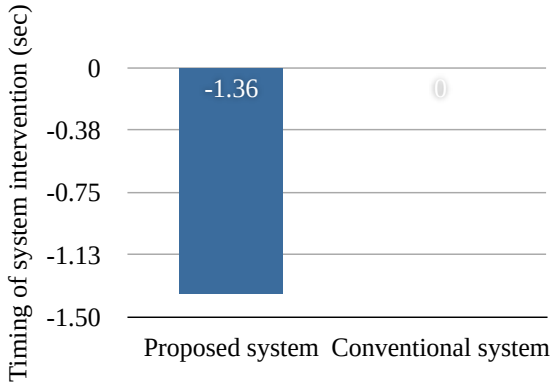


Figure 9 Intervention timing of the proposed system with respect to the conventional system

Comparison of average deceleration rate reveals interesting result, as shown in Figure 10. The average deceleration rate for the proposed system is 3.7 m/sec^2, meanwhile the rate for the conventional system is 6.2 m/sec^2. This difference shows that the proposed system would reduce jerk felt by occupants and thus make them less uncomfortable.

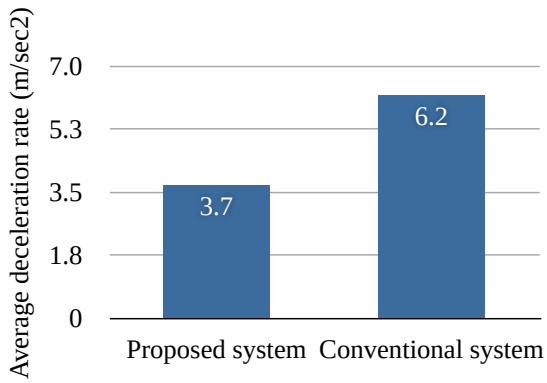


Figure 10 Average deceleration rate for the proposed and the conventional systems

Sudden Cut-in

The second evaluation scenario involves sudden cut-in by a vehicle in the next lane. While the host vehicle moves with the speed of 110 km/hr approximately, the vehicle in the next lane suddenly cuts into the driving lane with the speed of 60 km/hr.

Figure 11 shows that the proposed system intervenes 1.43 seconds earlier than the conventional system. This difference is because the proposed system keeps track of vehicles in neighboring lanes for collision risk estimation, and starts to intervene as soon as the vehicle in the next lane starts to cross over the lane, meanwhile the conventional system starts to intervene after the vehicle cuts into the driving lane.

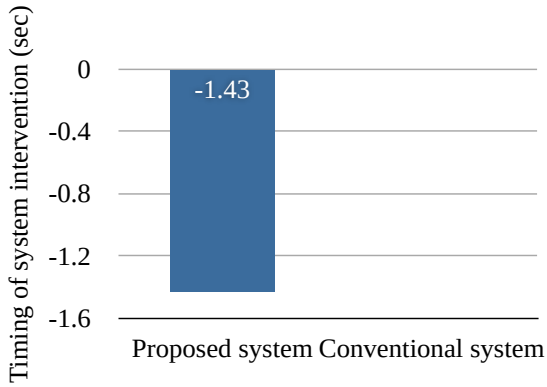


Figure 11 Intervention timing of the proposed system with respect to the conventional system

As a result, the distance between the host and the preceding vehicles after cut-in for the proposed and the conventional systems are 20.8 m and 16.4 m, respectively, as shown in Figure 12. Also,

when the preceding vehicle becomes directly ahead of the host vehicle, the speed of the host vehicle for the proposed system is reduced by 13.0 km/hr, meanwhile the speed for the conventional system is not reduced yet (Figure 13). This difference in the distance to the preceding vehicle and the speed reduction of the host vehicle causes the proposed system to avoid collision, but not the conventional system.

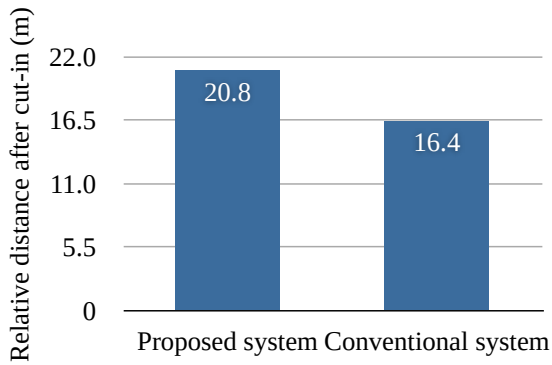


Figure 12 Distance between the host and the preceding vehicles for the proposed and the conventional systems

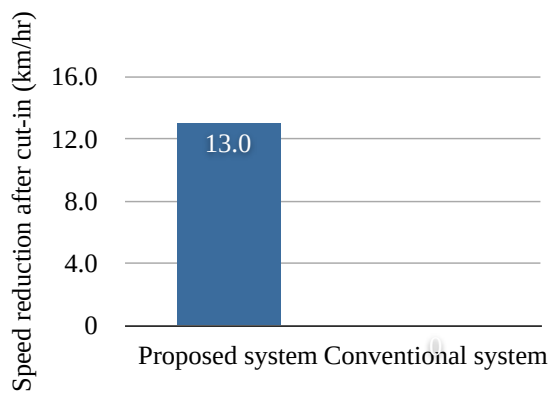


Figure 13 Speed reduction of the host vehicle for the proposed and the conventional systems

CONCLUDING REMARKS

Our approach for forward collision avoidance is to integrate automatic distance control and emergency braking in accordance with likelihood of collision. The driving simulation results showed the improvement in collision avoidance in terms of earlier system intervention, increased relative distance and reduced relative speed to a preceding car. Meanwhile, reduced deceleration rate implies that vehicle occupants will feel jerk less during system intervention.

Reliable sensing of hazards is critical for successful collision avoidance. Implementation and evaluation of a low-cost camera vision sensor on our driving simulator showed the potential of using the vision sensor for detecting lanes and vehicles, and estimating collision risks. However,

more intensive effort will be required to deal with sensor's inherent dependence on lighting conditions effectively and make the sensor more practical.

Future research will focus on evaluation and improvement of the proposed approach on larger-scale driving simulator experiments with a variety of emergency scenarios. Objective performance and subjective feelings will be evaluated in more detail.

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