AR-Based Vehicular Safety Information System for Forward Collision Warning

Hye Sun Park and Kyong-Ho Kim

Human-Vehicle Interaction Research Center, ETRI, Daejeon, Korea
hspark78@etri.re.kr

Abstract. This paper proposes an AR (augmented reality) based vehicular safety information system that provides warning information allowing drivers to easily avoid obstacles without being visually distracted. The proposed system consists of four stages: fusion data based object tracking, collision threat assessment, AR-registration, and a warning display strategy. It is shown experimentally that the proposed system can predict the threat of a collision from a tracked forward obstacle even during the nighttime and under bad weather conditions. The system can provide safety information for avoiding collisions by projecting information directly into the driver's field of view. The proposed system is expected to help drivers by conveniently providing safety information and allowing them to safely avoid forward obstacles.

Keywords: AR (augmented reality), vehicular safety information, forward collision, warning system, data fusion, object tracking, threat assessment, warning strategy.

1 Introduction

To avoid collisions with stationary obstacles, other moving vehicles, or pedestrians, drivers have to be aware of the possibility of a collision and be ready to start braking early enough. In addition, when following other vehicles, drivers need to keep a safe distance to allow for proper braking. An understanding of how drivers maintain such a safe distance, the type of visual information they use, and what visual factors affect their performance is clearly important for improving road safety. A driver has to rely on direct visual information to know how rapidly they are closing in on a forward vehicle. Therefore, if this information is poor, there is a danger of the driver not sufficiently braking in time. In addition, a system for the rapid detection of neighboring objects such as vehicles and pedestrians, a quick estimation of the threat of an obstacle, and a convenient way to avoid predicted collisions is needed. Automobile manufactures are highly concerned about problems related to motor vehicle safety, and are making greater effort to solve them, for example, adaptive cruise control (ACC) [1], antilock brake systems (ABSs) [2, 3], collision-warning systems (CWSs) [4], and emergency automatic brakes (EABs). AR-based driving support systems (AR-DSSs) have also been recently developed [5, 6]. These developed AR-DSSs differ from traditional in-vehicle collision avoidance systems (CASs) in that they provide warning signals overlapping with real physical objects. Compared to a

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traditional CAS, an AR-DSS attempts to support the direct perception of merging traffic rather than the generation of a warning signal. Therefore, an AR-DSS can lower the switching costs associated with a traditional CAS by providing signals that align with a driver's perceptual awareness [5]. Accordingly, an active visual-based safety information system for preventing collisions has become one of the major research topics in the field of safe driving. Thus, this paper proposes an AR-based vehicular safety information system that provides visual-based collision warning information to match the driver's viewpoint. We expect that the proposed system will contribute significantly to a reduction in the number of driving accidents and their severity.

2 AR-Based Vehicular Safety Information System

The proposed system consists of four stages: fusion data based object tracking, collision threat assessment, AR-registration, and a warning display strategy. An I/O flowchart of the proposed system is presented in Fig. 1. Once a driver starts driving, the system continuously detects and tracks forward objects and classifies the collision threat level. Simultaneously, the system tracks the driver's eye movement and presents potential collision threats on a see-through display; the results are then matched with the driver's visual viewpoint to help the driver identify and avoid obstacles. Unlike conventional ABS, the goal in this paper is to provide forward-object location based on the driver's viewpoint through an interactive AR-design for maintaining a safe distance from forward objects and preventing collisions. Thus, two modules, i.e., collision threat assessment and a warning display strategy, will be described in detail.

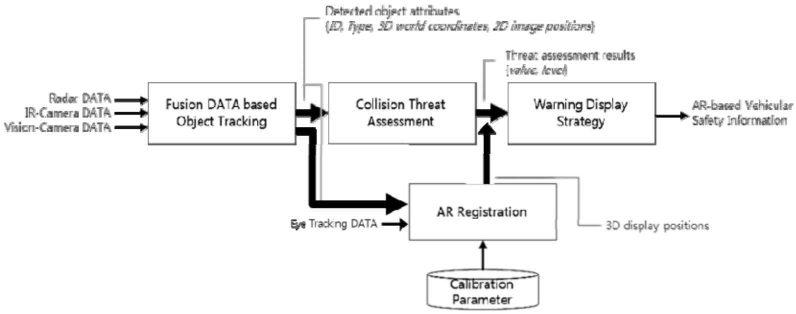


Fig. 1. The proposed system configuration

2.1 Fusion Data Based Object Tracking

To track forward objects accurately and robustly, the proposed system uses both video and radar information, which provide important clues regarding the ongoing traffic activity in the driver's path. Fig. 2 shows how to track based on fusion data.

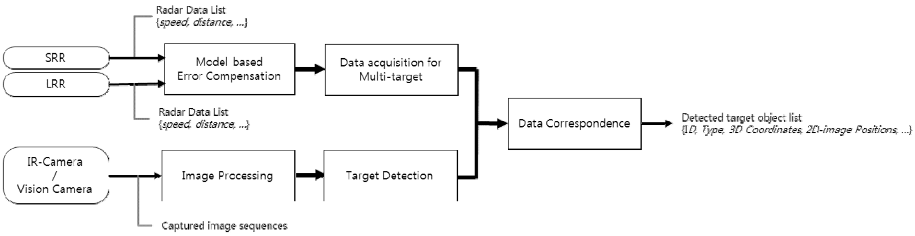


Fig. 2. Sensor Data Fusion for object tracking

In vision-based object tracking, all objects on a road can be deemed potential obstacles. In this system, we first extract all obstacles using their geometric properties. We also classify them into *significant* and *less significant* objects, which are triggered under certain circumstances. Significant objects are obtained using specialized detectors (i.e., vehicle and pedestrian detectors) [7, 8]. In an invisible environment, the proposed system detects multiple forward obstacles using three radar systems, and then recognizes and classifies them based on fusion with a night-vision camera through a processing shown in the flowchart in Fig. 2.

2.2 Collision Threat Assessment

The threat assessment measure of the proposed system is defined in Eq. (1). This measure is based on the basic assumption that a threatening object is in the same lane as the host vehicle, and is the closest object ahead. The proposed system estimates the collision possibility using the velocity and distance between the host vehicle and obstacle, which is referred to as TTC (time to collision) in this paper. To measure the TTC, an experimental DB is first generated, and the optimal threshold value is then extracted using this DB.

$$TTC = \frac{D_{c2o}}{V_c}, \qquad (1)$$

where D_{c2o} is defined as the distance between the host car and obstacle, and V_c is the velocity of the host car in Eq. (1).

Table 1. The compliled DB under various conditions

Type	Driving Condition		The compiled DB
Vehicle	Velocity (*V*)	≤60 *km/h*	Acquired images including more than 500 vehicles, which were taken during an 18-hour period
	Distance (*D*)	<100 *m*	
	Road Type	· Highway · Public road	
Pedestrian	Velocity (*V*)	≤40 *km/h*	Acquired images including more than 800 pedestrians, which were taken during a 12-hour period
	Distance (*D*)	<15 *m*	
	Road Type	· Crossway · Residential street	

The proposed system divides a threat into three levels according to the TTC value. To measure the TTC value of each of the three levels, an experimental DB of various driving conditions is first generated, as shown in Table 1. Next, the optimal threshold value is extracted using the DB, as shown in Table 2. In general, a TTC is defined as the time remaining until a collision between two vehicles that will occur if the collision course and difference speeds are maintained [9]. A TTC has been one of the well-recognized safety indicators for traffic conflicts on highways [10–12]. However, the proposed system provides warning information for safety fitting the driver's viewpoint through an interactive AR-design, and is applied to public road environments for both vehicles and pedestrians. Therefore, the TTC values used by the proposed system are extracted through various experiments.

Table 2. TTC threshold value of each of the three levels (*m/s*)

Type / Level	Vehicle	Pedestrian
1 (Danger)	$0.0 \le threshod < 0.3$	$0.0 \le threshod < 1.1$
2 (Warning)	$0.3 \le threshod < 0.7$	$1.1 \le threshod < 6.0$
3 (Attention)	$0.7 \le threshod < 5.0$	$6.0 \le threshod < 10.0$

2.3 AR Registration

For the registration, the calibration parameters are generated offline through an expression of the relations among the three coordinates of the vehicle, driver, and display. The system then detects and tracks the driver's head and eyes in real time. The coordinates of the target objects transform into display coordinates matching the driver's viewpoint. A flowchart of this AR registration module is shown in Fig. 3.

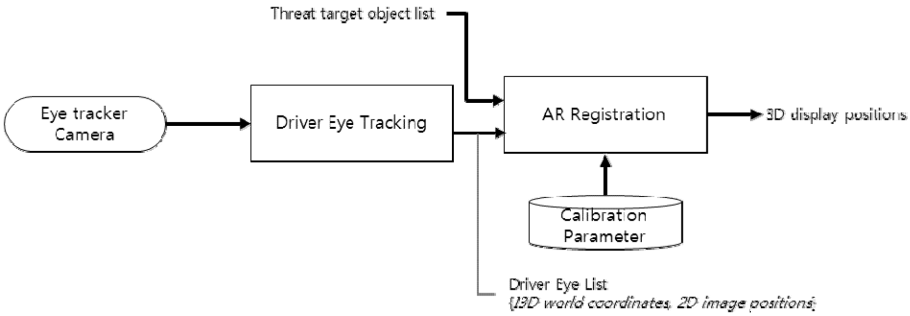
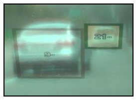
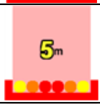
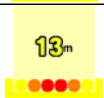
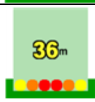
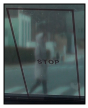
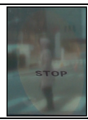


Fig. 3. AR registration module

2.4 Warning Display Strategy

To improve the driver's cognition of the displayed information, an interactive UX design is needed. For this, the information provided should not only be easier to understand, but also more intuitively acceptable by considering the driver's characteristics, the type of information provided, and the driving conditions. The system expresses information differently depending on both the threat level in the previous module and the study results from [13]. Table 3 shows the AR-display design and a representative scene on the see-through display according to the three levels of obstacle type. In the AR-display design, the color and line thickness are set based on the ISO rules [14]. In addition, the design type was determined through the study results of [13] and the HUD concept design in [15].

Table 3. AR-display design for three levels of obstacle type

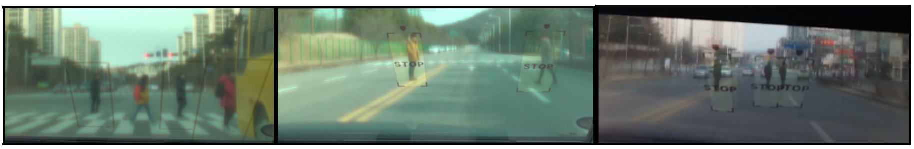
Obstacle Type	Design Type	Level			Real Display Scene
		1	2	3	
Vehicle	Type 1				
	Type 2				
Pedestrian	Type 1				
	Type 2				
	Type 3				

3 Experiment Results

To provide driving-safety information using the proposed AR-HUD, various sensors and devices were attached to the experimental test vehicle, as shown in Fig. 4. The two cameras used for the forward obstacle recognition are *GS2-FW-14S5* models from Point Grey Research Co., which are 12 *mm* cameras with a resolution of *1384 x 1036*, and can obtain an image at a speed of 30 *fps*. In addition, we used *IEEE 1394b* for the interface. To cover multi-target tracking, two SRRs (short range radar) and one LRR (long range radar) are used in environments with poor visibility such as under rainy conditions and at night. Both radar models are a *Delphi ESR* at 77*GHz* with a CAN interface. The IR-camera is a *PathfindIR* model from FLIR Co., and has a resolution of *320 x 240* with a speed of 30 *fps* using an RCA interface.

Fig. 4. Experimental test vehicle

To show our AR-based vehicle safety information system, we used a 22-*inch*, transparent Samsung LCD display with a transparency of 20%. This LCD display has low transparency, and thus cannot allow AR-based vehicle safety information to be seen very well at nighttime. To solve this problem, it is necessary to develop a large-area transparent OLED based display. Fig. 5 shows images of pedestrians detected by the proposed system based on the estimated optimal TTC value shown on the display.



(A) stopping in a crosswalk (B) jaywalkers crossing a public road (C) jaywalkers crossing a residential street

Fig. 5. Experiment results

To evaluate each module, the experimental DB was generated from various driving environments, including a simulated road environment and actual roads (a highway, public roads, and residential streets). For vehicle recognition in the daytime, a total of 10,320 frames were obtained from the experimental stereo camera. For pedestrian recognition, a total of 3,270 frames were acquired. Furthermore, a total of 5,400 frames were obtained from the IR-camera for recognition of both vehicles and pedestrians during the nighttime. Fig. 6 shows the real road test region. As indicated in Fig. 6, the test region includes public roads, residential streets, and crossways for recognition of both vehicles and pedestrians in the daytime. In contrast, Fig. 7 shows the test-bed used for obstacle recognition during the nighttime.

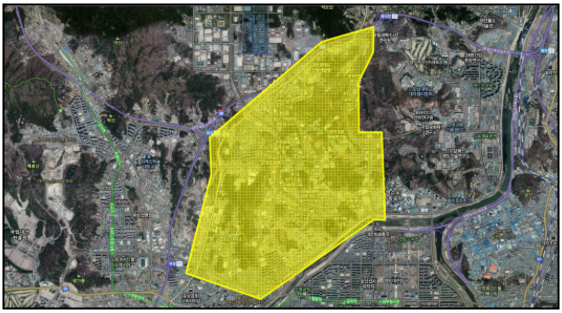


Fig. 6. Experiment test region on real roads

Fig. 7. Experiment test-bed for nighttime recognition

The recognition rate of the driving-safety information obtained by the proposed system during the daytime is 85.01%, and the system has a recognition speed of 15 *fps* for both vehicles and pedestrians. The recognition rate of the driving-safety information and recognition speed of the proposed system during the nighttime are 77% and 10 *fps* for both vehicles and pedestrians.

4 Conclusions

This paper proposed an AR-based vehicular safety information system for forward collision warning. This paper showed that 1) a forward obstacle can be successfully detected and tracked by fusing radar and two types of vision data, 2) fusion based forward obstacle tracking is robust compared to single sensor based obstacle detection, and objects can be reliably be detected, 3) collision threat assessments can be efficiently classified into threat levels by measuring the collision possibility of each obstacle, 4) AR-registration can provide warning information without visual distraction by matching the driver's viewpoint, and 5) a warning strategy can conveniently provide safety information considering both the obstacle and human-vision attributes. The experiment results show that the proposed system achieves an 81.01% recognition rate. We expect that the proposed system will provide suitable information according to the driver's viewpoint as a way to reduce traffic accidents.

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