Driving Simulation
for Evaluation of Driver Assistance Systems
and Driving Management Systems


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Abstract
Development of advanced driver assistance systems and driving management systems requires careful and thorough evaluation of not only algorithms, but also user acceptance and adaptation. For that purpose, driving simulation provides an ideal environment by creating various driving situations that may not be possible in a test track for safety reasons and putting drivers in a simulation loop to evaluate objective performance and subjective feelings. This paper describes our on-going effort to expand our driving simulation capability to evaluate driver assistance and driving management systems. First, we present our driving simulator and its major upgrade to provide better driving simulation environment. Second, we report case studies on Adaptive Cruise Control (ACC) and a safe driving management system. We have conducted a series of simulator experiments on ACC to determine effects of both positive and negative behavioral adaptation by the drivers. We have found that ACC draws consistency in headway-time regardless of drivers’ driving styles. However, ACC also induces drivers’ blind reliance and distraction, resulting in reduced lane keeping ability, larger head and eye movement, and slower response to simulated ACC failure. We also report progress being made on implementing the safe driving management system on the simulator and evaluating the effectiveness of the dangerous driving detection algorithm in a variety of driving situations.
Introduction

Advancement of vehicle electronic technology has led to development of various systems for assisting drivers and managing driving to improve vehicle safety and driver comfort. Driver assistance systems in general monitor driving situations continuously and take necessary actions to avoid possible accidents even without drivers’ intervention. Driving management systems store driving data and analyze driver behaviour and accidents to promote safe driving and identify accident causes.

Development of those driver assistance systems and driving management systems requires careful and thorough evaluation of not only algorithms, but also user acceptance and adaptation. For that purpose, driving simulation provides an ideal environment by creating various driving situations that may not be possible in a test track for safety reasons and putting drivers in a simulation loop to evaluate objective performance and subjective feelings.

This paper describes our on-going effort to expand our driving simulation capability to evaluate driver assistance and driving management systems. First, we present our driving simulator and its major upgrade to provide better driving simulation environment. We then describe case studies on Adaptive Cruise Control and a safe driving management system.

Kookmin University Driving Simulator

The driving simulator at Kookmin University has had substantial modifications since its first development in 1997, from a single seat simulator with a single channel visual system and a six DOF hydraulic motion platform to a half-car simulator with a three channel visual system and a fixed base in 1998 to a full-car simulator with a four channel visual system and a two DOF electric motion platform in 2001.

Our driving simulator had another major upgrade this year (Figure 1). The motion system had the most substantial change. We replaced a traditional motion platform with four electric motors and links installed at individual corners of the car body. The new motion system simulates suspension movement realistically and accurately. The system is effective and fast in creating special effects such as bumps and rumble strips as well as roll, pitch and heave cues.

We believe that motion envelop of a traditional motion platform must be substantially large in order to take full advantage of a motion washout algorithm. The washout algorithm can be more effective in generating correct cue and simulating sustained acceleration when implemented on a motion platform with sufficiently large strokes.

We also installed new visual computers, DLP projectors and a display screen to improve performance of the visual system. We installed a new steering system that provides
highly realistic steering feedback. We implemented Controller Area Network (CAN) for data transfer and reworked all wirings in the control force loading system.

The major features of the new simulator are summarized as: (1) a four channel visual system that provides 140x40 and 50x40 degrees of front and rear fields of view, (2) a fast-response, 4-axis electric motion platform that produces roll, pitch and heave motion, (3) a full-car cabin with realistic control loading and full instrumentation, and (4) human performance measuring equipment including a head and eye tracking system and a physiological signal measuring device.

Adaptive Cruise Control Study

Adaptive Cruise Control (ACC) is a representative driver assistance system. ACC automatically adjusts vehicle speed, if necessary, to maintain a desired distance to a preceding vehicle, and thus improves driver comfort and safety.

ACC, as an automated system, induces drivers’ trust and adaptation, which brings both positive and negative effects. ACC reduces driver error and accident possibility. ACC also reduces the number of sudden accelerations and decelerations, enables speed synchronization among vehicles, and encourages smooth lane change behaviours [1, 2]. On the other hand, drivers may use any freed visual, cognitive and physical resources to engage in non-driving tasks. These tasks may reduce their vigilance and attention to the primary driving task, which could result in driver distraction, and a failure to detect and respond to critical driving situations. ACC also deteriorates driving performance: Drivers’ lane keeping ability reduces and the drivers tend to brake harder and more often [3-5].

The objective of our simulator study is to develop a strategy to compensate negative behavioural adaptation to ACC. Possible approaches are to adjust assistance level depending on the extent of negative adaptation and to add lane keeping assistance capability. We first conducted a series of simulator experiments under normal driving and ACC failure situations to investigate driver behaviour [6, 7].
Normal Driving Experiment

Forty drivers participated in the experiment to drive the simulator with and without ACC. When driving with ACC, they were instructed to use a cruise control button on a steering wheel to select the most comfortable headway-time between 0.5 and 2.5 seconds with an interval of 0.5 seconds. When driving without ACC, they were asked to follow a preceding car, while keeping small, but safe distance.

Table 1 summarizes the experiment results for headway-time and standard deviation of lateral position of the car. The drivers maintained headway-time of 1.49 seconds when driving with ACC less than 2.31 seconds when driving without ACC. This implies that the drivers trusted ACC capability of controlling speed and distance, and felt comfortable with keeping shorter distance with ACC. In addition, the standard deviation of headway-time is very small when driving with ACC. This shows that ACC draws consistency in driving speed and safe distance regardless of the drivers’ driving styles.

The standard deviation of the lateral position of the car becomes larger when driving with ACC, although not significant. This is consistent with other researchers’ findings. This implies that the drivers’ lane keeping ability degraded, showing negative effect of behavioural adaptation to ACC.

Table 1 Headway-time and Standard Deviation of Lateral Position for Normal Driving Experiment

<table>
<thead>
<tr>
<th>Driver performance</th>
<th>ACC on</th>
<th>ACC off</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Headway-time (sec)</td>
<td>1.49</td>
<td>0.05</td>
</tr>
<tr>
<td>Standard deviation of lateral position (m)</td>
<td>0.71</td>
<td>0.06</td>
</tr>
</tbody>
</table>

* M: Mean, SD: Standard deviation

Figures 2 and 3 show head and eye movement areas of the drivers. The areas were obtained by projecting head and gaze direction vectors on the plane parallel to the driver’s face. When driving with ACC, both head and eye movement areas become larger and more dispersed. This shows the effect of driver distraction during driving. This is consistent with larger deviation of lateral position in Table 1.
ACC Failure Experiment

In this experiment, in addition to driving with and without ACC, another driving scenario was included to simulate failure of ACC braking algorithm in the middle of driving. The drivers were asked to follow a preceding car that decelerates suddenly during the experiment. Drivers’ reaction to the urgent situation was investigated. Twenty drivers participated in the experiment.

Table 2 summarizes the experiment results for reaction time, driver input and distance to the preceding car. Reaction time is the time from deceleration of the preceding car to driver’s reaction in terms of either braking or steering to avoid collision. The reaction time for the ACC off case was the shortest (0.81 seconds). Manual driving forced the drivers to focus on their driving and the focus led to fastest reaction. However, the reaction time for the ACC on case increased to 1.15 seconds. This implies that drivers’ trust and adaptation to automatic control of speed and distance by ACC induced slower response by the drivers. The reaction time for the ACC brake failure case was the longest (1.59 seconds). This suggests that drivers’ blind reliance on ACC prevented the drivers from recognizing ACC failure early and reacting to the unexpected behavior of the preceding car as early as possible.

Driver input in the table shows the amount of steering and braking effort by the drivers. For the ACC off case, the drivers pressed the brake pedal the hardest (91.2%), but turned the steering wheel the least (5.8 degrees). This is because the drivers decided that braking would be more effective than steering to avoid collision in that situation. For the ACC on case, the drivers did not take additional, manual braking action (0.0%). Steering input was relatively small (13.7 degrees). Since ACC had been fully operational, the drivers continued to trust ACC braking ability and thus did not press the brake pedal. For the ACC brake failure case, the drivers pressed the brake pedal very hard (84.4%) and turned the steering wheel the most (47.0 degrees). This implies that, due to slow reaction to the urgent situation, the drivers realized little margin for collision avoidance and attempted whatever action they could take in terms of braking and steering. Nonetheless, 30% of the drivers could not escape from collision.

The distance to the preceding car was about 25.9m for the ACC off case. Although the distance is short, the drivers could avoid collision because they had continued to focus on manual driving. For the ACC on case, the distance was 28.4m, which was still short.
However, the drivers could avoid collision because ACC had continued to control distance and speed, and initiated braking when the urgent situation occurred. For the ACC brake failure case, the distance was 24.4m. This shortest distance reflects the longest driver reaction time.

<table>
<thead>
<tr>
<th>Driver performance</th>
<th>ACC off</th>
<th>ACC on</th>
<th>ACC brake failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reaction time (sec)</td>
<td>0.81</td>
<td>1.15</td>
<td>1.59</td>
</tr>
<tr>
<td>Driver input:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>brake (%)</td>
<td>91.2</td>
<td>0.0</td>
<td>84.4</td>
</tr>
<tr>
<td>steering (degree)</td>
<td>5.8</td>
<td>13.7</td>
<td>47.0</td>
</tr>
<tr>
<td>Distance to</td>
<td>25.9</td>
<td>28.4</td>
<td>24.4</td>
</tr>
<tr>
<td>preceding car (m)</td>
<td></td>
<td></td>
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</tbody>
</table>

**Driving Management System Study**

Dangerous driving is a major cause of traffic accidents in Korea. Dangerous driving becomes more serious for commercial vehicles due to higher fatality rates. In order to promote safe driving and reduce traffic accidents, various measures have been introduced that include car black boxes and digital tachometers.

We developed a driving management system that monitors and stores driving conditions of vehicles, detects dangerous situations, and analyzes the driving results in real time. We have implemented the system on transit buses and commercial trucks, and found it to be useful in detecting and furthermore discouraging dangerous driving [8].

We are carrying out a simulator study to improve the driving management system, especially the dangerous driving detection algorithm, by providing additional information about driving environment and road conditions.

**Driving management system**

Figure 4 shows the driving management system hardware. It consists of a main control module and a sensor module. The main control module consists of the following components: a vehicle sensor interface for processing vehicle status information, a microcontroller for processing the dangerous driving detection algorithm and entire system management, a memory unit, a GPS module, and communication modules. The sensor module consists of accelerometers and a yaw rate sensor, a low-pass filter and a microcontroller.
The dangerous driving detection algorithm is a key component of the system. The algorithm detects dangerous driving instant and cleverly identifies its type in real time, utilizing information from the sensors in the sensor module.

Figure 5 shows dangerous driving situations identified by the algorithm during commuter bus operation. Upper three graphs show longitudinal acceleration, lateral acceleration and yaw rate of the bus. As shown in the fourth graph, the algorithm detects three instants as dangerous driving by analyzing shapes and magnitudes of the curves in real time. The dangerous driving types are identified as speeding during cornering, sudden start and sudden acceleration, respectively.

**Driving simulator implementation**

We implemented the dangerous driving detection algorithm on our driving simulator. Figure 6 shows a graphic user interface for monitoring the performance of the algorithm.
on the simulator. The upper left half and the bottom half of the interface displays vehicle status and the upper right half displays dangerous driving types identified by the algorithm.

We are carrying out a simulator study to improve the dangerous driving detection algorithm. We simulate a wide variety of driving environment and situations to improve accuracy of detecting dangerous driving instants and identifying its types. We will also improve the algorithm to distinguish intentional, dangerous driving due to drivers’ driving styles from forced, dangerous driving due to traffic situations by adding additional sensors to monitor driving environment and conditions.

Fig. 6 Driving Management System Interface

Conclusion

Driving simulation provides a safe and effective environment for developing driver assistance systems and driving management systems. Our simulator study on Adaptive Cruise Control verified positive and negative effects of behavioural adaptation. Further study is planned to develop a strategy to compensate negative behavioural adaptation effect in terms of adjusting assistance level or adding lane keeping assistance capability. We also implemented a driving management system on our driving simulator to evaluate performance of the dangerous driving detection algorithm. We will use the driving simulator to improve accuracy of detecting dangerous driving instants and types.

Acknowledgement

This research was sponsored by the Korea Transportation Institute under the research contract ‘Development of U-safety Traffic Safety Monitoring and Analysis System’ as a part of the research project, ‘Development of Safety-oriented Traffic Environment Improvement Technology’ under the national project, ‘Development of National Traffic Core Technology.’
References


