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A STUDY ON DRIVER ACCEPTANCE OF ADAPTIVE CRUISE CONTROL USING A DRIVING SIMULATOR

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ABSTRACT

The objective of Adaptive Cruise Control (ACC) is to maintain a desired distance and speed between a driver vehicle and a preceding vehicle. One of the key issues associated with ACC system development is driver acceptance. ACC controllers should be optimized in such a way that the system does not conflict with the driving behavior of a driver and further that the driver feels comfortable with the system.

The objective of this study is to investigate driver acceptance issues for ACC utilizing a driving simulator. A representative ACC simulation system has been implemented on a highly realistic, PC-based driving simulator. Participants with different driving styles have driven the simulator with and without ACC through a highway route. Driving behavior in terms of preferred headway-time, lateral position of a car, and head and eye movement has been investigated. A questionnaire has been also used to evaluate user acceptance and adaptation to ACC. The study results show usefulness of ACC with consistency and reduced variation in driving.

INTRODUCTION

A driving simulator has many advantages in that it can reproduce actual driving situations in a safe and controlled virtual environment and enables to conduct various experiments including emergency situations that are not possible with actual test vehicles. The driving simulator, by allowing driver-in-the-loop simulation, is an ideal research tool for evaluating driver acceptance and usability of driver support systems.

Adaptive Cruise Control (ACC) has been actively studied as an important and relatively easy to implement technology for realizing Intelligent Transportation Systems (ITS). In ACC, steering is done by a driver, but other devices are controlled electronically. The ACC should control a vehicle in a comfortable way and should ensure that the desired distance and speed to a preceding vehicle are faithfully maintained.

One of key issues associated with ACC system development is driver acceptance. Hoedemaeker et al. (1) conducted a driving simulator study to find favorable acceptance of ACC with respect to effort, comfort and usefulness, depending on the driving style. It was also found that the participants in the study, when driving with ACC, adapted their behavior with respect to speed according to expectation, irrespective of predetermined driving style. However, it was tentatively concluded that ACC would require caution for traffic safety improvement. Hoedemaeker in her another study (2) found that the distinction in the driving style was found to be important in the acceptance of ACC. Although it was shown that ACC seemed to be a promising new technology in traffic under certain conditions and limitations, it was also concluded that introduction of ACC for traffic safety would be cautioned.

The control parameters in the ACC controllers should be optimized in such a way that the ACC system does not conflict with driving behavior of a driver and further that the driver feels comfortable with the system. The authors (3) conducted a driving simulator study to determine most acceptable values of acceleration and deceleration limits and time-headway in the ACC algorithm.

The objective of this research is to expand a study on driver acceptance of ACC performed by the authors (3) to take into account driving styles of drivers. Driving behavior and acceptance of drivers with different driving styles are addressed in terms of preferred headway-time, lateral position of a car, and head and eye movement.

ADAPTIVE CRUISE CONTROL IMPLEMENTATION

Driving Simulator

Figure 1 shows an actual view of the driving simulator used in this study. The simulator has a 3 channel visual system with a field of view of 150 x 40 degrees and a 2 degree-of-freedom electric motion platform. It is controlled and operated in a network of 9 PCs connected by Ethernet (4).

FIGURE 1 Driving Simulator

Control Law

An ACC algorithm adopted in this study is based on the work by Kim (5). Figure 2 shows a block diagram of an ACC simulation system including the control algorithm in a dotted box. When a preceding vehicle is not detected, an ACC vehicle maintains the preset speed. If a preceding vehicle with a slower speed is detected, however, the relative distance and speed between the preceding and the ACC vehicles are used to activate throttle or brake control to maintain headway-time distance.

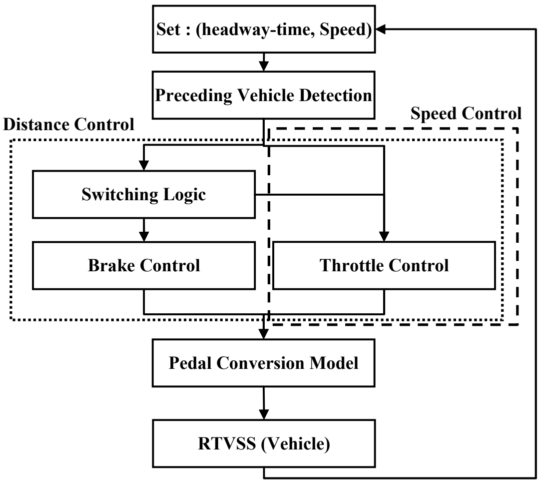


FIGURE 2 ACC Simulation System Block Diagram

Speed control is activated when a preceding vehicle is not detected or a preceding vehicle, if detected, is outside headway-time distance. The speed control algorithm is shown in Figure 3. A saturation function is used to limit the target acceleration/ deceleration considering the driver's driving pattern and preference. A previous study by the authors reveals that 0.15g is the most acceptable value for saturation limit (3).

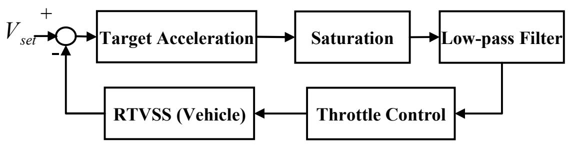


FIGURE 3 Speed Control

Distance control is activated when a preceding vehicle is within headway-time distance. Figure 4 shows the distance control algorithm. Throttle control enables to maintain the preset speed when desired acceleration is achievable with engine torque only. Brake control is activated if the target acceleration is not achievable by throttle control.

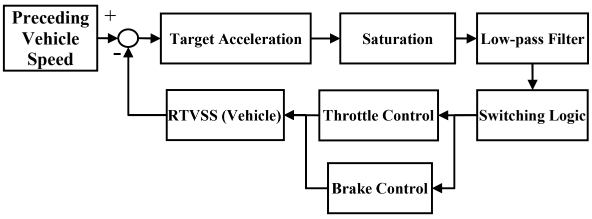


FIGURE 4 Distance Control

System Integration

Figure 5 illustrates the concept of integrating the ACC simulation system into the driving simulator. In ACC simulation, the realistic behavior of ambient cars should be ensured to obtain meaningful results. Such a scenario control, requiring artificial intelligence of many ambient cars running in real-time, has been implemented using SCANeR II. Information about a preceding vehicle shown on a screen is also extracted and passed to the ACC simulation system. The system then calculates desired accelerator and brake pedal angles and passes them to RTVSS, a real-time vehicle simulation system in the driving simulator. RTVSS simulates ACC vehicle motion and pass all the necessary information about the vehicle status to the ACC simulation system and other subsystems of the driving simulator for necessary cue generation.

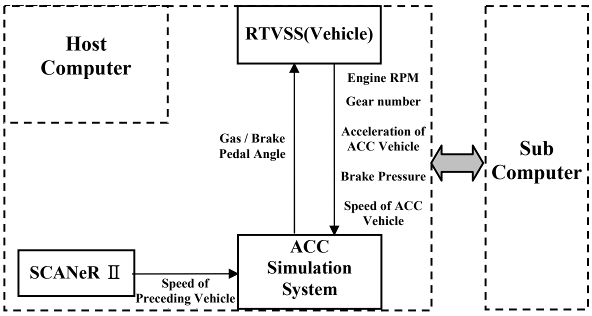


FIGURE 5 Integration of ACC system

Performance Evaluation

After the ACC simulation system is installed in the driving simulator, two types of maneuvers, approaching a preceding vehicle and cut-out of a preceding vehicle, have been tested to evaluate ACC performance.

Approaching a Preceding Vehicle

In this case, a preceding vehicle is about 230 m ahead of an ACC vehicle when ACC activates. The ACC vehicle speed has been set to 100 km/hr. The driving simulation results, as seen in Figure 6, show that the ACC vehicle initially accelerates to catch up with the preceding vehicle and then successfully maintains headway-time distance.

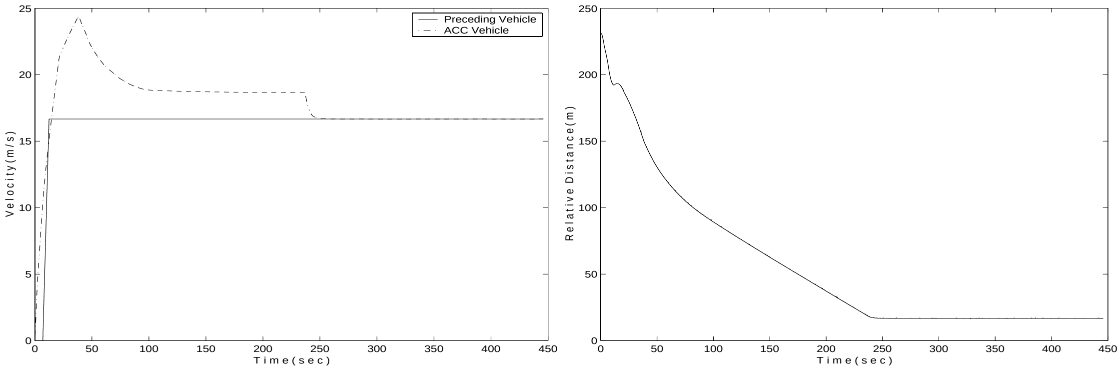


FIGURE 6 Approaching a Preceding Vehicle Case: (1) Velocity, (2) Relative Distance

Cut-Out of a Preceding Vehicle

In this case, the ACC vehicle follows a preceding vehicle changing a lane and also a new preceding vehicle. As shown in the simulation results of Figure 7, the ACC vehicle follows the preceding vehicles even if they are changed and keeps headway-time distance well.

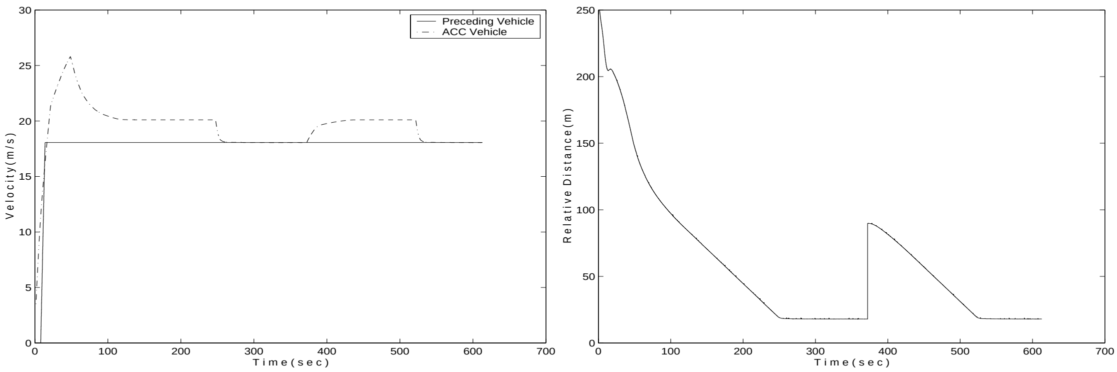


FIGURE 7 Cut-out of a Preceding Vehicle Case: (1) Velocity, (2) Relative Distance

DRIVER ACCEPTANCE STUDY

Participants

Forty participants were recruited among the staff and students of Kookmin University. All the participants, consisting of 21 male and 19 female, were of ages between 19 and 52 and had current driver's licenses with average driving experience of 3.7 years.

The Driving Style Questionnaire (DSQ), developed and validated by West et al., (6) has been used to classify driving styles of the participants. A high DSQ score generally implies high accident risk and vice versa. Individual dimensions of the DSQ have not been accounted for in this study mostly because cultural and environmental differences might lessen their effectiveness. The mean and standard deviation of the DSQ scores by the participants were 15.7 and 3.2, respectively. Since the standard deviation was relatively small, two groups of the participants with top and bottom 10% scores have been identified for comparison and detailed driving behavior analysis.

Procedure

Before the start of the experiment, each driver was explained in detail about the driving simulator, the ACC system, and the purpose of the experiment. The driver practiced driving about 10 minutes to feel comfortable with the simulator. After driving practice, the driver filled out the DSQ, followed by a period of rest.

During the experiment, the driver drove through a rural highway route without ACC first. The lateral position of the car and headway-time were measured while the driver maintained a small but safe distance from a preceding car moving with a speed of 90 Km/hr. The faceLAB (7), a stereo-vision based tracking device for head and eye movement, was also used to analyze head posture and eye behavior. The driver then drove with ACC with the preset speed of 90 Km/hr. A speed setting button for conventional cruise control had been modified to allow the driver to change and select the most comfortable headway-time between 0.5 and 2.5 seconds with an interval of 0.5 seconds. Once headway-time was set, the driver continued to drive with the setting. Meanwhile the lateral position was measured, and also head and eye movement was measured using the faceLAB. After the experiment, the driver answered a questionnaire regarding acceptance of ACC.

Results and Discussions

Figure 8 shows average headway-time results. Use of ACC reduced headway-time. It is shown that headway-time for the high DSQ score drivers with ACC is very long compared to the low score drivers. This counter-intuitive result is probably because 75% of the high DSQ score drivers are female and thus used more caution when driving without ACC. Driving with ACC does not show this difference in headway-time. Headway-time for ACC is consistent with the result obtained in a previous study by the authors (3).

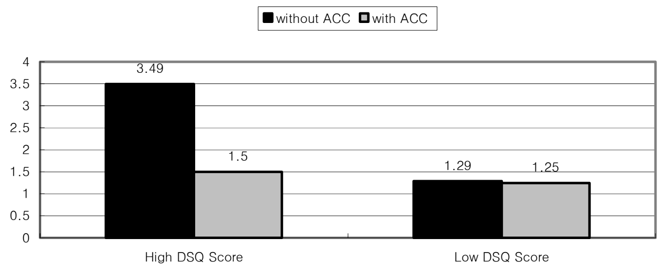


FIGURE 8 Average Headway-time

The standard deviation of the lateral position of the car increased when driving with ACC compared with driving without ACC, as shown in Figure 9. This result is consistent with the work of Ward et al. (8), implying that drivers have poorer control over lane position with ACC. The difference is shown more clearly for the high DSQ score drivers probably because the high DSQ score drivers have higher expectations on ACC and poorer car control.

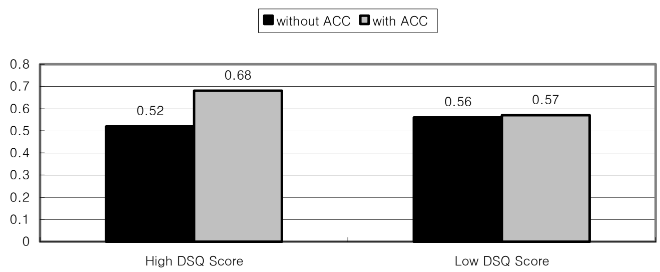
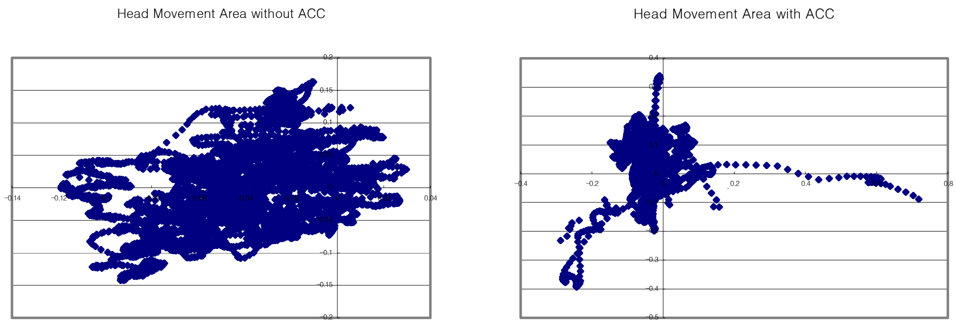
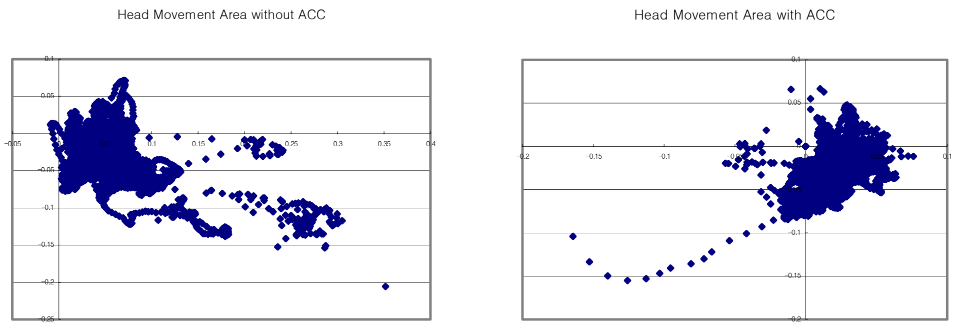


FIGURE 9 Standard Deviation of Lateral Position

Driving with and without ACC also showed a difference in head movement. Figure 10 shows the head movement of the highest and lowest DSQ score drivers in particular, which was projected on planes perpendicular to their faces. It is clear that the head movement area for driving with ACC is much smaller than for without ACC, especially for the highest DSQ score driver. This phenomenon can be associated with narrowing of attention and field of view, which can negatively influence traffic safety. It is also shown that when driving without ACC the head movement area for the highest DSQ score driver is much larger than for the lowest DSQ score driver. The same trend was observed for the drivers with top and bottom 10% DSQ scores.



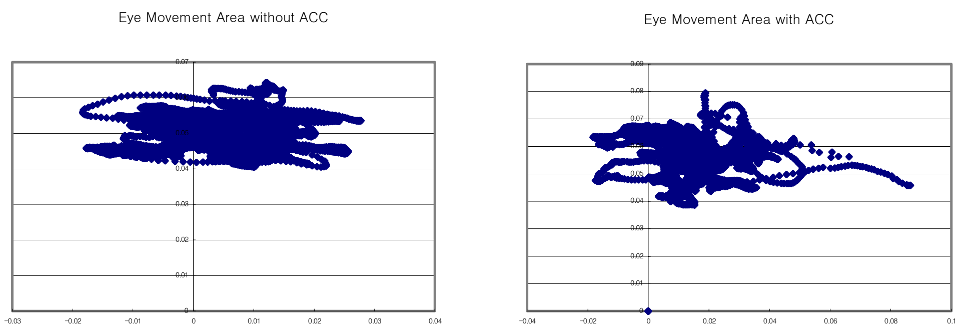
(a) The Highest DSQ Driver



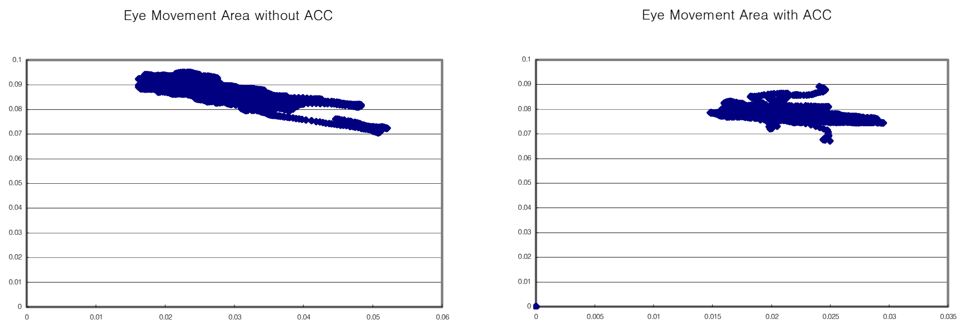
(b) The Lowest DSQ Driver

FIGURE 10 Head Movement Area

Figure 11 shows the eye movement of the same drivers, which was projected on the planes perpendicular to their faces again. Although not as clear as head movement, it is also shown that, when driving with ACC, the eye movement area becomes smaller. It is interesting to note that eye movement area for the low DSQ score drivers becomes flatter compared with high score drivers.



(a) The Highest DSQ Driver



(b) The Lowest DSQ Driver

FIGURE 11 Eye Movement Area

When the participants were asked whether they thought ACC was useful, 87% answered positive and 65% showed willingness to install ACC in the future. Safety, rather than comfort, was the main reason for positive answers. This result is somewhat consistent with a previous study by the authors (3), in which 22 participants gave an average score of 8.0 out of 10 for their degree of satisfaction with ACC.

CONCLUSIONS

This study shows that the driving behavior with ACC in terms of preferred headway-time, lateral position deviation, and head and eye movement leads to consistency and reduced variation in driving. However, this does not necessarily have a positive effect on traffic safety because consistency of head and eye movement can be associated with narrowing of attention and field of view, and reduction in situational awareness. Thus, ACC can be a promising technology for ITS and traffic safety, but with caution.

Driving behavior is shown to be influenced by driving style to a large extent when driving without ACC; meanwhile the degree of influence seems to reduce when driving with ACC. More extensive results from a more thorough analysis will be reported separately. Another study will be conducted to relate driving behavior and acceptance with ACC to physiological signals such as EEG and ERG.

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