A Study on Mode Awareness of Multi-level Automated Vehicles

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Abstract. Automated vehicles have multiple operating modes, and drivers may be unaware of the mode in which they are driving, leading to mode confusion and potential traffic accidents. To solve this problem, this paper proposes two user interfaces for automated vehicles that are expected to accurately describe vehicle states to reduce mode confusion. Driver-in-the-loop experiments were conducted to examine the possibility of mode confusion in the user interfaces while driving in different automation levels. Results suggest that reducing mode confusion requires a precise and concise user mental model, as well as a user interface designed for simplicity of driver-vehicle interaction, intuitiveness of operation, and consistency.

Keywords: Multi-level Automation · Automated Vehicles · Autonomous Vehicles · Mode Confusion · Situation Awareness · User Interface

1 Introduction

Automated vehicles have the potential to enhance road safety by supporting or supplementing the driver in various situations. Such vehicles are equipped with advanced driver assistance systems (ADAS) and an intelligent co-pilot system to provide appropriate support in all traffic situations, from normal to safety-critical emergency situations. Typically, automated vehicles have several different levels of automation ranging from manual to partially and fully automatic. Although automated systems promise increased safety and reduced human error, a number of substantive human factor challenges must be addressed before these types of automated systems can become a practical reality. These challenges include the potential for negative adaptations occurring due to misunderstanding, misuse, or overreliance on the system or change in attention and distraction from the driving task. In particular, as the driver's role shifts from active vehicle control to passive monitoring of the automated system and environment, the driver's situational awareness in detecting system state changes or perceiving critical environmental factors becomes very important.

Regarding mode confusion in vehicle automation, early studies have focused on adaptive cruise control (ACC) systems [1–5]. Recently, there has been researching on mode confusion in highly automated vehicles [6–11]. Heymann and Degani [6] described a hierarchy of automated driving aids and their functionalities, focusing on ACC and lane

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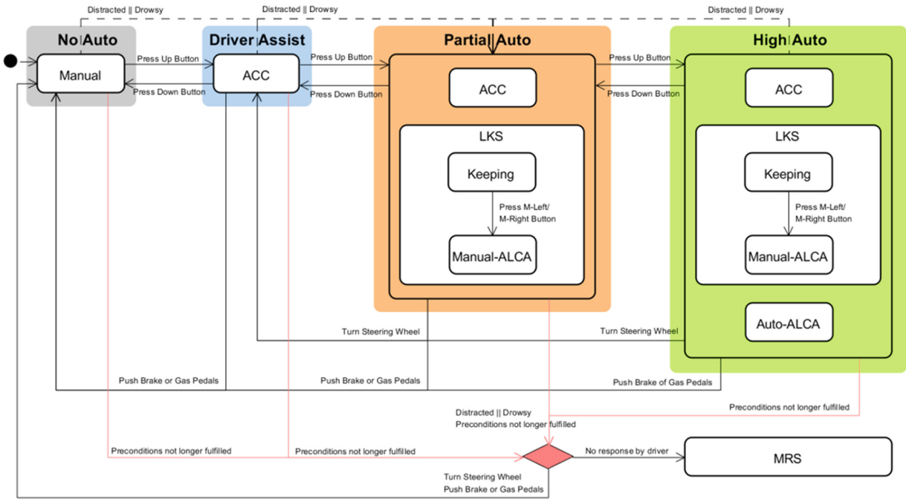

Fig. 1. The stepwise interface model created by grouping of the states of the corresponding machine model.

centering. In the intelligent transport (HAVEit) project [7], the researchers developed and verified a survey of users' cognitive modes and mode transition of the system. Lau et al. [8] investigated the impact of simple and advanced interface designs on driver behavior in a level 3 automated driving system. Miller et al. [9] evaluated four different automation conditions. Özkanet et al. [10] reviewed a state-of-the-art mode awareness from the related domains of automated driving, aviation, and human–robot interaction.

In this study, we designed two user interfaces for automated vehicles operated in modes corresponding to the SAE automation levels 0 to 3. The first is a stepwise interface that allows the driver to increase or decrease the automation level step-by-step. The second is an independence interface with independent driving controls in the longitudinal and lateral directions. We implemented prototypes for the two interfaces and conducted driver-in-the-loop experiments on a driving simulator to verify their effectiveness in the driver's mode awareness. For events on the road, the participants took actions to control the vehicle, which might cause mode changes, and answered the modes they believed. The experimental results show that the mode confusion rate of the stepwise interface is twice higher as that of the independent interface. Also, visual feedback can reduce the mode confusion rate dramatically. The results show that an independent user interface combined with adequate visual and auditory feedback is essential to improve driver's mode awareness when driving an automated vehicle.

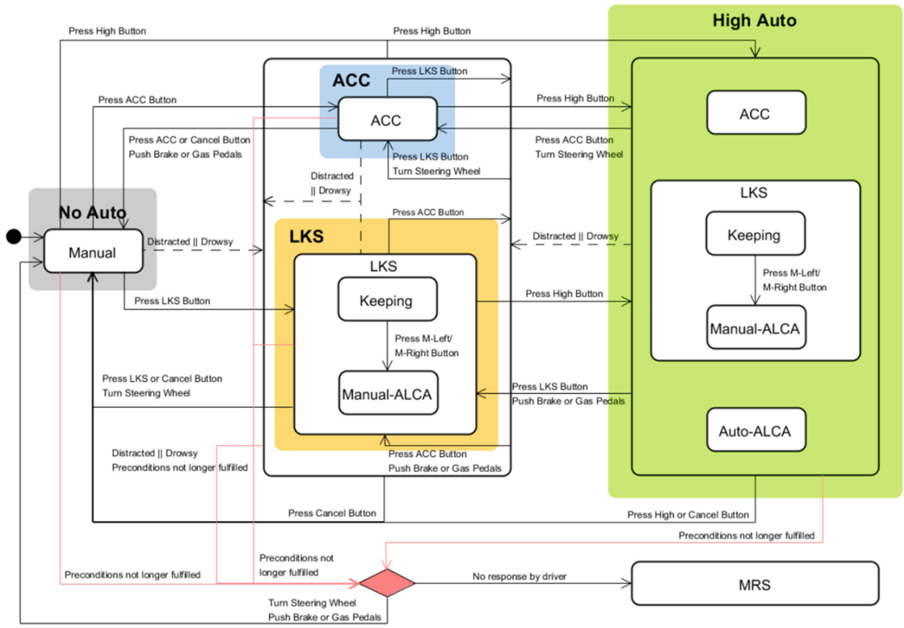

Fig. 2. Independent interface model created by grouping of the states of the corresponding machine model.

2 Machine and Interface Models of Autonomous Vehicles with Multiple Levels of Automation

We designed two different user interfaces, stepwise and independent, to enable the user to perform driving operations correctly and quickly. The stepwise interface model was developed based on that of the HAVEit project [7]. The names of the modes follow SAE's terminologies. "No-Auto' represents the mode in which the driver operates the vehicle manually, 'Driver Assist' refers to the mode in which the ACC system is solely active, 'Partial–Auto' is the mode in which both the ACC and lane keeping (LK) systems are active, and 'High–Auto' represents the mode in which not only the ACC and LK system but also the automatic active lane-change assist (Auto–ALCA) system are active. The combination of the machine and interface model is shown in Fig. 1.

For the independent interface, the mode names were given according to the states of the independent machine model. The state in which a driver operates manually is called 'No-Auto,' the state in which the ACC system is solely active is named 'ACC,' the state in which the LK system is active exclusively is called 'LKS,' and 'High–Auto' represents the state in which the ACC, LK, and Auto–ALCA systems are all active. The combination of the machine and interface model is shown in Fig. 2.

We investigated whether there were any incompatible mode transitions in the interface models using the state and mode transition table that was proposed by Lee et al. [4, 5]. The conclusion was that there were no incompatible transitions in both the stepwise and independent interfaces.

3 Driver-in-the-Loop Experiments

3.1 Participants

The 12 participants consisted of four females and eight males aged between 23 and 31 years (mean = 26.58, SD = 2.23) and students of Kookmin University. Information was obtained from the participants using a basic questionnaire. All the respondents had a valid driver's license and one or more years of driving experience. They had normal or corrected to normal vision.

3.2 Apparatus

The experiments were conducted in a fixed-base driving simulator using the TNO PreScan software. In the driving simulator, we implemented automated systems and the graphical user interface using Simulink and MATLAB. In addition, we modeled a road with three lanes using PreScan, imitating the Detroit Street Circuit of the USA Grand Prix. Ten events were designed to occur in specific regions in the proposed scenario. The host vehicle started to travel in the middle of three lanes. As the host vehicle approached a particular location, one or more surrounding vehicles exhibited predetermined behaviors, such as sudden accelerating or braking.

3.3 Procedure

We conducted experiments with stepwise and independent interfaces for different participants in different orders to eliminate any learning effect. In each experiment, the participant pressed the up/down buttons or turned on individual ADASs such as ACC and LK systems. Depending on the design scenario, a specific event occurred after the host vehicle arrived at a particular location. In response to each event, the participant tried to control the car by pressing the buttons, pushing the brake or gas pedal, and turning the steering wheel. The experimenter observed the participant's actions and the resulting mode changes in the systems. After completing each event, the experimenter covered the interface on the gauge cluster and interrupted the driving simulation to ask the participant about the mode change and the reason for the answer given. The experimenter then uncovered the interface and asked the participant the same question. The experimenter noted the answers given during the experiment. The participants were expected to use several ADASs while driving, and they were given no clues about the correct answers. When the driving experiments were finished, the participants were asked whether and why they felt any mode confusion. Each experimental session lasted 40 min from start to finish.

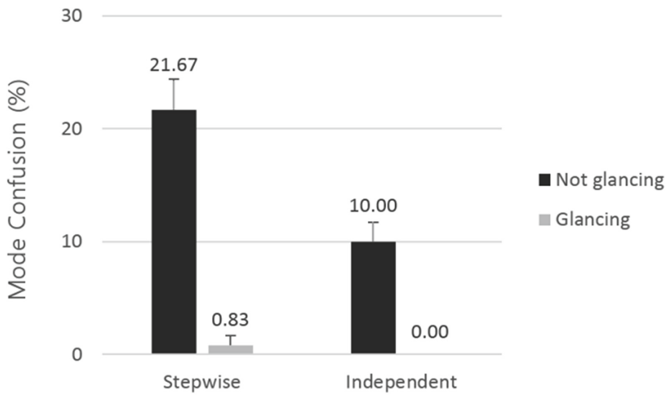

Fig. 3. Mode confusion rates obtained using the two user interfaces for users glancing and not glancing at the display.

4 Results

We examined the mode-confusion rates for two independent variables: the type of interface models and whether the participant glanced at the display. We considered two levels for the type of user interface (i.e., stepwise and independent models) and two levels for glancing at the display (i.e., glancing and not glancing). The mode confusion rates for the participants are shown in Fig. 3. To assess the significance of the two factors, we analyzed the variance (ANOVA) of the measurements using SPSS software.

5 Discussion

The experimental results showed that the independent interface was more effective than the stepwise interface in reducing mode confusion. The total rates of mode confusion with the stepwise and independent interface were 10% and 4%, respectively. As described in Sect. 2, we designed and verified newly proposed user interfaces for automated systems, i.e., designing the stepwise interface, which gradually increases the levels with the combined systems, designing the independent interface, which increases the levels with each system, and testing the compatibility between the modes.

The experimental results showed very little mode confusion after glancing at the display. This means that the interface indicates each mode. We expected that the mode confusion in the stepwise interface was less because the stepwise interface model is systematic and transparent. However, considerable mode confusion occurred before glancing at the display. This means that the actual mode of the systems was different from the user's expectation.

Based on the experimental results, we confirmed that the independent interface was more user-friendly than the stepwise one considering the driver's comfort and safety and that the position of a symbol and the terms of a mode should be moderately used when developing the interfaces.

6 Conclusions

In this paper, we developed and tested two different interface models. Using the proposed formal analysis, we reviewed the compatibility between the machine and interface models. The results of the driver-in-the-loop experiments support the hypothesis that the independent interface was a more compact and easy-to-understand user interface than the stepwise interface. In the future, we plan to conduct research on different user interfaces for drivers [12] and the application of deep learning techniques [13].

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