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# Mode Confusion in Driver Interfaces for Adaptive Cruise Control Systems

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***Abstract*—In this study, we developed a new driver interface for an adaptive cruise control system that suppresses mode confusion, based on a formal method for analyzing the correctness and succinctness of the interface and information. In the finite-state transition model for the interface, the states were grouped into a set of modes, each of which consists of the states that transition to the same state for the same user-triggered event. To test the mode awareness of our new interface and compare it with the mode awareness of a conventional interface, a set of human-in-the-loop experiments were conducted in a simulated environment using a driving simulator.**

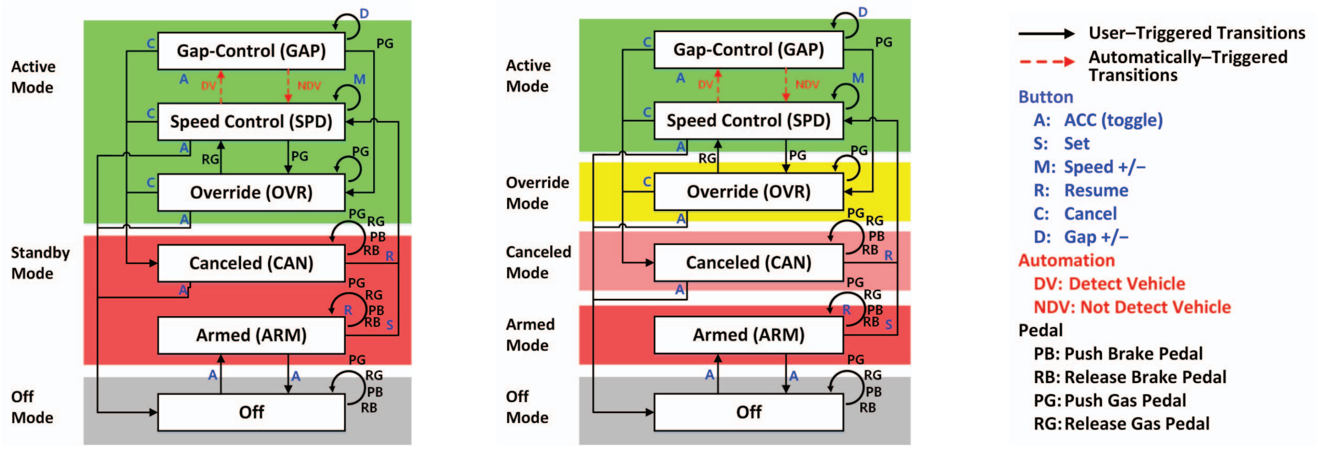
***Keywords*—*adaptive cruise control; driver interface; mode confusion; formal analysis; advanced driver assistance system***

## I. INTRODUCTION

Driver error is the most commonly cited cause of traffic accidents. With the introduction of advanced autonomous systems, such as adaptive cruise control (ACC) and lane-keeping assistance systems with multiple operational modes, to conventional vehicles, driver error due to mode confusion is increasingly emerging as a major contributing factor for traffic accidents. Mode confusion in human–automation interaction can be traced to at least three fundamental sources: opacity, complexity, and an incorrect mental model.[1] Therefore, to mitigate mode confusion, it is necessary to provide the driver with a transparent display of the automation state as well as correct and succinct information via the user interface.

Several researchers have explored mode confusion in ACC systems. Horiguchi et al. [2] suggested that the distance between mode vectors be used as a measure to predict the possibility of mode confusions. A mode vector is encoded by pairs of user inputs and their corresponding system outputs in a specific mode. Through experiments in a simulated environment, the suggestion that the likelihood of mode confusion increases as the distance decreases was confirmed. Furukawa et al. [3] conducted an experimental study on the mode awareness of an ACC system with high- and low-speed range modes. They investigated the types of information that may be effective in mode awareness through two experiments in a simulated environment in which ACC state information was suppressed and suggested a design guideline based on the experimental results.

In this study, we developed a new driver interface based on the formal method proposed by Heymann et al. for analyzing and verifying user interfaces [4]. We also investigated and compared possible mode confusions using our proposed interface and an existing typical interface through human-in-the-loop experiments in a simulated environment.



(a) (b)

Fig. 1. Combination of the machine state transition model and the user's mental model of the ACC system: (a) the models for a typical ACC system adopted by Hyundai, (b) the models proposed in this paper.

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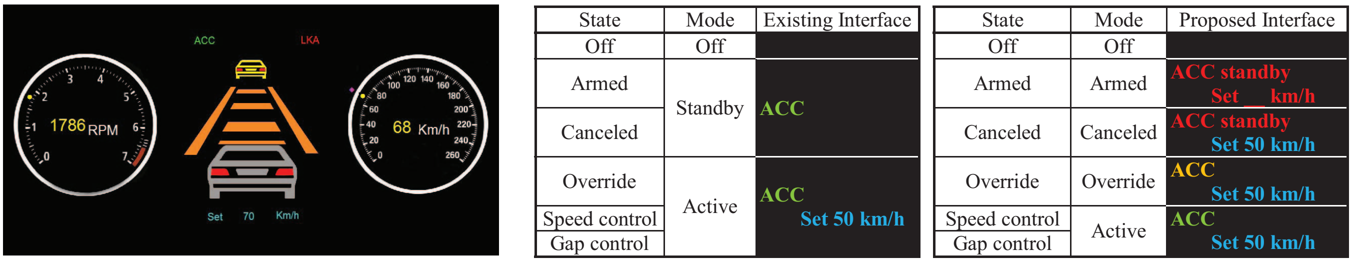

(a)

| State | Mode | Existing Interface |
|---|---|---|
| Off | Off | |
| Armed | Standby | ACC |
| Canceled | | |
| Override | Active | ACC<br>Set 50 km/h |
| Speed control | | |
| Gap control | | |

(b)

| State | Mode | Proposed Interface |
|---|---|---|
| Off | Off | |
| Armed | Armed | ACC standby<br>Set __ km/h |
| Canceled | Canceled | ACC standby<br>Set 50 km/h |
| Override | Override | ACC<br>Set 50 km/h |
| Speed control | Active | ACC<br>Set 50 km/h |
| Gap control | | |

(c)

Fig. 2. The graphic driver interfaces of the ACC system used in the experiments: (a) the graphic driver interface is shown in the center of the instrument cluster, (b) the current text displays for the modes and set speed, (c) our proposed text displays.

## II. DESIGN OF A DRIVER INTERFACE FOR AN ACC SYSTEM BASED ON FORMAL ANALYSIS

Based on the ISO 15622:2010 test specification for an ACC system and Heymann et al. [4]'s formal method for analyzing user interfaces, we designed a novel driver interface for an ACC system that can suppress mode confusion. As illustrated in Fig. 1, there are six states in a certain conventional finite-state machine model adopted by Hyundai and Toyota. Depending on the designers, states can be grouped into different sets of modes, with each mode being a cluster of states sharing the same functionality and display. To prevent mode confusion, starting from either of the two states of a mode and triggered by the same event sequence, the state pairs visited should also belong to the same mode. That is, if the state pairs visit different modes, they should not belong to the same mode. According to the ISO standard, the armed, canceled, and override states may initially belong to the standby mode, and the speed control and gap control states should belong to the active mode. However, when the gas pedal is released, the system in the override state transitions to the speed control state in the active mode, whereas the system in the armed or canceled state remains in the same state and mode. In addition, when the resume button is pressed, the system in the canceled state transitions to the speed control state in the active mode, whereas the system in the armed state remains in the same state and mode. Therefore, as illustrated in Fig. 1(b), we let the armed, canceled, and override states belong to different modes to prevent mode confusion. A conventional driver interface may cause a mode confusion because the armed and canceled states belong to the same standby mode. The graphical ACC interface located in the middle of the instrument cluster, which was used in the experiments, is shown in Fig. 2(a). The text displays for the mode and set speed in the conventional and proposed interfaces are shown in Figs. 2(b) and (c), respectively.

TABLE I. THE STATE AND MODE CONFUSION RATES OF THE CONVENTIONAL ACC DRIVER INTERFACE IN THE EXPERIMENTS.

Drivers' Recognized States/Modes

| Actual States/Modes | | Off | Standby | | | Active | | State Con-fusion | Mode Con-fusion |
|---|---|---|---|---|---|---|---|---|---|
| **Mode** | ***State*** | ***OFF*** | ***ARM*** | ***CAN*** | ***OVR*** | ***SPD*** | ***GAP*** | | |
| **Off** | ***OFF*** | 100% | 0 | 0 | 0 | 0 | 0 | 0% | 0% |
| **Standby** | ***ARM*** | 0 | 50% | 10% | 0 | 10% | 30% | 50% | 40% |
| | ***CAN*** | 23% | 9% | 36% | 0 | 0 | 32% | 64% | 55% |
| | ***OVR*** | 0 | 0 | 0 | 100% | 0 | 0 | 0% | 0% |
| **Active** | ***SPD*** | 0 | 0 | 0 | 0 | 80% | 20% | 20% | 0% |
| | ***GAP*** | 0 | 0 | 0 | 0 | 14% | 86% | 14% | 0% |

## III. HUMAN-IN-THE-LOOP EXPERIMENTS TO EXAMINE MODE CONFUSIONS IN THE ACC DRIVER INTERFACES

Ten graduate students participated in experiments to examine mode awareness with the new and conventional driver interfaces in a simulated environment, using a fixed-base driving simulator and the PreScan simulation software platform. A virtual host vehicle with the ACC system was driven by a subject while three surrounding vehicles were maneuvered by the system according to various scenarios. For ten events, such as a left-forward vehicle cutting into the target vehicle's path or the target vehicle suddenly braking, the driver or the system performed some necessary emergency maneuver to avoid collision, and this maneuver caused a mode change. After each event, the system was halted and the driver was asked which mode he/she was in. The experimental results are summarized in Tables I and II, which list the actual states and the states the drivers reported that they were in for the conventional and new interfaces. With the conventional interface, the armed and canceled states were recognized correctly at lower rates than with the proposed interface. The results prove that the formal method proposed is an effective and useful tool for the design of a human–automation interface.

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TABLE II. THE STATE AND MODE CONFUSION RATES OF THE PROPOSED ACC DRIVER INTERFACE IN THE EXPERIMENTS.

Drivers' Recognized States/Modes

| Actual States/Modes | | Off | Arm. | Can. | Over. | Active | | State Con-fusion | Mode Con-fusion |
|---|---|---|---|---|---|---|---|---|---|
| **Mode** | ***State*** | ***OFF*** | ***ARM*** | ***CAN*** | ***OVR*** | ***SPD*** | ***GAP*** | | |
| **Off** | ***OFF*** | 100% | 0 | 0 | 0 | 0 | 0 | 0% | 0% |
| **Armed** | ***ARM*** | 0 | 100% | 0 | 0 | 0 | 0 | 0% | 0% |
| **Canceled** | ***CAN*** | 0 | 0 | 95% | 5% | 0 | 0 | 5% | 5% |
| **Override** | ***OVR*** | 0 | 0 | 0 | 100% | 0 | 0 | 0% | 0% |
| **Active** | ***SPD*** | 0 | 0 | 0 | 0 | 80% | 20% | 20% | 0% |
| | ***GAP*** | 0 | 0 | 0 | 0 | 10% | 90% | 10% | 0% |