Human-Agent Collaborative Control in Automated Vehicles for Takeover Situations in Dynamic Unstructured Urban Environments

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***Abstract*—Automated vehicles operating in dynamic, unstructured urban environments will require human input in system limitations. Unscheduled transferring of control to manual driving will create safety issues due to inadequate situational awareness and sudden increase of driver workload. In this study, we propose and evaluate maneuver-based control method with a multimodal human-machine interface (HMI) for driver intervention in short-term system limitations. The HMI system consists of touchscreen, gesture, and haptic interfaces enabling bilateral driver-vehicle interaction. We evaluated the proposed control method for unscheduled takeover situation in urban environment using a driving simulator. Experimental results show that maneuver-based control can reduce driver workload, reaction times, and improve driver behavior.**

Keywords: human-robot interaction, collaborative control

I. Introduction

DYNAMIC and unstructured urban environments create significant technological challenges related to perception, reasoning, and human-machine interaction for automated vehicles. For example, traffic accident situations or unplanned roadwork that occur frequently in urban roads may involve secondary lane markings, signs, and especially, persons using hand gestures and signs to control traffic, as shown in Fig. 1. Even though an automated driving (AD) system can detect obstacles, lane markings, traffic signals, and recognize some hand gestures, it requires human judgment, and control input in such environments [1]. Humans are not required to monitor the road environment when AD systems operating in SAE level 3, thus, they can engage in non-driving related tasks (NDRTs). However, drivers are required to intervene in case of a system limitation. Drivers engaged in NDRTs are often distracted and may have low or zero situation awareness. Task switching from NDRT to manual driving requires a considerable time to engage in the driving task physically and cognitively, and requires sudden allocation of driver's attentional resources. This could result in increase of workload to meet demands of driving scenario, and may consequently decrease the quality of driver input, such as steering and speed control. Thus, manual takeover in level 3 involves a considerable risk of traffic safety.

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Fig. 1 Examples of unscheduled takeover scenarios

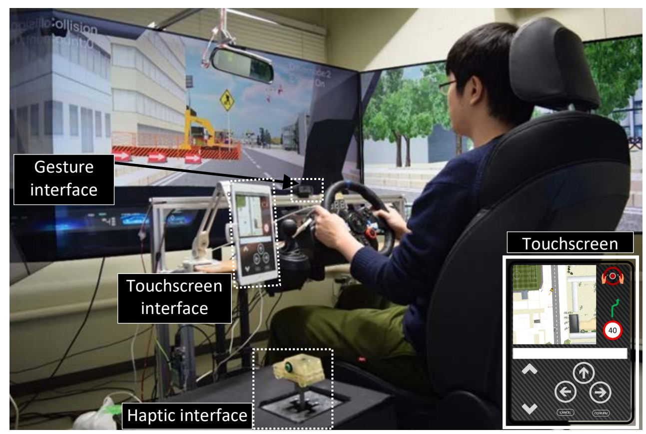

Fig. 2 Experimental Setup

In collaborative control, human and AD system (agent) can act as partners to compensate for inadequacies of each other. When AD system encounter complex urban scenarios, therefore, we hypothesized that driver can use maneuver-based tactical level input (TLI) for collaborative control [2] rather than switching to manual driving. Since the AD system can detect obstacles and control the lateral and longitudinal motions, a maneuver-based command such as 'overtake', 'change lane', 'turn left', 'proceed' from the driver would suffice to cope with complex situations. In this study, we conducted driving experiments with eleven drivers in a simulator to evaluate driver intervention using TLI comparing with manual takeover. Experimental scenario includes an unscheduled roadwork with secondary lane markings and manual traffic control in an urban environment. We show that tactical level input with an appropriate human-machine interface (HMI) [3] enables safe, seamless and effective vehicle control and result in lower driver workload in unscheduled takeovers.

II. Background

A. *Human factors issues in transition of control*

Previous research have shown that increasing degree of automation generally reduce situation awareness and mental workload [4], [5]. Moreover, it has been found that with decrease of time to takeover, the gazes to mirrors and shoulder checks decrease [6]. The lack of driver situation awareness in the takeover process thus creates safety issues.

B. *Requirement for an HMI for human-robot collaboration*

Looking from a human-robot interaction (HRI) perspective, [7] provides a set of guidelines to improve situation awareness in human-robot systems. In designing the HMI and HRI in our study, therefore, we adopted the following guidelines; providing a map to show robot's path, providing fused sensor information to lower the cognitive workload, and providing spatial information to make operator aware of robot's immediate surroundings.

III. EXPERIMENTAL EVALUATION

A. *Participants and procedure*

Eleven participants (6 males and 5 females, age M: 28.6 years, SD: 4.2) took part in this study. They had 0 to 16 years of driving experience (M: 5.3, SD: 5.5), and 6 (54.5%) of them had previous experience in a driving simulator.

The experiment consisted of three trials: manual driving from start to end (with no automation), takeover using TLI, and takeover using manual driving. The two trials involving takeover starts in AD mode, and drivers engage in NDRT. We used a 2-back cognitive task implemented in an Android tablet as the NDRT, and drivers engaged in the task until they receive a request to intervene. Experimental setup and HMI system is shown in Fig. 2.

B. *Results and analysis*

1) Driver reaction time: Fig. 3 (a) and (b) show the individual reaction times and mean reaction time, respectively. Driver reaction time in TLI (M = 4.27, SD = 1.19) was significantly lower ($p<0.05$) than in manual takeover (M = 6.27, SD = 1.90). Thus, it shows that TLI enables efficient interaction.

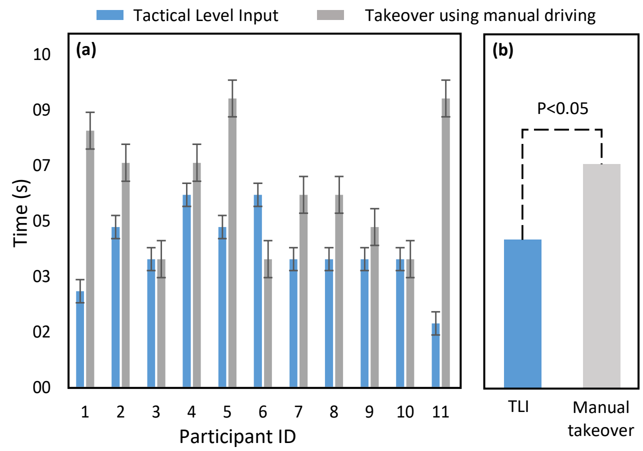

Fig. 3 Driver reaction time

2) Physiological reaction: We recorded skin conductance as a measure of driver electrodermal activity using E4 wristband[1]. Higher skin conductance corresponds to higher cognitive load. The average of the maximum skin conductance values in TLI (M = 0.5215, SD = 0.139) was lower than in manual takeover (M = 0.7082, SD = 0.3433).

3) Perceived workload: We obtained driver perceived workload scores using NASA task load index. TLI resulted in lower subjective workload compared to manual takeover in all the categories. Moreover, scores corresponding to *physical* and *effort* were significantly lower ($p<0.05$) in TLI (*Physical*: M = 17.72, SD = 19.79; *Effort:* M = 28.63, SD = 21.45) compared to manual takeover (*Physical*: M = 42.72, SD = 29.01; *Effort:* M = 58.63, SD = 24.80).

IV. DISCUSSION AND CONCLUSION

Collaborative control can utilize human judgment and reasoning to overcome system limitations in automated vehicles operating in complex urban environments. Our results indicate that by adopting a tactical-level input method can significantly lower driver reaction times, and perceived workload compared to manual takeover. Moreover, HMI for facilitating collaborative control must be designed for effective human-robot interaction in mind. Our HMI system along with tactical-level input resulted in 90.9% of drivers opting for collaborative control over manual takeover in system limitations in unstructured urban environments.

Takeover using manual driving creates safety issues due to lack of situation awareness and sudden increase of workload of human drivers. In this study, we presented and evaluated human-agent collaboration method for automated vehicles using tactical-level input. Collaborative control can compensate for inadequacies of both agents and can result in safe, seamless, and effective vehicle control.

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