Human Sensing and HMI for Safe Transition from L2 and L3 Automated to Manual Driving

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Keywords: Human sensing, Automated driving, Attentive, HMI (Human Machine Interface), and Behavior

ABSTRACT

This paper describes human factor issues of system-initiated transitions from level 2 and level 3 automated (SAE definition) to manual driving. We investigated biometric indices that could detect a decline in driver states during level 2 use. As for the planned transition from the level 3 system, we have developed quantitative evaluation methods for the driver's attentiveness before he/she receives RtI (Request to Intervene). HMI (Human Machine Interface) requirements for the smooth transition from either level 2 or level 3 automated to manual driving are also described.

1 Introduction

Level 2 or level 3 automated driving systems [1] will be developed all over the world, and some systems are already on the market. The automated driving system will cease in case of a system failure or limitations of ODD (operational design domain). The control authority of the system will be transferred to a driver through take-over mode, and RtI will be provided to the driver at the onset of the transition (system-initiated transition).

The physical workload of the driver might be lower because the driver does not need to operate the steering wheel or pedals while the automated driving system is active. However, the driver should be ready for the transition, and such readiness states might lead to an increased mental and cognitive workload. It is essential to solve human factor issues to manage the workload of the driver's preparation for the RtI.

This paper outlines human sensing techniques for assessing driver states before the transition from level 2 and level 3 automated driving. Human factor issues to consider before taking over the driving are different between the level 2 and level 3 automated systems. This paper describes driver state assessments before the transition from either level 2 or level 3 automated to manual driving. In addition to the human sensing techniques, this paper describes HMI requirements to promote the smooth transition to manual driving. It is important to investigate HMI design for RtI in the transition from level 2 automated driving. On the other hand, for a planned transition from level 3 automated driving, it is necessary to consider HMI regarding the presentation of information to prepare the driver for the transition before presenting the RtI.

2 Transition from Level 2 Automated

2.1 Driver Monitoring in Level 2 Automated Driving Systems

Drivers are required to monitor the system states and the road traffic environments surrounding the ego vehicle when the level 2 automated driving system is active. The driver conditions might temporarily decline because non-driving related activities (NDRA) distract the driver's attention (distracted driving might occur even in manual driving conditions). Driver monitoring system during the usage of the level 2 automated driving systems is necessary to detect the temporary deterioration of the driver states and determine if the driver's condition is lower than a threshold.

Research is needed to search for indicators that can evaluate the driver's state during level 2 automated driving to develop such driver monitoring systems [2]-[4]. Driving simulator experiments revealed physiological metrics to measure the driver states including cognitive loaded, visual-manual loaded, and lower arousal conditions, respectively (Fig. 1). Camera-based sensing items were common indicators for both cognitive and visual-manual loaded conditions. Test course and public road experiments using instrumented vehicles suggested that these indices can be measured in real road environments and that they influence behaviors after the transition to manual driving in real road traffic conditions [5]-[7].

In addition to the measurement of driver status, a method to accurately predict the extent to which a decline in driver status during automated driving leads to a decline in driving performance after a change of driving was also investigated [8].

2.2 HMI of RtI in Level 2 Automated Driving Systems

HMI modalities to convey RtI-related information have been investigated in several research studies [9]. Visual, auditory, and haptic information and some combination of these were used to analyze the effects on the take-over time after the driver receives the provided information.

When the driver state is lower than the threshold value, some kind of alert should be presented to the driver from

		Cognitive load	Visual-manual load	Arousal level
Brain activity	P2-N1 amplitude for task-irrelevant probes	○	○	
	Eye fixation related potentials in small saccade	○		
Face direction	Head movement variability		○	
Glancing behaviors	Percent time of forward looking	○	○	
	Percent time of glancing at in-vehicle display		○	
Eye movements	Frequency of small saccade (5-8 degrees)	○	○	
	Frequency of small saccade (20-40 degrees)		○	
	Variability of saccade amplitude		○	
	Frequency of micro saccade (below 1 degrees)	○	○	○
	Pupil diameter	○		○
Eyelid movements	Blinking frequency	○	○	○
	Blinking duration		○	○
	PERCLOS (percent time of eye closure)			○
Autonomic nerve	Heart rate	○	○	
	Blood pressure	○		

Fig. 1 Physiological metrics for driver monitoring in level 2 automated driving systems

the in-vehicle display to improve the driver’s state. The findings of the traditional warning design can be applied to the design of such alarms [10]. The visual images and auditory displays with higher urgency and criticality are efficient if the driver's condition before the transition is much lower than the threshold value, corresponding to the condition where the driver’s capability is considerably lower than the task demand [11].

3 Transition from Level 3 Automated

Level 3 automated driving systems have two kinds of transitions: planned and unplanned transitions. The planned transition occurs during a transition at the boundary of the ODD, where the location of the transition is determined in advance. An unplanned transition can occur when faced with a system failure or a situation that exceeds the performance limitations of the automated system. While using level 3 automated driving, the driver can be immersed in the NDRA. In the planned transition, the driver can prepare for the take-over to some extent in advance, however, even if he/she prepares, he/she may return to NDRA if the time between the transition is too long. Under such time constraints, it is necessary to properly evaluate the driver’s readiness to drive. The readiness corresponds to the state in which the driver is aware of the surrounding situation.

3.1 Driver Situation Awareness Assessment in Level 3 Automated Driving Systems

Driving simulator experiments were conducted to explore a quantitative evaluation method for driver situation awareness before the planned transition of level 3 automated to manual driving [12]. In the driving simulator experiment, the ego vehicle drove at a speed of approximately 60 km/h in the center lane of a three-lane road using an automated driving function. A few minutes after the start of automated driving, the transition occurred, and the driver manually changed lanes within a set section. We measured the driver's eye and head movements during automated driving. The driver's driving behavior after switching to manual driving was also measured, and the success rate of lane change was calculated. The followings are the findings from the simulator experiments:

- Evaluation metrics of the attentiveness are driver’s gaze and driver’s head movements.
- About 20 seconds from the onset of monitoring the surrounding situations is the interval in which the drivers are paying attention to their surroundings and enhancing their situational awareness.
- The stable rate of forward and peripheral (mirror) gazing after a process of increased situation awareness corresponds to the driver’s state of being able to recognize both the front and peripheral road traffic conditions.
- Driving performance was higher (i.e., lane change success rate was higher) when the driver was switched after a stable transition in the front gaze rate compared to when the driver was switched without situational awareness or when the driver was switched during the process of increasing the front gaze rate.

3.2 HMI of “Request to Monitor” in Level 3 Automated Driving Systems

The results of the driving simulator experiments in section 3.1 suggest that a long time for the attentive phase before the driver received the RtI leads to a smooth transition. However, the driver may continue to perform the NDRA without monitoring due to the long length of time required for the driver to be monitored, which might lead to lower driving performance after the transition.

To examine HMI requirements for encouraging situational awareness when asking drivers to recognize their surroundings before the planned transition, we set the following HMI conditions: HMI to clearly indicate the take-over timing as "take over after 60 seconds," HMI to count down in addition to clearly indicating the transition timing, HMI to assume the driving posture with the steering wheel during situation awareness, and HMI to present an alarm if situational awareness is not performed. Then, we compared their effects on driving performance after the transition using a driving simulator.

A comparison of the time to complete the lane change and the collision rate showed that the results of the condition in which a countdown was performed in addition to clearly indicating the timing of the transition and the condition in which the driver assumed the driving posture with the steering wheel while recognizing the surroundings were better than those of the other conditions.

VMS (Variable Message Sign) can be utilized to explicitly indicate the timing of the planned transition, i.e., the boundaries of ODD [13]. It was shown that taking the driving operation posture was effective in improving driving performance after the transition. Tactile information that encourages the driver to hold the steering wheel, which is provided in the currently commercialized level 2 automated driving systems, can be applied to maintaining driving readiness.

4 Conclusions

This paper outlines the measurement of driver state and HMI before taking over, divided into levels of automated driving systems. Figure 2 presents the summary. In an unplanned transition in level 3 automated systems, the first step is to detect whether the driver is responding to the RtI. If the driver is responding to RtI and the driver's operation is inappropriate, the system can help correct the inappropriate operation. If the driver is not responding to RtI, MRM (Minimum Risk Maneuver) will be activated [14].

Acknowledgments

This paper includes the results of Cross-ministerial Strategic Innovation Promotion Program (SIP) 2nd Phase, Automated Driving for Universal Services (SIP-adus, NEDO management number: JPNP18012) that was implemented by the Cabinet Office and was served by the New Energy and Industrial Technology Development Organization (NEDO) as a secretariat.

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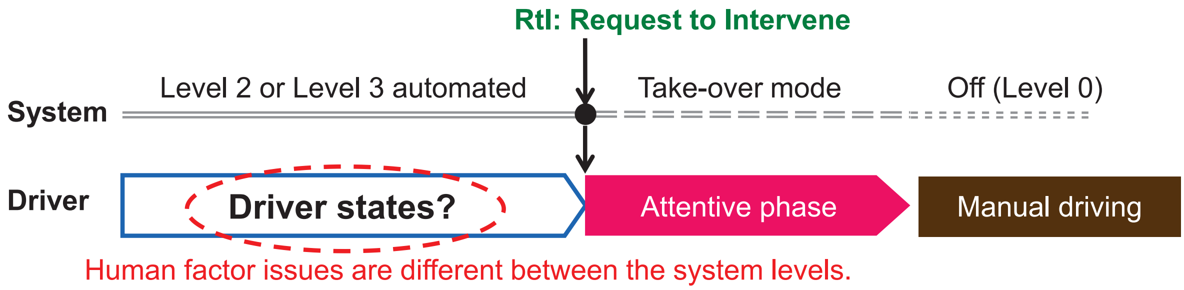

	Human Sensing	HMI
Level 2	Driver monitoring system to measure driver's readiness/ availability and to detect it lower than criteria	● Visual, auditory, haptic messages of RtI ● Warnings with higher urgency and criticality to improve driver conditions above criteria
Level 3 Planned	Evaluation of driver' attentiveness using the glancing behaviors and head movements	● Information to promote the attentive phase that the driver comes back in the driving-loop and recognizes the surrounding situations ● Information of taking the driving operation posture to maintain driving readiness
Level 3 Unplanned	■ Detection of driver's responses to the RtI ■ Detection of an imminent collision risk due to the driver input	● Strong message to stop NDRA ● Execute MRM (Minimum Risk Maneuver)

Fig. 2 Human sensing and HMI in level2, level 3 planned, and level 3 unplanned transition

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