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UNDERSTANDING METRICS OF VEHICLE CONTROL TAKE-OVER REQUESTS IN SIMULATED AUTOMATED VEHICLES

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ABSTRACT−This paper derives an effective take-over alarm method for a Society of Automotive Engineers Level 3 automated vehicle using vehicle parameters. An experiment was conducted using a driving simulator. Forty-one subjects participated in two different scenarios: unplanned and planned operational design domain. Subjects drove on a highway at 100 km/h in automated mode. Experiment participants resumed manual control of the vehicle when the alarm was provided in the take-over state. A visual and auditory combined alarm was the most effective in terms of drivers' cognitive load showing low steering angle deviation and steering reversal rate values compared to the combined visual, auditory, and haptic alarm ($p = 0.01$ and 0.003). The auditory alarm was the most effective in terms of the quality of the driver's reaction showing a low maximum acceleration value compared to the combined visual, haptic alarm ($p = 0.002$). The combined visual, auditory, and haptic alarm was the most effective in terms of post-take-over lateral control showing a low standard deviation lateral position value compared to the haptic alarm ($p < 0.001$). The auditory and haptic combined alarm was the most effective in terms of post-take-over longitudinal control showing a low number of gas pedal inputs value compared to the haptic alarm ($p = 0.002$).

KEY WORDS : Automated vehicles, Take-over, Maximum acceleration (MA), Steering reversal rate (SRR), Standard deviation lateral position (SDLP), Steering angle deviation (SAD), Number of gas pedal inputs (NGI), Take-over request (TOR)

NOMENCLATURE

TOR : take-over request
MA : maximum acceleration
SRR : steering reversal rate
SDLP : standard deviation lateral position
SAD : steering angle deviation
NGI : number of gas pedal inputs
A : auditory
V : visual
H : haptic
ODD : operation design domain

1. INTRODUCTION

The development of automated driving system technology will result in many unforeseeable changes. It will create new markets and enhance human convenience (Goldin, 2018). The traffic accident ratio will be reduced, productivity will be improved, and time spent on driving will become available for leisure activities (Ranft *et al*., 2016). The Victoria Transport Policy Institute expects that automated vehicles will be commercialized sometime between 2020 and 2030 (Litman, 2018).

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In step with automated vehicle commercialization, measures should also be established to prevent dangerous situations from occurring in the operation of automated vehicles. The state of California (USA) permits pilot operation of automated driving and requires the submission of reports on any accidental collision or disengagement event during automated driving (State of California Department of Motor Vehicles, 2018). According to the 2015-2016 Self-Driving Car Testing Report on Disengagements of Automated Mode, of the total of 3,271 cases of automated mode disengagements, 21.7 % were disengagements by human drivers, 49.4 % by automated systems, 4.0 % by automated vehicles, 0.2 % by others, 11.1 % by traffic participants, 5.2 % by roads, 4.5 % by the climate, 3.5 % by traffic flow, and 0.4 % by obstacles (Yun *et al*., 2018). This clearly shows the need for research on measures to overcome the limitations of automated driving technology as it becomes more sophisticated.

Automated vehicles at the Automation Level 3 of the Society of Automotive Engineers (SAE) are expected to be commercialized between 2020 and 2021. In such vehicles, the automated driving system controls the vehicle and monitors the driving situation (SAE Standard J3016, 2016). However, the automated system cannot handle emergent situations and transfers vehicle driving control over to a human driver. Such a take-over situation (Melcher *et al*.,