

Technical Correspondence

Takeover Requests in Simulated Partially Autonomous Vehicles Considering Human Factors

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Abstract—In the development of autonomous vehicles, the main focus of sensor research has been in relation to environmental perception, and only minimal work has focused on the human–vehicle interaction perspective. However, human factors need to be considered to ensure the safe operation of partially autonomous vehicles. This study briefly introduces a design methodology for the takeover request (TOR) time in National Highway Traffic Safety Administration Level 3 vehicles and compares four different TORs in a simulated environment based on human-in-the-loop experiments with various driving scenarios. A total of 30 drivers participated in the study, and the quantitative/qualitative data obtained show statistically significant differences between the four TOR thresholds. This study shows that the timing involved in the takeover can be obtained by using a performance-based approach considering human factors.

Index Terms—Autonomous levels, autonomous vehicle, driver behavior, driver reaction time, human factor, human-in-the-loop, takeover request (TOR).

I. INTRODUCTION

Autonomous vehicles that rely on the use of sensors have been developed to improve driver safety and simultaneously enhance vehicle convenience. In the initial stages, the Defense Advanced Research Projects Agency developed autonomous vehicles that use specific sensors, such as those for parking, intersection, and lane change navigation, and emergencies. However, the development of a concentrated sensor has now produced an improved advanced driver assistance system (ADAS), and autonomous vehicles are now the subject of considerable research. When developing such a vehicle, it is necessary to consider not only high-quality sensors but also the driver in relation to the human–vehicle interaction.

Autonomous vehicles rely on their detection ability, and by using sensors, it is possible for a vehicle to be operated without considering the driver characteristics, such as driver reaction time, driver behavior, and driver states. However, based on research carried out in the 1970s, although the role of the driver can be taken over by automation, in addition to replacing the role of the driver, the car also needs to deliver

a performance identical to that of the driver if it is to be trusted [1]. This ability is particularly relevant during high traffic situations because all drivers operate their vehicles differently at such times, and although they potentially receive the same information, their individual reaction abilities differ. Recently, automated vehicle risk has been determined in the United States by using naturalistic data [2], in which different standards for incidents and unreported crashes complicated the comparison between currently published crash data and automated vehicle crash data. In this regard, it is essential to consider human–vehicle interactions [3].

In 2008, the National Highway Traffic Safety Administration (NHTSA) defined the levels of autonomous vehicles, from levels 0 to 4, by classifying the driving roles of the driver and the autonomous vehicle [4], [5]. Autonomous Level 3 involves a considerable amount of interaction between the system and the driver; if such interaction does not adequately occur, then neither the system nor the driver can react appropriately to an external stimulus [6]. Therefore, this research focuses on vehicles at Autonomous Level 3. The main human factor considered in this study is reaction time.

Reaction time refers to the time gap from the initiation of a stimulus up to the instant before the intended reaction occurs, and this differs both between drivers and for individual drivers at different times. Spirduso *et al.* [7] classify reaction time into three parts: simple reaction time (SRT), detectable reaction time (DRT), and choice reaction time (CRT). SRT refers to the process that occurs when the driver already knows the object is going to appear, DRT is when the subjects have no previous knowledge of the appearance of an object, and CRT is the decision time involved when an object appears among diverse hazards and is thus potentially much more dangerous.

Takeover request (TOR) time has been studied by using autonomous vehicles generally in a simulated environment [8], [9], [24], [25]. Gold *et al.* (2013) designed a PC-based autonomous vehicle in a simulation and explored appropriate applications of the TOR alert with secondary tasks. They designed an event in which an autonomous vehicle makes a TOR sound when it changes lanes. The TOR times were set at 5 and 7 s, and the results showed that it took 2.06 and 3.10 s to press the brake pedal and 2.28 and 3.65 s to control the steering wheel, respectively. Therefore, as the TOR time increased, the driver's reaction time increased as well [8].

Gold *et al.* (2013) used both auditory (sinusoidal tone) and visual (icons in the instrument cluster) cues to provide TOR requests, whereas Mok *et al.* (2015) applied only an auditory message ("Emergency, automation off"). The latter investigated how long a driver has to take over the control of an autonomous vehicle that is shut off suddenly after an error by using "Automation off." The experiment was designed by using a curb lane with TOR times of 2, 5, and 8 s. The results showed that the lane departure distance for the TOR time of 5 s ($M = 0.02$, $SD = 0.05$) was shorter than that for 2 s ($M = 1.03$, $SD = 1.12$)

Manuscript received May 20, 2016; revised August 31, 2016 and November 17, 2016; accepted January 17, 2017. Date of publication March 20, 2017; date of current version September 15, 2017. This work was supported in part by the Basic Science Research Program (2014R1A1A1002037) through the National Research Foundation of Korea funded by the Ministry of Science, ICT, and Future Planning, and in part by the Technology Innovation Program (1004761, Development of connectivity-based personalized intelligent integration cockpit module with analysis function of driver's condition and driving environment) funded by the Ministry of Trade, Industry and Energy. This paper was recommended by Editor-in-Chief D. Kaber.

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Digital Object Identifier 10.1109/THMS.2017.2674998