Autonomous Driving:
Investigating the Feasibility of Bimodal Take-Over Requests

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ABSTRACT

Autonomous vehicles will need de-escalation strategies to compensate when reaching system limitations. Car-driver handovers can be considered one possible method to deal with system boundaries. The authors suggest a bimodal (auditory and visual) handover assistant based on user preferences and design principles for automated systems. They conducted a driving simulator study with 30 participants to investigate the take-over performance of drivers. In particular, the authors examined the effect of different warning conditions (take-over request only with 4 and 6 seconds time budget vs. an additional pre-cue, which states why the take-over request will follow) in different hazardous situations. Their results indicated that all warning conditions were feasible in all situations, although the short time budget (4 seconds) was rather challenging and led to a less safe performance. An alert ahead of a take-over request had the positive effect that the participants took over and intervened earlier in relation to the appearance of the take-over request. Overall, the authors’ evaluation showed that bimodal warnings composed of textual and iconographic visual displays accompanied by alerting jingles and spoken messages are a promising approach to alert drivers and to ask them to take over.

KEYWORDS

Automated Driving, Automotive, Autonomous Driving, Driving Simulator Study, Handover, Human-Computer Interaction, Human Factors, Human-Vehicle Interaction, Multimodal Interfaces, Take-Over

INTRODUCTION

The future of driving will be automated. This trend is already noticeable through applied advanced driver assistance systems, for example collision avoidance or lane departure warnings, as well as partially automated systems, such as adaptive cruise control (ACC), full speed range ACC, lane centering, or automatic lane changing. In addition, almost every automotive original equipment manufacturer (OEM) has presented a self-driving prototype, and some are already being tested on public roads, for instance the off-the-shelf Mercedes-Benz Actros-equipped with a Highway Pilot.
Drivers can benefit greatly from these new technologies. Automated driving is likely to increase traffic safety, reduce traffic congestion as well as gas emissions and fuel consumption (European Comission, 2011), and also yield improvements to the driver’s well-being (Stanton & Marsden, 1996) provided that the automation is fully reliable. However, today’s automated systems cannot handle all daily usage scenarios, although they are being continuously improved. Due to external factors such as weather or road conditions, even future automated systems may still contain limitations. Accordingly, both current and future automated systems need an effective strategy for drivers to take over the control from the automated system. These handover situations are defined by Gold and Bengler (2014): As soon as a system senses a system boundary, it asks the driver to take over via a take-over request (TOR). Beginning with the moment in which the driver starts to steer, the automation mode is shifted from self-driving automation to manual driving. The time that the driver has at their disposal to take over (from the TOR until the system boundary is reached) is called time budget. Transition area denotes the transition from automated driving to manual driving, beginning with the driver glancing at the traffic scene, and ending with the driver taking over control entirely.

Current research is investigating take-over scenarios to determine in which time budget durations drivers are able to safely take over control (Damböck, Bengler, Farid, & Tönert, 2012; Gold, Damböck, Lorenz, & Bengler, 2013). In addition, Zeeb, Buchner, and Schrauf (2015) proposed a model based on the underlying processes of a take-over: First, a distracted driver has to achieve motor readiness (grasping the steering wheel and moving the feet into position). In parallel, the driver will perceptually and cognitively process the take-over situation. Finally, as soon as the mental model has been updated, the driver can execute a suitable action. A first evaluation of Zeeb et al. (2015) indicated that achieving motor readiness seems to be mainly reflexive and almost independent of the driver’s distraction. In contrast, they stated that there seemed to be effects of different driver states (e.g. high situation awareness through recurrent monitoring of the traffic scene) on the visual and cognitive processing. The importance of the assessment of the driver state within highly automated driving was also emphasized by Rauch, Kaussner, Kruger, Boverie, and Flemisch (2009).

It has to be considered that automated driving changes the role and tasks of drivers. That is, they are passengers rather than active drivers, with the benefit of doing other things like reading news, checking emails or watching videos. Consequently, drivers direct their attention away from the driving task, resulting in the out-of-the-loop phenomenon. This has been connected to various factors such as slower task performance and a decrease in situation awareness after using fully automated systems – more so than compared to manual or partly automated systems (Endsley & Kiris, 1995; Kaber & Endsley, 2004). According to the model by Endsley (1995), situation representation can be impaired on three levels: the perception of elements of the current situation (Level 1), the comprehension of the perceived stimuli (Level 2), and the projection of future status (Level 3). Even if the driver perceives relevant elements of the scenery, cognitive distraction can impede them from processing and integrating the elements in a coherent model of the situation. Similarly, handling a distracting task while driving in automated mode was observed to lead to impaired performance after regaining control and within the take-over process (Merat, Jamson, Lai, & Carsten, 2012; Radlmayr, Gold, Lorenz, Farid, & Bengler, 2014). Moreover, Brandenburg and Skottke (2014) found that automated driving (platooning) has a sustained effect on the post-automation behavior of drivers for up to 10 km after a take-over maneuver.

In general, it is recommended to keep the driver in the loop, or to support the driver as much as possible in the process of getting back in the loop. Martens and van den Beukel (2013) recommended first design solutions for the take-over process, e.g. to interrupt secondary tasks and to implement
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