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USE OF AUDITORY INTERFACES FOR TAKEOVER REQUESTS IN HIGHLY AUTOMATED DRIVING: A PROPOSED DRIVING SIMULATOR STUDY

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ABSTRACT

Highly automated driving can potentially provide enormous benefits to society. However, it is unclear what types of interfaces should be used for takeover requests during highly automated driving, in which a driver is asked to switch back to manual driving. In this paper, a proposal for a driving simulator study on the use of six auditory signals during such takeover requests is outlined. The auditory signals to be tested in the experiment are based on the results of an online international survey previously conducted by the authors. The experiment will involve 24 participants performing a secondary task, and the takeover scenario will be represented by an accident in the middle lane of a three-lane freeway. The time margin prior to takeover will be 7 s. The driving time between subsequent takeover requests will be 2 to 3 min. The application of the results of the proposed study as well as plans for future studies are presented in the last section.

1. INTRODUCTION

There are five levels of automation for on-road vehicles: (1) manual driving, (2) driver assistance, (3) partially automated driving, (4) highly automated driving, and (5) fully automated driving [1]. In the 1990s, Adaptive Cruise Control (ACC), a technology that controls the longitudinal motion of a vehicle, made driver assistance a reality. Further advancements introduced in the 2000s laid ground for partially automated driving, where drivers are no longer required to manually control the lateral movements of the car but still have to keep their eyes focused on the road and/or occasionally touch the steering wheel. The current focus of the scientific community is directed at the fourth level, highly automated vehicles, where the driver no longer needs to keep his/her attention to the road and can remove the hands from the steering wheel. However, even in highly automated driving (HAD) the vehicle cannot control all situations, and the driver may be asked to take back manual control by means of a so-called takeover request (TOR). The time between issuing a TOR and the required moment of transition of control is a critical variable in the design of such automated driving systems [2], [3]. Fully automated driving (FAD) is envisioned to be the final iteration of automated driving, where the vehicle will control the entire task of driving.

We have previously conducted a study that analyzed anonymous textual comments regarding fully automated driving extracted from three online surveys with 8,862 respondents from 112 countries (males represented 74% of the sample, mean age of the participants was 32.6 years) [4]. A crowdsourcing task was created and 69 workers were requested to assign each of 1,952 comments to at least one of 12 predefined categories: positive and negative attitude to automated driving, enjoyment in manual driving, concerns about trust, reliability of software, and readiness of road infrastructure. The public opinion was found to be heterogeneous. A positive attitude towards automated driving was identified in 29% of 1,050 meaningful comments, whereas 18% of the comments were classified as ‘negative attitude towards automated driving’.

1.1. Auditory interfaces for takeover requests in highly automated driving

Our proposed research study investigates the potential of auditory feedback in automated driving. Present day cars often come with Advanced Driver Assistance Systems (ADAS), which offer assistance with driving and monitor the environment for the detection of road safety risks. Most of such systems can provide auditory warnings to the driver.

We have previously conducted an international online-based survey to investigate the opinion of 2,000 participants from 96 countries on the usage of auditory interfaces in modern and future vehicles [5]. The participants reported their attitudes towards two existing auditory driver assistance systems, a parking assistant (PA) and a forward-collision warning system (FCWS), as well as towards a futuristic augmented sound system (FS) intended for fully automated driving. The respondents were generally positive towards the PA and FCWS. The willingness to use them was rated as 3.93 and 3.82, respectively on a scale from 1 = disagree strongly to 5 = agree strongly. The respondents tolerated the FS. The mean of willingness to use it was 3.04 on the same scale from 1 to 5.

Auditory warning signals will not be required in FAD, since, by definition, the automation will be able to keep control of the vehicle in all possible conditions. Our previous study [5] proposed an experimental setup aimed at the auditory 3D representation of the environment outside of a vehicle, which could be used in FAD for comfort and entertainment. The respondents of the survey were not particularly positive about the FS, possibly because they could not envision the system, or because of the lack of experience with such a system.

Results in [5] also showed that a female voice is the most preferred feedback for the support of TOR in highly automated driving. The female voice was perceived as the third most preferred warning signal for supporting TORs by the participants in [6] after a head-up display with a green icon, and a green icon on the dashboard.

The participants in the survey [6] were also asked to select the most urgent and the most annoying auditory warning signal from six options:

1. One beep
2. Two beeps
3. Horn sound
4. Bell sound
5. Female voice saying “Take over please”
6. Male voice saying “Take over please”

The horn sound was judged to be the most annoying while the male voice saying “Take over please” was considered the least annoying signal. The male voice was found to be the most urgent signal, and the bell sound was seen as the least urgent auditory warning signal.

1.2. Aim of the proposed experiment

The results from the authors’ survey studies [5], [6] will be validated in a driving simulator experiment. Specifically, urgency and annoyance of the six auditory warning signals will be evaluated, and the preferences of the participants for the type of warning signal for TOR in HAD will be polled in a questionnaire offered after the completion of the simulator experiment. The hypothesis that the female voice is the most preferred auditory signal, as was shown in [5], will be tested. An additional hypothesis that the first eye gaze after receiving a TOR will be directed to the side of the source of such cue will be evaluated.

2. EXPERIMENT ON THE USE OF AUDITORY INTERFACES FOR TAKEOVER REQUESTS DURING HAD

The experiment will be conducted with a Green Dino simulator at the Delft University of Technology. A TOR in the form of an auditory warning signal will support switching from HAD to manual driving.

All participants will be required to have a driver’s license. In the experiment, at least 24 participants, all students of Delft University of Technology, will be exposed to the six auditory signals listed in Section 1.1 during TORs.

Both directional (right and left) and non-directional cues will be provided via speakers in the simulator. The participants will be asked to rank the warning signals based on their urgency and other attributes to be defined in the later stages of the planning. The brake and steering reaction times of the participants will be also measured. The driver’s head and eye movements will be recorded with a non-obtrusive eye tracking system.

2.1. Secondary task

In order to ensure that the participants will have their eyes off the road, the participants in the experiments will be asked to perform a secondary task. A screen will be placed on the right side of the steering wheel during HAD. The participants will be required to perform the Surrogate Reference Task (SuRT, [7]) on the secondary screen.

2.2. Scenario

A within-subject, repeated measures design will be used. The participants will experience 18 TORs (six warning signals and three requests for each, left/right/non-directional). The sequence of TORs will be counterbalanced. The participants will drive a scenario similar to that in Gold et al. [8].

Figure 1 illustrates that the takeover scenario will be represented by an accident on the middle lane of a three-lane freeway. The driver will have the option to either stop on his/her lane by braking, or to swerve to the left or to the right lane. To make a lane change possible, the other lanes will not be occupied by other road users. Participants will be asked beforehand to use the mirrors and perform a shoulder check prior to making lane changes. At the time of the TOR, the stationary vehicle will appear 233 m in the middle lane. At a speed of 120 km/h this implies a takeover request time of 7 sec.

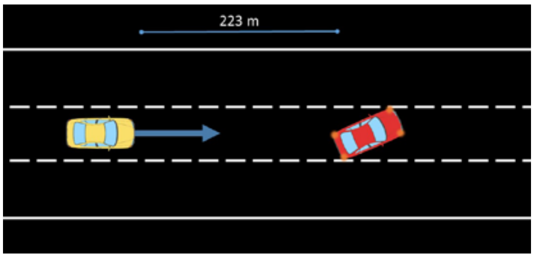

Figure 1: Takeover scenario.

The driving time between TORs will be 2 to 3 min. At the moment of the TOR the participant will have to take over control by turning the steering wheel or applying the brakes. Either of these actions will disengage the automation. The experiment will take approximately 1 hour per participant. Two breaks will be planned per participant.

2.3. Procedure and instructions

At arrival at the driving simulator laboratory, the participant will sign a consent form, explaining the purpose and procedures of the experiment. After signing the consent form the participant will be asked to fill out a general questionnaire about his/her driving behavior, demographic information, and general opinion about TOR modalities. Before entering the simulator, the participant will be reminded that he/she can stop the experiment at any time. Next, the participant will be asked to enter the simulator and start a training trial, which will take 2 min to complete. The participant will be familiarized with the SURT task, learn how to disengage the automation, and experience a non-directional TORs. A second questionnaire with items on preferences for the warning signal for TOR in HAD, urgency, and annoyance of the signals will be given to the participant after finishing the scenario.

2.4. Dependent measures

We will record the reaction time and the takeover quality of the participants. The following measures will be calculated:

1. Mean and SD reaction time first gaze reaction: The time from the warning signal to the moment that the eyes of the participants first move away from the secondary task.
2. Mean and SD reaction time road fixation: The time from the warning signal to the moment that the eyes of the participants are directed back on the road.
3. Mean and SD reaction time hands on steering wheel: The time from the warning signal to the moment that the hands are back on the steering wheel.
4. Mean and SD reaction time intervention: The time from the warning signal to the moment that the driver uses either the brake or steering wheel.
5. X- and Y-trajectories of the drivers, which allow inferring take-over quality smoothness [3], [8].
6. Number of safety checks performed: The number of areas of interest (e.g., side mirror or blind spot) that the drivers checked before making a maneuver.
7. Mean and SD of the Time-to-collision (TTC) to the stationary vehicle during TOR.
8. Mean and SD of the longitudinal and lateral accelerations during TOR.
9. Mean and SD of the steering wheel reversal rate [9].

3. RESULTS OF THE EXPERIMENT AND FUTURE STUDIES

The results of the proposed experiment will be analyzed to derive recommendations for the development of a user interface for supporting TORs during HAD. These recommendations will be used in the preparation of a series of follow-up studies. One of these follow-up experiments will be conducted together with three researchers involved in the HFAuto project [10], at TU München, the University of Southampton, and the Swedish National Road and Transport Research Institute (VTI). It will conducted during 2016 and incorporate a three-modal auditory/haptic/visual interface.

The first author started his PhD in August 2015. The goal of the author’s PhD research will incorporate two online surveys, a number of driving simulator experiments, and, possibly, field studies, resulting in the creation of an auditory interface that (in combination with a haptic and/or visual interface) will be capable of supporting takeover requests in HAD.

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