Interaction design for nomadic devices in highly automated vehicles

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Abstract

Following the roadmaps of (inter)national committees, highly automated driving will be available in the next decade in production vehicles. This technology allows the driver to do some other tasks while driving and to remain only as a fallback in situations the automation is not capable to handle. This study tested if nomadic devices, that drivers might use while driving highly automated, can be integrated to support the driver in taking over control when requested. 33 drivers participated in a simulator study and drove in a highly automated vehicle on a motorway. The results showed that the takeover performance of drivers improve if the takeover request is displayed additionally on the nomadic device. Therefore, the integration of additional interfaces such as smartphones into a holistic interaction concept may be a key aspect for designing a secure and comfortable takeover process.

1 Introduction and theoretical background

The overall concept of self-driving vehicles is motivated by the vision of increased safety, respectively the “vision zero” (iMobility Forum, 2013), comfort in transportation and the decrease of the ecological impact on the environment. The automation levels “conditional” and “high automation” define the preliminary stages to self-driving vehicles. They are available in a subset of the road system, meaning the automation is in control and is capable of handling one or multiple situations and hands over the vehicle control to the driver when the situation ends (SAE International, 2014). The automation allows to free the driver from monitoring tasks, but he still has to be ready to take over the control within a sufficient time horizon when the system is not capable of handling the situation. Thus, these levels offer manifold possibilities for the driver to engage in other tasks than driving e.g. using his personal nomadic devices. Whether the integration of these nomadic devices in a holistic interaction concept improves the driver performance in takeover request situations is the main research question addressed in this work.

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A vehicle which offers one or more automated driving functions but is not fully automated, in a sense that it is driving driverless, transitions of control will occur. Transitions describe dynamic mode changes (i.e. switching between different automation levels). A transition is a very sensitive point in the interaction of human driver and automation as the vehicle control is shifted between the vehicle automation and the driver. Cases of a “control vacuum” can occur meaning neither the driver nor the vehicle automation controls the vehicle (Flemisch, et al., 2012). To avoid such dangerous situations the careful interaction design of transitions is essential.

Non-related driving tasks (tertiary tasks compared to primary and secondary driving task; Wolf et al. 2006) may be allowed during periods of SAE level 3 or 4 driving and become the primary task for drivers who do not need to control the vehicle or monitor the automation anymore. An already quite popular, although currently not allowed tertiary task in most countries, is the usage of nomadic devices such as smartphones behind the steering wheel. In 2011, the NHTSA recorded 385 fatal crashes and 21.000 crashes with injured traffic participants due to nomadic devices usage while driving (National Highway Traffic Safety Administration, 2011). In Germany, 450.000 violations against the legal prohibition of phone usage while driving were recorded during the same period of time (Kraftfahrt-Bundesamt, 2011). That in mind, it is not surprising that the operation of nomadic devices is mentioned as one of the most desirable activities while driving automated in the future (Carnegie Mellon University, 2015). However, also in SAE level 4 drivers have to react quickly and appropriately to transition requests of the vehicle even when they are distracted by tertiary tasks. Utilizing displays of devices that are used in future automated vehicles, such as tablets, smartphones, notebooks, infotainment systems or even augmented reality glasses to indicate that a takeover is pending seems to be a promising solution. Thus, an interaction design needs to be implemented to inform, warn and reactivate drivers for taking over vehicle control while being distracted by tertiary tasks.

2 Research questions and hypotheses

Three different interaction designs were used to communicate information on the traditional instrument cluster/ head-down display (HDD) and on a nomadic device about a situation where a control transition is necessary. Technically, the nomadic device of the driver was coupled with the automation of the vehicle. This coupling allows displaying information and takeover requests directly on the nomadic device (the location the driver most probably is looking at). The present study investigates whether the information displayed on a nomadic device increases the takeover quality in regard to conventional systems that use the HDD combined with an alert sound. The hypotheses of the study are as follows:

H_1*: While driving in highly automated driving mode (SAE 4), an additional takeover request on a nomadic device will improve the takeover quality compared to a takeover request only presented on the traditional HDD.*

Furthermore, two interaction designs were tested for the nomadic device with a) a pure takeover request and b) a takeover request enriched with preceding information of the driver about the upcoming event.

H_2: *While driving in highly automated driving mode (SAE 4), preceding information about an upcoming takeover request will improve the takeover quality compared to a pure takeover request on the nomadic device.*

3 Method

3.1 Simulation environment

Participants drove on a simulated motorway with a VW Passat that was placed in a 360° driving simulator. The control room was auditory and visually isolated from the simulator. A speaker and a microphone were placed in the car to communicate with the driver if necessary. For the purpose of this study, the steering wheel was equipped with a hands-on detection. Two buttons, with the ability to light up, were available on the steering wheel and were used to switch between the two different automation modes. In this study, only manual driving (SAE 0) and highly automated driving (SAE 4) were implemented. Participants operated a tablet-pc, connected to the processing unit of the vehicle via Bluetooth. The tablet-pc was a Google Nexus 7 (Android version 4.1, seven inches screen diagonal, resolution of 1200 x 1920 pixels and 323 ppi). The concept of linking the device to the automation is described by Lapoehn et al. (2015).

3.2 Scenario design

The scenario consisted of a curved three-lane motorway with a total length of 15 km. A roadwork section was placed at the end of the track. There, the right lane was closed by a barrier. The automation was not able to manage the situation and initiated a request for the driver to take over control. After taking over control the driver had to change to the mid-lane to avoid a collision. To ensure that every participant experienced the same environmental setting during the TOR, other vehicles on the road were slowing down until the mid-lane was not occupied and no vehicle was visible in the rear view mirror right before the TOR occurred. Participants started in the manual driving mode and were instructed to switch into the highly automated driving mode as soon as possible**.** 5 km before the roadwork area began the first road signs signaled the approaching roadwork area and the automation gradually decreased the speed from 120 km/h to 80 km/h**.** The automation limit began at the position of the first barrier on the outer left lane (see Figure 1). The driver had to take over the vehicle control prior to the automation limit and guide the vehicle manually through the roadwork. If the driver did not take over the control the vehicle performed a minimum risk maneuver (MRM). The MRM guided the vehicle to the emergency lane, brake to zero and started flashing the hazard lights. The simulation was stopped after passing the roadwork (or after initiation of MRM).

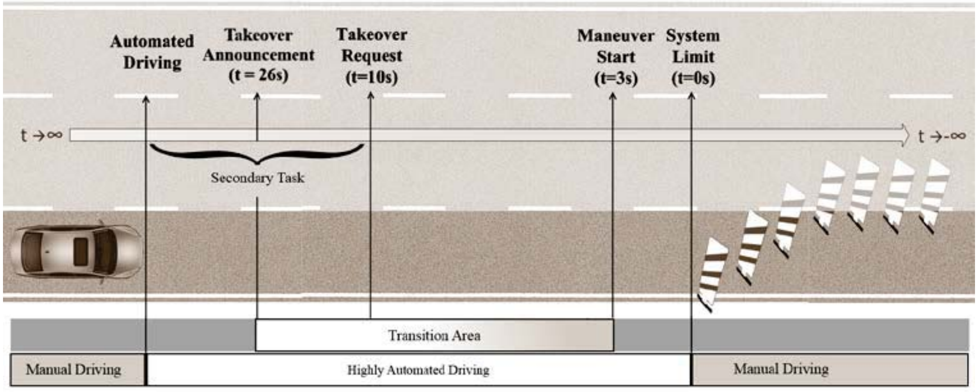

Figure 1: Consecutive stages of the interaction design when approaching the roadwork

3.3 Secondary task

To distract the driver in the described scenario, the *Surrogate Reference Task* **(**SuRT) (International Organization for Standardization, 2012) was used on the tablet-pc. The participants had to find and mark a pre-specified target within multiple similar distractors. The target in the used implementation was a circle with an increased diameter in relation to the other circles (distractors). The driver was instructed to work on the SuRT throughout the highly automated driving.

3.4 Tested HMI

The study tested three different interaction designs: The interaction design “TOR on HDD” presented a takeover request 10s prior the system limit in the HDD, only accompanied by an alert sound. The interaction design “TOR on Tablet” extended the “TOR on HDD” design by showing the takeover request on the tablet-pc in addition to the display on the HDD accompanied by the same alert tone. The message presented to the driver was a takeover request 10s prior to the automation limit (see Figure 2b). The display was locked for inputs and the media sound was muted. The same icon was shown on the HDD at the same time the alert was shown on the tablet-pc. The driver was instructed beforehand to put the tablet-pc at the co-driver’s seat in case of a TOR. To acknowledge the control transition from the vehicle to the driver, the driver had to press the “manual-driving” button on the steering wheel while the hands touched the steering wheel. In the interaction design “Info & TOR on Tablet” drivers were informed about an upcoming roadwork 26s prior to the automation reached its limits (see Figure 2a) in addition to the takeover request. This message was used to inform the driver timely about the pending takeover request and was presented on the nomadic device only. When this first message was displayed, the driver was not required to take over the vehicle control. The message in the center of the nomadic device closed after three seconds, while the upper bar remained on the screen indicating the distance to the system limit. The distance information was updated with 15 Hz. This message was followed by the takeover request described above for “TOR on tablet”.

a b

Figure 2: Early information about a pending takeover request due to roadworks (a) and the takeover request on the tablet-pc of the driver (b).

3.5 Study design

To measure differences between the three different design concepts (see section 3.4), a within-subject design was chosen. In every condition, drivers were instructed to switch into the highly automated driving mode and to operate the *SuRT* (see section 3.3) on a tablet-pc. In the condition “TOR on HDD” the TOR was shown 10s prior to the system limit on the HDD (see Table 1). Condition “TOR on Tablet” differs to “TOR on HDD” in the utilization of the tablet-pc as additional display for the TOR. In condition “Info & TOR on Tablet” additional information about the roadworks was presented 26s prior to the system limit via the tablet-pc (the timing for the additional information was based on the work of Werneke et al. 2014). The order of the conditions was permuted for each participant.

Medium:	**HDD**	**Tablet**	
Msg.- Type:	TOR (10s)	TOR(10s)	Info(26s)
TOR on HDD	√	-	-
TOR on Tablet	√	√	-
Info & TOR on Tablet	√	√	√

Table 1: The three conditions of the study testing different interaction designs [1].

3.6 Participants

A total of 33 participants participated in the simulator study. Participants were recruited from the DLR participant database. Participants’ age ranged from 18 to 64 years (*M=26*, *SD= 10.49*). 16 female and 17 male participated in this study. 75.8% of the participants indicated driving less than 10,000 km per year, but up to 5000 km on highways. Most of the participants (93.9%) also indicated having no or little experience with driver assistance systems, such as Adaptive Cruise Control (ACC).

[1] the condition “Info & TOR on HDD” was excluded, because the expected result is the same as in “Info & TOR on Tablet” minus the bias that is measured between the two conditions with the TOR only.

3.7 Dependent variables

To evaluate the hypotheses, driving data of the lateral / maximum acceleration, the takeover-time and the distance to the automation limit was recorded for every participant. The takeover-time denoted the remaining time to the automation limit based on the point in time when the driver took over vehicle control. The acceleration values are a measurement for the criticality and comfort of a lane change (Gold et al. 2013). Additionally, participants completed a questionnaire on the tablet-pc which queried the acceptance of the system. Acceptance ratings were based on the acceptance scale constructed by Van der Laan et. al (1997). The scale ranged from -2 (eg. useless) to +2 (eg. usefull). The parameters assessed by driving data along with the ratings from the questionnaire describe the takeover quality in this investigation, based on preceding research in this area (Radlmayr et al. 2014, Lorenz et al. 2014, Louw et al. 2015).

4 Results

Trials of participants experiencing technical problems or took over control of the vehicle before the TOR was triggered, were excluded from the data analysis. In total, 13 out of 99 trials had to be excluded from data analyses. Runs with triggered MRM were only relevant for the measurement of the “number of successful transitions” and excluded from other evaluations. For the comparison of the conditions, ANOVAs and χ^2 -tests were calculated. In all cases, the preconditions of the ANOVA were not fulfilled, a Greenhouse-Geisser correction was used. A Bonferroni correction was applied for post-hoc tests. No differences for gender or sequence effects were found for any of the dependent variables.

	Tor on HDD		Tor on Tablet		Info & Tor on Tablet	
nr. of successful transitions	-		-		-	
	S= 25	NS= 5	S= 28	NS= 2	S= 33	NS= 0
hands-on time	-		-		**+**	
	M= 6.80s	SD= 1.46	M= 6.92s	SD= 0.9	M= 17s	SD= 5.1
takeover time	-		**+**		**+**	
	M= 4.49s	SD= 1.67	M= 5.55s	SD= 1.01	M= 10.28s	SD= 4.71
lateral acceleration	-		-		**+**	
	M= 1.44 m/s^2	SD=1.14	M= 0.98 m/s^2	SD=0.54	M= 0.95 m/s^2	SD= 0.8
max. acceleration	-		-		**+**	
	M= 2.27 m/s^2	SD= 1.87	M=1.53 m/s^2	SD= 0.91	M= 1.23 m/s^2	SD= 0.83
usefulness	-		-		**+**	
	M= 0.80	SD= 0.65	M=0.93	SD= 0.61	M= 1.18	SD= 0.39
satisfaction	-		-		-	
	M= 1.07	SD= 0.77	M=1.17	SD= 0.67	M= 1.33	SD= 0.51

Table: results of the driving-data and acceptance-rate analysis. Bold marked + represent significant differences regarding other conditions as described below. S: successful, NS: not successful, M: mean, SD: standard deviation

A χ^2- test revealed no significant differences for *number of successful transitions* between the conditions. The drivers put their *hands on* the steering wheel significantly earlier in condition "Info & TOR on Tablet" than in the other two conditions ($p < .001$ each). For the *takeover time* a post-hoc comparison showed that participants had more time left before reaching the automation limit when driving in condition "Info & TOR on Tablet" than in condition "TOR on Tablet" ($p = .001$) and "TOR on HDD"($p < .001$). But also the differences between "TOR on Tablet" and "TOR on HDD" reached significance ($p = .022$). For the *mean lateral acceleration* a significant difference between condition "TOR on HDD" and "Info & TOR on Tablet" ($p = .018$) was found. For the *mean maximum acceleration*, a post-hoc test showed that "TOR on HDD" and "TOR on Tablet" did not differ significantly, but both differ significantly from condition "Info & TOR on Tablet" ($p = .002$ & $p = .045$). Regarding the acceptance, the system "Info & TOR on Tablet" was rated as significantly more useful than "TOR on HDD" $F(1,29) = 12.53$, $p < .05$, $r = .55$ and "TOR on Tablet" $F(1,29) = 10.56$, $p < .05$, $r = .51$. For the *satisfaction* scale no significant differences were found between the three systems $F(1.44, 41.38) = 2.97$, $p = .08$.

5 Discussion and Conclusion

In the near future, the role and tasks of the driver will change due to the availability of automated vehicles. However, the driver will still be the fall-back in specific situations. The proposed concept showed how personal nomadic devices can be integrated as additional interface to support the driver in taking over control in these situations. The first hypothesis of this work was that presenting the takeover request on a nomadic device increases the takeover quality, compared to showing it in the head-down display only. The hypothesis was confirmed by significantly higher takeover-times (see comparison "TOR on HDD" vs "TOR on Tablet"). For the second hypothesis, the condition with additional early information on the tablet with the condition, where the device was used for the takeover request only ("Info & TOR on Tablet" vs. "TOR on Tablet") was compared. When drivers received information about an upcoming transition on the tablet, they started timely to prepare for the takeover. Consequentially, they rated the condition with the early information as most useful. This indicates that the tablet was indeed adapted and utilized as informational display for the vehicle activity. It appears that drivers understood the importance of monitoring the autonomous vehicle's activity and wanted to stay in the loop when the opportunity was offered. Further investigations regarding familiarization effects, other takeover situations and different time periods of highly automated driving have to be considered before the formulation of a recommendation for future systems are possible. However, the usage of the nomadic devices as additional interface to the automated vehicle improved the takeover behavior of the drivers. In future conditionally or highly automated vehicles, it has to be ensured that every driver is able to comprehend the takeover request and react appropriately to avoid that MRM are commonly triggered. Therefore, the modification of the HMI design has not come to an end yet. Some aspects showed to be not intuitive ascertainable for some participants which resulted in unsuccessful or delayed transitions. To further improve the system and choose between human-machine interaction concepts based on the behavior of the driver in the vehicle, the integration of driver state assessment will be necessary.

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