Evaluating a Smart Car Interface in Terms of Usability, User Experience and User Acceptance

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Although the automation of cars aims to facilitate driving, current systems still rely on the driver for handling critical driving situations. As long as fully automatic systems are not available, the driver has to be supported in the take-over maneuver. We thus propose an interface that relies on auditory and visual signals to support the take-over process. Our interface further provides assistance for driving in poor visibility conditions, such as bad weather or darkness, by highlighting other traffic participants and lane boundaries. An online evaluation of our interface with 22 participants indicates a good usability, user experience, and acceptance.

CCS Concepts: • **Human-centered computing → Empirical studies in interaction design**; *Empirical studies in visualization*; *Interface design prototyping*.

Additional Key Words and Phrases: Autonomated driving, Smart car interface, user study

Car Interface - Usability, User Experience and User Acceptance of a Human Machine Interface

1 INTRODUCTION

Automated driving has gained immense relevance due to continuous advancements in research and technological innovations. The reason for this push towards self-driving-cars should not come as a surprise, since everyone who is driving every day to work e.g., for hours at a time, can foresee the benefits of a stress-free commute to their desired destination. Additionally, the time gained by not having to keep an eye on the road could be used for other work-related tasks or even relaxing activities. As it stands now, however, fully self-driving cars cannot yet be made available for the public for various safety, technological, legislative and ethical reasons.

The Society for Automotive Engineers (SAE) [18] created the SAE J3016 standard, which defines six levels of automation for driving vehicles, expressing the range of automation in vehicles in road traffic. The spectrum of automation starts at level 0, which describes no automation whatsoever. Levels 1 and 2 express assisted driving and partial automation, respectively. In levels 3 and 4, the the automated vehicle takes over more driving tasks, whereby the intensity of and reliance on automation rises from level 3 to 4. Level 5 describes the fully automated mode of the vehicle, in which the driver does not have to take over any further driving duties. Up to this point, advanced driving assistance systems (ADAS) are approved at levels 1 through 3. Researchers and developers are, therefore, trying to

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develop systems at these levels of automation. Their goal should be to create systems that account not only for safe and comfortable driving, but also to meet the acceptance of drivers and elicit the willingness to use such systems.

This task of creating systems that are safe for their agents and help create a positive relationship between humans and machines can be a difficult challenge. In the field of safety management, the classical approach of designing systems that are safe was often focused on failures within the system and were analyzing the system after the incident to prepare for future events. However, a a different approach emerged going by the term “Resilience Engineering”. Within this framework the focus primarily lies on strengths the system might have that can be used effectively to allow for adjustments prior to, during, or following unexpected events to support a resilient system that sustains its required functioning [7].

Based on prior research in the field of developing ADAS and the framework of resilience engineering, we have developed a prototype of a human-machine interface (HMI) including a head-up display (HUD) and evaluated its effectiveness based on usability, user experience, and user acceptance within three driving scenarios. In the following sections we will present related work on this topic. Subsequently, we will present the developed interface and present the methodology with which we evaluated the users’ response regarding usability, user acceptance and user experience when presented with this system. Results will be presented in section 4 and finally we will discuss the findings and their implications in section 5.

2 RELATED WORK

There is some research regarding users’ response to and acceptance of automated driving, since new technologies can only be implemented if they meet the acceptance of their users. For example, it has been shown that users’ familiarity with automated driving is low and that human drivers believe to be more capable in dealing with driving tasks [5]. Furthermore, it has been found that trust in automated cars is somewhat higher than familiarity with partially self-driving cars and that users’ assessment on safety was high [5]. While users indicated to prefer to be able to easily operate the system and wish to not have the prerequisite of prior knowledge or ability, they also showed reluctance to use self-driving cars [5]. In another study the acceptance and user experience of ADAS could be linked with specific SAE automation levels [17]. The study showed that user acceptance and user experience are highest in SAE levels of automation that already exist in cars today [17]. Prior use of ADAS along with demographic characteristics such as age and gender are influencing user acceptance and user experience [17]. Venkatesh, Morris & Davis [20] have developed a theory regarding the acceptance of new technologies, called the “Unified Theory of Acceptance and Use of Technology” (UTAUT). UTAUT intends to predict user intentions and the actual usage of new technology [20]. Arndt [1] analyzed requirements for the emergence of acceptance in ADAS and has also developed an acceptance model that allows to make predictions on acceptance of those systems.

Additionally, research on human-machine interaction in automated driving scenarios has also been important in order to assess contributing factors in the design of ADAS that meet usability and user experience needs and address safety concerns. HMIs are useful in take-over driving scenarios from the automated driving mode, since they can indicate the continuous status of the system with which drivers can stay up to date with all relevant information on the road ahead. Studies have tested visual, auditory, haptic or combinations of warning modal displays at SAE levels 3 and 4 within HMIs [12, 15, 16]. Petermeijer, De Winter & Bengler [14] could show that bimodal visual and auditory HMIs lead to shorter take-over reaction time than unimodal HMIs. Furthermore, information should also be displayed that states the reason for a take-over from the automated driving mode of the vehicle [13].

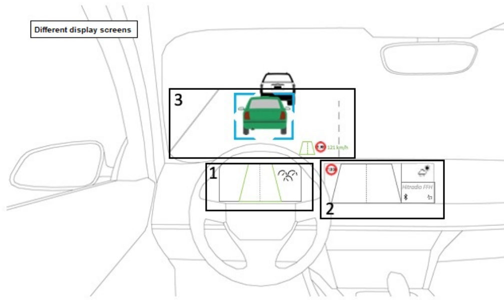

Fig. 1. Three different display screens within the car interface

Similar elements are included in a safety management framework going by the term "Resilience Engineering". As mentioned before, Resilience Engineering is the approach of designing systems that are resilient and have the ability to adjust to different circumstances [7]. This framework presents four elements that a system should have to achieve resiliency. These are, first, the ability to *respond* in regular and irregular situations, whereby present reactions are implemented to adjust performance. Second, *monitoring* should be the available ability of a system to oversee potential dangers and situations in the future. Third, *anticipating* developments, dangers and possibilities in the future is important to recognize potential consequences at an early stage. Finally, *learning* is the fourth element i.e. the ability to learn from positive and negative experiences and use this knowledge for future scenarios [7].

3 METHODOLOGY

We have developed a prototype of a car interface and tested its functions in an online survey study by acquiring data from users based on usability, user acceptance and user experience along with other variables.

3.1 Interface

We have developed different functions of an interface in an automated vehicle at SAE level 3 of automation. The interface includes three display screens which display signals and activities of their functions. First, a display behind the steering wheel. Second, a display in the center console and third, an HUD on the car windshield (see Figure 1).

The following three functions of the available display screens were tested. First, in order to better locate and detect other vehicles on the road ahead, especially in poor visibility conditions such as during snowing conditions or at night, the HUD was used. The transparent display on the car windshield outlines the vehicles in front of the car while in traffic and indicates the distance to those vehicles by the color of the outline. Ideally the color of the outline is blue and gradually turns to red, if the vehicle gets too close (see Figure 2).

Second, another function within the HUD, was the display of colored boundaries on the road lane ahead to counter poor visibility conditions and keep the driver from steering off the lane (see Figure 3).

Third, the final function was the warning signal to take over the driving tasks from the automated driving mode. In case the system notices a potential event on the road ahead that needs the take-over of the driving duties e.g. due to a traffic jam, it warns the driver to do so. The warning signal includes a "hands on the wheel"-symbol on all three displays screens and an auditory signal that intends to gain the driver's attention regarding the altered situation on the road. The signaling cues stop as soon as the driver takes over the driving duties (see Figure 4).

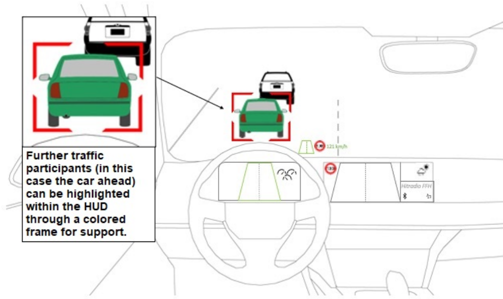

Fig. 2. Highlighting a vehicle on the road ahead through colored outline

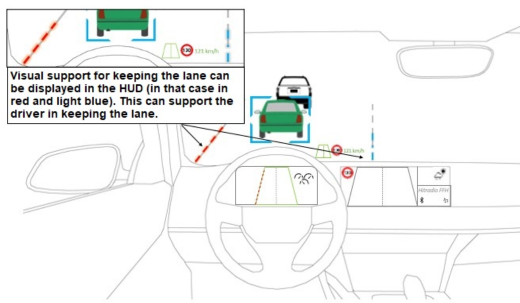

Fig. 3. Display of colored lane boundaries

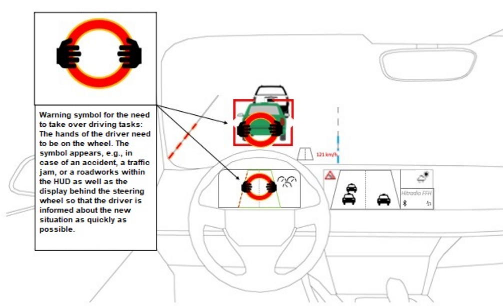

Fig. 4. Auditory and visual warning signals to indicate take-over of driving tasks

3.2 Procedure & Measuring Instruments

The study took place in an online survey format using the online survey tool "SoSci Survey" due to the contact restrictions of the COVID-19 pandemic. Subjects could participate from home, by opening a link that led them to the online survey. Within the online questionnaire, all three functions and driving scenarios of the car interface were presented through screenshots (see Figures 1 - 3) and were accompanied by a text description to explain the functions in more detail. Following all three driving scenarios, participants were asked to fill out questionnaires and answer questions for every presented interface function in the subsequent pages of the online survey.

The questionnaires and questions that were used included function-specific and function-unrelated questions. The System Usability Scale (SUS) [2] was used to derive a usability score for the relevant functions of the presented interface. The SUS is a robust and reliable evaluation instrument that allows for a subjective usability assessment of a system. The sum out of 10 items is multiplied by 2.5 to gain a SUS-score between 0 and 100 [2]. Moreover, the User Experience Questionnaire (UEQ) was used [9]. The UEQ measures the user experience with a system in the dimensions of *attractiveness*, *perspicuity*, *efficiency*, *dependability*, *stimulation* and *novelty* through 26 bipolar items. For the sake of consistency, we applied a 5-point Likert scale for the UEQ. Additionally, to assess the acceptance of our presented three functions in the interface, the “Unified Theory of Acceptance and Use of Technology” (UTAUT) was used [20]. The UTAUT aims to explain user intentions and subsequent actual usage behavior (dependent variables) and includes four independent variables, namely *performance expectancy*, *effort expectancy*, *social influence* and *facilitating conditions*. Performance expectancy, effort expectancy and social influence determine user intentions and usage behavior and facilitating conditions determine usage behavior only [20].

Additionally, following these questions on usability, user experience and user acceptance, we included function-unrelated questions. In order to evaluate the technological affinity of the users, the affinity for technology interaction (ATI)-scale was used [6]. The ATI-scale includes nine items which aim to measure the user’s tendency to actively and intensively interact with technology or the lack thereof. The ATI scale can therefore assess user personalities which can be used to identify user characteristics and incorporate that in research on technology interaction. Finally, demographic data was collected such as age, gender, educational background and occupation. Additionally, questions about driving behavior or rather driving frequency were posed. The questions about the driving behavior of the participants consist of 7 bipolar items and were developed in various studies [3, 4, 8, 11, 19].

3.3 Sample

A total of 22 people were recruited at a university by contacting students via mailing lists and an online university learning platform. Additionally, course credit was given for their participation. Of these, the majority were between 20 and 24 years old, 16 (72.7 %) identified as female, and 6 (27.3 %) as male. The majority stated to have a high school diploma as highest form of education, while only one held a university degree. The majority of the sample were students, while 15 were studying psychology and 6 were studying cognitive science. One participant did not provide a definitive occupation or study field. The prerequisite of the study was the possession of a driver’s license, which was predominantly held for at least three years. Driving experience was also queried with questions about frequency of driving as a driver, access to a car, and estimated kilometers driven per year. Only one person reported driving daily. "Less than 1 time a month" was the most common response with seven responses (31.8 %), followed by "several times a week" with 6 notions. Six participants owned a car, 11 shared a car, one person used the services of a car sharing company and three people stated that they do not have a car available. The number of kilometers driven per year is less than 5,000 kilometers per year for the majority (14 notions). Our participants reported a slightly above average affinity for technology, as indicated by the Affinity for Technology Interaction Scale (1=low affinity, 5=high affinity). The *mean* value across our sample was 3.11 with an *SD* of 0.67.

Table 1. System Usability Scores for the 3 Car Interface Functions

Function 1			Function 2			Function 3		
Mean	*SD*	SUS-Score	*Mean*	*SD*	SUS-Score	*Mean*	*SD*	SUS-Score
2.98	0.44	74.45	3.45	0.54	86.6	3.27	0.61	81.87

Table 2. Descriptive Values of the UTAUT-Scale for all 3 Car Interface Funtions

	Function 1		Function 2		Function 3	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
Performance expectancy	3.60	0.90	4.35	0.88	3.95	1.03
Effort expectancy	4.42	0.73	4.58	0.51	4.50	0.56
Attitude toward using technology	3.45	0.91	3.83	0.78	3.61	0.99
Social influence	3.24	0.66	3.86	0.80	3.69	1.02
Facilitating conditions	3.35	0.47	3.67	0.55	3.52	0.56
Self-efficacy	3.05	1.09	3.61	1.16	3.26	1.33
Anxiety	2.64	1.18	1.82	0.80	2.43	1.10
Behavioral intention to use the system	3.23	0.99	4.20	0.95	3.64	1.15

4 RESULTS

In this section, we report the quantitative results regarding usability, user experience, and acceptance, as well as qualitative feedback captured through free text answers.

4.1 Quantitative Results

The analysis of the individual scales was done per function of the car interface, so that there are three values each, which can be compared. For the usability of the car interface, the System Usability Scale (SUS) collected a score of each function, which is formed by multiplying the sum of the 10 items by 2.5, thus indicating a SUS score out of 100. Table 1 shows the descriptive values and SUS-Scores for each of the three car interface functions. Function 1 (highlighting other road users) received a score of 74.45 points, Function 2 (highlighting lane boundaries) 86.6 points, and Function 3 (indicating take-over of driving tasks) 81.87 points. Thus, Function 2, the HUD lane boundary display, received the highest score followed by the visual and auditory signals to return responsibility to the driver (Function 3). Both SUS scores indicate an above average usability [10]. With a value of 74.45, Function 1 constitutes the lowest SUS score of the 3 interface functions to be evaluated.

The values for user experience were collected through the UEQ-questionnaire[1]. Function 1 had a mean of 3.08 (*SD* = 0.14). Function 2 had a mean of 3.06 (*SD* = 0.13) and function 3 had a mean of 3.01 (*SD* = 0.12). Using the UTAUT model for user acceptance of the interface, descriptive values were calculated for all of the scales within the UTAUT model and for an additional descriptive value of behavioral intention to use the system [2] (see Table 2). The behavioral intention to use Function 2 (Display of colored lane boundaries) had a mean of 4.20 (*SD* = 0.95) and constituted the highest *mean* value out of three functions of the car interfaces presented. Functions 1 and 3 were rated at a *mean* of 3.23 (*SD* = 0.99) and 3.64 (*SD* = 1.15) respectively for behavioral intention to use the system.

[1]Please note that we used a 5-point Likert scale for the UEQ, with 1 indicating bad and 5 good user experience.
[2]Again, a a 5-point Likert scale was used.

4.2 Qualitative Results

For each function, participants could indicate through free text what they liked, what they did not like and what suggestions for improvement they might have. These open-ended responses were clustered and sorted by frequency.

For Function 1 (highlighting other road users) there were ten entries. The display of other traffic participants was perceived as positive in the presented function. It was noted five times that it could be easier to maintain the needed distance and that this function can be especially helpful in poor visibility conditions. Four people found the color coding, indicating the proximity of other road users, useful or assume that fewer accidents would occur due to the increase in attention through the use of the function. Distraction from real road events by looking at the HUD was mentioned eight times and was evaluated as a negative factor. The disturbance or distraction was also addressed in other mentions. For example, the display could be too large and other things could be overlooked as a result (3 mentions), or if the display was constantly on, this function could be perceived as disturbing (2 mentions). Three participants rated the color scheme as not ideal. The color red could cause stress, although, e.g. in a traffic jam, there is no high risk. By concentrating on other vehicles, other things important for safe driving could be overlooked (2 mentions). Suggestions for improvement were the possibility to switch Function 1 off and on, depending on the driving distance (4 mentions). A different color scheme was suggested three times, e.g., a more subtle color scheme by using a more translucent gray. A different implementation of the information transfer, e.g. via vibration on the steering wheel with different intensity levels or by an auditory signal was suggested two times.

Function 2 (highlighting lane boundaries) is described as useful in lane keeping by 11 people, especially in low visibility conditions. Fewer accidents or dangerous situations are mentioned by 3 individuals, and 2 find the function especially useful when driving on the highway. Individuals note that the display does not take up too much space in the HUD, the warning is considered useful as well as the red coloring when exceeding the lane. It was noted once, that the function could not be used everywhere and that there could be incorrect displays for certain lines or that the display distracts from other objects on the road. When asked for suggestions for improvement, a different display of the function was mentioned three times. In addition, a warning tone when crossing the lane or the integration of cues for curves was suggested.

Function 3 (indicating take-over of driving tasks) has a visual and an auditory signal, which was noted as good by seven participants. It was rated as good by four people that the warning is clear, so that the signal can be grasped quickly. The quick elicitation of attention was mentioned four times. It was negatively noted that there was no guarantee that the system really works properly (4 mentions). Two times each it was mentioned that the driver could be frightened by the signals, in contrast to the fear that the signals could be overlooked. The fact that the system assumes that the driver wants to take back control when unintentionally touching the steering wheel, although this is not the case, was mentioned two times. Suggestions for improvement through the use of further cues for taking over driving responsibility were stated by five people. The auditory cue could be adapted to the wishes of the driver, e.g. by adjusting the volume.

5 DISCUSSION

The present study aimed to evaluate the usability, user experience and user acceptance of a car interface with three proposed functions (highlighting other road users, highlighting lane boundaries, indicating take-over) along with an evaluation of other variables, including the affinity to interact with new technologies. Users' opinions and suggestions on the car interface were also taken into account.

The findings suggest that the usability of the car interface is generally well-perceived by the users, while the function of the interface that indicates vehicles on the road ahead through visual outline and color-coded signals was rated lowest in usability. Auditory and visual signals that indicate to take over the driving duties from the automated driving mode (Function 3) and displaying the lane boundaries on the road (Function 2) were assessed as being highly usable, while the latter was the highest. Additionally, the users' experience of the presented car interface suggests to have a slightly above average response in terms of overall impression of the system, easiness to get familiar with the interface, its efficiency, dependability along with the stimulating factor and novelty aspect of the car interface in all three functions.

The users' response regarding their acceptance of the car interface indicates the willingness to use the system for all three functions. The display of lane boundaries in the HUD during poor visibility conditions seems to elicit the highest intention to use this function. The highlighting of cars ahead and the auditory and visual signaling to over-take driving tasks were also accepted by the users, with a similar rate.

Users' opinions and suggestions on the functions of the car interface point to predominantly positive responses. Overall, all three functions are associated with safer driving and are seen as supportive. Fears are associated with a possible distraction from road traffic. Suggestions for improvement concern the visualization of the signals in the HUD or the auditory signals. In the case of Function 3, which is used to alert drivers to resume driving responsibility, the mentions indicate that confidence in the technology is not always present. For example, fears are expressed that the signals might not be noticed or that it cannot be safely assumed that the system is providing the correct information.

In total, the findings of this study suggest that highlighting the lane boundaries in poor visibility conditions (Function 2) and the auditory and visual warning signal to take over driving duties (Function 3) are preferred in comparison to the highlighting of vehicles in traffic ahead. This evaluation could be due to the fact that drivers are already familiar with these functions and have not yet come across a function that highlights cars on the road ahead. Warning the driver to take over the driving tasks because of a critical situation could be viewed as more necessary than the highlighting of cars ahead. Additionally, the warning cues for a take-over situation are of short duration and the lane boundaries on the HUD do not seem to be that distracting or overly prevalent. A constant visual indicator on the car windshield, however, could be viewed as most invasive and distracting while driving. Based on this interpretation of the findings, we assume that drivers are more hesitant to use driving assistance systems that intend to assist them in driving tasks they already perform by themselves and do not find additional value in them. Also, functions that might distract the driver could be a relevant factor that prevents people from using them. Drivers seem to be more open with using driving assistance systems that intend to aid them with new functions of the system, i.e. the take-over of the steering wheel from the automated driving mode.

5.1 Limitations and Future Work

Our study suffers from several limitations: First, we used a survey study design relying on screenshots and text explanations. Thus, our results only serve as a first step towards understanding users' perceptions of the considered functions and further research is needed that allows participants to actually interact with the prototype. We plan to investigate this in a laboratory setting as soon as the pandemic situation allows for this kind of study. Further research is also needed to test how users would respond to the proposed functions of the car interface after using them in a real life scenario on the road. Second, our sample is rather small and skewed towards young students. Future research should consider a more heterogeneous sample. Third, we only investigated three specific functions of the smart car interface. It should thus be evaluated whether the findings of this study also apply to other functions, which drivers currently perform without assistance.

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