Increasing Trust in Fully Automated Driving: Route Indication on an Augmented Reality Head-up Display

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ABSTRACT

Cooperative, intelligent transportation systems (C-ITSs) have capabilities far beyond what human drivers can achieve. For instance, intelligent systems that plan the exact trajectories of vehicles could increase throughput at intersections, allowing vehicles to pass with high speed and without any need for traffic lights. It is imaginable that C-ITS will manage traffic in fully automated driving (FAD). However, the unpredictable behavior patterns of the automated vehicle (AV) are also likely to make the occupants feel uncomfortable. FAD systems operate based on a vast amount of information. As this information is potentially invisible to individuals, the question is if users trust FAD systems. We hypothesize that users experiencing such scenarios would demand system feedback to anticipate upcoming system decisions and maneuvers. Therefore, we evaluated five augmented reality (AR) user interface (UI) concepts aiming to increase system transparency in a user study ($N = 30$) in a driving simulation in virtual reality (VR). Our results support the assumption that feedback about the system state (in the form of route information) significantly increases trust in AVs. As trust is highly subjective, we propose to provide experience-based route visualization systems in FAD to meet individuals' needs.

CCS CONCEPTS

• **Human-centered computing** → *User studies*; **Mixed / augmented reality**.

KEYWORDS

fully automated driving, augmented reality, head-up displays, route indication, trust, human factors

ACM Reference Format:

Tamara von Sawitzky, Philipp Wintersberger, Andreas Riener, and Joseph L. Gabbard. 2019. Increasing Trust in Fully Automated Driving: Route Indication on an Augmented Reality Head-up Display. In *Proceedings of the 8th ACM International Symposium on Pervasive Displays (PerDis '19)*. ACM, New York, NY, USA, 7 pages. <https://doi.org/10.1145/3321335.3324947>

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PerDis '19, June 12–14, 2019, Palermo, Italy

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ACM ISBN 978-1-4503-6751-6/19/06...\$15.00

<https://doi.org/10.1145/3321335.3324947>

1 INTRODUCTION

Trust and acceptance by potential users are essential prerequisites for the success of AVs [17]. To exploit the full benefit of technology advances, drivers must trust the system's capabilities, in particular in highly safety-critical domains like road transport [23]. Visions of highly coordinated automated vehicles and C-ITSs describe scenarios that go far beyond what human drivers can achieve, due to collaborative sensing or artificial intelligence, AVs could achieve "superhuman" driving capabilities [22]. For instance, concepts propose future intersections without traffic lights, entered by multiple vehicles at the same time and with high speeds [20], coordinating collision-free passage through Car-to-everything (C2X) communication. We hypothesize that this will demand even higher trust from users.

Consequently, methods that can establish, increase, and calibrate trust in AVs, and C-ITSs technology must be found. A possible attempt is to increase system transparency by communicating "why-and-how" information [10], an approach that can take advantage of AR [25]. We hypothesize that in the future, while the level of automation [2] steadily increases, AR will be available on full-sized windshield displays (WSDs) [12] and head-mounted displays (HMDs; either glasses or contact lenses) [18], providing new opportunities for improved feedback. Thus, it is valid to ask how AR views can support the presentation of AV-based information.

We believe that it is important to investigate whether or not users are inclined to accept futuristic vehicle maneuvers and concepts for C-ITS applications (especially those that would be perceived as dangerous in human-controlled traffic), as otherwise, we might design future transportation systems against users' expectations. We are aware that even in FAD vehicles will not always be completely reliable and can still fail. However, this work focuses only on visualization concepts that can support passengers by grasping the vehicles' intentions and actions. As a result, we are interested in investigating users perception and feeling towards future road intersections controlled by C-ITS. To this end, this work examines how users perceive such scenarios, and if UI concepts communicating upcoming vehicle actions with directional cues on WSDs can increase trust towards AVs. Next to a baseline, we elaborated five UI concepts with varying detail in a user study in which participants experienced multiple fully automated drives in VR.

(1) *Baseline* (2) *Arrow* (3) *Map* (4) *World-fixed* (5) *Preview* (6) *Combination*

Figure 1: Overview of the *Baseline* and the five UI concepts displayed on a WSD: (2) *Arrow* (directional cues by arrows), (3) *Map* (a bird's-view representation of the intersection), (4) *World-fixed* (cues drawn as 3D overlay on the road), (5) *Preview* (*Map* with a 4s preview), and (6) *Combination* (combining *Map* and *World-fixed*).

2 RELATED WORK

According to Lee and See, trust in automation can be defined as "*the attitude that an agent will help achieve an individual's goals in a situation characterized by uncertainty and vulnerability*" [11]. Analytic, analogical and affective processes further build a "*relationship between the truster and the trustee*". Trust is a multidimensional

construct that can be investigated from a multitude of perspectives. For example, Marsh and Dibben proposed three layers of trust: dispositional trust (general attitudes towards trusting automated systems), situational trust (emerging from interaction), and learned trust (built when working with a system for longer periods) [14]. Especially in automated driving (AD), trust has become a highly

relevant topic in recent years, as the potential success of the technology cannot be guaranteed by technological advances alone [23]. When FAD becomes true, former drivers will completely hand over control of their vehicle to automated systems, whereas an increase in the "levels of automation" [2] also increases the complexity of AD functions (as well as the complexity of C-ITS). When there are only fully automated vehicles on the roads, concepts such as VANET [5], Internet of Vehicle (IoV) [1] and C-ITS will control dynamic traffic situations. At the moment we do not know when FAD will be fully realized, to what extent drivers are willing to hand over control of their vehicle, and which dimensions of trust are most important in this context [17]. Still, the realization of FAD depends crucially on technology acceptance [23]. To be able to reach high acceptance, users' trust levels have to be calibrated [16] to emerging and novel vehicle behavior associated with automation as well as the underlying automation principles. Although humans seem to trust AVs similarly as other human drivers, some users tend to refuse automation [24], or fear the loss of control [4].

Recent work has shown that AR is a suitable means to calibrate workload, improve on road safety, but also increase the driver's trust. To allow drivers to gain a deeper understanding of upcoming actions and maneuvers in FAD, we propose a method that leverages AR to overlay relevant information on a WSD. Tönnis et al. [21], for example, investigated the impact of overlaying AR visualizations in the form of a brake bar and the vehicles current path in the context of manual driving in a driving simulator. They discovered that the overlays support the driver and are not increasing the driver's workload. Recent studies have already addressed the impact of information visualization on automation trust and emphasized the utilization of AR-HUDs or WSDs [7, 25]. The prepared information can thereby be displayed in the drivers' line of sight. For example, Häuslschmidt et al. [7] compared three different visualization methods for route indication of the own vehicle driving on autopilot, a symbolic representation, a miniature world, and a chauffeur avatar on a HUD. They concluded that the proposed visualizations increased trust in AVs and suggested that future research should try to apply navigational cues on a WSD. Displaying supporting information on a HUD or WSD was also further investigated in the context of motorcyclist safety [6], over-take scenarios [13], and in situations of restricted visibility [25].

To sum up, most studies so far addressed the problem of indicating directional cues only for their vehicle. In this work, we investigate indicating directional cues not only for the own, but also for surrounding vehicles and their effect on trust in FAD. To the best of our knowledge, such an approach has not been evaluated in C-ITS application in highly dynamic traffic situations by now.

3 METHODOLOGY

In this work, we want to evaluate the impact of different visualizations of "why-and-how" information on user trust in FAD and C-ITS. We refined our visualization concepts in a previously conducted focus group discussion to assess our hypotheses.

3.1 Hypotheses

To investigate the following hypotheses, we applied a within-subjects design, in which each study participants is experiencing all UI concepts described below.

H1. Provision of system transparency (here in the form of UI visualization) can significantly increase trust in C-ITS applications.

H2. Presenting a preview of upcoming scenarios leads to higher levels of trust as compared to a real-time indication.

H3. Customization of "why-and-how" information is desired.

3.2 Concept

Six maneuver visualizations and a baseline condition were discussed and tested beforehand within a focus group. This discussion's purpose was to analyze the potential and drawbacks of differently proposed AR route visualizations. The study's base conditions are a reference condition (*Baseline*), in which no visualization is provided to help drivers anticipate the own and other vehicles' maneuvers, and conditions based on the three UI concepts described below, as well as combinations of the described concepts.

An already popular type of direction indication used by navigation systems are plain *Arrows*, see Figure 1 (2). Displaying directional information in real-time on a *Map* in birds-eye-perspective gives the driver-passenger an overview of all vehicles crossing the upcoming intersection. To distinguish the vehicles, the representations are color-coded (here, light blue for the own vehicle) and the vehicles' positions are displayed as a navigation arrow (own vehicle) and as filled circles (other traffic, see Figure 1 (3)). The *World-fixed* concept represents routes of all vehicles as an overlay on top of the road as visible in Figure 1 (5). This kind of representation is also used in video games to point players the way, usually only indicating the route of the own player. The underlying idea of concept *Preview*, an amended version of *Map* displaying information 10s before happening, is to give participants time to process the provided route information.

The results of the focus group discussion lead to the six concepts evaluated in the conducted user study. Apart from (1) the *Baseline*, (2) *Arrow*, (3) *Map*, and (4) *World-fixed* concepts, two modified concepts were used: (5) *Preview* with a reduced preview time of 4s, as 10s preview was perceived as too long, and (6) *Combination* combining *Preview* and *World-fixed*. Except for conditions containing a 4s *Preview*, all visualization appeared on the WSD 60 meters before entering the intersection.

4 STUDY SETUP AND EXECUTION

Just as simulation plays an important role in testing technical safety of AD functions of the future [19], VR-based testing may play an equally important role in understanding humans' attitude towards novel technology. In our virtual testbed, we integrated the previously introduced UI concepts displayed on a WSD.

4.1 Technical Setup

As both, fully automated vehicles and large WSDs, do not exist yet, we developed a VR driving simulation testbed in Unity 3D, displayed on an Oculus Rift VR-headset. The testbed allowed to

create an immersive driving environment suitable to investigate C-ITS controlled intersections. For a higher feeling of immersion, the experiment took place in a seat box equipped with a real car seat.

The driving scene consists of many straight 4-lane roads (two lanes per direction) that intersect each other at various points, allowing to pass through various routes. In randomized order, each route contained a junction with (1) incoming cross traffic from both sides, the ego vehicle is passing straight, (2) incoming traffic from all four sides, the ego vehicle making a left turn, (3) incoming traffic from all four sides, the ego vehicle performing a right turn, and (4) incoming traffic from all four sides, the ego vehicle passing straight. At each junction, five vehicles trafficked the intersection simultaneously. The vehicles' speed was set to 120 km/h and decelerated to 30 km/h for sharp turns. By design, all vehicles passed very close to each other, and only slight changes in their maneuvers would have resulted in an accident. The aim was to convey strange, stressful, but still (considering the potentials of AVs and C-ITSs), realistic situations that would be considered as dangerous in a manual driving context.

4.2 Procedure

First off, participants were provided with a consent form that included details about the experiment and completed a demographics questionnaire. They then sat down in the driving seat where they put on an Oculus Rift headset and adjusted it to fit comfortably. Participants then performed a familiarization drive (with no traffic) to get used to the VR driving experience and the headset. Successively, participants experienced six trips in randomized order (one for each UI concept, randomly paired with one of the six configured routes to minimize order effects). After each condition, and at the end of the experiment (duration roughly 50 minutes per subject), participants completed a set of subjective measures emphasized in the following.

4.3 Measurements

To gain insight into participants' impressions and the effect of the UI concepts proposed in this study, we used self-rated questionnaires

and semi-structured interviews, that are briefly introduced in the following. The participants were asked to rate the entire system, thus, the automation in combination with the visualization if there was any.

Questionnaires. For evaluation, we used three self-rating questionnaires: the Technology Acceptance Model (TAM) [3], the Trust Scale (TS) [15] and the "trust in automation questionnaire" proposed by Jian et al. [9] (JB). TAM is a useful model to ground research related to acceptance of AVs. For our study, we used the subscales *Perceived Ease Of Use*, *Attractiveness*, *Trust*, and *Intent*. TS is a scale with eight items addressing trust-dependent factors, such as functionality and reliability. JB measures mistrust (5 items) and trust (7 items) between humans and automation and is one of the most commonly used scales for assessing trust in automation [8].

Ranking and Semi-structured Interviews. After completion of the study, we asked each participant to rank the different experienced UI concepts on a 6-point Likert scale. We then interviewed them to better understand their preferred form of visualization as well as their reasoning.

4.4 Participants

A total of 30 participants aged 28.6 ± 8.19 took part in the study. They were either students or university staff, 20 participants were males and 10 females. The participants all held a valid driver's license. No data set had to be excluded due to simulation sickness.

5 RESULTS

All scales' internal consistency showed a sufficient Cronbach's Alpha (> 0.76), allowing to calculate scale values. To check for differences between conditions we used a Friedman ANOVA. Post-hoc analysis with Wilcoxon signed-rank test was conducted using an alpha-adjusted significance level of $\alpha = 0.003$ (for 15 combinations).

5.1 TAM and Trust Scales

Friedman ANOVA reported significant differences in the TAM subscales for *Perceived Ease of Use* ($\chi^2 = 15.092, p = 0.010$), *Attractiveness* ($\chi^2 = 21.328, p = 0.001$), and *Trust* ($\chi^2 = 26.331, p < 0.001$).

Table 1: Mean values of all conditions for the used scales TAM, TS and JB

Scales		Conditions						Significant Diff. ($p < 0.003$)
		Baseline	Arrow	Map	World-fixed	Preview	Combination	
TAM	<i>Perceived Ease Of Use</i>	4.72	5.89	4.31	5.27	4.83	4.69	A > [M, B]
	<i>Attractiveness</i>	3.56	5.26	4.04	5.20	4.94	4.72	[A, W, P] > B
	<i>Trust</i>	3.66	5.18	4.37	5.02	4.93	4.80	[A, W, P, C] > B
	<i>Intent</i>	3.67	4.93	3.63	4.47	4.47	4.30	-
TS	<i>Trust Scale</i>	4.12	5.33	4.42	5.00	5.13	5.08	[A, W, P] > B, P > M
JB	<i>Mistrust</i>	4.39	3.03	3.85	3.55	3.54	3.74	B > A
	<i>Trust</i>	3.91	5.06	4.20	4.78	4.75	4.79	A > [B, M]

Furthermore, there are significant differences for *Trust* assessed by TS ($\chi^2 = 27.001, p < 0.001$), and *Trust* ($\chi^2 = 15.840, p = 0.007$) and *Mistrust* ($\chi^2 = 18.947, p = 0.002$) assessed by JB.

Mean values of all subscales and conditions as well as significant differences are listed in Table 1.

Condition *Arrow* was perceived significantly *easier to use* than *Map* ($p < 0.001$) and *Baseline* ($p = 0.001$). Regarding *attractiveness* of the proposed systems, *Baseline* scored significantly poorer than *Arrow* ($p = 0.001$), *World-fixed* ($p = 0.001$) and *Preview* ($p < 0.0031$). *Trust* (TAM) was rated significantly lower for *Baseline* compared to *Arrow* ($p = 0.001$), *World-fixed* ($p = 0.001$), *Combination* ($p < 0.0031$) and *Preview* ($p < 0.003$). For TS trust in *Baseline* was evaluated significantly lower compared to *Arrow* ($p < 0.001$), *World-fixed* ($p < 0.0030$) and *Preview* ($p = 0.002$). Additionally trust in *Preview* was rated higher than trust in *Map* ($p < 0.001$). The JB trust scale revealed that mistrust in *Baseline* was significantly higher as in *Arrow* ($p < 0.001$), and trust was rated higher for *Arrow* than for *Map* ($p < 0.0030$) and *Baseline* ($p = 0.001$).

5.2 Ranking

The Friedman ANOVA ($\chi^2 = 33.447, p < 0.001$) shows a significant difference in the ratings. Results of Wilcoxon tests indicate that *Baseline* (mean = 2.00) was rated significantly worse than *Preview* (mean = 4.03, $p = 0.001$), *World-fixed* (mean = 4.43, $p < 0.001$) and *Arrow* (mean = 4.07, $p < 0.001$), further *Preview* was rated better as *Map* (mean = 3.07, $p < 0.0031$).

5.3 Interviews

After completion of the study, participants were interviewed about their perception of the UI concepts.

Map. Thirteen participants stated that it was very confusing to use *Map* since the participants had to concentrate on information on the *Map* and the vehicles on the road at the same time. Thus, they could not process the obtained information timely.

Preview. *Preview* was remarked positively by 8 participants as they were able to gain previous knowledge of upcoming maneuvers and were prepared for them. Some participants ($n=4$) noted that the preview time has to be longer to be able to process the information.

Arrow. One participant said that the *Arrow* visualization was already familiar as arrows are used by traditional navigation systems to indicate direction changes. It was noted that this type of AR route visualization provided sufficient information by enabling participants to know their route on the next intersection by only taking a glance.

Baseline. The *Baseline* drive, with no maneuver information provided, was often ($n=23$) said to be too surprising, and there was no indication if the system is still running. On the one hand, it was stated that it is preferable to have no information, so they would not overthink the whole situation as knowing about upcoming maneuvers would make them feel more scared, on the other hand, it was mentioned that no route information is also leading to overthinking due to missing information.

Combination. *Combination* was often referred to as the visualization with the biggest information overload ($n=7$).

World-fixed. Two participants noted that only highlighting the own route during the entire drive would be a welcomed improvement.

6 DISCUSSION

In the following, we discuss the obtained results in relation to the postulated hypotheses.

System Transparency Increases Trust. We hypothesized that by increasing system transparency, trust in AVs would be raised significantly (H1). Except for the real-time route indication for all vehicles on a *Map*, the used trust scales and the participants' rating of the UI concepts confirmed H1. Participants also expressed route information in FAD as necessary to prepare for turns physically and mitigate motion sickness. As the indication also reassured them that the AV is still running, a majority of participants felt much safer.

Trust in a Route Preview is Higher. In H2, we assumed that a preview of upcoming maneuvers could lead to higher trust than the real-time indication. Therefore, we compared *Map* and *Preview*. Both conditions represent the same information, but *Map* in real-time, and *Preview* 4s in advance. Significant differences were found for *Trust* in which *Map* was rated lower than *Preview*. In contrast to receiving real-time information which could not be processed fast enough and led to confusion, a timely preview gave participants time to process the information, and understand the upcoming situation beforehand. Some participants also recommended extending the preview time in *Preview* to have more time to process the obtained information. We conclude that by displaying the current situation in real-time on a *Map*, users do not gain additional value and are likely to feel overwhelmed as they cannot match the displayed vehicle routes on the map to the vehicles they see at the same time.

Customizable Route Indication is Preferred. We further proposed that displaying "why-and-how" information should be customizable to individuals' needs (H3). As trust in the vehicle and understanding of the upcoming situation can be very subjective, allowing for tailored information based on the individual's preferences would be reasonable. Some participants preferred no information at all as they would tend to overthink the situation. However, one participant stated he does not need any information since he would be busy with other things, such as reading or watching movies. Most of the participants said that they prefer information about their own and other vehicles' routes, but would like to adjust them to their needs. Participants further stated that information only about their vehicle would be sufficient since a large number of presented trajectories was too confusing. Customizing route information depending on the preferences and needs of the individual drivers seems reasonable and important for most users (H3).

Understanding vehicle behavior and establishing trust in FAD is a continuous learning process. By utilizing AR visualizations, trust may supposedly increase over time. As people process information differently, we propose an experience-based visualization system in which drivers can choose from a range of visualization types. Such a system could also be useful to prevent overtrust in lower levels of automation [23]. Displaying experience-based information

fits well with the model of personalized visualization and scalable information.

When drivers get to a level of high trust in FAD, they can deactivate the visualization and focus on other activities. Even though participants liked the idea of visualizations displayed in their (near) field of view, only the *World-fixed* visualization needed to be displayed on the WSD, as its information is overlaid on fixed positions of the road. The other four visualizations could potentially be placed on other in-vehicle displays (center console or on dashboard panels) since the provided information is still understandable. However, participants commented that having information spatially co-located to the real world scene was desirable. As some concepts already propose that future drivers may not sit and face the driving direction, it may be reasonable to investigate impacts on trust depending on different seating positions [22] and other kinds of displays.

6.1 Limitations and Future Work

Due to the lack of existing fully automated vehicles, we conducted our study in VR. Even though participants stated high immersion, i.e., felt like sitting in a real car, we assume that trust issues would be more powerful in a real driving environment. Further, we are well aware that concepts such as *World-fixed*, *Preview*, and *Combination*, are likely to confuse due to information overload with increasing traffic. For these cases, we would propose scalable information representation, e.g., not dependent on the size of the intersection or number of involved vehicles. We also assumed that AVs are always reliable which will be unlikely as, e.g., sensors can break, or the wireless C2X connection can be lost. Future research needs to investigate problems occurring in such cases to find ways to also convey system failure towards drivers. This future research is highly relevant, as visualized route information should increase trust, but prevent overreliance and distrust.

In future studies with different target groups (age, culture, technophilia), we expect to provide greater insights into the opinions of older people as well as unknown problems which could arise. Additionally, we plan to investigate other, potentially scalable UI concepts, that are suitable for higher traffic densities or other intersection types and scenarios, and plan additional experiments in a real driving simulator. Future studies should also address differences in trust and acceptance of navigational UI concepts between drivers with and without a driving license.

7 CONCLUSION

In this paper, we present the results of a user study in which we investigated the impact of UI concepts displaying AR-based route information on a WSD on users' trust in FAD with the application of C-ITS-supported automated traffic crossroads. We proposed five different AR visualization types for route indication on intersections which were compared to a *Baseline* drive with no visual information presented regarding the own or other vehicles' routes.

Most participants stated that they would prefer route information over no information at all (except for information shown in real-time). Our findings confirm that a preview of route information (animated position and course) was more trustworthy than the same visualization in real-time (H2) (comparing *Map* and *Preview*).

The timely preview allows to process the information before entering the intersection, whereas real-time information led to great confusion as information about maneuvers is obtained at the same time maneuvers are happening.

In summary, UI concepts visualizing route information of the own (and/or other vehicles) are a feasible approach to increase and calibrate trust in AD. Furthermore, a preview of oncoming scenarios could benefit the processing and understanding of the vehicles' behavior. As trust is highly subjective, we propose customizable and adaptable route information based on the driver's experience.

ACKNOWLEDGMENTS

We applied the SDC approach for the sequence of authors. This work is supported under the funding program Forschung an Fachhochschulen of the German Federal Ministry of Education and Research (BMBF), contract number 13FH7I01IA (SAFIR). It is further based upon work supported by the National Science Foundation under Award No. 1816721 and supported by a fellowship within the FITweltweit program of the German Academic Exchange Service (DAAD).

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