Fostering User Acceptance and Trust in Fully Automated Vehicles: Evaluating the Potential of Augmented Reality

Abstract

Lack of trust in or acceptance of technology are some of the fundamental problems that might prevent the dissemination of automated driving. Technological advances, such as augmented reality aids like full-sized windshield displays or AR contact lenses, could be of help to provide a better system understanding to the user. In this work, we picked up on the question of whether augmented reality assistance has the potential to increase user acceptance and trust by communicating system decisions (i.e., transparent system behavior). To prove our hypothesis, we conducted two driving simulator studies to investigate the benefit of scenario augmentation in fully automated driving—first in normal \( N = 26 \) and then in rearward viewing \( N = 18 \) direction. Quantitative results indicate that the augmentation of traffic objects/participants otherwise invisible (e.g., due to dense fog), or the presentation of upcoming driving maneuvers while sitting backwards, is a feasible approach to increase user acceptance and trust. Results are further backed by qualitative findings from semistructured interviews and UX curves (a method to retrospectively report experience over time). We conclude that the application of augmented reality, in particular with the emergence of more powerful, lightweight, or integrated devices, is a good opportunity with high potential for automated driving.

1 Introduction

Automated driving systems (ADS) and cooperative, intelligent, transportation systems (C-ITS) promise to revolutionize mobility as we are used to, and visions of tomorrow’s traffic do not have much in common with the reality present on our roads today. Inspired by network and control theory (Parent, 2007), decreased travel time and maximized throughput while eliminating headways, traffic lights, or signs (Au, Zhang, & Stone, 2015) are promised. Finally, also the fixed assigned directions of lanes will be abandoned (Riener & Ferscha, 2013). System performance, usually demonstrated in theory or by traffic simulation, depicts a nearly perfect image of a future without congestion, pollution, or accidents. However, although it is clear that the path towards this future depends on technological, societal, and legal transformations (Litman, 2014), crucial hurdles will emerge from human factors. Exploiting the full benefits of ADSs and C-ITSs demands a high (or even full) penetration of...
automated vehicles (Zhang, Au, & Stone, 2015), so human users must accept and trust safety-critical systems as they proverbially put their lives in the hands of computers (Wintersberger & Riener, 2016).

### 1.1 Trust Issues in Automated Driving

As of today, many people express skepticism towards the concept of automated driving. Reasons include loss of control (Kyriakidis, Happee, & de Winter, 2014), reduced pleasure (Frison, Wintersberger, Riener, & Schartmüller, 2017), but also lack of trust (Wintersberger, Frison, & Riener, 2016). Since fully automated level-5 vehicles (SAE, 2014) have not yet been developed, studies on trust in automated vehicles (AVs) either address lower levels of automation (Helldin, Falkman, Riveiro, & Davidsson, 2013), are purely survey-based (Rödel, Stadler, Meschtscherjakov, & Tscheligi, 2014), or just put automated vehicles in today’s traffic scenarios (Lee, Kim et al., 2016). However, reality will be more complex: A wide penetration of fully automated vehicles is not expected before 2050 (Bansal & Kockelman, 2017). Therefore, we should consider accompanying developments and technical advances to investigate trust in fully automated driving. To accept and trust level-5 vehicles as part of fully automated C-ITSs means more than just believing that a computer can operate a vehicle as good as a human driver. It will mean to trust traffic systems that have superhuman (Siegwart, Nourbakhsh, & Scaramuzza, 2011) capabilities (such as being able to operate on environmental information beyond the line of sight, maintain ultimately short headways, etc.) emerging from advances in communication, cooperation, or artificial intelligence. To increase user trust (and deal with distrust), a promising approach is to present why-and-how information (Koo et al., 2015), and make system decisions transparent to the user—a method that can take advantage of head-up-displays (HUD) or augmented reality (AR) techniques (Haeuslschmid, Von Buelow, Pfleging, & Butz, 2017).

The great potential of AR applications has already been shown in the context of manual driving, where the presentation of information in the driver’s line of sight can diminish distraction and improve driving performance (Smith, Streeter, Burnett, & Gabbard, 2015). Recent work shows examples of superimposing sensor information, such as radar-vision for improved forward collision warnings (Park, Lee, Yoon, & Kyong-Ho, 2015), displaying warning information (Hosseini, Bacara, & Linkamp, 2014), enhancing night vision for drivers (Hu, Zhou, & Li, 2015), or augmenting the brake way of vehicles to prevent crashes (Tangmanee & Teeravanrunyou, 2012). AR-HUDs currently are still facing problems like change blindness (Rensink, O’Regan, & Clark, 1997) or limited interaction space and field of view. However, future technologies such as optical see-through light-field displays (Lee, Changwon et al., 2016) could eliminate these issues, finally allowing “windshield displays” (WSDs, AR-HUDs that cover the entire windshield), AR glasses with a small form factor, or even AR contact lenses (Perlin, 2016).

### 1.2 Approach

The aim of our work is to demonstrate the applicability of AR for fostering trust and acceptance in fully automated driving under consideration of technological advances in both display and C-ITS technologies. For the context of our studies, we define acceptance according to the technology acceptance model (TAM) as a user’s intention to actually use a given system, determined by his/her “overall attitude towards using [it]” (Davis, 1993, p. 475). We further argue that trust, the “attitude that an agent will achieve an individual’s goals in a situation characterized by uncertainty and vulnerability” (Lee & See, 2004, p. 51), is an important determinant for acceptance of safety critical systems, such as automated vehicles. To prove our hypotheses, we conducted two driving simulator studies addressing potential level-5 driving scenarios (see Figure 1).

The first experiment evaluates whether augmenting other traffic objects, which are relevant for maneuver decisions, can foster trust in AVs with superhuman capabilities. More precisely, participants faced a trip in an automated vehicle that, due to advances in sensor fusion and C2X communication, is able to drive through dense
fog faster than the direct line of sight in manual driving would allow. To increase user trust, we simulated an artificial full-sized windshield display that can augment any object outside the vehicle.

In the second experiment, participants were sitting on a rotated seat, facing against the driving direction. Vehicle manufacturers (e.g., the Mercedes Benz F015 concept car) have already presented similar concepts. To communicate system decisions, participants were presented upcoming maneuvers on a head-mounted display (Microsoft HoloLens) that could be substituted in the future by enhanced AR glasses or contact lenses.

Both experiments are unique in a way that they holistically address the potential of AR to foster trust in and acceptance of future automated driving concepts. AR thereby shows advantages compared to classical in-vehicle displays: It provides the opportunity to highlight objects directly in the environment (what we call “implicit communication of system decisions”; see Section 3), head-mounted displays (HMDs) further allow perceiving visual feedback regardless of the head/body pose.

The rest of the article is structured as follows: In Section 2, we present relevant groundwork addressing user acceptance and trust, discuss them along the levels of automation, and highlight future C-ITS scenarios. In Section 3, we present the underlying concept shared by both of our experiments, while in Sections 4 and 5 the studies are introduced in detail. We conclude with a comprehensive discussion about our results and present an outlook.

2 Acceptance of and Trust in Automated Vehicle Technology

User acceptance is one of the critical factors determining whether or not information systems succeed or fail (Davis, 1993). Especially the success of automated driving is strongly dependent on a widespread acceptance in society. Davis (1993) postulated the Technology Acceptance Model (TAM), which is based on the Psychological Attitude Paradigm (Ajzen & Fishbein, 1975), linking between users’ beliefs, attitudes, and behaviors. Here, the perceived usefulness (PU) and ease of use (PEOU) of an external stimuli (or design feature) influence the general attitude towards using a system (ATT, affective response), which in turn leads to use or disuse (Intent, behavioral response). Over the years, TAM was extended with additional attributes, leading to TAM 2 (Venkatesh & Davis, 2000) and TAM 3 (Venkatesh, Morris, Davis, & Davis, 2003). Belanche, Casalo, and Carlos (2012) added another factor to the TAM: trust. By including uncertainty and vulnerability, they postulate a research model addressing the causality between trust, perceived usefulness, ease of use, attitude, and intention to use a system. Their
studies revealed that both attitude and intention to use significantly connect to trust, and thus they added trust as a third belief “able to explain the mechanisms” (Belanche, Casalo, & Carlos, 2012, p. 199) to the TAM framework.

Trust is a multidimensional construct built by analytic, analogical and affective processes (Lee & See, 2004). Marsh and Dibben (2003) categorized trust into three different layers: dispositional trust, representing someone’s general trust in automation (influenced by culture, gender, personality, etc.); situational trust, depending on context and interaction with the automation; and learned trust, which emerges from working with the system for a certain period. Hoff and Bashir (2015) further divided learned trust into initial learned trust (given by understanding, attitudes, or brand reputation) and dynamic learned trust (depending on a system’s performance and reliability). Ekman, Johansson, and Sochor (2016, p. 4) summarized the three main components of trust: “trust is built on the possibility to observe the system’s behavior (performance), understand the intended use of the system (purpose), as well as understand how it makes decisions (process).” They further identified 11 key factors that affect trust: feedback, error information, uncertainty information, why-and-how information, training, common goals, adaptive information, anthropomorphism, customization, expert/reputable, and mental models.

However, it is not enough to trust and use AVs—to responsibly operate safety critical systems, one must trust them appropriately and use them properly. Trust research thereby provides principles for safe operation by introducing the terms use, disuse, and misuse ( Parasuraman & Riley, 1997). While use reflects proper interaction, misuse stands for use under wrong circumstances, and disuse finally means not using the automation at all. Both disuse and misuse can be the result of trust issues ( distrust and, respectively, overtrust) and automated systems should aim to foster use and prevent disuse/misuse. This process, also called “calibration of trust” (Muir, 1987, p. 535), should eliminate wrongly calibrated trust by education and retraining. In the following, we discuss trust issues in automated driving along the six levels of automation as introduced by SAE (2014).

### 2.1 Human Driver Monitors the Driving Environment (Levels 0–2)

Both distrust and overtrust can be relevant barriers for the success of automated vehicle technology; however, we expect changing priorities with increasing levels of automation. Dickie and Boyle (2009) showed that many users of adaptive cruise control (ACC) face overtrust and use these systems in circumstances they were not designed for (e.g., road with high curvature, etc.). Further on, the first known fatality in automated driving (Tesla Accident, May 2016) is suspected to be a result of overtrust. This presumption indicates that overtrust is a crucial problem for automated vehicles upon level-3—as long as the human is responsible for monitoring, systems must deal with misuse emerging from overtrust or limited knowledge about system boundaries.

### 2.2 ADS Monitors the Driving Environment (Levels 3–5)

In higher levels of automation, overtrust will become less safety critical since the vehicle itself will be able to reach the minimal risk condition. Still, a special case is level-3 (conditional automation), where the driver is not required to monitor the vehicle but must be able to take over control on short notice. Here, appropriately calibrated trust will be a key issue to guarantee a safe collaboration between the driver and the vehicle, as overtrust could lead to delayed reactions (Hellman, Falkman, Riveiro, & Davidsson, 2013). As soon as sophisticated fully automated driving systems become available, distrust will become the more important trust issue. According to recent publications, level-4 capabilities are expected to be implemented in 24.8% (pessimistic guess) to 87.2% (optimistic guess) of all vehicles in 2045 (Bansal & Kockelman, 2017) at the earliest. At the latest when large numbers of level-5 vehicles are penetrating the markets, users must quickly be convinced of the
technology to exploit the benefit of C-ITS systems and trust them in various potentially ambiguous situations, such as:

2.2.1 Platooning. Multiple vehicles build up a platoon to reduce fuel consumption and increase throughput (Kamali, Dennis, McAree, Fisher, & Veres, 2017), and thus the headway to the preceding vehicle is much smaller than what can be called “safe” in manual driving.

2.2.2 Dynamic Lane Reversal. To maximize throughput, driving lanes can be dynamically assigned to different directions by C-ITS (Riener & Ferscha, 2013). Such dynamic adaptations could be perceived as dangerous and must be properly communicated to the user.

2.2.3 Intersection Management. Traditional traffic lights might disappear at future intersections that dynamically open corridors to vehicles. Such junctions are characterized by small gaps, multiple open directions, and speeds higher than in manual driving (Au, Zhang, & Stone, 2015).

2.2.4 Superhuman Driving. Due to the possibilities emerging from cooperative sensing (Hobert et al., 2015), vehicles can see parts of the environment that are invisible to human eyes. Thus, they could drive faster or overtake other vehicles in ambiguous situations (foggy environments, etc.).

2.2.5 Rotated Vehicle Seats. As the need for the driver to monitor the environment vanishes, rotating seats will allow to face backwards to interact with other occupants in a comfortable environment, or effectively work in office-like settings (Diels & Bos, 2016). However, drivers must trust the vehicle to behave correctly, as they have no longer a chance for quick intervention.

3 Concept and Research Questions

We conducted two user studies in a high-fidelity driving simulator (hexapod moving platform) addressing potentially ambiguous future automated driving concepts (see Figure 2).

In the first study, participants had to ride in a fully automated vehicle that performs multiple overtaking maneuvers in dense fog (superhuman driving). In the second experiment, participants were sitting on a rotated seat, facing backwards (backward driving). Thus, in both scenarios, important parts of the environment were invisible for participants, and we aimed for creating augmented reality aids that communicate system decisions, increase transparency, and let users anticipate upcoming driving maneuvers. Therefore, we designed a visualization strategy for each scenario and thereby distinguish between implicit and explicit communication of system decisions.

Traffic Augmentation. In contrast to already known methods for presenting why-and-how information that
explicitly explain vehicle behavior, we decided to just augment sensor data and highlight objects in the scene that are relevant for maneuver decisions. We call this method “implicit communication of system decisions,” as the actual system output (maneuver) is not presented to users, but they can “see what the vehicle sees” and thus anticipate upcoming actions. The justification, therefore, is that driving consists of plenty of maneuvers that can be initiated by arbitrary reasons—designing display information capable of explaining all these variations might be hard to achieve and could further overwhelm users. Augmenting relevant objects, on the other hand, is possible with a few symbols, while we believe most users can predict the vehicle’s behavior based on knowledge about the objects most relevant for a decision. To present the augmentation, we used an additional layer in the driving simulation software representing a full-size windshield display.

**Maneuver Augmentation.** In the backward driving scenario, augmenting objects directly in the environment makes no sense because of two reasons: first, due to the facing direction, the user can only see objects that have already been passed. Second, rotating the driver’s seat will usually happen to engage in other tasks, such as communicating with other occupants, working, etc., and thus the driver will not permanently be able to observe the environment through the rear window or an in-vehicle display. Consequently, we chose to present upcoming maneuvers (or more precisely: turns, stops, overtaking, etc.; see Figure 4) in form of indicators on a head-mounted display. We call this method “explicit communication,” as here system decisions are directly presented to users. For our experiment, we used the Microsoft HoloLens device.

Currently, it is not fully clear whether or not people will adopt AR glasses/contact lenses, but research highlights the importance of presenting useful concepts to ease adoption by potential customers (Koelle, Ali, Cobus, V., & Boll, 2017; Kalantari & Rauschnabel, 2018). We argue that our setting highlights such an advantage: in contrast to visualizations on an in-vehicle display, users can perceive visualizations in their peripheral vision, regardless of their head and body position during arbitrary secondary activities.

3.1 Measurements

To quantitatively evaluate the impact of the presented AR visualizations on user acceptance and trust at the subjective level, we used the TAM model with trust integration (see Figure 3) as proposed by Belanche, Casalo, and Carlos (2012). Additionally, we adapted the “Trust in Automation Questionnaire” that was used by Moeckli et al. (2015, p. 115) for the evaluation of adaptive cruise control. We removed four items that we believed to be not relevant for our experiment. Two questions were removed as they address manual intervention and interactions (as participants in our experiments were just passive observers), one question considering trust development in different circumstances, and another two questions have been merged into a single one (as we did not differ between subsystems and wanted to evaluate the AV as a whole). The resulting questionnaire consisting of eight items is further referred to as the “trust scale” (TS).

3.2 Research Question

By statistically evaluating the results of the subjective measurements addressing user acceptance and trust as described above in both user studies, we wanted to investigate our main research question:

RQ: Are augmented reality aids eligible to increase user acceptance and trust (in automated driving) by displaying the relevant information about environment (implicit communication) and behavior (explicit communication)?
4 Study 1: Traffic Augmentation in Superhuman Driving

In the first study, we evaluated the effect of augmented reality aids presented on a windshield display on trust in ambiguous driving scenarios. Participants were instructed to perform a trip with a fully automated vehicle on a straight rural road in dense fog (line of sight approximately 25 m). We argued that the vehicle can take advantage of future Lidar/Radar sensors, while getting information from the cars ahead via cooperative sensing (Hobert et al., 2015), and thus it can drive with a much higher speed than the situation would allow in manual driving. To provoke additional trust issues, the vehicle performed multiple overtaking maneuvers, where participants could not see whether overtaking was safely possible or not, as oncoming traffic was hidden by fog. Participants faced two conditions—they experienced the scenario once with augmentation (A), and once without any aids (B) in a between-subjects design (see Figure 4).

By statistical investigation of the employed measures, we investigated the following hypothesis:

H1.i: Augmenting sensory data by highlighting traffic objects on a windshield display significantly increases user acceptance and trust in automated driving systems.

4.1 Interaction Concept and Implementation

We used bounding boxes to highlight other, due to fog temporarily invisible (preceding and oncoming) vehicles in the scene. A triangle pointing downwards was used to highlight oncoming vehicles, a triangle pointing upwards preceding vehicles.

To encode additional information we implemented a color coding concept (see Figure 5): Oncoming vehicles were highlighted in green as long as the distance remaining allows for safe overtaking with a speed difference of 20 km/h without a collision, and red otherwise. Preceding vehicles used an additional color code inspired by...
Table 1: Overview of the Employed Subscales of TAM and TS Including Cronbach’s α, the Median, and the Mean (in parenthesis) Rating for the Conditions A (with Augmentation) and B (without Augmentation)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Nr. of Items</th>
<th>Cronbach’s α</th>
<th>Mdn (M) Cond. A</th>
<th>Mdn (M) Cond. B</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAM</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PU</td>
<td>3</td>
<td>.769</td>
<td>5 (4.22)</td>
<td>4 (3.08)</td>
</tr>
<tr>
<td>PEOU</td>
<td>3</td>
<td>.838</td>
<td>5 (5.01)</td>
<td>3 (3.88)</td>
</tr>
<tr>
<td>Trust</td>
<td>3</td>
<td>.907</td>
<td>4 (4.23)</td>
<td>3 (3.48)</td>
</tr>
<tr>
<td>ATT</td>
<td>3</td>
<td>.798</td>
<td>5 (5.06)</td>
<td>4 (4.18)</td>
</tr>
<tr>
<td>Intention</td>
<td>1</td>
<td>–</td>
<td>5 (4.31)</td>
<td>3 (3.38)</td>
</tr>
<tr>
<td>TS</td>
<td>8</td>
<td>.901</td>
<td>5 (4.59)</td>
<td>4 (3.86)</td>
</tr>
</tbody>
</table>

(Park, Lec, Yoon, & Kyong-Ho, 2015) with the colors green, yellow, orange, and red. The different colors used indicate the danger of a rear-end collision considering the time-to-collision (TTC) as present in typical Forward Collision Warning (FCW) systems (see Figure 4). The augmented-reality aids were presented on a transparent layer placed above the visual output of the driving simulation software.

Therefore, we directly rooted the positions of the vehicles in 3D space to a C#-Unity application that was responsible for showing the bounding boxes in the desired size and color.

4.2 Method

4.2.1 Participants. Twenty-six students and members of university staff voluntarily participated in the experiment. They were aged between 19 and 35 (11 female, 15 male, $M_{age} = 23.77, SD_{age} = 3.99$) and all hold a valid driver’s license. No participant had to be excluded because of missing data or simulator sickness.

4.2.2 Procedure. The ego vehicle drove with a speed of 70 km/h. In every scenario, we placed 8 preceding and 8 oncoming vehicles with a speed of 50 km/h each. The ego vehicle thus frequently overtook these vehicles to potentially stress participant’s trust levels. Each participant experienced both conditions (A, with; B, without augmentation) in randomized order, and was further instructed to look out of the window, perceive the environment and do not engage in side activities. After each condition, participants completed TAM and TS on a tablet computer. Afterwards, we asked participants to describe their experience in a short semi-structured interview. In total, every session took about 20 minutes (5 minutes for preparation, 5 minutes for each trip in conditions A and B, and another 5 minutes for the interview).

4.3 Results

4.3.1 Quantitative Evaluation. TAM and TS results were collected on a 7-point Likert scale. Before evaluation, we confirmed the validity of our results using Cronbach’s α (see Table 1). The medians of the evaluated TAM subscales (perceived usefulness PU, perceived ease of use PEOU, attitude towards using ATT, Intention to use, and Trust of the system) show that condition A (with augmentation) received better ratings than condition B in all scales.
This effect is also apparent when performing Wilcoxon test (reported as significant with $p < .05$). Perceived usefulness (PU) was significantly higher for condition A ($\text{Mdn} = 5$) than for B ($\text{Mdn} = 4, T = 78, p = .000, r = -.58$). Similarly, perceived ease of use (PEOU) showed a significant difference for condition A ($\text{Mdn} = 5$) compared to condition B ($\text{Mdn} = 4, T = 76, p = .000, r = -.60$). Also, driving with augmentation ($\text{Mdn} = 5$) was rated a higher attitude (ATT) than driving without visual assistance ($\text{Mdn} = 4, T = 77, p = .000, r = -.57$). Condition A ($\text{Mdn} = 5$) further received higher values for intention to use the system (condition B: $\text{Mdn} = 3, T = 26, p = .001, r = -.63$). Interestingly, Trust was the only TAM subscale with a median below 5 in condition A ($\text{Mdn} = 4$), what is, however, still significantly higher than condition B ($\text{Mdn} = 3, T = 76, p = .000, r = -.51$).

Considering the Trust Scale (TS), condition A ($\text{Mdn} = 5$) received significantly higher scores than condition B ($\text{Mdn} = 4, T = 206, p = .000, r = -.52$). To summarize, augmenting relevant traffic objects led to a statistically significant increase in all investigated scales of TAM and TS.

### 4.3.2 Qualitative Evaluation

Participants expressed their experiences and attitudes towards the system in a short semi-structured interview after the experiment. Nearly all participants stated trust issues to be highly relevant in the presented scenario and reported to have tense or even anxious feelings during the “blind” overtaking maneuvers when experiencing the scenario without augmentation (translated from German): “Driving without highlighting of traffic totally feared me,” or “due to the fog, you can never know if a vehicle is oncoming.” As expected, highlighting relevant traffic objects increased trust and acceptance and further allowed participants to comprehend the vehicle’s behavior: “In the driving scenario with additional augmentation of the surrounding traffic you know if there is a vehicle or not,” “I was able to see why the car is reacting and understand its actions.” Still, level-5 driving with all its consequences (relinquishing full vehicle control to the car) raised concerns. A participant stated: “indicating the oncoming and preceding vehicles conveys a feeling of control.” One also suggested that the “reduction or complete omission of the vehicle’s indication over time would be reasonable when other drivers or I are understanding the car’s action (of specific maneuvers) completely.”

### 4.4 Discussion

Consideration of TAM and TS results shows that augmenting traffic objects relevant for a driving scenario can increase user trust as well as other related acceptance parameters. This is confirmed by a statistically significant increase in all investigated subscales. Participants rated PU, PEOU, ATT, Intention, and Trust of the system (condition A) higher than in the control condition. In addition, the results of the TS, composed of eight trust-influencing factors, confirm the improvement. Subjects further stated that experiencing the scenario without augmentation led to anxious feelings or fear, while augmentation helped to comprehend the situation even when they (due to dense fog) could not see the objects themselves. It seems that when presenting why-and-how information, augmenting relevant objects (implicit communication of system decisions) is sufficient to explain upcoming driving actions as users become familiar with the consequences and can easily anticipate the vehicle’s behavior. Consequently, we accept our hypothesis H1.i: Augmenting sensory data by highlighting traffic objects on a WSD indeed increases user acceptance and trust in ADS.

### 5 Study 2: Maneuver Augmentation in Backward Driving

The second experiment addressed the concept of rotated drivers’ seats, which was already presented in multiple design concepts for automated vehicles. Since the immediate future of the traffic situation becomes invisible for the driver/passenger, upcoming turns and maneuvers cannot be anticipated and the resulting surprise effect might decrease acceptance, comfort and system trust. To cope with these issues, we presented
details about upcoming maneuvers on a HMD (Microsoft HoloLens). In contrast to the previous experiment, we believe presentation on a WSD not to fulfill the requirements of the driving situation—users will not necessarily look outside the rear window (or at an in-vehicle display) all the time, but we wanted them to perceive the upcoming maneuvers with any head or body position. To simulate such a situation, participants performed a Skype call that was interrupted by search tasks in an Oxford dictionary. To evaluate how a proper communication of upcoming maneuvers could look like, we evaluated two different types of visualization: arrows pointing in the perceived direction (condition P, arrows facing downwards) and arrows pointing in the driving direction (condition L, arrows facing upwards; see Figure 6 for a more detailed explanation). By comparison with the baseline condition (N, no visual feedback), we evaluated the following hypotheses:

H2.i: Presenting upcoming maneuvers significantly increases user acceptance and trust in automated driving systems when users sit facing backwards.

H2.ii: When sitting facing backwards, symbols depicting upcoming maneuvers as perceived from the perspective of the driver/passenger are significantly rated better than a representation of the real driving direction.

5.1 Interaction Concept and Implementation

We used different symbols to encode upcoming maneuvers that were presented in the peripheral region on the top right of the HMD. For our experiment we discriminated between four different symbols that we believed to be relevant for anticipating the immediate future of the driving situation—indicators for curves/turns in both directions, one symbol representing a stop or decrease of speed, and another one to indicate an upcoming overtaking or lane change maneuver. Upcoming maneuvers were announced 500 ms before execution to give users enough time to interpret the scenario (Kosinski, 2015).

5.2 Method

5.2.1 Participants. In total 18 participants (6 women, 12 men, $M_{\text{age}} = 24.8, SD_{\text{age}} = 4.84$), all students and university staff aged between 19 and 41 years, took part in our experiment. We recruited them via mailing lists, and all participated voluntarily without compensation. No participant had to be excluded due to technical problems or simulator sickness. In total 66% stated to be technology oriented; only 16% described themselves as not particularly interested in new technology. Thirty-eight percent of them liked the idea of possessing an automated vehicle, while 16% did not—all other participants did not reveal a preference.

5.2.2 Additional Materials. In addition to the measurements as utilized in both studies, we used the UX Curve (Kujala, Roto, Väänänen-Vainio-Mattila, & Sinnelä, 2011) method during the semistructured interview to evaluate participants’ user acceptance and trust in the overall system by exploring their user
Table 2: Overview of the Employed Subscales of TAM and TS Including Cronbach’s α, the Median Rating, and the Mean (in Parenthesis) for the Conditions L (Logical Direction), P (Perceived Direction), and N (Baseline)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Nr. Items</th>
<th>Cronbach’s α</th>
<th>Mdn (M) Cond. P</th>
<th>Mdn (M) Cond. L</th>
<th>Mdn (M) Cond. N</th>
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</thead>
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<tr>
<td>TAM</td>
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<td></td>
</tr>
<tr>
<td>PU</td>
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<td>.870</td>
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<td>3 (3.32)</td>
<td>4 (3.00)</td>
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<td>PEOU</td>
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<td>3 (2.47)</td>
</tr>
<tr>
<td>ATT</td>
<td>3</td>
<td>.922</td>
<td>4 (4.21)</td>
<td>3 (2.22)</td>
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<tr>
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<td>3 (2.68)</td>
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<td>TS</td>
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<td>.949</td>
<td>5 (4.16)</td>
<td>3 (3.68)</td>
<td>4 (3.08)</td>
</tr>
</tbody>
</table>

experience over time. Participants had to draw a line in a two-dimensional coordinate system in which the x-axis represents the timeline of each condition. Positive values at the y-axis represent a positive experience and vice versa. The emerging graph represents the experience over time for a specific condition. Thereby we focused on the relation between their user experience and trust in the overall system. Additionally, we utilized the simulator sickness questionnaire (SSQ) proposed by Kennedy et al. (1993), to evaluate if knowledge about upcoming maneuvers can reduce the effect of motion sickness.

5.2.3 Procedure. We used a within-subject, full-factorial design in randomized order. Each participant had to pass three drives in the simulator, experiencing each condition. Before entering the simulator, participants were equipped with the Microsoft HoloLens. After a short test of the functionality (correct orientation of the HMD for a correct field of view), they were instructed into the scenario (short explanation of the upcoming condition). During the drive, participants performed a Skype video call with the experimenter as additional visual/auditory task. A research assistant conducted the interview and tried to get additional insights into participants’ views on automated driving. We emphasize here, that the interview had no connection to the experiment itself (augmented reality, trust or rotated seats) and assessed other questions (such as “do you think driving in a train is similar to automated driving,” “do you own a vehicle, and if yes, which one,” etc.). In addition, participants periodically had to look for the meaning of specific words in an Oxford dictionary. Participants could thus not permanently concentrate on the driving situation (or focus on the environment) and had to switch between different tasks frequently. After each driving scenario, participants completed the questionnaires. At the end of the study, we conducted a semistructured interview, utilizing the UX curve, which should help subjects to describe their experience during all three conditions.

5.3 Results

5.3.1 Quantitative Evaluation. As in study 1, we used a 7-Point Likert to collect data for TAM and TS. Again, we can report acceptable values for the internal reliability of multi-item scales by calculating Cronbach’s α (see Table 2). The medians values for PU, PEOU, ATT, Intention, Trust and as well the trust scale (TS) are higher for maneuver augmentation in perceived direction (P) than in logical direction (L). For some scales, such as TS or TAM PU, the logical direction of
Figure 7. UX-Curves, drawn by participants describing their experience over time while exposed to the individual conditions.

Maneuver augmentation has even lower rates than no augmentation at all (N). Comparing condition P and N shows similar values for PU and ATT. PEOU, Intention, Trust, and TS values are rated better for condition P than for condition N.

Statistical analysis using Friedman’s ANOVA (as the data was not normally distributed) shows significant effects for all variables. We further applied Wilcoxon tests with Bonferroni correction using a significance level of \( p < .017 \), and report only significant effects, such as visible for perceived usefulness (PU), \( \chi^2(2) = 18.636, p = .000 \). Here we can report significant differences between conditions P and N \( (Z = −3.320, p = .003) \), and P and L \( (Z = −2.887, p = .012) \). Also for PEOU we can observe significant effects, \( \chi^2(2) = 17.152, p = .000 \), but here only a significant difference between P and N was found.

Also for Trust, only between N and P a statistically significant difference exists, \( \chi^2(2) = 19.563, p = .000 \) \( (Z = 3.300, p = .003) \). Concerning ATT, we can report a significant effect \( (\chi^2(2) = 9.542, p = .008) \), but the post-hoc tests do not reveal any significant differences between the conditions. For the intention to use a system, there is no significant effect at all, \( (\chi^2(2) = 2.909, p = 2.34) \).

Considering TS, we can observe a significant effect, \( \chi^2(2) = 70.240, p = .000 \), where Wilcoxon follow-up tests reveal differences between all conditions. Augmentation in the perceived direction (P) leads to significantly higher trust in the overall system than no augmentation \( (N, Z = −6425, p = .000) \), and augmentation in logical direction (L, \( Z = −3.340, p = .003 \)). Further, no augmentation (N) was rated significantly better than the logical direction (L, \( Z = 3.085, p = .006 \)).

The total scores of the simulator sickness questionnaire (SSQ), however, showed no significant differences between the three conditions P \( (M = 59.00, SD = 43.20) \), L \( (M = 70.43, SD = 48.19) \) and N \( (58.17, SD = 48.19) \).

5.3.2 Qualitative Evaluation. A structured analysis of semistructured interviews with respect to the UX-Curves drawn by participants confirms the results. Overall, condition P led to better experiences that are more heterogeneous (see Figure 7). In the following, we discuss interview statements of participants and relate them to the corresponding UX curve. Interview statements were translated from German to English.

In total 83.3\% \( (n = 15) \) reported positive experiences for condition P, compared to the conditions L \( (39.0\%, n = 7) \) and N \( (33.3\%, n = 6) \). Further, for condition P, 10 participants \( (55.6\%) \) stated that trust increased while using the system, 3 \( (16.7\%) \) reported a stable but positive experience, while only one participant emphasized his experience as negative (this participant also rated the other conditions L and N as continuously negative). Comparison of the gradients in the (positive) UX curves reveals, that in condition P, 60\% \( (n = 9) \) positively increase over time, 13\% \( (n = 2) \) remain stable, and 13\% \( (n = 2) \) are developing negatively. One curve thereby changed from the positive to the negative range, also one vice-versa. Participant P1 expressed that his trust was increasing from the moment when he recognized and understood the maneuver augmentations. Especially the indications of upcoming overtaking maneuvers helped him not to be “surprised by unexpected behavior” (P1).
Another participant (P2) described the experience during condition P as better, but because of a risky overtaking maneuver, his trust decreased. After some time, he stated his trust becoming stable again (but still staying in the negative range).

Having a detailed look at conditions L and N reveals that both have similar results. 38.9% \((n = 7)\) of the curves showed a positive change over time, for 38.9\% \((n = 7)\) remained stable, and for 16.7\% \((n = 3)\) the experience impaired. Gradients show that for all positive curves in condition L, 28.5\% \((n = 2)\) improved, while 57.1\% \((n = 4)\) stay at a certain level in the positive range. Further, three curves in condition L changed from a positive to a negative and even five from a negative to a positive experience.

L1 described his experience as “scary” from the beginning, but then his trust increased continuously during a learning process. He/she stated to “try to understand it first, and after a certain time, it became clear and then I also had a good experience” (L1). Others, such as L2, stated to become more and more “puzzled” by the system. He/she stated that even no augmentation would be better than condition L.

In condition N, 50\% \((n = 3)\) of experiences in the positive range further increased, another 50\% \((n = 3)\) remained stable. Only two participants stated that their experience changed from a negative to a positive one, but four reported a change from the positive to the negative range. Four curves continuously remained negative. For example, participant N2 described the experience without any visual aid as “strange from beginning to the end.” He/she emphasized that without any system feedback, he/she would never be able to trust an automated vehicle. Participant N1 reported a positive experience in the beginning, as he/she was excited to drive with an AV. After some unexpected situations (such as overtaking maneuvers or turns), his trust decreased. He stated his sense of balance to be troubled, which led to a dizzy feeling.

### 5.4 Discussion

Considering our hypothesis, we accept H2.i as presenting upcoming driving maneuvers to driver/passengers that sit facing rearwards indeed increases user acceptance and trust. Especially for scales addressing trust, such as TS and TAM trust, a statistically significant difference is visible—at least for one of the investigated visualization methods (condition P) that used aids oriented in the direction as perceived by participants. However, for some TAM scales (ATT, Intention) there was no significant difference between any of the conditions at all. Still, condition P received significantly higher scores than condition L in TAM PU and TS. Semi-structured interviews and UX curves confirmed the assumption that it is easier for passengers to interpret and anticipate upcoming maneuvers when indicators point in the direction as experienced, and we thus accept H2.ii. Of course, the advantage of condition P compared to condition L could be due to the mental effort needed to “rotate” the visualization to fit the driving direction. Maybe this advantage would diminish after a learning phase when exposed to condition L. However, participants emphasized condition P to be more intuitive from the beginning, and interview statements confirmed our initial assumption: facing backwards while driving with a fully automated vehicle raises concerns for some users. Beside the lack of trust that can emerge from the impossibility to monitor the vehicle behavior, some users also feared to suffer from motion sickness while driving. Our assumption that knowledge about upcoming maneuvers may reduce motion sickness was, at least by investigation of SSQ scores, not confirmed. However, this could also be an effect of the complex setup (the combination of moving-based driving simulator, HMD, permanent need to switch between activities), and should be addressed in future experiments.

### 6 Conclusion

In this article, we have presented the results of two studies addressing user acceptance and trust for future situations of fully automated driving. We have investigated two scenarios for level-5 vehicles that demand high levels of trust from potential users, such as superhuman driving (where vehicles benefit from cooperative sensing and can drive much faster than the direct line
of sight would allow in manual driving) and backward driving (where the driver/passenger sits in a rotated seat facing rearwards). In both experiments, we used augmented reality aids aiming to foster trust by increasing system transparency and communicating upcoming maneuvers. Statistical evaluation of results obtained from measurements targeting trust and acceptance (TAM and TS) resulted in significant improvements, and demonstrate the potential of the presented approach in both studies (see Figure 8). This was confirmed in additional qualitative statements given by study participants. In semistructured interviews, participants further expressed that negative feelings resulting from the loss of control in automated driving become more intense in situations where it becomes harder to anticipate system decisions and foresee vehicle behavior, like in the scenarios evaluated.

As soon as large numbers of fully automated vehicles are going to pervade into our traffic systems it will be highly important to implement means for fostering user acceptance and trust. To exploit the full benefit of automated vehicle and C-ITS technology a large ratio of AVs is essential, and thus skeptic drivers need to be convinced of the advantages. Therefore, augmented reality is an approach with high potential. Although some arguments for utilizing AR (information in the line of sight to follow the eyes-on-the-road mantra) in driving applications become obsolete in fully automated driving, there are many advantages.

World-fixed augmentation (as evaluated in Study 1) can use the real environment as display to highlight which objects in the surrounding are currently important for decisions of the automation. This method (implicit communication of system decisions) lets users quickly anticipate vehicle behavior from the spatial information encoded in the augmentation. In contrast to explicit communication of system decisions (such as symbolic representation), the approach can more easily be tailored to fit the needs of individual users and environments, and further allows to automatically extend to new, yet unknown driving situations. However, when letting users “see what the vehicle sees,” an important question remaining is, which and how (in terms of color coding, timing, etc.) objects need to be highlighted/augmented. Still, screen fixed augmentations as presented in Study 2 also have advantages—when presented on a HMD, they allow notifying the user independent of the viewing direction, further they could also be presented on classical in-vehicle displays that need less advanced display technology.

### 7 Limitations and Future Work

Studies about trust in automation are highly important considering the great potential of automated vehicle and C-ITS technology. The scenarios used within this article are just examples, but future visions of
Traffic systems show many other scenarios where users must trust technology in potentially ambiguous situations (such as listed in Section 2). All these concepts are eligible, but it will be essential to discuss these visions from a human factors perspective, as humans are more than just simple goods that do not care about how they are transported. Further, also the underlying relations between the theoretical constructs of user acceptance, user experience and trust need to be investigated in order to uncover possible inter-correlations. Since no fully automated vehicle have been developed yet, it is hard to draw conclusions on general acceptance.

Although we believe our results to be valid, there are some limitations. Both studies suffer from a relatively small sample size, and mainly young people from a technical university have been included. Future studies should re-evaluate the concepts with additional participants representing users of different age, education or cultural background. Further on, the presented studies only lay the groundwork for many important investigations. It must be evaluated which symbols and color coding has the most potential, and which maneuvers should be addressed, or how to successfully deal with motion sickness when users perform arbitrary activities while driving. Additionally, good timings for the presentations must be identified, and the temporal development of trust as well as personality traits of individuals must be considered. To support users in an optimal way, that is, build a personalized and experience-based support system, their individual preconditions (such as dispositional and learned trust, driving experience, etc.) should be considered, too. Finally, the concept should also be evaluated in other potentially ambiguous future automated driving scenarios, such as platooning, lane reversal, or dynamic intersection management.

Acknowledgments

This work is supported under the FH-Impuls program of the German Federal Ministry of Education and Research (BMBF) under Grant No. 13FH7I011A (SAFIR). We further acknowledge the help of our colleagues Thomas Kundinger, Andreas Riegler, and Clemens Schartmüller in the implementation of software components and the execution of the user study, and Julia Reibel for designing the maneuver augmentations.

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of the 5th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, 210–217.


