# Watch Your Vehicle Driving at the City: Interior HMI with Augmented Reality for Automated Driving

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## ABSTRACT

It is very likely that automated vehicles will have to operate in mixed traffic environments for a longer period in the future. To deploy highly automated vehicles (HAV) in urban mixed traffic, it is essential to be able to communicate externally with other human road users (drivers of non-automated vehicles, cyclists, pedestrians) and internally with the passenger of the HAV. Internal communication through an interior human machine interface (HMI) keeps the passenger informed about the HAV's automation state and actions, in order to build trust and enable a more comfortable ride experience. In this study, we explore augmented reality (AR) as part of an interior HMI for this purpose. We follow a user-centric approach with user research, prototyping, and user experience evaluation. Results suggest that the passengers of HAVs have specific information needs concerning surrounding traffic and the current driving situation. AR could help to serve this need, for instance by highlighting relevant objects in the driving scene.

## CCS CONCEPTS

• **Human-centered computing** → Human computer interaction (HCI); Interaction paradigms; Mixed / augmented reality; Human computer interaction (HCI); HCI design and evaluation methods; User studies.

## KEYWORDS

Augmented reality, highly automated driving, human-machine interaction, eye-gaze tracking

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## 1 INTRODUCTION

The advancement of automated driving technology from partially towards highly automated vehicles (HAV) raises issues for the human machine interaction (HMI) regarding the user's role changing from driver to passenger and the associated change in information needs. Focus group discussions and simulator experiments concluded that information needs are dependent on the level of automation. The demands mainly include status, transparency, comprehensibility, and predictability of system actions [3]. These demands closely relate to trust in automation [9, 10] and suggest that users request extensive information in the beginning but less information with growing experience [6]. Carsten and Martens [5] propose a set of design principles for in-vehicle HMI and review various state-of-the-art solutions. Most of the current research addresses L2 or L3 automation on highways. However, what about HAV in mixed urban traffic environments?

Within the framework of the German national research initiative @CITY [1], the consortium partners from industry and academia are researching potential HMI solutions for the internal communication with the driver or passenger [7, 8] and the external communication with other non-automated road users in the city. Bengler et al. [4] propose an HMI framework for automated driving and distinguish between five types of HMI: automation HMI (aHMI), vehicle HMI (vHMI), infotainment HMI (iHMI), external HMI (eHMI) and dynamic HMI (dHMI). In this contribution, we summarize all HMI types for the internal communication with the term "interior HMI".

Bosch explores the use of Augmented Reality (AR) for the interior HMI. AR has the potential to bring the driving scene outside the vehicle and additional requested information from the automation system closer together. Ideally, an AR display is integrated into the windshield to augment the real world directly [2, 11]. However, this approach comes with additional technical challenges and high costs for head position detection, eye-gaze tracking, transparent display, and projection technology. An AR head-up display (AR-HUD) needs a higher virtual image distance and a wider field of view compared to a conventional head-up display, resulting in increased installation space [12]. Moreover, recent vehicles are equipped with large displays or touchscreens (e.g. Tesla Model S, Byton M-Byte) to allow for new infotainment applications, thus drawing away the driver's attention from the windshield. For these reasons, we explored the idea of an AR solution on a touchscreen, as a central element to integrate the information from aHMI and iHMI at one place. The development of this initial idea follows a user-centric approach, starting with user research of the requirements. An AR-HMI prototype based on recorded videos has been developed and finally evaluated in a driving simulator experiment.

## 2 USER RESEARCH

In the first user survey, the goal was to examine the information demands and expectations of users in a HAV. The scenario presented to participants was a (privately owned or shared) HAV with SAE Level 4 automation [13] in an urban mixed traffic environment with the user placed in the driver seat.

### 2.1 Experimental Setup

User interviews were performed in a static driving simulator. A selection of eight short videos with urban traffic scenes was presented on a large screen in front of the test vehicle. Forty participants (N = 40, Female: 15, Male: 25) with an average age of 39.2 (SD = 9.9; Min = 23; Max= 64) were interviewed regarding their expectations towards the HAV behavior and their information needs in these specific situations. More specifically, the participants were asked the following questions after watching each of the video scenes: (1) How do you expect the HAV to behave in this situation? (2) What information would you like to get from your HAV in this situation? (3) How should the HAV present the information? (4) Would you intervene in this situation and how?

### 2.2 Findings

The participants often expected the HAV to behave compliant to the traffic rules, be defensive and considerate of other road users. In some cases with pedestrians, the answers regarding the expected HAV behavior were contradictory, ranging from driving on, driving slowly to stopping and waiting. E.g. at a roundabout with a crossing pedestrian, it seemed to be unclear who has the right of way. The participants demanded navigational information about the own route, changes of the route, turning announcements, but also more detailed information on lanes and trajectories. Very often, they requested information about the intention of the HAV, the current and next maneuvers as well as the recognition and intention of other road users. In addition, the participants wanted to know about the current state of the HAV and the predicted time when the human is expected to take over driving. Particularly in complex situations, e.g. blocked roads and deadlocks, participants requested information whether and how the HAV would cope with the situation or whether an intervention would be necessary. Generally, most participants expected information that is relevant to the current situation.

### 2.3 Discussion

The main findings are in line with other research studies on this topic. Beggiato et al. [3] suggest an interior HMI should communicate the following information: "1) status of the system, 2) degree of certainty that the automation is able to handle the current situation, 3) trip-related information such as distance/time driven, 4) current and planned maneuvers, 5) current speed and speed limits, and 6) oncoming critical situations such as construction zones." All of these aspects were relevant in our analysis of participant responses suggesting a consensus concerning information need. In contrast, we noted differences between participants regarding their expectations of the HAV's behavior, with some participants even changing their mind during the interview. This highlights a lack of common ground and experience in the interaction with HAVs, resulting in the need for an appropriate interior HMI. It is expected that there should be more information in the beginning, but reduced or even no information is necessary over time when trust in the HAV has been built up. Therefore, the amount and type of information should depend on the previous experience with the HAV and be configurable according to personal preferences.

## 3 AR-HMI PROTOTYPE

Based on the findings of the user survey, a prototype of the interior HMI with AR was developed. It addresses the following information needs: (1) Status information of the automation system, (2) Navigational route information, (3) Information on lanes and driving corridors with regard to the HAV's own trajectory, (4) Detected relevant objects and other road users, and (5) Intention of the HAV and information on upcoming maneuvers. The HMI can be controlled using a touchscreen. For pragmatic reasons we decided for a 15.6" touchscreen device in portrait format fitting into a vehicle cockpit at the position of the center stack. The interior HMI is divided into four interaction areas (Figure 1).

At the top, the HMI presents information on the actual automation status, the current maneuver, and the driving context (e.g. speed limits, traffic lights, right of way). The navigation area below displays route information, such as selected destination, arrival time, travel time, and distance to destination, information on traffic congestion, and a list of turns. In the central area, the user is able to switch between an augmented reality view of the current driving scene and a conventional map view of the route. The augmented reality view highlights relevant objects in the current driving scene superimposed on the camera image. Additional navigation and maneuver hints are displayed as augmented reality arrows. Finally, in the lower section, the user is provided with multimedia applications that offer users the possibility to listen to music or radio, make calls, write and read text messages or surf the Internet. If necessary, the user can enlarge this multimedia area and hide the augmented reality view.

## 4 EVALUATION

In the second part of the study, the AR-HMI prototype was evaluated from the user's point of view. The main objectives were the evaluation of the user experience (UX) and a data collection for the usage of the AR representation during a highly automated city trip. Various video sequences were recorded with a test vehicle on an inner-city circuit in Hildesheim with a length of 7.7 km for preparation of the AR-HMI prototype. The circuit covered a wide variety of urban traffic situations, in particular use cases in longitudinal traffic, roundabouts and intersections as well as driving on multi-lane roads and in traffic-restricted zones.


**Figure 1: User interface of the AR-HMI prototype with four interaction areas (automation state and driving context, navigation, AR view, and multimedia)**

## 4.1 Experimental Setup

The study was conducted in a static driving simulator at the Bosch site in Renningen with internal participants. The sample of participants (N = 14; Female: 6; Male: 8) has an average age of 36.6 years (SD = 10.7; Min = 23; Max= 56). Pre- and post-experimental questionnaires and the "think aloud" method during the test drive were used to subjectively assess the user experience. Additionally, eye-tracking glasses [14] collected data on participants' gaze behavior. Each session was also recorded on a video camera with a view of the participant, HMI, and driving scene. The evaluation procedure included three sections. (1) Before the test drive, the participants signed a declaration of participation and data protection and completed a survey questionnaire. The calibration of the eye-tracking glasses and a brief explanation of the AR-HMI prototype followed. A pre-experimental questionnaire then asked about the importance of individual information elements of the HMI. (2) The participants experienced the AR-HMI prototype during a simulated city trip of approx. 25 min. duration consisting of an edited sequence from the recorded video data. During the ride, the participants had the opportunity to use the prototype freely and they were asked to "think aloud". (3) In the post-experimental survey after the test drive, a reassessment for the importance of the information elements and a questionnaire on the user experience were completed. Finally, the participants rated five selected variants for the AR visualization.

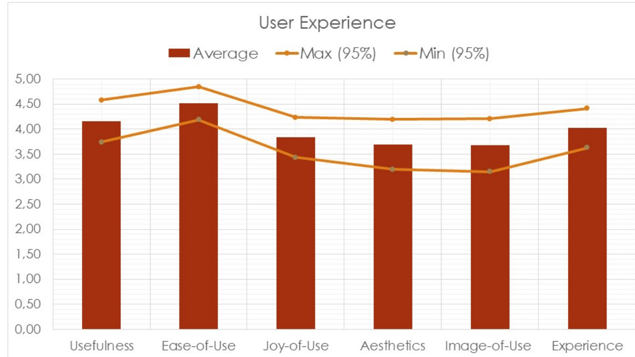


**Figure 2: User experience ratings**

## 4.2 Results

*4.2.1 USER EXPERIENCE.* We applied a Bosch-internal questionnaire for general user experience assessment in this study. Different dimensions of the user's experience were determined on a set of various statements about the product. The participants indicated their consent to the individual statements on a 5-point Likert scale from "disagree" (1) to "agree entirely" (5). Figure 2 shows the aggregated dimensions of usefulness, ease-of-use, joy-of-use, aesthetics, image-of-use and experience.

All results are in the "positive" range above 3.0. The best ratings received usefulness (avg. 4.16) and ease-of-use (avg. 4.52). Lower ratings for aesthetics (avg. 3.70) and image-of-use (avg. 3.68) were expected because the interface was based on a rather dated design from 2012.

*4.2.2 IMPORTANCE RATING.* The importance of the individual HMI elements was assessed on a 5-point Likert scale from "not important" (1) to "very important" (5). Figure 3 shows the averages of the evaluations for all participants before and after the test. After the test drive, information on traffic jams, important traffic signs on the current driving situation, and driving-relevant objects in the surrounding area scored as "rather important" or "very important". "Status of automation" showed the biggest decrease between pre- and post-experimental importance rating (-0.93). This is presumably so, because no take-over situations or other status changes were presented during the test drive.

*4.2.3 EYE GAZE BEHAVIOR.* Areas-of-Interest (AOI) were defined for the analysis of viewing directions and fixations (Figure 4). About 54% of the fixations refer to the street scene outside which was shown on the "windshield" in front of the vehicle. The AR view showing the same scene with augmented information received only 19.4% of fixations.

However, the individual distribution of fixations is highly participant-specific. While four participants (14, 12, 5, 3) almost exclusively looked at the outer street scene on the windshield, two participants (10, 6) mainly used the center console, with additional local differences in fixation distributions (e.g., AR view or multimedia area, Figure 5).

Between these extremes, the other participants show diverse proportions of fixations across all AOI. Similarly, in individual traffic situations we observed three different fixation behaviors: While

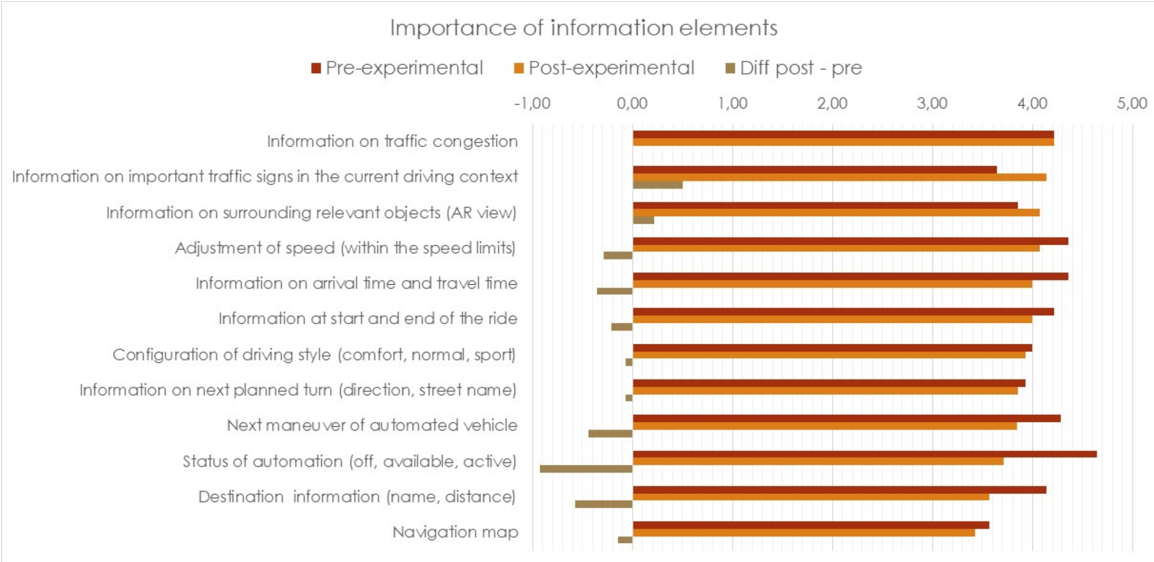


**Figure 3: Importance ratings before and after the test drive**

**Figure 4: Defined Areas of Interest (AOI) for street scene (pink), AR view (light blue), multimedia (violet), navigation (green), and driving context information (green-brown)**

some participants follow the driving scene only on the windshield or exclusively at the AR view on the touch screen, others constantly switch between outside street scene and AR view to match the information.

## 4.3 Discussion

The evaluation of the AR-HMI prototype included subjective ratings of user experience and importance as well as objective measurements of eye gaze behavior. For the AR view we followed the principle, that the highlighted objects must have direct influence on the vehicles driving behavior, thus avoiding a cluttered AR image on the touchscreen. High ratings for usefulness and ease-of-use suggest that the right information and relevant objects are presented in most cases. Sometimes the participants requested additional highlighting especially of nearby pedestrians. By analyzing the individual gaze behavior in these situations, we have validated the suggestions. However, we were not able to derive a general connection between the importance ratings and the eye gaze behavior from the data. The analysis of the gaze fixations yielded inter-individual differences regarding the AOIs and the gaze patterns in specific situations. Due to the small number of participants, a general classification of gaze behavior types would not be valid. We also note that the video-based AR-HMI prototype has some limitations compared to a real-world drive. The vehicle motion is missing and we did not provide 360{°} view for the participants. Therefore, the immersion may be more similar to watching a movie than riding a car. Although, we tried to capture real urban traffic situations on the videos instead of using a completely artificial simulator environment. Further research with a highly automated vehicle in real urban traffic would be necessary to validate the findings from this study.

# 5 CONCLUSIONS

The results of this study represent an initial evaluation of the developed concept for the interior HMI with augmented reality. The prototype with AR representation of the driving-relevant objects and additional information received good ratings in the user test, especially with regard to usefulness and ease-of-use. The study confirmed the importance of the information on the current driving context (driving-relevant objects, traffic signs, next maneuver). Eye tracking has proven to be a good tool for analyzing the usage behavior of the participants in different situations. The analysis of the eye tracking data revealed different patterns of viewing behavior, which indicates an individually differing use of the AR view. Therefore, the AR representation is probably not equally suitable for all users and should be configurable. The comments of the participants during the ride provide possibilities for improvement in the final demonstrator.

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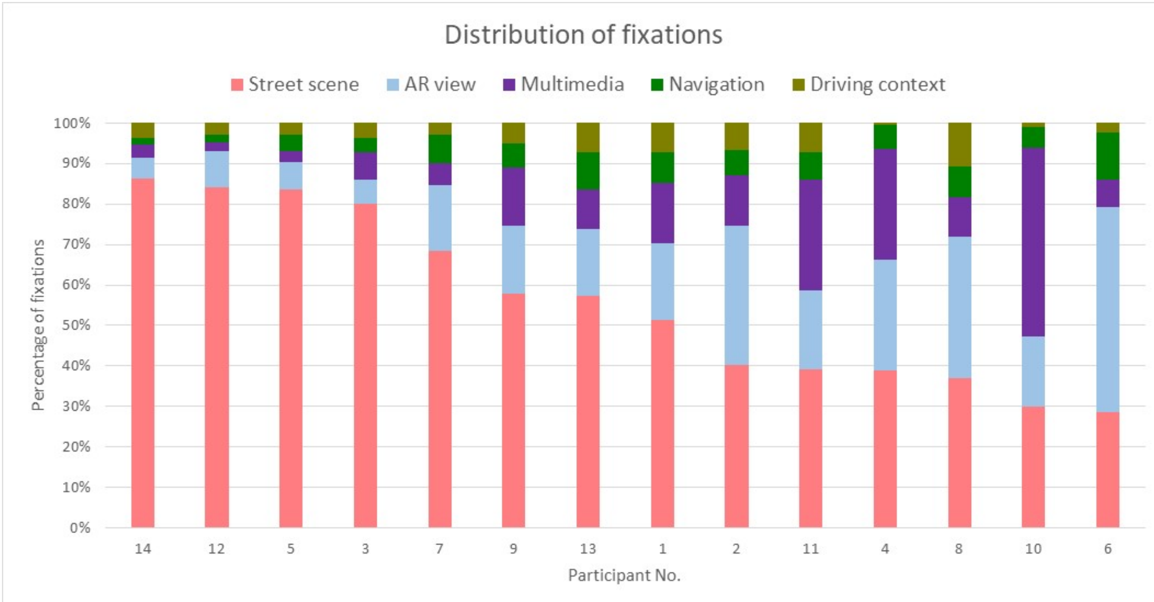


**Figure 5: Distribution of fixations for individual participants**

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