# Driving Cross-Reality Experiences for Future Mobility

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**ABSTRACT**

Autonomous vehicles at SAE level 5 will remove the necessity for a human driver, enabling passengers to engage in non-driving activities, like accessing infotainment services or conducting office tasks. Previous studies have explored the use of non-driving content on windshield displays; however, this approach has limitations due to restricted placement and visibility from just one viewpoint (resulting in perspective issues). To address this, our proposal involves separating the content from the windshield and employing the augmented reality space to visualize immersive content to passengers. In a virtual reality pilot study, we investigated how passengers positioned infotainment content windows, along with their specific characteristics, in the available space using VR controllers while seated in the front of a fully automated vehicle. The results show that particularly engaging video content was preferred to be placed on an AR windshield display, while other content placements were influenced by traditional vehicle interface designs.

**Index Terms:** H.5.2 [Information Interfaces and Presentation]: User Interfaces—Transitional Interfaces; I.6.3 [Simulation and Modeling]: Applications—Mixed Reality

## 1 INTRODUCTION

With the emergence of modern cars equipped with augmented reality (AR) head-up displays (HUDs), an increasing number of drivers are becoming acquainted with AR technology [9]. Currently, AR HUDs primarily offer driving-related information to assist drivers [5–7, 12, 17]. However, recent studies have explored the interaction with non-driving related tasks during travel in automated vehicles (AVs) [4, 13, 16].

Pfleging et al. [13] explored user preferences for non-driving related tasks (NDRTs) among drivers and passengers in manually operated vehicles. They also investigated expectations regarding NDRTs in higher automation levels (SAE level 3–5). Their findings revealed that people preferred engaging in activities such as listening to music or other audible content, conversing with passengers, surfing the internet, using mobile communication for texting or calling, and interacting with social media. Interestingly, the research also showed that when traveling in highly automated vehicles, people preferred not to perform any specific tasks, indicating a preference for relaxation and leisure during such journeys.

Riegler et al. [16] primarily focused on the visual presentations of NDRTs. Their user study involved participants adjusting the position, scale, opacity, and number of content windows on a 3D windshield display (WSD) within a virtual reality (VR) simulator. The goal of these studies on AR HUDs/WSDs was to address the need for front view displays that minimize driver distraction [3, 7, 10, 18, 20].

Increasingly, car manufacturers introduce an alternative approach to using AR content in a spatial context by employing AR glasses to display a digital console, allowing users (drivers or passengers) to interact with and control the vehicle system and infotainment content through a spatial interface or virtual screen projection [1, 2]. Fully automated vehicles offer new opportunities for the utilization of AR technology, enabling interactions with the surrounding space instead of being confined to a limited area. As the automotive industry introduces future concepts with AR glasses, it becomes essential to conduct studies focusing on the in-vehicle user experience with AR glasses. While previous studies have been limited to WSDs, the aim of our study is to **broaden the scope of in-vehicle infotainment through an AR spatial interface**. Thus, we conducted a pilot study to examine how users position content within a 3D spatial interface, unrestricted by physical boundaries, as could be provided by AR glasses. The cross-reality approach [15] allows driver-passengers to seamlessly transition their preferred content between traditional in-vehicle dashboard screens and augmented or virtual visualizations, in order to achieve more immersive user experiences [14].


Figure 1: Overview of the content drawer and the effect of different manipulations (changing opacity, switching between light and dark mode and scaling).

## 2 METHOD AND USER STUDY

For the study, participants were seated in car seats and equipped with an HTC Vive Focus headset. They held controllers while facing forward towards the virtual road. To create the simulation, we utilized Unity [19], where automated vehicles drove in an urban environment with right-hand traffic on two-lane streets. In the virtual reality (VR) simulation, we replicated the experience of augmented reality (AR) content and its interaction using handheld controllers. The participants' hands and controllers were visible in the VR environment.

To provide infotainment options, we projected a content drawer onto the middle console of the vehicle. The participants could choose from seven options: email content (GMail icon), a messaging service (WhatsApp), a social network (Twitter), a dashboard, a radio, video content (YouTube), and additional music content (Spotify).

Placing content windows was done by pointing at the drawer, indicated by a laser pointer overlay, and pressing the trigger on the controller. This action spawned the chosen content window directly under the content drawer with default properties (full opacity, light mode, and default scale). To enable dark mode, participants pressed the button again, and a third press closed the window (see Figure 1).

Participants could freely move the content window by pointing at

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it and holding the trigger. To move the window further away, they needed to adjust the joystick on the controller, moving it up or down to increase or decrease the distance along the laser pointer. Using only the joystick, participants could fine-tune the opacity (up and down) and scale (left and right) of the content window. An overview of these options is depicted in Fig. Fig. 1.

## 2.1 Procedure

The participants were welcomed and provided with information about the study. Subsequently, they gave their consent for participation, and completed a general questionnaire covering demographics, gaming/VR experience, and their affinity for technology interaction [11] on 7-point Likert scales. After demonstrating how to interact with the contents, the participants were assisted in putting on the VR glasses and adjusting the interpupillary distance. While the virtual vehicle was still parked, participants had the opportunity to familiarize themselves with the content drawer and practice content manipulation. Once they felt comfortable, the vehicle began moving, and the participants could continue to arrange and consume their placed contents. Participants were allowed to make adjustments until they were satisfied and then confirmed their choices by pressing a virtual button located above the content drawer. At this point, the properties of the opened content windows were logged, and the vehicle came to a stop.

Since we conducted our pilot study in VR, the participants were asked to complete the Simulator Sickness Questionnaire (SSQ) [8] on a 4-point scale. The study concluded with a semi-structured interview inquiring about the participants' attitudes towards using in-vehicle AR infotainment. The entire study duration was 30 minutes, with approximately 10 minutes spent in the VR environment. Participation was voluntary, and the study adhered to ethical guidelines based on the Declaration of Helsinki [21]. Participants did not receive any compensation for their involvement.

# 3 Preliminary Results and Discussion

We recruited 19 participants from our university, with ages ranging from 19 to 41 years ($Mean = 28.16, SD = 6.5$). They were either university students or staff, consisting of fourteen males and five females. Participants had a strong affinity for technology interaction ($Mean = 5.13, SD = 0.92$), and were to some extent familiar with VR ($Mean = 4.74, SD = 1.62$) and computer games ($Mean = 4.89, SD = 1.65$).

All of our participants reported no simulator sickness during the study. Regarding content placements, we observed that participants predominantly positioned content in a way that did not obstruct the windshield or other windows. However, video content was frequently placed on a larger scale, blocking the windshield in order to allow for a more immersive viewing experience. In terms of content opacity, participants preferred an average opacity of approx. 75%. In comparison to a related user study that focused on content placement in a level 3 automated vehicle [16], the mean opacity in our study was generally higher for non-driving related contents. This disparity suggests a distinction between the automation levels in terms of opacity preferences.

Following the main study, we conducted post-experiment interviews focused on gathering participants' thoughts during the simulation experience and their feedback on using the spatial interface. Based on the responses from participants (multiple answers per participant were possible), content placement in the vehicle was influenced by habit and familiarity (mentioned by 11 participants), placing content peripherally to avoid constant focus on it (mentioned by 7 participants), positioning important content in the center and front view (mentioned by 6 participants), placing content in a way that does not obstruct the windshield for better monitoring of the environment (mentioned by 6 participants), or arranging content based on its assigned importance (mentioned by 5 participants).

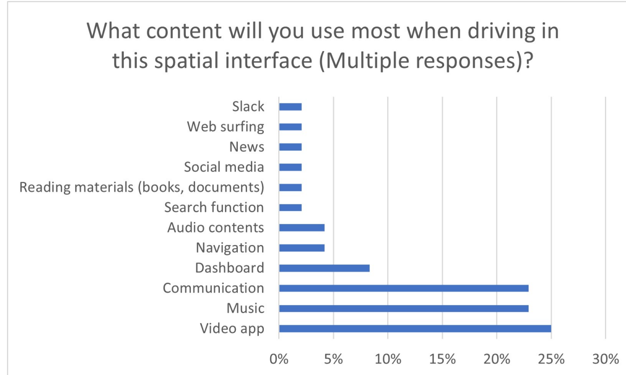


Figure 2: Preferred content types for conducting non-driving related activities in fully automated vehicles.

Regarding desired applications (see Figure 2), participants expressed their preferences, with video applications like YouTube or Netflix being the most desired (mentioned by 12 participants), followed by music and communication apps (both mentioned by 11 participants). Other preferred applications included dashboard information about the vehicle state (mentioned by 4 participants, including speed and heading), navigation (mentioned by 2 participants), podcasts and audio books (mentioned by 2 participants), and other miscellaneous applications (mentioned by 6 participants). When asked if they were willing to use such a spatial interface, a large number of participants ($n = 18$) responded positively. Two participants expressed conditional agreement, stating that they would use the spatial interface for longer car trips but might find it too cumbersome for short 5-minute commutes.

Regarding the use of AR glasses to display infotainment content, fourteen participants expressed interest, while three preferred glasses over headsets, provided they had a lightweight and regular glasses-like form factor. Three participants expressed concerns about wearing AR glasses for short trips or commutes, and were inclined to use them only during longer journeys.

# 4 Conclusion

In this work, we explored how users would position infotainment content in fully automated vehicles using an unrestricted AR interface. Based on our pilot study in VR ($N = 19$), we found that passengers' content placement was influenced by current vehicle designs, as they mainly avoided blocking windows and utilized spaces beyond the windshield. This supports the idea of cross-reality displays, seamlessly transitioning content between driver and passenger sides. However, the frequent use of the dashboard in both positions indicates lingering mistrust towards fully automated vehicles' operation. To enhance user trust and acceptance, future in-vehicle interaction designs should focus on providing adequate information.

Future research should address the design language for this content interaction, including managing notifications and alternative content representations. Additionally, investigating VR simulator sickness reduction potential with this interface, as it allows direct front-facing content viewing, would be valuable in future studies.


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