Evaluating Stereoscopic 3D for Automotive User Interfaces in a Real-World Driving Study

Nora Broy[1], **Stefan Schneegass**[2], **Mengbing Guo**[3], **Florian Alt**[3], **Albrecht Schmidt**[2]

[1]BMW Research and Technology
Nora.NB.Broy@bmw.de

[2]VIS, University of Stuttgart
{firstname.lastname}@vis.uni-stuttgart.de

[3]Group for Media Informatics, University of Munich
{firstname.lastname}@ifi.lmu.de

Figure 1: Test vehicle with an autostereoscopic display showing the instrument cluster.

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Abstract

This paper reports on the use of in-car 3D displays in a real-world driving scenario. Today, stereoscopic displays are becoming ubiquitous in many domains such as mobile phones or TVs. Instead of using 3D for entertainment, we explore the 3D effect as a mean to spatially structure user interface (UI) elements. To evaluate potentials and drawbacks of in-car 3D displays we mounted an autostereoscopic display as instrument cluster in a vehicle and conducted a real-world driving study with 15 experts in automotive UI design. The results show that the 3D effect increases the perceived quality of the UI and enhances the presentation of spatial information (e.g., navigation cues) compared to 2D. However, the effect should be used well-considered to avoid spatial clutter which can increase the system's complexity.

Author Keywords

Stereoscopic 3D; automotive user interfaces

ACM Classification Keywords

H.5.2 [Information Interfaces and Presentation]: User Interfaces—*Screen design (e.g., text, graphics, color)*

Introduction

Recent advances in digital display technology are making stereoscopic 3D (S3D) displays more popular. Increased display resolutions and improved autostereoscopic technologies allow the user to see 3D content without wearing special glasses. This enables the advent of S3D in application domains other than cinema and home entertainment. Instead of using S3D solely for entertainment, the research community notices the potential of spatially structuring user interface elements with S3D to convey information in an unobtrusive and easy-to-understand manner. For example, Häkkilä et al. [3] demonstrated the utilitarian value of a S3D UI for a mobile phone on the basis of a phonebook application. In the domain of automotive user interfaces (AUI), S3D can be utilized to emphasize warnings through a pop-out effect or encoding the distance to the next navigation maneuver [1].

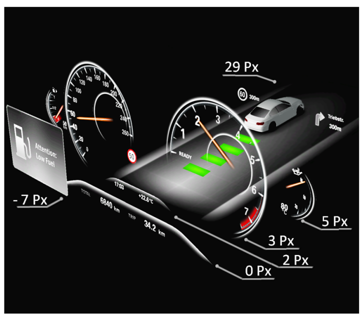

Figure 2: Side view of the instrument cluster showing the depth layout of the UI elements as parallaxes in pixels.

While earlier research concerning in-car S3D UIs is conducted in the lab there is a need to validate the findings in a real-world driving scenario. Especially for AUI, this is an important step since driving through a virtual environment can have a significant influence on the driver's behavior (e.g., driving mistakes do not have serious consequences) and consequently reduces the ecological validity [6]. Thus, we assume that interacting with a 3D display while maneuvering the car through a real 3D world can significantly impact the user's perception of the system. In this work, we introduce our prototype of a S3D car dashboard integrated into a test vehicle equipped with an autostereoscopic display (cf. Figure 1). We report on a real-world driving study using this prototype and investigating the difference between a S3D UI and its 2D counterpart. We conducted the study in an urban environment with 15 experts in AUI design providing their expert opinion about the in-car use of 3D displays. Our results reveal both, particular strengths but also challenges of introducing S3D in the car.

Prototype

To explore the effects of a 3D display during a real-world driving study we replaced the instrument cluster (IC) of a BMW 5 series with a 13.3" autostereoscopic display (native resolution: 1920 x 1080; 3D resolution: 1114 x 626 for each eye). The viewing distance from driver to the display can vary between 60 and 90 cm. Lenticular lenses are used to create the autostereoscopic effect. To enhance the 3D effect, the display employs an eye-tracking mechanism which adjusts the sweet spot in accordance to the viewer's eye position. The vehicle is equipped with a PC running a S3D IC application. This application arranges its typical UI components in space (cf. Figure 2) based on the recommendations by Broy et al. [2]. It receives real-time vehicle data such as speed, revolutions per minute (rpm), etc. via Ethernet. We integrate the different elements necessary in a car as follows:

Gauges: Two large gauges for rpm and speed are located slightly behind the screen. In addition, two small gauges for fuel level and oil temperature are positioned behind the layer of the big gauges conveying the lower relevance.

Active Cruise Control (ACC): In the center, an abstract visualization of the road is provided. It displays distance information, such as navigation cues and preceding vehicles detected by ACC. Steering wheel buttons allow to activate ACC and to adjust its distance, which is visualized by green bars.

Status Information: At the origin of the abstract street status information (trip, outside temperature, etc.) is placed at screen depth.

Check Controls: Since control lights have a warning character they are placed on screen depth to visually separate them from the gauges. The foremost layer in

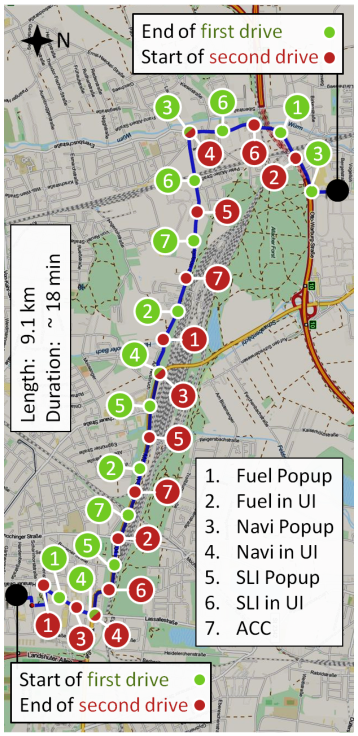

Figure 3: Driving Route: The task order is adapted to the characteristics of the route. It slightly differs between the first and second drive.

front of the screen plane is used for urgent warnings. These components represent the actual car state and are fully functional. Beside the vehicle information, we integrate three types of notifications that can be triggered by the experimenter and be displayed as pop-ups or integral UI objects.

Navigation Cues: Cues announce navigation instructions in the form of an arrow, street name, and distance in meters, appearing 400 m before an intersection. While pop-ups appear and stay in front of the screen layer (decreasing the distance value in discrete steps as the car approaches the intersection), the visualization inside the UI appears at the rearmost depth layer and moves in concrete steps towards the screen plane, thus encoding the actual distance to the maneuver.

Speed Limit: The speed limit info (SLI) notifies the driver about a new speed limit by means of a speed limit sign. The UI visualization shows the upcoming SLI shortly before reaching it. Like navigation cues, the upcoming SLI sign starts at a rearmost depth layer and moves towards the screen layer encoding its distance to the vehicle.

Low Fuel Level: The pop-up visualization shows a gas station symbol and the text "Fuel level low". The variant inside the UI highlights the fuel gauge by moving it towards the screen layer and flashing it.

Real-World Driving Study

We conducted a real-world driving study with experts from the AUI domain based on a heuristic evaluation approach to gather qualitative feedback on the usefulness of in-car 3D displays. The participants conducted two drives, one with the monoscopic (2D) and one with the S3D version of the IC. We counterbalanced the order of the IC versions to avoid sequence effects.

Participants
We recruited 15 participants (6 female) with an average age of 32.6 years (SD=4.48). All of them are experts in AUI development and work as UI concept designers. Their backgrounds cover the fields of computer science, engineering, design, and psychology. We choose this test sample for two reasons. First, all participants are particularly trained on test vehicles and are able to react safely on unexpected issues. In this way we could maximize road safety. Second, we are particularly interested in feedback from expert users that have experience in creating novel UIs for cars and are used to test new interface technologies. All of them are familiar with S3D displays, reducing a possible novelty effect.

Task, and Test Track
While driving the 9 km test track, participants had to react to 14 different notifications per drive (three content types: navigation, SLI, low fuel level; two display variants: within UI, pop-up) by pressing a button on the steering wheel. They also had to drive short distances with ACC. Note, that for safety reasons we focus on tasks causing minimal distraction and that users were familiar with from everyday driving. The task order was adjusted to the characteristics of the route (cf. Figure 3).

Procedure
As participants arrived, we showed them one vision mode (2D/3D) of the IC and all notifications used during the study. We instructed them to press a button on the steering wheel once they recognized a notification. Moreover, we encouraged participants to think aloud during the test drive to express their impressions and feelings. Most importantly, we told the participants to focus on the driving task at any time and ignore tasks if they felt uncomfortable to attend to these.

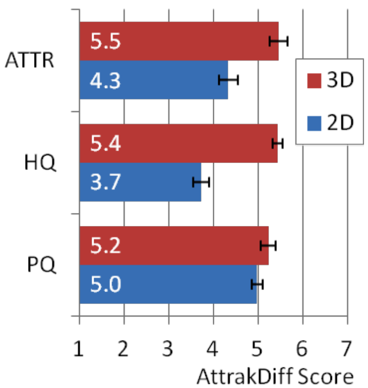

Figure 4: Means and standard errors as error bars for the dimensions PQ, HQ, and ATTR of the AttrakDiff questionnaire.

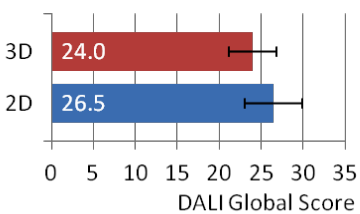

Figure 5: Means and standard errors as error bars for the global score of the DALI questionnaire (lower values correspond to a lower workload level).

After participants adjusted seat, mirror, and steering wheel they began driving. The first drive ended in a large parking lot where we handed out a mini AttrakDiff [4] and a Driving Activity Load Index (DALI) questionnaire [5]. After completing the questionnaires, we interviewed the participants about their experience. Then we started the second drive with the other vision mode – again followed by questionnaires and an interview concerning the last drive and the comparison between driving with a 2D and S3D IC. The interviews were semi-structured and consisted of open questions about the acceptance (2D/3D preference, potentials and drawbacks of S3D), readability and gaze behavior, depth layout, and the presented functions (e.g., ACC, navi cues). Each test session took about 90 minutes and was videotaped using two GoPro cameras. Videos were used to post-hoc code task completion times (TCTs) for reacting on notifications.

Quantitative Results

Figure 4 and 5 depict the descriptive statistics for the AttrakDiff and DALI questionnaire. It shows that 3D outperforms 2D for the three dimensions of the AttrakDiff, pragmatic quality (PQ), hedonic quality (HQ), and attractiveness (ATTR). However, the differences are not statistically significant for PQ, $t(14){=}{-}1.662, p{=}.119$, but for HQ, $t(14){=}{-}7.218$, $p{<}.001$, and ATTR, $t(14){=}{-}5,724$, $p{<}.001$. Moreover, Figure 5 shows that the mean DALI score is lower for 3D than for 2D, but not significantly, $t(14){=}0.947, p{=}.360$. Thus, S3D does not negatively affect the driver's workload level.

We analyze the TCT data regarding 3 independent variables (Figure 6): representation (2D, 3D), content (navigation, SLI, fuel), and visualization (in UI, pop-up). Due to technical issues in logging the button presses we had to exclude 3 participants for analyzing the TCT. We use a three-way repeated measures analysis of variance (ANOVA) that shows significant main effects for the three content types, $F(2,22){=}4.073$, $p{=}.031$, and the two visualizations, $F(1,11){=}30.164$, $p{<}.001$. There are no significant differences regarding the representation mode, $F(1,11){=}.031$, $p{=}.864$.

Qualitative Results

For presenting the qualitative results from the interviews and discussions with the experts (referred to as P1–P15) we clustered the statements regarding different categories. Furthermore, we tagged if they were positive/negative towards the 3D/2D representation. We also analyzed opinions about the visualization of the presented functions (notifications, ACC).

Acceptance

14 out of 15 participants favor the 3D version of the UI. The participant favoring 2D stated to have strong interocular differences, causing problems to perceive the 3D effect. The other experts explain their preference for 3D as it appears more natural than 2D (P3, P4, P13, P14) and entails an innovative character (P4, P6, P8, P15). In addition, participants rated the 2D version as boring (P1, P4, P8, P9) and ordinary (P1, P2, P5, P8, P9, P11, P13). Looking at usability aspects, all participants emphasized the usefulness of the spatiality that 3D offers to clarify relations between UI objects and to facilitate the estimation of distances. Moreover, 6 participants explicitly stated that 3D declutters the display.

Although nobody felt discomfort or visual fatigue, 5 experts mentioned possible discomfort as disadvantage of S3D, particularly in combination with long term use. 5 experts warned not to use the 3D effect too excessively and 3 explicitly mentioned that the 3D space can confuse

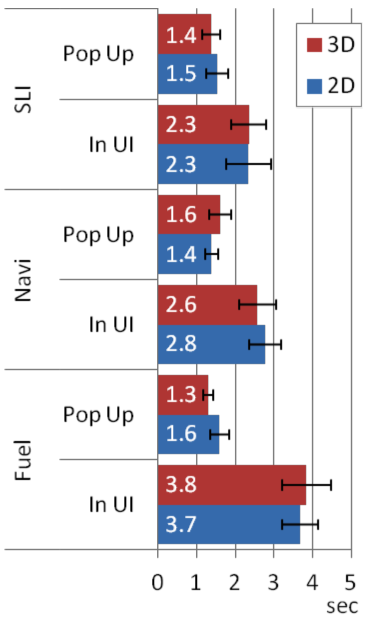

Figure 6: Means and standard errors as error bars for the TCTs regarding the different presentations of the notifications.

the user. As a result, users may need to develop new search strategies, since more than one depth layer has to be scanned. They propose to use depth in a subtle way and just for those elements that obviously benefit from S3D. Regarding the display technology, 12 experts mentioned issues pertaining an automotive application, such as the high reflections of the display, the performance of the tracker, the display's contrast, and the reduced resolution. 5 participants were positively surprised by the quality of the used autostereoscopic technology.

Readability and Gaze Behavior
In total 12 participants positively mentioned the readability of the S3D IC, but only 4 rated it better in 3D and 7 in 2D. Mentioned reasons for the reduced readability in 3D are of technical nature: Reflections are perceived more prominent in 3D than 2D and the tracker sometimes induces jitter for S3D presentations.

Altogether 5 participants felt to look more frequently and also longer at the IC in the 3D version. Moreover, 3 participants voiced misgivings about perceiving the information in 3D. They said that this requires an "increased level of concentration" (P11, P12) and that they could "process information quicker in 2D" (P1). 6 participants perceived no difference in their gaze behavior between 2D and 3D. However, 4 participants considered the 3D effect to positively influence their gaze strategy, since "it declutters the display" (P5, P7, P12) and "is more comfortable to look at" (P15).

We explicitly asked the participants to comment on the attention switch between display and driving scene. 13 participants had no problems with switching between the 3D IC and the real world at all. 4 participants even stated that switching was easier with 3D since it "appears more natural" (P3), "does not confront the user with one cluttered plane" (P4), and allows "faster" (P1) and "more effortless" (P15) switches. However, 2 participants stated that they do not perceive the 3D effect at once while 9 participants noted that the 3D effect is instantly visible.

Depth Layout
All participants recognized that more important and urgent objects are placed further to the front. They welcomed the use of S3D to structure information on layers since it increases the "clearness of the display" (P7, P9), "declutters"(P2, P5, P6, P9, P13, P14), "improves the usability" (P13), "comprehensibility" (P3), "comfort and mode awareness" (P12), and "facilitates the separation of objects" (P9, P15).

A major challenge is the distribution of the check controls on the screen layer. While following a well-known arrangement in 2D, these controls seem to be "lost in space" (P3, P4, P5, P9, P13, P14) in 3D. A "better integration in the 3D UI is required" (P5), e.g., "by additional grouping in the x and y dimension" (P3, P14). Moreover, 3 experts were confused by the depth position of the pointers belonging to the big gauges since those are located behind the dial. They considered this arrangement as "unintuitive" (P4, P5) since "it dissents from expectation towards familiar analogue gauges" (P13).

In general, 11 participants appreciated the use of S3D for highlighting objects (pop-ups) since it expresses "urgency" (P8, P12, P13) and "currentness" (P2, P6). Using this semantic, P8 proposed to visualize several urgency levels via S3D with the pop-out effect being the ultimate escalation level. The other 4 participants did not cherish highlighting with S3D since depth positions in front of the display are difficult to perceive (P15) and other cues, such as size and color are sufficient (P7) and more suitable (P9, P10).

Functions
Regarding the fuel notification in the UI, 7 participants did not notice that the fuel gauge steps slightly forward. 5 participants liked the depth movement of the in-UI fuel gauge, since it is a "comfortable" and "ambient" solution that "corresponds" to its urgency level (P2, P5, P13, P14, P15). However, two participants rated this effect as critical as it is contradicting and unexpected that "physical objects" move to the front (P3, P15). All participants saw great potential in S3D for visualizing timely and spatial relations. Using depth as a metaphor for the distance to upcoming signs or navigation maneuvers is "supportive" (P1, P5, P6, P8, P9) and "clarifying" (P2, P3, P4, P7, P13, P14, P15). This is also reflected by the fact that 4 experts did not understand the movement of SLI and navigation cues in 2D but all for the 3D vision mode. Concerning ACC, participants felt that S3D increases the comprehensibility of "spatial relations between objects" (P3, P4, P5, P6, P7) and the "analogy to the driving scene" (P6, P8, P11, P13).

Conclusion
In this paper, we present the first real-world driving study investigating an S3D IC in comparison to its 2D counterpart. In this way, we can derive conclusions of high external validity, complementing and validating findings of an earlier simulator study [1].

The main potential of S3D UIs in cars is the *clear visual communication of spatial relations* and thus particularly useful for use cases such as navigation and ACC. This is reflected through feedback from experts who emphasize that S3D visualizations have a strong benefit to improve the comprehensibility of such UI elements. Furthermore, a well-considered depth layout of these elements *helps to declutter the displayed content*. At the same time, interface designers need to take care that depth positions correspond to user expectations and that the S3D effect is applied reasonably to avoid *spatial clutter* and *discomfort*. Our study shows that even while driving through the real world a reasonable S3D effect does not evoke discomfort. Additionally, S3D can be used to *increase the perceived urgency of UI elements* although there is no significant influence on TCT. Finally, S3D significantly *improves the hedonic quality of the UI*. Our study shows that the 3D effect *is well accepted* though display technology needs to improve for commercial use. For future work, we plan to validate the presented results with novices in a long term field study, particularly to ensure S3D acceptance taking visual discomfort and novelty effects into account.

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