Design and Evaluation of 3D GUI Widgets for Stereoscopic Touch-Displays

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Abstract: Recent developments in the area of interactive entertainment have suggested to combine stereoscopic visualization with multi-touch displays, which has the potential to open up new vistas for natural interaction with interactive three-dimensional applications. However, the question arises how user interfaces for such setups should be designed in order to provide an effective user experience. In this paper we introduce 3D GUI widgets for interaction with stereoscopic touch displays. We have designed the widgets according to skeuomorph features and affordances. We evaluated the developed widgets in the scope of an example application in order to analyze the usability of and user behavior with this 3D user interface. The results reveal differences in user behavior with and without stereoscopic display during touch interaction, and show that the developed 3D GUI widgets can be used effectively in different applications.

Keywords: 3D GUI widgets, 3D user interfaces, touch interaction, stereoscopic displays.

1 Introduction

Recent advances in research and development have laid the groundwork for the combination of two engaging technologies: stereoscopic display and (multi-)touch interaction [VSB^{+}10, VSBH11, BSS13a, FLBS12, iMU]. While touch interaction has been found to be well-suited and intuitive for interaction with monoscopically displayed content on responsive tabletops and handhelds, introducing stereoscopic display to such surfaces raises challenges for natural interaction [HBCd11, BSS13b, HHC^{+}09]. Stereoscopic display provides the affordances to display virtual objects either with negative parallax in front of the display surface, with zero parallax centered around the display, or with positive parallax behind the display [Bou99]. While direct on-surface touch interaction with objects displayed at a large distance in front of or behind the surface is not possible without significant limitations [VSB^{+}10], objects displayed stereoscopically near zero parallax can elicit the illusion of a registered perceptual space and motor feedback. Thus, graphical elements (e. g., buttons, sliders, etc.) displayed close to zero parallax may afford a more natural interaction than their monoscopically displayed counterparts. However, it is not yet fully understood how users interact with such simple objects on a stereoscopic touch display. In particular, while the affordances of such widgets may be known from the real world, e. g., that a slider may be moved by pushing it with a finger, many of these mental models for interactions with widgets have been abstracted for use in traditional monoscopically displayed Desktop environments and for use with touch-enabled handhelds. This multitude of realizations of simple mental models results in the question how users behave in case graphical widgets are displayed stereoscopically in 3D close to a touch-enabled surface [DCJH13]. Moreover, the question arises how 3D widgets should be designed to provide intuitive interaction when only 2D touches can be detected.

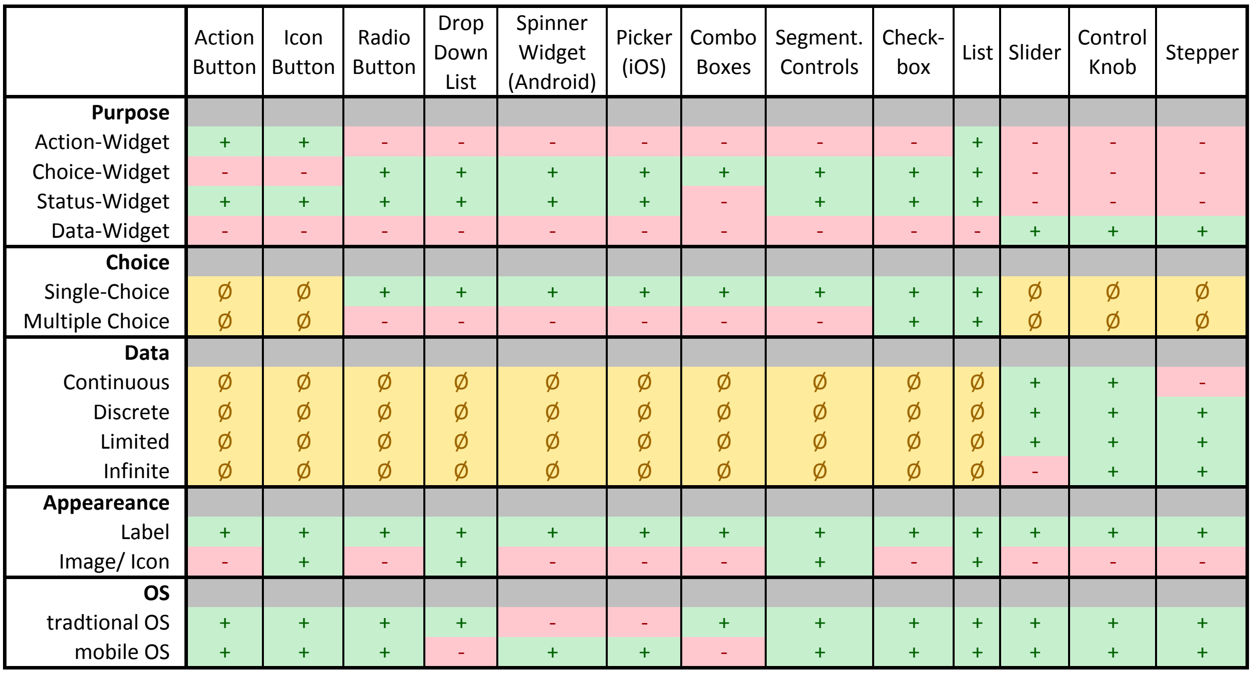
In this paper we present initial results to address these questions. In particular, we introduce 3D widgets in a graphical user interface (GUI) with well-known mental models that can be used on touch-enabled stereoscopic displays. Moreover, we present a user evaluation, which shows differences in user behavior and illustrates the potential of 3D GUI widgets for stereoscopic touch displays.

The remainder of this paper is structured as follows. Section 2 summarizes the design process of the 3D GUI widgets. Section 3 describes the application and hardware setup in which we integrated the 3D GUI widgets. Section 4 explains the user study and discusses the results. Section 5 concludes the paper and gives an overview about future work.

2 Design of 3D GUI Widgets

For the design of 3D GUI widgets for stereoscopic displays we first analyzed which 2D widgets are typically used in current operating systems in Desktop environments and on handhelds from the vendors Apple, Google, Microsoft and also the Linux surface Gnome [CSH^{+}92]. For each widget, we identified whether the widget is *skeuomorph*, i. e., if physical ornaments or designs on the widget resemble another material, technique or object in the real world. Moreover, we analyzed the design of the widgets by comparing them to their counterparts in different operating systems. All considered widgets have a similar look and feel due to the need for external consistency [BMH09]. Finally, we categorized the widgets according to their primary purpose. We identified four different types of widgets (see Figure 1):

- *Action Widgets* trigger an immediate action, when the user clicks on them, e. g., by touching with a finger. Usually, a label or an icon symbolizes the behavior that the user can expect.
- *Choice Widgets* allow either single or multiple-choices. In most of the cases the options must be pre-defined. The only widget that allows users to add new options is the combo box. The appearances of choice widgets vary, in particular, on mobile platforms.
- *Status Widgets* display their current status inherently in their design. They can be used to change the status of a software, e. g., “enable/disable 24-hour time”. Mobile



	Action Button	Icon Button	Radio Button	Drop Down List	Spinner Widget (Android)	Picker (iOS)	Combo Boxes	Segment. Controls	Check-box	List	Slider	Control Knob	Stepper
Purpose													
Action-Widget	+	+	-	-	-	-	-	-	-	+	-	-	-
Choice-Widget	-	-	+	+	+	+	+	+	+	+	-	-	-
Status-Widget	+	+	+	+	+	+	-	+	+	+	-	-	-
Data-Widget	-	-	-	-	-	-	-	-	-	-	+	+	+
Choice													
Single-Choice	ø	ø	+	+	+	+	+	+	+	+	ø	ø	ø
Multiple Choice	ø	ø	-	-	-	-	-	-	+	+	ø	ø	ø
Data													
Continuous	ø	ø	ø	ø	ø	ø	ø	ø	ø	ø	+	+	-
Discrete	ø	ø	ø	ø	ø	ø	ø	ø	ø	ø	+	+	+
Limited	ø	ø	ø	ø	ø	ø	ø	ø	ø	ø	+	+	+
Infinite	ø	ø	ø	ø	ø	ø	ø	ø	ø	ø	-	+	+
Appeareance													
Label	+	+	+	+	+	+	+	+	+	+	+	+	+
Image/ Icon	-	+	-	+	-	-	-	+	-	+	-	-	-
OS													
tradtional OS	+	+	+	+	-	-	+	+	+	+	+	+	+
mobile OS	+	+	+	-	+	+	-	+	+	+	+	+	+

Figure 1: This table lists considered widgets with well-known mental models. Available features are marked with (+), whereas unavailable features for respective widgets are marked with (−). The symbol (ø) indicates that features of that category are not supported.

platform mainly use toggle buttons to perform status changes. Traditional operating systems prefer check boxes.

- *Data Widgets* allow manipulation of any kind of value. The slider, the control knob and the stepper all belong to this kind of category. These three widgets can further be divided depending on whether the value is changed continuously or discretely and whether the value is limited or infinite. The control knob, for example, is the most generalizable of all widgets; it supports all types of value changing.

Based on the classification, we realized at least one representative of each of the categories for use on touch-enabled stereoscopic displays. Therefore, we created a 3D model from a corresponding real-world object, e. g. the slider of an audio mixer console. Figure 2 shows the 3D widgets that we have designed. The sliders and the control knobs (upper right corner) are examples for *data widgets*. The two switches (lower left corner) represent the *status widgets*. Examples of the *choice widgets* (displayed next of the switches) allow single and multiple choice and are here shown with their two possible states. Finally, the two *action widgets* allow to initiate immediate actions.

As illustrated in Figure 2 the skeuomorph nature of the corresponding real-world objects was maintained for their 3D counterparts. We hypothesize that users will interact differently with the 3D GUI widgets on stereoscopic touch displays than with similar objects in the real world, and may be influenced by known interactions in Desktop- or touch environments. Moreover, we hypothesize that stereoscopic display and support of head tracking will result in different user behavior, and may change how users interpret interaction affordances.

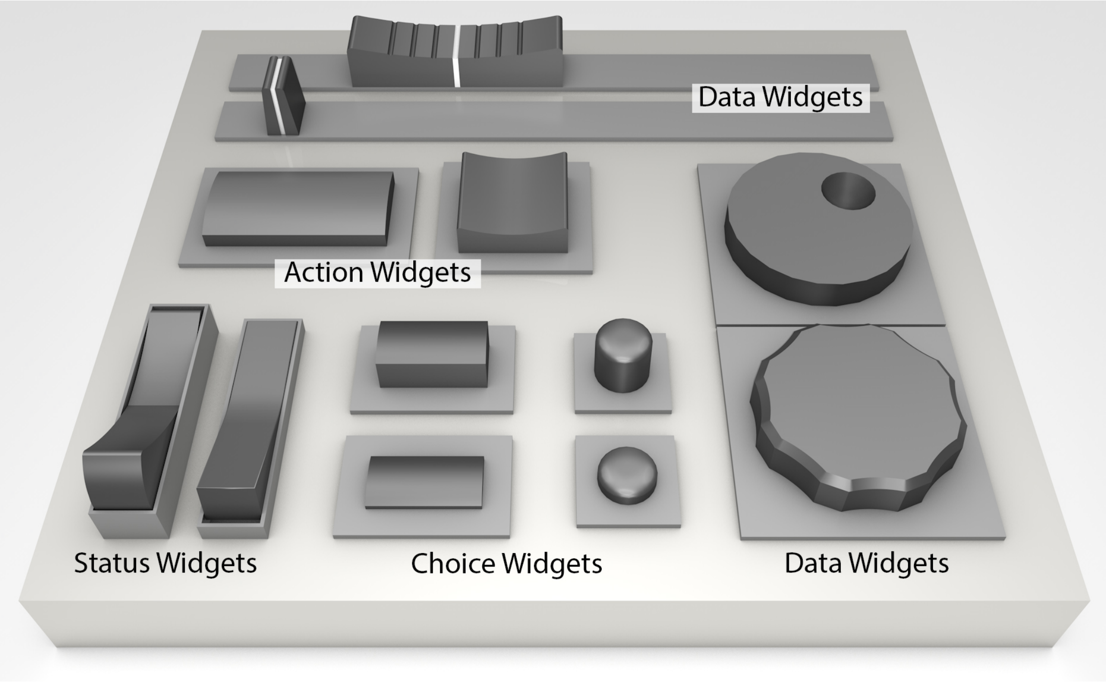


Figure 2: Illustration of the considered 3D GUI widgets.

3 Proof-of-Concept Application: Vehicle Configurator

In order to evaluate interactions with the 3D GUI widgets in a real-world application, we integrated the widgets in a visualization environment for vehicle configurations in cooperation with T-Systems Multimedia Solutions GmbH. The prototype runs on a responsive touch-enabled stereoscopic display (cf. [FLBS12]).

3.1 Stereoscopic Touch-Enabled Tabletop Surface

The 62cm × 112cm multi-touch enabled active stereoscopic tabletop system uses rear diffuse illumination [$\mathrm{SHB}^{+}10$] for the detection of touch points. Therefore, six high-power infrared (IR) LEDs illuminate the screen from behind. When an object, such as a finger or palm, comes in contact with the diffuse surface it reflects the IR light, which is then sensed by a camera. The setup uses a PointGrey Dragonfly2 camera with a resolution of 1024 × 768 pixels and a wide-angle lens with a matching IR band-pass filter at 30 frames per second. We use a modified version of the NUI Group's CCV software for detection of touch gestures [CCV] with a Mac Mini server. Our setup uses a matte diffusing screen with a gain of 1.6 for the stereoscopic back projection. For stereoscopic display on the back projection screen we use an Optoma GT720 projector with a wide-angle lens and a resolution of 1280 × 720 pixels. The beamer supports an active DLP-based shutter at 60Hz per eye. For view-dependent rendering we attached wireless markers to the shutter glasses and tracked them with a WorldViz PPT X4 optical tracking system.

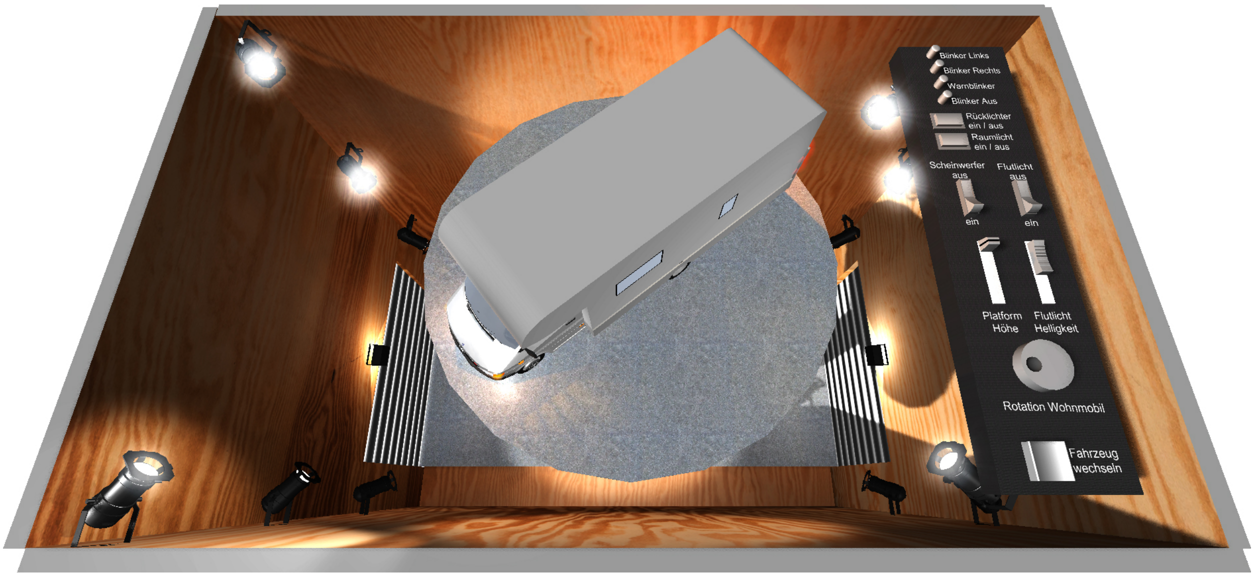


Figure 3: Screenshot of the implemented prototype. The widgets are displayed on the right.

3.2 Application and 3D GUI Widgets

The vehicle visualization and configurator application is shown in Figure 3 and was implemented using the game engine Unity3D [U3D]. Unity3D provides a simple development environment for virtual scenes, animations and interactions. In order to synchronize virtual camera objects with the head movements of a user, we integrated the *MiddleVR for Unity* software framework [MVR], ensuring a correct perspective from the user's point of view.

The application for vehicle configurations consisted of the registered view of the virtual "inside" of the wooden tabletop box (see Figure 4), in which virtual cars could be visualized. The 3D GUI widgets are displayed on the right of the virtual view with a base at zero parallax. The widgets were labeled for users to change the visual appearance of the currently displayed vehicle (see Figure 3). For instance, widgets allow users to turn on blinkers or headlamps, or change the height and orientation of the vehicle. The vehicle was positioned on a large interactive plate (i. e., a control knob widget) in the center.

4 User Study

In the user study we evaluate our 3D GUI widgets with the use of stereoscopic display and head tracking in the scope of the touch-enabled tabletop environment, and compare them in terms of usability and user behavior.

4.1 Participants

8 male and 28 female subjects (ages 19–27, M=21.4, heights 158–185cm, M=171.2cm) participated in the user study. All subjects were students of the Department of Human-Computer-Media and obtained classed credit for participating in the experiment. All subjects had normal or corrected to normal vision. 9 subjects wore glasses and 11 subjects wore

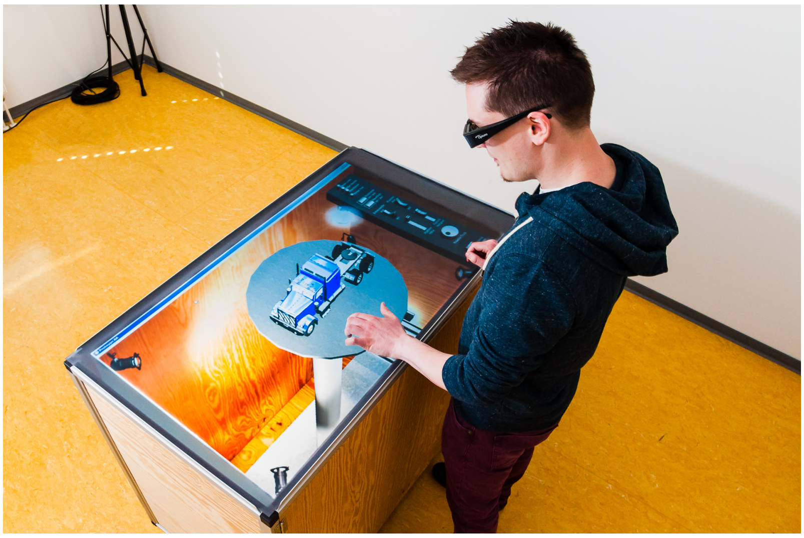


Figure 4: A participant interacting with the prototype during the user study.

contact lenses during the user study. One subject reported a known red-green color weakness. None of the other subjects reported known eye disorders, such as color weaknesses, amblyopia or stereopsis disruptions. We measured the interpupillary distance (IPD) of each subject before the experiment, which revealed IPDs between 5.6cm and 7.3cm (M=6.25cm). 34 subjects reported experience with stereoscopic 3D displays, 9 reported experience with touch screens, and 10 had previously participated in a study involving touch surfaces. Subjects were allowed to take a break at any time during the user study in order to minimize effects of exhaustion or lack of concentration. The total time per subject including questionnaires, instructions, conditions, breaks, and debriefing was about 30 minutes.

4.2 Materials and Methods

The user study used a 2×2 within-subjects design. The independent variables were display modality (stereoscopic vs. monoscopic) and head tracking (activated vs. deactivated). We randomized their order between subjects. All subjects were informed about the widget panel on the right side and the touchable area of the widget on which the vehicles rested.

At the beginning of the trials, subjects were positioned in front of the tabletop surface for each condition (see Figure 4). Then they performed tasks given by the examiner and were asked to share their thoughts using the “think aloud” protocol [Joe89]. The tasks varied in complexity, e. g., rotating the vehicle or turning on a single light could be solved straight-forward. In contrary, tasks like lighting and positioning the favorite vehicle to the user’s pleasing, required the subjects to make use of multiple widgets. Additionally the subjects were given the opportunity to explore the application on their own. We captured the subjects with a webcam during these phases. After each condition the subjects were asked to complete the *AttrakDiff* [HBK03] and a general usability questionnaire, in which we asked subjects to judge the technique according to the criteria learnability, efficiency, memorability, errors and satisfaction on 5-point Likert scales. *AttrakDiff* is a questionnaire

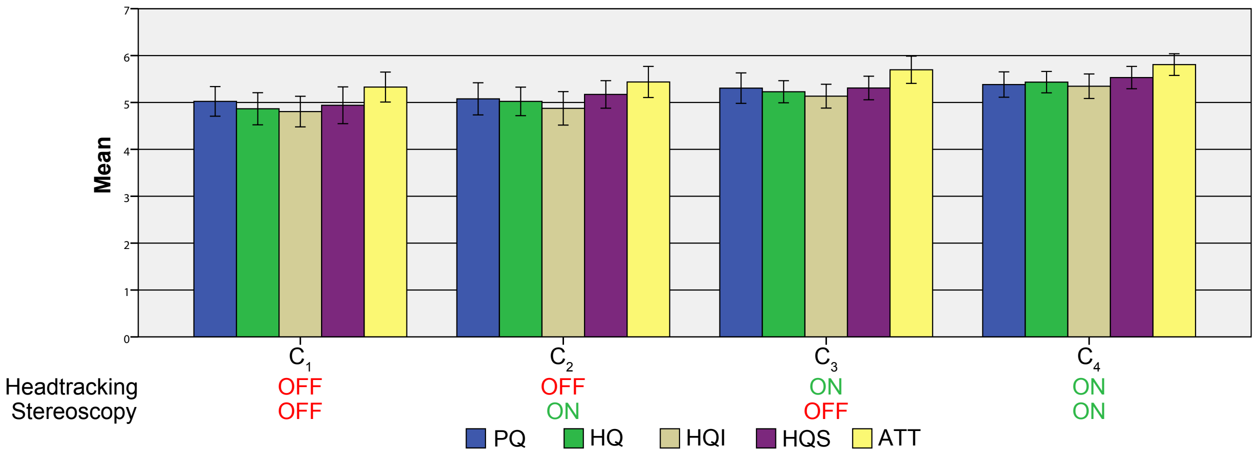


Figure 5: Mean scores from the AttrakDiff questionnaire (higher is better). The vertical bars show the standard error.

used to analyze the overall attractiveness of an interactive product. The questionnaire splits attractiveness (ATT) into pragmatic and hedonic qualities. The pragmatic quality (PQ) describes the estimated ability of a product to achieve action goals by providing useful and usable features. The hedonic quality (HQ) is composed of the HQS and the HQI. HQS (hedonic quality of stimulation) describes the product's ability to satisfy one's need for knowledge and skill improvement by providing creative, novel or challenging features. HQI (hedonic quality of identity) describes the product's ability to communicate self-providing messages to relevant others with connecting and professional features.

4.3 Results

In this section we summarize the results from the user study. Results were normally distributed according to a Shapiro-Wilk test at the 5% level. We analyzed these results with a repeated measure ANOVA and Tukey multiple comparisons at the 5% significance level (with Bonferonni correction). Degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity when Mauchly's test indicated that the assumption of sphericity had been violated.

AttrakDiff

The results for the AttrakDiff questionnaire are illustrated in Figure 5.

We found a significant main effect of condition ($F(2.460, 86.108){=}7.844$, $p{<}.001$, $\eta_p^2{=}.183$) on HQ (hedonic quality). Post hoc tests revealed that HQ was significantly different between all conditions ($p{<}.05$) except between C_1 and C_2 ($p{<}.12$) and between C_3 and C_4 ($p{<}.34$).

We found a significant main effect of condition ($F(3, 105){=}7.826$, $p{<}.001$, $\eta_p^2{=}.183$) on HQI (hedonic quality of identity). Post hoc tests revealed that HQI was significantly different between all conditions ($p{<}.01$) except between C_1 and C_2 ($p{<}.5$) and between C_3 and C_4 ($p{<}.34$).

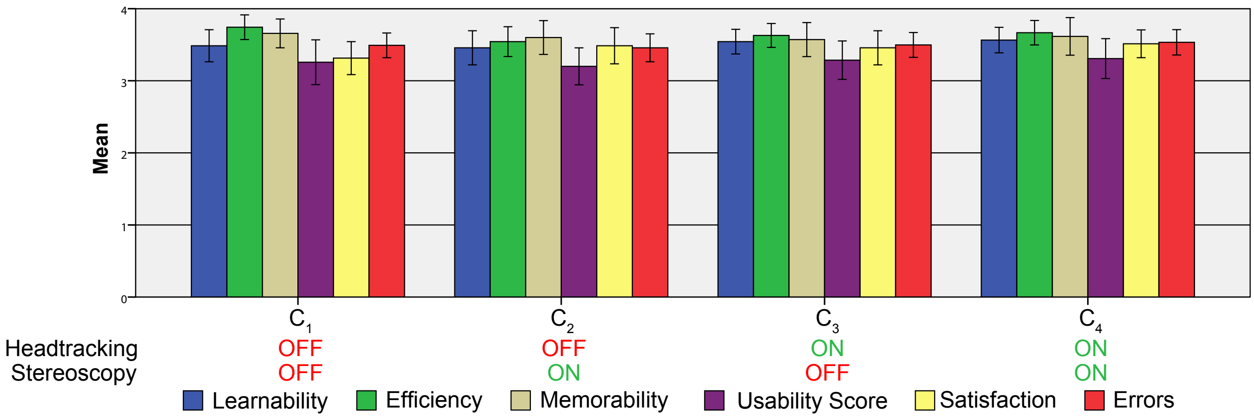


Figure 6: Mean scores of the different components of the usability questionnaire (higher is better). The vertical bars show the standard error.

We found a significant main effect of condition ($F(3, 105){=}5.122$, $p{<}.005$, $\eta_p^2{=}.128$) on HQS (hedonic quality of stimulation). Post hoc tests revealed that HQS was significantly different only between C_1 and C_3 ($p{<}.02$) and between C_1 and C_4 ($p{<}.01$).

We found a trend for a main effect of condition ($F(3, 105){=}2.567$, $p{<}.06$, $\eta_p^2{=}.068$) on PQ (pragmatic quality).

We found a significant main effect of condition ($F(2.359, 82.561){=}5.400$, $p{<}.005$, $\eta_p^2{=}.134$) on ATT. Post hoc tests revealed that ATT was significantly different between all conditions ($p{<}.05$) except between C_1 and C_2 ($p{<}.32$) and between C_3 and C_4 ($p{<}.82$).

Usability

The results for the usability questionnaire are illustrated in Figure 6.

The average mean usability score during the experiment was M=3.51 (SD=0.56) for C_1, M=3.44 (SD=0.57) for C_2, M=3.51 (SD=0.51) for C_3, and M=3.52 (SD=0.55) for C_4. We found no main effect of condition ($F(2.475, 86.633){=}.418$, $p{<}.8$, $\eta_p^2{=}.012$) on usability.

Video Data

With the captured videos we observed that all subjects immediately understood the functionality of the 3D GUI widgets and could quickly solve the given tasks. In line with our hypotheses, when users tried to “touch” the 3D widgets, they often adapted their actions to the affordances provided by the widget. For instance, when they changed the platform height (small slider, see Figure 2) some users used the pincher grip to perform the task and all subjects touched the switch at its lifted part, although we did not distinguish between touch positions on the surface.

We observed that all subjects tried to rotate the platform widget in the center on which the vehicle rested by using multiple fingers or even both hands. One subject stated that it was her impression that such a heavy vehicle could not be rotated with just one finger.

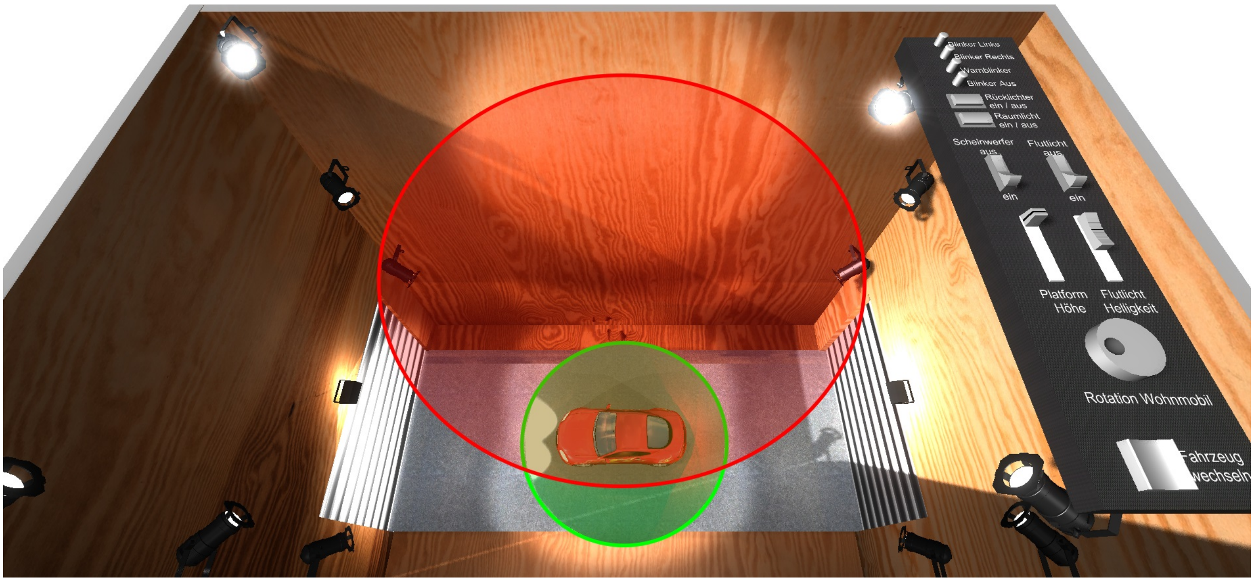


Figure 7: Observed differences in touch behavior for the task to rotate the lowered platform: Subjects either touched the surface in the direction of the lowered platform (green), or at the orthogonal projection towards the surface (red), or refrained from touching towards the platform, and used the corresponding widgets displayed on the right.

For our radio button set we observed an interesting behavior. The radio buttons control the turning lights allowing to (i) signal left, (ii) signal right, (iii) turn on hazards and (iv) turn off all lights. Only one button at a time is allowed to be active. Nearly all subjects apparently did not understand the radio button behavior and tried to reverse the current state by touching the same button instead of touching another non-active button. We currently do not have an explanation for this behavior.

Furthermore, many subjects had problems with the "inactive" state of a widget. We indicated inactive widgets by displaying a plastic wrap, similar to the plastic covers that protects kill switches from accidental activation. Many subjects noted that they did not understand the idea behind the approach, but liked it once they understood it.

We observed a tendency that users behaved differently with or without stereoscopic display. In particular, for the task to rotate the platform widget if the vehicle was lowered into the box, i. e., away from the interactive surface (see Figure 7), we observed the following general strategies:

- Without stereoscopic display, the majority of the subjects touched towards the green circle displayed in Figure 7, indicating the projected on-screen area of the lowered platform. The remaining subjects used the corresponding widgets on the right.

- With stereoscopic display, many subjects touched towards the red circle displayed in Figure 7, indicating the on-screen area after orthogonal projection of the lowered platform towards the surface. The remaining subjects refrained from touching the platform, and used the corresponding widgets displayed on the right.

One subject remarked in this context that she felt she was no longer able to reach the platform with her hand if stereoscopic display was activated, and hence used the widgets. This remark represents many informal comments we received during the debriefing phase.

4.4 Discussion

Our results show a significant difference of overall attractiveness for HQ, HQI, HQS, and ATT between conditions with activated and deactivated headtracking, but no significant difference for stereoscopic display. The overall quite high values suggest that the attractiveness was judged as considerably good. The results indicate that headtracking had a positive impact on the user experience and that stereoscopic display works best with headtracking. Stereoscopic display without headtracking was judged as worse and reveals no added value over the monoscopic representation. Furthermore our results show a trend for PQ, suggesting that the perceived pragmatic qualities were improved by stereoscopic display or headtracking. Since PQ is mainly composed by attributes that are influenced by the interface, a trend for PQ suggests that the 3D GUI widgets benefit from stereoscopy and headtracking. Our results show no significant differences for usability. However, the values were all quite high, suggesting that the usability of the 3D GUI widgets is sufficiently high over different display environments and is not heavily impacted by stereoscopic display or headtracking.

The video data indicated that the 3D widgets were all easy to understand and use, and user behavior suggests that the physical affordances of the widgets were usually perceived as dominating (e. g., all subjects touched towards the lifted part of a switch widget). The recordings also revealed differences between touch behavior with and without stereoscopic display. In particular, we observed that subjects touched different areas if virtual objects were displayed detached from the interactive surface. The results suggest different mental models used to resolve the conflicts that arise when touches are restricted to a 2D surface, but objects are displayed stereoscopically at positive parallax.

5 Conclusion and Future Work

In this paper we introduced and investigated the use of different 3D GUI widgets for stereoscopic multi-touch displays. We analyzed 2D widgets of current operating systems and identified four categories of widgets, which we used to design a set of 3D GUI widgets with strong mental models of real-world interactions. In order to evaluate these widgets we implemented them in a vehicle visualization application and performed a user study. The application was realized on a touch-enabled stereoscopic tabletop.

The results of our user study reveal that the developed 3D GUI widgets for stereoscopic touch displays are easy and effective to use. We observed an effect of the 3D nature of the widgets on user behavior if stereoscopic display was activated, which differed from behavior in case of monoscopic display, i. e., users adapted their actions to the perceived affordances of the widgets. These differences have to be evaluated in more detail in future work.

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