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Touching Floating Objects in Projection-based Virtual Reality Environments

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Abstract

Touch-sensitive screens enable natural interaction without any instrumentation and support tangible feedback on the touch surface. In particular multi-touch interaction has proven its usability for 2D tasks, but the challenges to exploit these technologies in virtual reality (VR) setups have rarely been studied.
In this paper we address the challenge to allow users to interact with stereoscopically displayed virtual environments when the input is constrained to a 2D touch surface. During interaction with a large-scale touch display a user changes between three different states: (1) beyond the arm-reach distance from the surface, (2) at arm-reach distance and (3) interaction. We have analyzed the user's ability to discriminate stereoscopic display parallaxes while she moves through these states, i. e., if objects can be imperceptibly shifted onto the interactive surface and become accessible for natural touch interaction. Our results show that the detection thresholds for such manipulations are related to both user motion and stereoscopic parallax, and that users have problems to discriminate whether they touched an object or not, when tangible feedback is expected.

Categories and Subject Descriptors (according to ACM CCS): Information Interfaces and Presentation [H.5.1]: Multimedia Information Systems—Artificial, augmented, and virtual realities; Information Interfaces and Presentation [H.5.2]: User Interfaces—Input devices and strategies;

1. Introduction

Common virtual reality (VR) techniques such as stereoscopic rendering and head tracking often allow to easily explore and better understand complex data sets reducing the overall cognitive effort for the user. However, VR systems usually require complex and inconvenient instrumentations, such as tracked gloves, head-mounted displays, etc., which limits their acceptance by common users and even by experts. Using devices with six degrees-of-freedom is often perceived as complicated, and users can be easily confused by non-intuitive interaction techniques or unintended input actions. Another issue for interaction in virtual environments (VEs) is that in most setups virtual objects lack haptic feedback reducing the naturalness of the interaction [BKLP04, Min95]. Many different devices exist to support active haptic by specialized hardware which generates certain haptic stimuli [Cal05]. Although these technologies can provide compelling haptic feedback, they are usually cumbersome to use as well as limited in their application scope. In head-mounted display (HMD) environments *passive haptic* feedback to users may be provided [Ins01] by physical props registered to virtual objects. For instance, a user might touch a physical table while viewing a virtual representation of it in the VE. Until now, only little effort has been undertaken to extend passive haptic feedback into projection-based VEs.

Theoretically, a projection screen itself might serve as a physical prop and provide passive feedback for the objects displayed on it, for instance, if a virtual object is aligned with the projection wall (as it is the case in 2D touch displays). In addition, a touch-sensitive surface could provide a powerful extension of this approach. Furthermore, separating the touch-enabled surface from the projection screen, for example, by using a physical *transparent prop* as pro-

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posed by Schmalstieg [SES99], increases the possible interaction volume in which touch-based interaction may be available. Recently, the FTIR (frustrated total internal reflection) and DI (diffused illumination) technologies and their inexpensive footprint [Han05, SHB*10] provide an option to turn almost any large-scale projection display into a touch or multi-touch enabled surface. Multi-touch technology extends the capabilities of traditional touch-based surfaces by tracking multiple finger or palm contacts simultaneously [DL01, SHB*10, ML04]. Since humans in their everyday life usually use multiple fingers and both hands for interaction with their real world surroundings, such technologies have the potential to build intuitive and natural metaphors.

However, the usage of the projection wall as a physical haptic prop as well as an input device introduces new challenges. The touch sensitivity of most multi-touch surfaces is limited to the 2D plane determined by the surface or only a small area above it, whereas stereoscopic displays allow to render objects which might be floating in space with different parallaxes. While objects rendered with *zero parallax* are perfectly suited for touch-based interaction, especially if 2D input is intended, floating objects with *positive parallax* cannot be touched directly, since the screen surface limits the user's reach [GWB05]. In this case indirect selection and manipulation techniques [BKLP04, Min95, PFC*97] can be used. Those techniques cannot be applied for objects in front of the screen. In fact, objects that float in front of the projection screen, i. e., objects with *negative parallax*, introduce the major challenge in this context. When the user wants to touch such an object, she is limited to touching the area behind the object, i. e., the user has to reach "through" virtual objects to the touch surface, and the stereoscopic impression would be disturbed. As illustrated in Figure 1 (left), if the users reaches through a virtual object while focusing on her finger, the stereoscopic impression would be disturbed due to the difference in accommodation and convergence between virtual object and the finger. As a result, left and right stereo images could not be merged anymore, since the object appears blurred. On the other hand, focusing on the virtual object would lead to the opposite effect in described situation (see Figure 1 (right)). In both cases touching an object may become unnatural and ambiguous.

Recent findings in the area of human perception in VEs have shown that users have problems to estimate their own motions [BRP*05, SBJ*10], and in particular that vision usually dominates the other senses if they disagree [BRP*05]. Therefore it sounds reasonable that the virtual scene could be imperceptibly moved along or against the user's motion direction, such that a floating object is shifted onto the interactive surface potentially providing passive haptic feedback. Another relevant question is to what extent a visual representation could be misaligned from its physical counterpart without the user noticing. In other words, how precisely can users discriminate between visual and haptic contact of their finger with a floating object.

Figure 1: *Illustration of a common problem for touch interaction with stereoscopic data.*

In this paper we address the challenges to allow users to interact with stereoscopically rendered data sets when the input is constrained to a 2D plane. When interacting with large scale touch displays a user usually changes between three different states: (1) beyond the arm-reach distance from the surface, (2) at arm-reach distance (but not interacting), and (3) interaction. We have performed two experiments in order to determine if, and how much, the stereoscopic parallax can be manipulated during the user's transitions between those states, and how precisely a user can determine the exact point of contact with a virtual object, when haptic feedback is expected.

The remainder of this paper is structured as follows: Section 2 summarizes related work. Section 3 describes the setup and the options for shifting objects to the interactive surface. Sections 4 and 5 present the experiments. Section 6 discusses the results and gives an overview of future work.

2. Related Work

The challenges introduced by touch interaction with stereoscopically rendered VEs are described by Schöning et al. [SSV*09]. In their work anaglyph-based and passive-polarized stereo visualization systems were combined with FTIR-technology on a multi-touch enabled wall. Furthermore, approaches based on mobile devices for addressing the described parallax problems were discussed. The separation of the touch surface from the projection screen has been proposed by Schmalstieg et al. [SES99]. In this approach, a tracked *transparent prop* is proposed, which can be moved while associated floating objects (such as a menu) are displayed on top of it. Recently, multi-touch devices with non planar touch surfaces, e. g., cubic [dlRKOD08] or spherical [BWB08], were proposed, which could be used to specify 3D axes or points for indirect object manipulation.

The option to provide passive haptic feedback in HMD setups by representing each virtual object by means of a registered physical prop has considerable potential to enhance the user experience [Ins01]. However, if each virtual object shall be represented by a physical prop, the physical interaction space would be populated with several physical obstacles restricting the interaction space of the user. Recently, various approaches for VR have been proposed that exploit the human's imperfection to discriminate between discrepancies induced by different stimuli from at least two senses. In this context experiments have demonstrated that humans tolerate a certain amount of inconsistency between visual and proprioceptive sensation [BRP*05, KBMF05]. In these approaches users can touch several different virtual objects, which are all physically represented by a single real-world object. Such scenarios are often combined with redirected walking techniques to guide users to a corresponding physical prop [KBMF05, SBK*08]. In this context, many psychological and VR research groups have also considered the limitations of human perception of locomotion and reorientation [BIL00, BRP*05]. Experiments have demonstrated that humans tolerate inconsistencies during locomotion [BIL00, SBJ*10] or head rotation [JAH*02] within certain detection thresholds. Similar to the approach described in this paper, Steinicke et al. [SBJ*10] have determined detection thresholds for self-motion speed in HMD display environments, and they have shown that humans are usually not able to determine their own locomotion speed with accuracy better than 20%. While those results have significant impact on the development of HMD-based VR interfaces, their applicability to projection-based VEs has not yet been investigated in depth.

3. Touching Floating Objects

In this section we explain our setup and discuss user interaction states within a large scale stereoscopic touch-enabled display environment. Furthermore, we describe options to shift floating objects to the interactive surface while the user is transiting through these different states.

3.1. Setup

In our setup (sketched in Figure 2) we use a $300cm \times 200cm$ screen with passive-stereoscopic, circular polarized back projection for visualization. Two DLP projectors with a resolution of 1280×1024 pixels provide stereo images for the left and the right eye of the user. The VE is rendered on an Intel Core i7 @ 2.66GHz processor (4 GB RAM) with nVidia GTX295 graphics card. We tracked the user's head position with an optical IR tracking system (InnoTeamS EOS 3D Tracking). We have extended the setup by *Rear-DI* [SHB*10] instrumentation in order to support multi-touch interaction. Using this approach, infrared (IR) light illuminates the screen from behind the touch surface. When an object, such as a finger or palm, comes in contact with the surface it reflects the IR light, which is then sensed by a camera. Therefore, we have added four IR illuminators (i. e., high power IR LED-lamps) for back-lighting the projection screen and a digital video camera (PointGrey Dragonfly2) equipped with a wide-angle lens and a matching infrared band-pass filter, which is mounted at a distance of $3m$

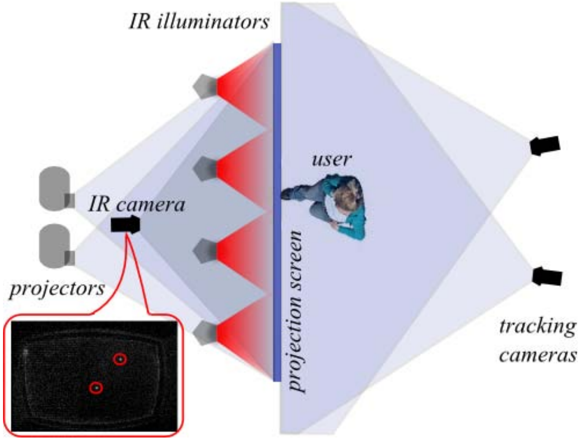


Figure 2: *Sketch of stereoscopic multi-touch surface setup.*

from the screen. The camera captures an 8-bit monochrome video stream with resolution of 1024×768 pixels at $30fps$ ($2.95mm^2$ precision on the surface). Since our projection screen is made from a mat, diffusing material, we do not need an additional diffusing layer for it.

3.2. User Interaction States

During observation of several users interacting within the setup described above, we have identified typical user behavior similar to their activities in front of large public displays [VB04], where users change between different states of interaction. In contrast to public displays where the focus is on different "levels" of user involvement, and attracting the user's attention is one major goal, in most VR setups usually the user already intends to interact with the VE. To illustrate the user's activities while she interacts within the described VR-based touch display environment, we adapt Norman's interaction cycle [Nor98] resulting in three different states (see Figure 3).

In the *observation* state the user is at such a distance from the display that the whole scene is in the view. Because of the size of our display this is usually beyond her arm-reach distance. In this state often the goal of the intended interaction is formed, and the global task is subdivided. Users usually switch to this state in order to keep track of the scene as a whole (i. e., to get the "big picture") and to identify new local areas or objects for further local interaction. The user is in the *specification* state while she is within arm-reach distance from the surface but still not interacting. We have observed that the user spends only a short period of time in this state, plans the local input action and speculates about the system's reaction. The key feature of the transition between the *observation* state and the *specification* state is that real walking is involved. In the *observation* state the user is approximately $1.5-2m$ away from the interactive surface, whereas during

Figure 3: *Illustration of the states of user interaction with a wide, stereoscopic multi-touch display.*

the *specification* state she is within $50-60cm$ of the screen in our setup. Finally, in the *execution* state the user might perform the actions planned in the *specification* state. By touch-based interaction the user is applying an input action while simultaneously observing and evaluating the result of this action and correcting the input. Once the execution of the current action is finished, the user may return back to the *specification* or *observation* state to evaluate the results.

While the described user interaction states and the transitions between them are similar for different kinds of tasks and visualizations, the time spent in each state and the number of transitions between them depends on the application scenario. For instance, in tasks in which only local interaction is required, users usually do not need to switch to the observation state at any time, in contrast to situations where some interrelation between the objects exists. Furthermore, it is likely that the observed phases and user behavior are affected by the parameters of the particular setup, such as the form factor of the display, the brightness of the projection, the type of the virtual scene being projected, etc. The goal of our illustration is not to provide a universal description of user interaction in front of an interactive projection wall, but it points out some of the aspects involved in touch-based interaction in stereoscopically rendered projection VR setups and underlines the states examined in our experiments.

3.3. Shifting the Virtual Scene

As mentioned above, visual information often dominates extraretinal cues, such as proprioception, vestibular signals, etc., in a way that humans usually experience difficulties to detect introduced discrepancies between visually perceived motion and physical movement of their body [KBMF05, PWF08]. In this context, the question arises, if and how much a virtual scene can be imperceptibly shifted during a user's transition from one interaction state to another (see Section 3.2). For instance, one can slightly translate the virtual scene in the same direction as the user's motion, while she is approaching the screen (i. e., switching from *observation* to *specification* state). Thus, an object of interest, which had negative parallax, may be shifted on top of the interactive surface, where the user would receive passive haptic feedback if she touches it. Scene shifts can also be applied during the transition from *specification* state to *execution* state. In studies measuring the real-time kinematics of limb movement, it has been shown that total arm movement during grasping actually consists of two distinct component phases [GCE08]: (1) an initial, ballistic phase during which the user's attention is focused on the object to be grasped (or touched) and the motion is basically controlled by proprioceptive senses, and (2) a correction phase that reflects refinement and error-correction of the movement, incorporating visual feedback in order to minimize the error between the arm and the target. The implementation of scene shifts during the ballistic or correction phase poses considerable technical problems since both phases are usually very short, and precise 3D finger tracking would be required. Nevertheless, for objects rendered in front of the projection screen the user will usually expect to either touch the object (i. e., to experience haptic feedback) or penetrate it with her finger. Thus the question arises, how the user will react if none of this happens, i. e., if she would unconsciously move her hand further until the object is finally penetrated or haptic feedback is received by the wall.

In most VR setups the user's head motions in the real world are captured by a tracking system and mapped to translations (and rotations) of the virtual camera so that the virtual scene appears static from the user's point of view. As mentioned above, humans usually tolerate a certain amount of instability of the virtual scene. We describe this instability with a translation shift $T_{shift} \in \mathbb{R}^3$, i. e., if $P \in \mathbb{R}^3$ is the stable position of an arbitrary object and $P_{shift} \in \mathbb{R}^3$ is the shifted position of the same object, then:

$$P_{shift} = P + T_{shift}$$

In most cases no scene shifts are intended, thus $T_{shift} \approx 0$. In our setup we want to apply induced scene shifts in the same or in the opposite direction as the motion of the virtual camera. Therefore, we define the *shift factor* $\rho \in \mathbb{R}$ as the amount of virtual camera motion used to translate the scene in the same or in the opposite direction, i. e.,

$$T_{shift} = \rho \cdot T_{camera}$$

In the most simple case the user moves orthogonal to the

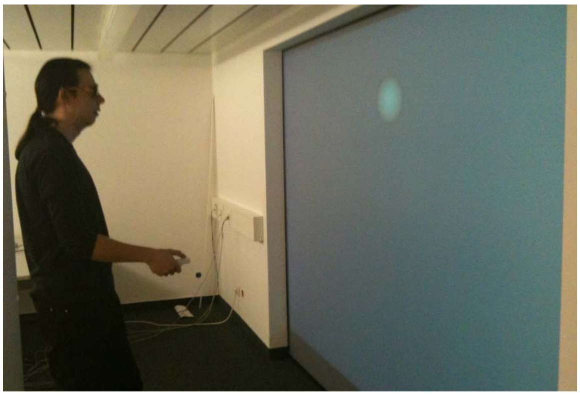


Figure 4: *Participant in experiments E1 and E2.*

projection screen, and her motions are mapped one-to-one to virtual camera translations. In this case a shift factor of $\rho = 0.3$ means that, if the user walks $1m$ toward the projection screen, the scene will be translated $30cm$ in the *same direction*, while with $\rho = -0.3$ the scene will be translated $30cm$ *opposite* to the user's direction of motion.

4. Experiment E1: Detection of Scene Shifts

In this experiment we analyzed subjects' ability to detect induced scene motion while approaching the projection wall. Therefore, subjects had to discriminate whether a stereoscopically displayed virtual object moved in the same or opposite to their direction of movement. We performed the experiment using the hardware setup described in the previous section.

4.1. Participants in E1

15 male and 4 female subjects (age 23-42, ∅: 26.9; height $1.54m-1.96m$, ∅: $1.80m$) participated in the experiment. Subjects were students or members of the departments of computer science, mathematics or geoinformatics. All had normal or corrected to normal vision; 15 subjects had experience with stereoscopic projections, and 12 had already participated in a study in which stereoscopic projections were used. Two of the authors participated in the experiment; all other subjects were naïve to the experimental conditions. The total time per subject including pre-questionnaire, instructions, training, experiment, breaks, and debriefing took 45 minutes. Subjects were allowed to take breaks at any time.

4.2. Material and Methods for E1

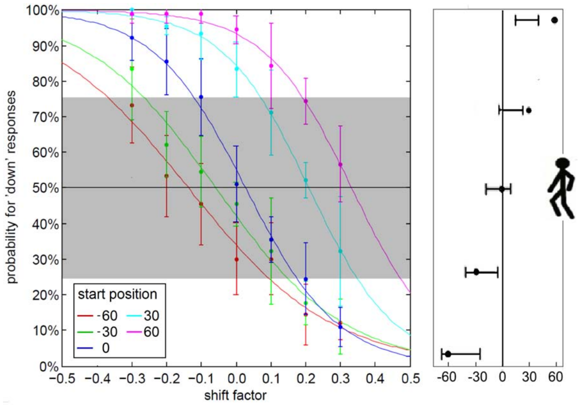
At the beginning of the experiment subjects judged the parallax of three small spheres displayed stereoscopically on the projection wall. We included this stereopsis test to confirm the subject's ability of binocular vision. If this test was accomplished successfully, a written task description and experiment walk-through was presented via slides on the projection wall.

At the beginning of each trial, subjects were instructed to walk to the start position in front of the projection wall, which we marked with a white line on the ground. For visual stimuli we used a virtual scene that consisted of a single dark gray sphere projected at eye-height of the subject. To minimize ghosting artifacts of passive stereoscopic projection, we used a light gray color for the background. Once the virtual sphere was displayed, subjects had to walk forward to the projection wall until a written message indicated to stop. The walk distance in the real world was $1m$ in all trials. Subjects started $1.675m$ in front of the projection wall and stopped at their mean arm-reach distance. We determined the arm-reach distance as $0.675m$, i. e., the $3/8$ part of the statistical median of the body height in our local area. In a *two-alternative forced-choice (2AFC)* task subjects had to judge with a Nintendo Wii remote controller if the virtual sphere moved in or opposite to their walking direction. The 'up' button on the controller indicated scene motion in the same direction as the subject, whereas the 'down' button indicated scene motion in the opposite direction. After subjects judged the perceived scene motion by pressing the corresponding button, we displayed a blank screen for $200ms$ as short interstimulus interval, followed by the written instruction to walk back to the start position to begin the next trial.

For the experiment we used the method of constant stimuli. In this method the applied shift factors $\rho \in \mathbb{R}$ (see Section 3.3) as well as the scene's initial start positions are not related from one trial to the next, but presented randomly and uniformly distributed. We varied the factor ρ in the range between -0.3 and 0.3 in steps of 0.1. We tested five initial start positions of the stereoscopically displayed virtual sphere relative to the projection wall (-60cm, -30cm, 0cm, +30cm, +60cm). Each pair of start position and factor was presented exactly 5 times in randomized order, which results in a total of 175 trials per subject. Before these trials started, 10 test trials in which we applied strong scene manipulations (factors $\rho = \pm 0.4$ and $\rho = \pm 0.5$) were presented to the subjects in order to ensure that subjects understood the task.

4.3. Results of E1

Figure 5(a) shows the mean probability for a subject's judgment that the scene moved opposite to her walking direction for the tested shift factors and virtual start distances. The x-axis shows the applied shift factor ρ, the y-axis shows the probability for 'down' responses on the Wii remote controller, i. e., the judgment that the scene moved towards the subject while approaching the projection wall. The solid lines show the fitted psychometric functions of the form $f(x) = \frac{1}{1+e^{a \cdot x+b}}$ with real numbers a and b for the scene's virtual start distances from the projection wall -60cm (red),



a) b)

Figure 5: *Experiment E1: (a) pooled results of the discrimination task; (b) scene translations, which cannot be reliably discriminated by users walking* 1*m distance.*

-30*cm* (green), 0*cm* (blue), +30*cm* (cyan) and +60*cm* (magenta). The vertical bars show the standard error.

The points of subjective equality (PSEs) as well as detection thresholds (DTs) of 75% for 'opposite' and for 'same' responses are given in Table 1. Differences within the range defined by these thresholds cannot be estimated reliably. For instance, for the 0*cm* virtual start distance subjects had problems to discriminate scene translations between 17.5*cm* in the 'same' direction and 11.5*cm* in the 'opposite' direction of their own motion, during 1*m* forward movement (see Figure 5(b)).

4.4. Discussion of E1

Our results show that subjects generally had problems to detect even large shifts of the stereoscopic depth of rendered objects during active movements, i. e., when approaching the projection wall by walking. In general, our results show smaller manipulation intervals than determined in similar experiments for HMD environments [SBJ*10]. This may be due to real-world references in our non-fully immersive setup as well as the short walking distances of about 1*m*. Figure 5(a) shows that for objects on the projection surface subjects were accurate at detecting scene motions corresponding to shift factors outside the interval between $\rho = -0.115$ and $\rho = 0.175$. For objects starting in front of the projection wall we determined a stepwise shift of the fitted psychophysical curves towards $\rho > 0$. The subjects rather show a significant bias towards underestimation of the motion speed of the virtual object relative to the observer's own motion. This result is in line with results found for underestimation of distances in studies conducted in HMD environments [SBJ*10]. However, we found this shift exclusively for objects displayed with negative parallax, which motivates that other factors may have influenced the results, in particular the accommodation and convergence difference introduced by the virtual object's offset from the projection wall, or intensified ghosting artifacts via the increased stereoscopic disparity. For objects starting behind the projection wall subjects estimated objects slightly shifted opposite to their movement direction with $\rho < 0$ as spatially stable. Compared to the results for objects in front of the projection wall, this result represents an overestimation of the subject's perceived self-motion relative to the virtual object. This difference to the results often found in fully-immersive environments may in part be caused by references to the real world in our projection-based experiment setup, such as the projection wall's bezel.

start position	75% DT 'opposite'	PSE	75% DT 'same'
-60	-0.365	-0.137	0.095
-30	-0.265	-0.058	0.145
0	-0.115	0.025	0.175
+30	0.075	0.209	0.345
+60	0.195	0.332	0.465

Table 1: *Table listing PSEs and DTs for the tested start distances in E1.*

5. Experiment E2: Discrimination of Binocular Disparity

In this experiment we analyzed how sensitive subjects are to a slight discrepancy of visual and haptic depth cues while performing touch gestures. We evaluated subjects' ability to determine the exact point of contact with an object projected with different stereoscopic parallaxes on our multi-touch wall. We performed the experiment using the same hardware setup as in E1.

5.1. Participants in E2

18 of the 19 subjects who participated in E1 participated also in this experiment. The total time per subject including pre-questionnaire, instructions, training, experiment, breaks, and debriefing took 30 minutes. Subjects were allowed to take breaks at any time.

5.2. Material and Methods for E2

We presented a written task description and experiment walk-through via slides on the projection wall. As visual stimuli we used a virtual gray sphere projected stereoscopically on the touch-surface as used for experiment E1. However, in this experiment the subjects were positioned at arm-reach distance from the projection wall and were instructed to perform touch gestures while remaining in place. The subjects' task was to touch a virtual sphere projected on the multi-touch wall, after which they had to judge in a 2AFC

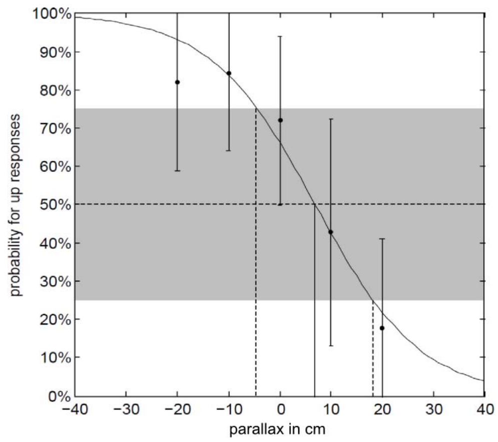


Figure 6: *Experiment E2: pooled results of the discrimination task.*

task if they first touched the projection wall ('up' button on the Wii remote controller) or penetrated the sphere's surface ('down' button) while performing the touch gesture. After subjects judged the perceived stereoscopic depth by pressing the corresponding button, we displayed a blank screen for 200*ms* as short interstimulus interval. As experimental conditions we varied the position of the sphere, so that the point of the sphere's surface which is closest to the subject was displayed stereoscopically behind the interaction surface, in front of it or exactly on it. We have tested 5 positions (sphere's surface displayed -20*cm* and -10*cm* behind the projection wall, +20*cm* and +10*cm* in front, and 0*cm* on the projection wall). Additionally, we varied the sphere's size using a radius of 10*cm*, 8*cm*, 6*cm* or 4*cm*. The sphere's position and size were not related from one trial to the next, but presented randomly and uniformly distributed. Each subject tested each of the pairs of position and size 5 times, resulting in a total of 100 trials. Before these trials started we presented 10 randomly chosen test trials to the subjects to provide training and ensure that they understood the task.

5.3. Results of E2

We found no significant difference between results for the different sizes of the spheres so we pooled these responses. Figure 6 plots the mean probability for a subject's judgment of having touched the projection wall first ('up' button) against the tested distance between the sphere's surface and the projection plane. The x-axis shows the distance between the sphere's surface and the projection plane, the y-axis shows the probability for 'up' responses on the Wii remote controller, i. e., the judgment of having touched the projection wall first and not the sphere. The solid line shows the fitted psychometric function of the form $f(x) = \frac{1}{1+e^{a \cdot x+b}}$ with real numbers a and b. The vertical bars show the standard error.

From the psychometric function we determined a slight bias for the $PSE = 6.92cm$. Detection thresholds of 75% were reached at distances of $-4.5cm$ for 'up' responses and at $+18.5cm$ for 'down' responses, although the standard error is quite high in this experiment.

5.4. Discussion of E2

Our results show that subjects had problems detecting a slight discrepancy between zero and non-zero parallax of an object while performing a touch gesture. For the simple virtual sphere used in our experiment, subjects judged distances of $4.5cm$ behind the projection surface up to $18.5cm$ in front of it as resulting in perceptually accurate touches in 75% of the cases. The results motivate that touch gestures with virtual objects displayed on the projection wall with almost zero parallax can be performed even if there is a slight discrepancy of convergence and accommodation cues with respect to the subject's real finger as well as projection surface and a virtual object, respectively.

6. Discussion and Future Work

In this paper we have addressed the challenge to bring passive haptic feedback and touch interaction with floating objects to projection-based VR setups. The detection thresholds determined in E1 for objects with negative, positive and zero parallax show that we can shift virtual objects of interest closer to the projection wall without users detecting scene shifts, thus enabling natural touch feedback for these objects. The results of E2 indicate the possibility to interact with stereoscopically rendered objects even if they are not exactly on the touch-enabled surface. As a consequence, the required scene offset applied during user motion could be reduced, since it is not necessary for the object to be exactly on the projection surface in order to be available for touch interaction.

We successfully applied the results determined in our experiments with the touch-enabled stereoscopic display system in a more complex geospatial application in the context of the AVIGLE (www.avigle.de) project. In this project an aviation service platform for Miniature Unmanned Aerial Vehicles (MUAVs) is developed which supports different high-tech services. Such MUAVs, which are equipped with range sensors, can for example be used to explore inaccessible areas. The end user can steer the MUAVs and explore the reconstructed VE during operation. Therefore, stereoscopic visualizations and fast and natural interaction metaphors are needed. Figure 7 shows the multi-touch stereoscopic setup we have used for this application. We have observed that most users were not aware of scene shifts that corresponded to even twice the thresholds found in E1, which motivates that users who focus on other tasks than observing manipulations are less sensitive to detect scene shifts.

Our results represent first steps towards touch interac-

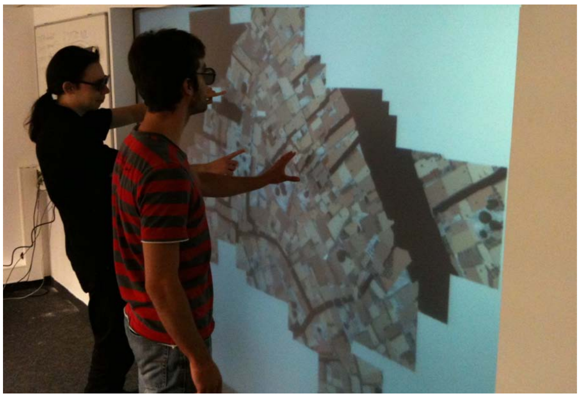


Figure 7: *AVIGLE project's stereoscopic multi-touch setup.*

tion in stereoscopic projection environments, but are limited in various ways. From our application tests we believe that touch interaction has the potential to provide a vital enhancement of stereoscopic projection-based setups for a wide range of applications requiring touch interaction. However, further research has to be done in this direction to provide generally applicable manipulation ranges and techniques. For instance, the derived shift factors may be affected by the object's position in relation to the projection wall's bezel, since the bezel provides a non-manipulative reference to the user. Furthermore, the options to apply shift factors, while the user remains in the interaction area and only moves her hands, as well as rotational or curvature gains [SBJ*10] have not been studied sufficiently and will be addressed in future work.

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