Effects of Interaction-Display Offset on User Performance in Surround Screen Virtual Environments

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ABSTRACT

We present a study exploring the effect of positional offset between the user's interaction and display frame-of-reference in a surround-screen virtual environment (SSVE). In our experiment, users were asked to match a target color using a 3D color widget under three different display-interaction offset conditions: no offset (i.e., collocation), a three inch offset, and a two foot offset. Our results suggest that collocation of the display and interaction frames-of-reference may degrade accuracy in widget-based tasks and that collocation does not necessarily lead the user to spend more time on the task.

Keywords: 3D interaction, collocation, interaction-display offset.

Index Terms: I.3.6 [Computer Graphics]: Methodology and Techniques—Interaction techniques; H.5.2 [Information Interfaces and Presentation]: User Interfaces—Evaluation/methodology

1 INTRODUCTION

3D interaction techniques centered on the user's body constitute a commonly described class of interaction techniques found in VEs. For example, a user can use his or her hands to spatially interact with virtual objects and widgets. A fundamental question that has gone relatively unexplored in the class of body-centered interaction techniques asks where ought a given virtual object be placed with respect to the user.

According to Mine [3], virtual objects that are collocated with the user's body provide higher levels of performance for docking tasks than when an offset is present between the user's body and the virtual object. However, Mine's work was conducted using a head mounted display (HMD). In such a VE platform the user cannot see his or her physical body. Therefore, it is important to explore whether Mine's findings extend to surround screen VEs, where the user can see his or her body and virtual objects cannot occlude the line of sight to the hands or input devices. Such an exploration was undertaken by Paljic, et al. [4] Using a projector-based Responsive Workbench, they found that a zero or minimal offset between the interaction and display frames-of-reference minimized time-to-completion in a docking task similar to Mine's technique. Our intuition, contrary to the results of Mine and Paljic, is that a positional offset could improve performance in our SSVE by minimizing the visual interference of the user's own body.

2 EXPERIMENT

2.1 Hypothesis

An experiment was designed to test the effect of varying the offset of the display frame-of-reference with respect to a fixed interaction frame-of-reference for a 3D widget-based task. We chose a 3D color-picking widget based on the one deployed in the CavePainting application [2]. The widget maps the position of the user's hand to a color. Interaction using this widget is representative of many types of 3D spatial interaction tasks requiring users to move a virtual cursor in 3D space. Our hypothesis for this study was that a translational offset between interaction and display frames-of-reference would improve user performance for the color-matching task.

2.2 Experimental Design

2.2.1 Participants

Twenty-nine subjects (15 male, 14 female) completed the study. 17 out of 29 subjects wore glasses and two subjects were left-handed. Subjects were drawn from the Brown University community at large.

2.2.2 Apparatus

The surround-screen display used in our study is a four-walled Cave-like device [1]. Active stereo imagery was provided via Nvidia FX 3000G graphics cards synchronized by infrared with Sterographics CrystalEyes3 LCD shutter glasses. The physical size of each wall was 8 ft. squared with a display resolution of 1024 x 768. Four Marquee Electrohome 9500LC projectors, one per wall, provided images updated at 85 Hz (42.5 Hz for each eye). Head and hand six degree-of-freedom position and orientation information was acquired using Polhemus Fasttrak magnetic trackers.

2.2.3 Procedure

The basic task of the experiment was color-matching using the CavePainting [2] color picking widget. The widget operates as follows. Using cylindrical coordinates in the interaction frame-of-reference, the user's hand position determines a point in HSV color-space.

For the task of color matching, two horizontally-adjacent rectangular blocks (swatches) were rendered slightly above the color-picking widget. One of the boxes was colored with the target color and did not change. The other was colored with the currently selected color of the color-picking widget.

Each subject was asked to complete a calibration step and a practice session of six color matching trials. The calibration step measured the height and reach of each subject. The basis units of Poupyrev's body-centered coordinate system were used as parameters for specifying the interaction frame-of-reference (see [5]).

The subject first performed a centering task to ensure he or she began in the same position for each trial. This prevented the target location of one trial from affecting the movement distance required to match the target in the subsequent trial. Centering involved two steps: ensuring a standing position in the center of the display (the point on the floor of the SSVE four feet from each wall) and ensuring that the hand, holding the tracked wireless mouse, was positioned at a the origin of the interaction frame-of-reference.

As each subject was informed in the instructions, the goal was to match the target color as closely and as quickly as possible, but that no time limit would be imposed. The subject adjusted the position

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of his or her hand in the interaction frame-of-reference, moving the cursor in the display frame-of-reference (the color picking widget), until a satisfactory match was achieved. The subject clicked the mouse button to signify he or she was satisfied with the match and a new trial would begin after a short pause.

Each subject completed 45 trials, 15 per condition. After completion of these 45 trials, the subject was asked to complete a short second phase of the experiment. During this part of the experiment, the fundamental task remained color matching, but the subject was allowed to manipulate the offset distance between the interaction and display frames-of-reference.

2.2.4 Performance Metrics

Quantitative data were collected from all subjects. Two values were collected per color matching trial: time to completion and chosen color. Distance and accuracy-per-time scalars were derived from these raw measurements.

3 RESULTS

The experiment was conducted using a within-subjects design with three offset conditions. Six ordering types were possible. Given 29 subjects, some ordering types are necessarily represented more frequently. If ANOVA is applied to the full set 29 subjects, ordering type emerges as a significant factor in the distance scalar means (F-value 2.8397, Pr(>F) 0.03863). To minimize the impact of this effect during analysis of the measured results, we adopted a balanced design with each ordering type used an equal number of times. Therefore, we discard data for five subjects and used only twenty-four subjects in the analysis, each ordering type being represented four times. We discarded subject data not only to balance the design with respect to ordering types, but also with respect to gender. Balancing the design with respect to ordering type and gender requires that there be exactly two female and two male subjects per ordering type. Thus, one observation must be discarded for those ordering type-gender pairs that have three subject measurements. For these cases, the subject who participated earliest in the course of the overall experiment was removed.

3.1 Comparison of means

The null hypothesis under investigation states that the means of each condition are equal. In the distance metric, ANOVA analysis allows this hypothesis to be rejected with Pr(>F) = 0.0224. The other metrics in the matching task do not show significant differences between means. The centering task performance, in which the time was minimized in the short offset condition, demonstrates a strong significance.

The results of paired-sample t-tests with Bonferroni correction show that the accuracy differences between the collocated and each of the offset conditions were significant (p-values $< .003$), but that little difference exists between the two offset conditions for the color matching task. In contrast, the short offset and collocated condition perform similarly for the centering task, whereas the long offset condition exhibited definitively inferior performance (p-values $< 10^{-5}$).

3.2 Second Experiment Phase: Widget Placement

The second part of the experiment allowed the subject to specify the offset between the interaction frame-of-reference and the display frame-of-reference prior to each color matching attempt.Ultimately, subjects, on average, preferred an offset of $1\,\frac{1}{3}$ feet with a standard deviation of 1.026.

4 DISCUSSION

Each of the two offset conditions proved to be significantly better. Prior to the experiment, it was posited that the offset conditions would be best as they would minimize distraction during use of the color-picking widget. This hypothesis can be accepted based on the results. No significant difference for any performance metric was found between the two offset conditions. In the second experiment phase, subjects rarely moved the widget to an offset greater than the long offset, suggesting that two feet is larger than the optimal offset. The results indicate that performance degrades as display-interaction offset distance is decreased from three to zero inches for this color-matching task.

Although our initial goal was to explore the effect of display-interaction offset on user-performance with the color-picking widget, we ultimately garnered statistical results for the centering task as well. This task is most comparable to the previous results reported by Mine and Paljic. Much like their chosen tasks, the centering task performed prior to each matching trial involved aligning a movable virtual object with one of identical shape fixed in virtual space. For the centering task, our results confirm those found by Mine and Paljic: collocation or a short offset maximizes user performance.

The results of our analysis for color matching lead to a different conclusion. We believe that the color-picking widget borrowed from the CavePainting application may embody an interaction technique not generalized by previous studies.

5 CONCLUSION

We have presented an experiment that explored how positional offsets affect user performance in a color matching task using a 3D color-picking widget in a surround screen virtual environment. Each trial of the experiment included an object-docking task (centering) prior to the matching attempt. Our results both agree and disagree with previous work. On the one hand, our centering task demonstrates increased user performance with minimal offset. This is in line with previous work, which has hypothesized that shorter offsets between the display and interaction frames-of-reference maximize performance. On the other hand, our analysis of the color matching task reveals that performance at the zero offset condition is worse than at a small or a large offset. We believe this contrast exposes a separate class of task that is not precisely governed by any previous guideline. While object-docking is a coarse task during which the subject must not necessarily look at any precise location of the given virtual objects, color matching requires close attention to exact areas of the color-picking widget. We believe that since our experiment employed a virtual widget borrowed from an established VE application, we were able to identify performance differences from other previous studies. Thus, we recommend that future work in display-interaction offset studies explore other elements of deployed VE applications in order that a more complete understanding of offset effect across the taxonomy of interaction techniques be established.

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