Effectiveness of Occluded Object Representations at Displaying Ordinal Depth Information in Augmented Reality

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ABSTRACT

An experiment was conducted to investigate the utility of a number of iconographic styles in relaying ordinal depth information at vista space distances of more than 1900m. The experiment consisted of two tasks: distance judgments with respect to discrete zones, and ordinal depth determination in the presence of icon overlap. The virtual object representations were chosen based on their effectiveness, as demonstrated in previous studies. The first task is an adaptation of a previous study investigating distance judgments of occluded objects at medium field distances. We found that only one of the icon styles fared better than guessing. The second is a novel task important to situation awareness and tested two specific cases: ordinal depth of icons with 50% and 100% overlap. We found that the case of full overlap made the task effectively impossible with all icon styles, whereas in the case of partial overlap, the Ground Plane had a clear advantage.

Keywords: Augmented reality, human factors evaluation, situation awareness, ordinal depth, X-ray vision.

1 INTRODUCTION

Many challenges have limited the ability of AR systems to provide adequate *situation awareness* (SA) information, particularly distance information for virtual object representations. The experiment outlined in this abstract investigates the utility of various visual representations in providing distance and ordinal depth information for occluded objects. It is a continuation of a previous study [4] which investigated judgments of virtual object placements at medium field distances. As in our previous work, we used outline shapes for military standard icons [3]: a square and a diamond. These shapes were accompanied by four occlusion representations (Figure 1), as well as a baseline case in which no distance information appeared with the icon.

- *Distance Label*
  Egocentric distance (meters) was displayed beside each icon.
- *Ground Plane*
  Concentric circles, centered at the user, with "tie lines," extending downward, provide distance information [5, 6].
- *Virtual Wall*
  This technique was taken from [4], without further adaptation.
- *Virtual Tunnel*
  We altered the technique, as presented in [1, 2, 4] to represent "tunnels" through discrete distance zones, instead of objects.

Two tasks were used to measure the effectiveness of each representation at relaying distance information: determining ordinal depth relative to the real world (Zone Identification), and identifying the closer of two overlapping virtual objects (Proximity). These fundamental tasks are critical to establishing and maintaining SA, and thus constituted appropriate tasks for our evaluation. Furthermore, the virtual objects in this experiment are at far greater distances than in previous evaluations.

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2 USER STUDY

We conducted a single user study with two separate tasks, both of which were performed by each participant, outdoors in an open parking area with an unobstructed view of an airport and surrounding buildings. All virtual representations were placed in and around the airport and buildings at distances greater than 1900m.

2.1 Experimental Hardware

A custom prototype AR display was used in this study. It was a monocular, monochrome green, holographic display with a resolution of 1024×768 and field of view of $40^\circ \times 30^\circ$. Three to six layers of 0.3 neutral density filter (one f-stop, 50% transmission) helped balance the brightness of the graphics with the brightness of the real environment. The display was mounted to a rigid frame to control registration error and prevent unwanted motion due to wind and other environmental factors. The frame enabled freedom of movement in the vertical direction, allowing the height to be adjusted for each user. The graphics were rendered by a platform consisting of a 3.4 GHz Pentium-D processor with 2.87 GB of RAM running Windows XP and an NVIDIA GeForce 7950 GX2 graphics card.

2.2 Experimental Tasks

Reaction time was recorded in addition to the task responses below.

Zone Identification The real environment was partitioned into three discrete zones: the area in front of the airport buildings (1900-2500m), from the airport buildings up to the city skyline (2500-3100m), and beyond the city skyline (3100-3600m). Users were then tasked with identifying in which of the three zones each virtual object representation was placed [4]. For each trial, users viewed two icons drawn in the same occlusion style. The zone placement was independent for the two icons, and users sequentially entered their responses, leftmost icon first followed by the rightmost.

Proximity Task Pairs of icons at Half (50%) and Full (100%) overlap were shown to users, who determined which of the two was closer. They were not forced to guess, and an option was included for them to indicate that the information provided by the representation was to inadequate to conjecture a response.

2.3 Subjects and Procedures

Eighteen subjects (14 male, 4 female), 18-56 years of age (mean=33), participated in the study. All reported normal or corrected-to-normal vision and average to heavy computer use. Two reported significant experience with head-worn AR displays.

Before beginning the experiment, the display was adjusted to the user's eye height, and a calibration image set was used to adjust the yaw and pitch of the display according to user feedback. Each subject was provided an overhead map of the area, and a thorough

Figure 1: Views through the HMD of several representations used in this study. Left to Right: Ground Plane, Distance Label, Virtual Tunnel, Virtual Wall (all from the Zone Identification task), Ground Plane 50% overlap, Ground Plane 100% overlap (both from the Proximity task).

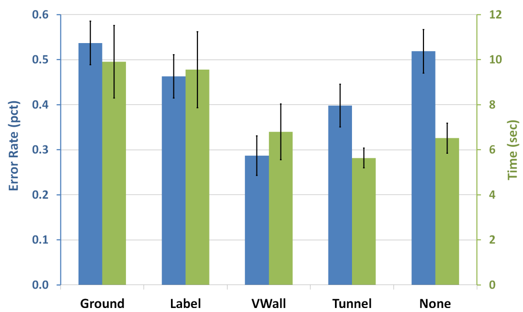

Figure 2: Occlusion representation had a main effect on both error (blue) and response time (green) for Zone Identification. Users were most accurate with the Virtual Wall, but trended faster with the Virtual Tunnel. Error bars in all graphs denote one standard error unit.

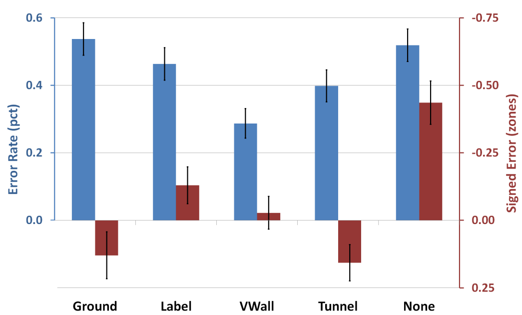

Figure 3: The signed error (red) showed a main effect on Zone Identification based on occlusion representation; by comparing this with the error rate graph (blue, repeated from Figure 2), we can understand both the frequency and direction of errors. In the signed error, positive error means that users said the object was farther than it really was; negative error means users said it was closer.

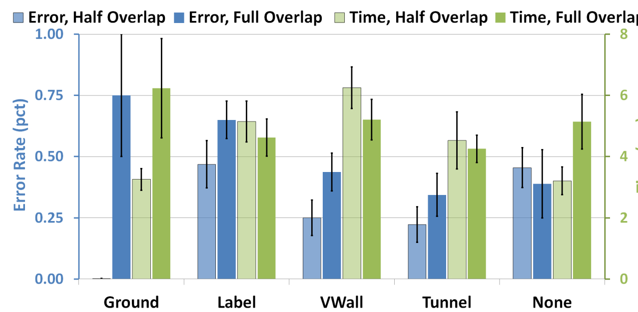

Figure 4: Analysis of the Proximity task for error (blue) and response time (green), separated into sub-cases of Half overlap (lighter shades) and Full overlap (darker shades), showed the Ground Plane enabled almost error-free performance in the case of Half overlap, but revealed no significant differences in the case of Full overlap.

explanation of the occlusion representations. The subject then proceeded through the experiment, with the task order determined by a Latin square balanced for first-order residual effects. The ordering of trials within each task was determined by random permutation.

3 Study Results

There was a significant main effect of the occlusion representation on the unsigned error in Zone Identification (Figure 2). Users also tended to make a judgment faster with the Virtual Tunnel than with the Ground Plane or Label. Using a signed error metric, the occlusion representation again showed a significant main effect (Figure 3). For this metric, error was counted by how many zones off it was, since there is a qualitative difference in misunderstanding a representation by two zones rather than one. The baseline condition more often caused users to believe the icon was closer than it really was. The Virtual Wall was the closest to a mean of zero, and both the Ground Plane and Virtual Tunnel led users to believe an icon was farther than it really was.

Errors in the Proximity task were analyzed by occlusion representation and amount of icon overlap. Error was significantly higher for Full overlap, and participants were most accurate with the Ground Plane, but only in the 50% overlap condition (Figure 4), making only one mistake. Similarly, users felt confident enough to respond with the Virtual Wall and Virtual Tunnel in the 50% case.

4 Conclusions

Some issues with the occlusion representations, such as legibility, may have limited their utility and user performance. The brightness of the real environment may have also inhibited the effectivness of the display. Future revisions may benefit from alterations to the representations to optimize them for the environmental conditions.

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