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Depth Judgment Tasks and Environments in Near-Field Augmented Reality

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ABSTRACT

In this poster abstract we describe an experiment that measured depth judgments in optical see-through augmented reality at near-field distances of 34 to 50 centimeters. The experiment compared two depth judgment tasks: *perceptual matching*, a closed-loop task, and *blind reaching*, a visually open-loop task. The experiment tested each of these tasks in both a *real-world* environment and an *augmented reality* environment, and used a between-subjects design that included 40 participants. The experiment found that matching judgments were very accurate in the real world, with errors on the order of millimeters and very little variance. In contrast, matching judgments in augmented reality showed a linear trend of increasing overestimation with increasing distance, with a mean overestimation of ~ 1 cm. With reaching judgments participants underestimated ~ 4.5 cm in both augmented reality and the real world. We also discovered and solved a calibration problem that arises at near-field distances.

Keywords: depth perception, augmented reality, optical see-through display, x-ray vision

1 INTRODUCTION

Previous studies have used *perceptual matching* techniques to study depth judgments in near-field augmented reality (e.g., Ellis and Menges [1], Rolland et al. [3]). Even though many near-field AR applications have used perceptual matching, many perceptual scientists do not consider it an appropriate measure of depth perception, because it can only measure the depth perception of one object *relative* to that of another object.

This abstract describes an experiment that studied depth judgments in near-field AR using both perceptual matching and *blind reaching* tasks. This experiment extends our previous experiment (Singh et al. [4]) that studied the same tasks, but uses a between-subjects design, and improves the experimental methodology. In particular, we discovered and solved a systematic calibration problem in near-field AR which is related to how the display fits on the participant's head.

2 THE EXPERIMENT

Figure 1 displays the apparatus that we developed for this experiment; the apparatus is modified from the one that we reported previously (Singh et al. [4]). The apparatus is a height-adjustable tabletop. In the *real-world* environment, observers saw a slowly rotating (4 rpm) physical white wireframe diamond shape with a 10 cm base and 10 cm height. As shown in Figure 1, this target object was attached to an arm and could be positioned at a variety of distances in front of the participant. In the *augmented reality* environment, observers saw a virtual rendering of the same target object. In both environments participants viewed the target object through our AR head-mounted display, an nVisor ST model by NVIS, Inc.; in the real-world environment the HMD did not show any graphics.

For the *perceptual matching* task, observers manipulated a slider located underneath the table; this slider adjusted a small light located above the table. The task was to align the bottom of the target object with the top of the light to match the depth of the bottom of the target object. For the *blind reaching* task, participants adjusted the same slider underneath the table until they believed that their thumb was located directly underneath the tip of the target object. Because participants rested the front of the display on the tabletop, they could not see their hand, and so this task was performed blind.

The experiment involved 40 participants in a between-subjects design; 10 participants experienced each of the four main conditions of (1) matching, real-world; (2) matching, AR; (3) reaching, real-world; and (4) reaching, AR. Each participant saw the target object presented at 5 distances (34, 38, 42, 46 and 50 cm), with each distance repeated 6 times, for a total of $5 \times 6 = 30$ depth judgments per participant.

3 NEAR-FIELD CALIBRATION PROBLEM AND SOLUTION

While conducting this study we discovered a problem with the calibration technique we described in our previous study (Singh et al. [4]). We believe that this calibration problem, and our solution, has not been previously reported. The problem results in a lateral separation of up to 2 cm between real and virtual objects. Our calibration technique was originally developed for medium-field distances (Jones et al. [2]); at these distances a 2 cm separation is relatively small and can be ignored. However, 2 cm is a large error at near-field distances.

Figure 2 illustrates the problem. In Figure 2(a) the HMD's eyepieces are at equal distances from the center of the HMD. When the participant aligns everything (the real and virtual calibration crosses, the translational crosshair, and the rotational crosshair; see Jones et al. [2]), the system is calibrated, and therefore real and virtual objects overlap. However, Figure 2(b) shows what happens when the HMD's eyepieces are not centered. When the translational and rotational crosshairs are aligned, there can be a lateral separation of up to 2 cm between the real and virtual calibration crosses, because the whole scene is shifted to appear between the HMD's eyepieces. Figure 2(c) shows how participants compensate for this: they rotate (yaw) their head to eliminate the lateral separation between the calibration crosses; this configuration does not result in any translational error, but it does create rotational error that shows up as a misalignment in the rotational crosshair. Figure 2(d) shows what happens when participants correct this rotational error. Note that here everything is properly aligned, but the real and virtual objects, which should be collocated, do not overlap.

Therefore, the calibration technique described by Jones et al. [2] and used in our previous study (Singh et al. [4]) only works when the eyepieces are centered in the display (Figure 2(a)). The problem described here was difficult to find because often the eyepieces are properly centered. However, Figure 3(a) shows what happens when the HMD is worn while shifted to one side of the head. The first step of the calibration procedure described by Jones et al. [2] is to monocularly adjust concentric circles so that equal amounts of

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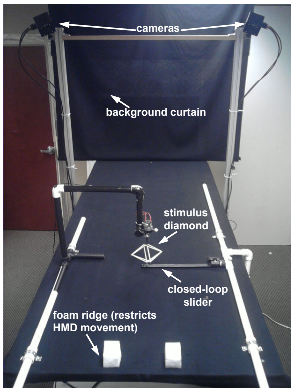

Figure 1: The experimental apparatus.

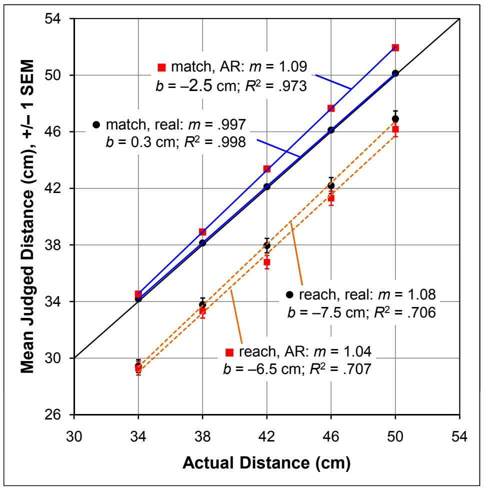

Figure 4: The experimental results.

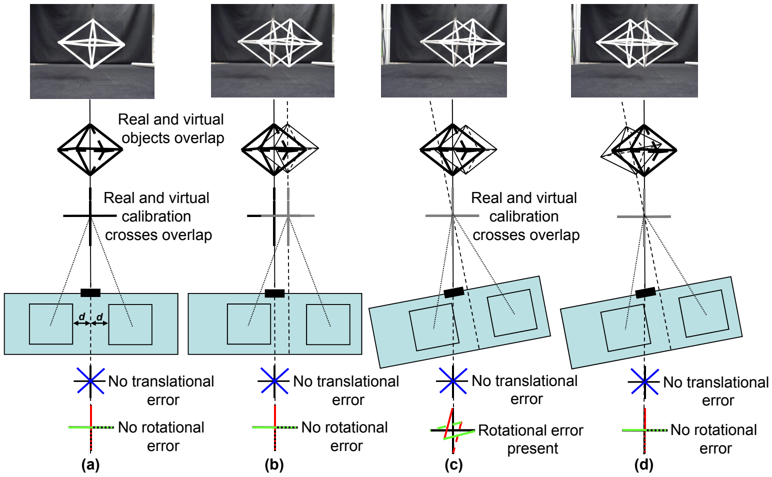

Figure 2: The calibration problem arises when the HMD is shifted to one side on the participant's head.

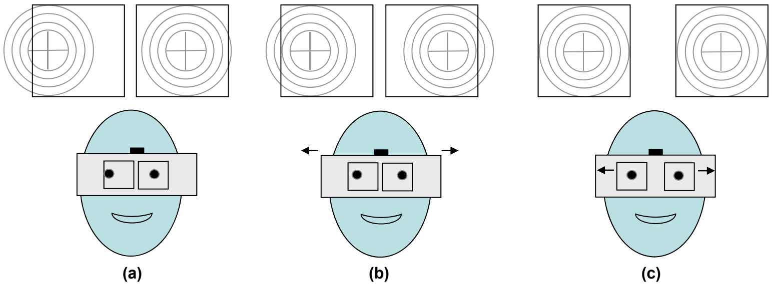

Figure 3: The solution is to align the HMD on the head as part of the optical calibration step.

the outermost circle are visible; this ensures that each of the participant's eyes are looking down the middle of each monocle's optical axis. In Figure 3(a) the participant would adjust the left monocle more than the right, resulting in the calibration problem described above.

Figure 3 describes the solution. First, both monocles are adjusted all the way inward. If the situation of Figure 3(a) occurs, the participant shifts the entire HMD left and right on the head until they have a symmetric view of each set of concentric circles (Figure 3(b)). This ensures that the HMD is centered on the head. Then, as shown in Figure 3(c), the participant adjusts each monocle until equal amounts of the concentric circles are visible. This solves the calibration problem described here.

4 RESULTS

Figure 4 displays the main experimental results; as demonstrated, a linear model describes the results in each condition very well. Participants were extremely accurate matching in the real-world, but increasingly overestimated matches in AR. While this suggests that there are still display and/or calibration problems with this AR system, these problems are bounded within ~ 1 cm at these distances.

Reaching results were very similar in both the real-world and AR; we found no statistical evidence of a difference due to environment, and our preliminary analysis indicates that if the small effect size (Cohen's $d = .175$) were to remain constant as additional participants were run, then a total of 808 participants would be required for this effect to become significant (assuming $\alpha = .05$, power = .80, and participant groups of equal size). This is strong statistical evidence that the blind reaching judgments generated equivalent slopes and biases for both environments, and argues that blind reaching may be a suitable depth judgment task for near-field AR. This argument is somewhat tempered by the underestimation of ~ 4 cm for reaching tasks, but we are currently replicating this study with a modified reaching task that may result in more accurate reaching.

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