The Effect of an Occluder on Near Field Depth Matching in Optical See-Through Augmented Reality

Chunya Hua* J. Edward Swan II*

Mississippi State University

Abstract

We have conducted an experiment to study the effect of an occluding surface on the accuracy of near field depth matching in augmented reality (AR). Our experiment was based on replicating a similar experiment conducted by Edwards et al. [2]. We used an AR haploscope, which allows us to independently manipulate accommodative demand and vergence angle. Sixteen observers matched the perceived depth of an AR-presented virtual object with a physical pointer. Overall, observers overestimated depth by 6 mm or less with or without the presence of the occluder. The data from Edwards et al. [2] is normalized, and when we performed the same normalization procedure on our own data, our results do not agree with Edwards et al. [2]. We suspect that eye vergence explains these results.

Keywords: Depth perception, augmented reality.

1 Introduction

Accurate depth perception is known to be a difficult problem for Augmented Reality (AR) systems, and for many compelling AR application domains, it is important to understand how depth perception operates. Some promising application domains, such as medical applications, involve precise hand manipulations in the context of AR-presented guides or makers at near field reaching distances of 1 meter or less. However, to date only a small number of near field depth perception experiments have been conducted. In his dissertation, Singh [1] provides a comprehensive literature review of near field depth perception, and in addition studies the effects of accommodative demand, brightness, and participant age on depth perception. Among the additional near field depth perception experiments, Edwards et al. [2] conducted a perceptual experiment, in the context of introducing AR-presented virtual objects in a surgical microscope.

A key requirement for AR-assisted medical applications is for users to have the ability to place a real world object, such as scalpel, at a precise depth, where the depth is indicated by a virtual mark or indicator (Edwards et al. [2]). This can be studied with perceptual matching, where observers indicate the perceived depth of a virtual object by placing the tip of a physical pointer at the same distance. Singh [1], studying near field reaching distances, found that observers could match the depth of a real world object with high precision (error < 1 mm), and the depth of an AR object with somewhat less precision (error < 5 mm).

The surgical context of Edwards et al.'s [2] work was brain surgery, and therefore they used a plastic model of a human head as an occluding surface. Their AR-presented virtual object represented a flat slice of scanned anatomical data. They placed the AR object at depths ranging from 20 mm in front of the occluding surface to 80 mm behind (see Figure 3). Five observers, seated 400 mm from the head, matched the depth of the AR object with a physical pointer. They report depth errors of less than 3 mm, which may be accurate enough for some image-guided surgical techniques. As shown in Figure 3, their maximum error of ~3 mm was an overestimation, and occurred about 10 mm behind the occluding surface. However, Edwards et al. [2] normalized their data so that each observer had zero average error in front of the occluding surface (see Figure 3). They did this to remove any remaining calibration error after adjusting their system according to each observer's inter-pupillary distance.

In our experiment, we have replicated the experiment of Edwards et al. [2], using the AR haploscope developed by Singh [1]. We wanted to see if we found the same pattern of depth judgments with our device.

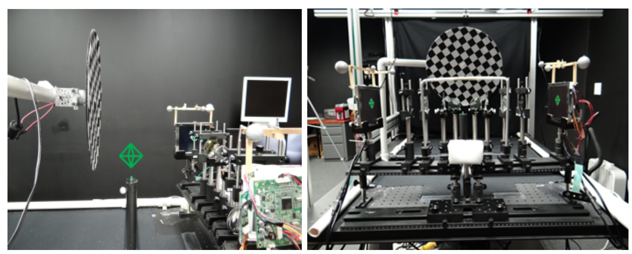

Figure 1: Our AR haploscope.

2 Experiment

Figure 1 shows our AR haploscope. We duplicated the experimental setup and design of Edwards et al. [2], to the degree possible with our equipment. Our primary experimental variable was occluder (present, absent); when present, our occluder was a disk printed with a highly salient black and white checkerboard pattern, rotating at 4 rpm (see Figure 1). We placed the occluder 400 mm from our observers' eyes. Our virtual target object was a green pyramid, which also rotated at 4 rpm. We presented the target object at the same distances as Edwards et al [2]: 380, 385, 390, 395, 400, 405, 410, 415, 420, 440, and 480 mm from the observer. Our AR haploscope presented this object with an accommodative demand of 400 mm, and accurately modeled the correct eye vergence for each distance. We calibrated our system by carefully matching the size and position of an identically-sized real world target object at each distance. Each observer saw the target at each distance twice. For each observer, we randomly permuted the distances, with the restriction that each distance varied in depth at least 20mm from the previous distance. Observers matched the depth of the virtual target with a physical pointer, which ran in a track so that the tip of the pointer could be placed directly below the target's bottom tip. Sixteen observers participated, 8 in the occluder = present condition, and 8 in the occluder = absent condition.

* Chunya Hua <ch1242@msstate.edu>,
J. Edward Swan II <swan@acm.org>

3 RESULTS

Figures 2–4 show the results. In these figures, the surface relative depth shows the position of the virtual target relative to the position of the occluder, from 20 mm in front to 80 mm behind. Error is calculated as *matched depth – actual depth*, so positive numbers indicate overestimation, while negative numbers indicate underestimation.

Figure 2 shows our results. Overall, observers overestimated depth by 3 to 6 mm on average in the presence of the occluder and in the absence of the occluder. For both conditions, the results vary with target depth. The overall variation in depth is 3 mm or less, over a total tested depth range of 100 mm under both conditions. A repeated-measures ANOVA did not find a difference between the depth errors of the two conditions, $F(1,14) = 0.014$, $p = 0.91$.

Figure 3 shows the results of Edwards et al. [2]. In order to compare our results to theirs, we normalized our results so that each observer had zero average error in front of the occluding surface (Figure 4). We found underestimation of 1 mm or less in the first 20 mm behind the occluding surface. Again, a repeated-measures ANOVA did not find a difference between the normalized depth errors of the two conditions, $F(1,14) = 0.024$, $p = 0.88$. Overall, our results are more accurate, with normalized error of –1 to 1.3 mm at distances of 20 to –40 mm, and 2.2 mm at distance of –80. In contrast, Edwards et al. [2] found an overestimation of 2.1 ± 3 mm.

The physical setup of the two experiments was quite different, and we suspect that this explains these different results. In particular, in our experiment, our haploscope accurately modeled the eye vergence for each distance, while Edwards et al. [2] created disparity by modifying the virtual image. In addition, our occluding surface was much more salient than Edwards et al.'s [2] plastic head model.

In future experiments, we plan to investigate the effect of an occluding surface with a less salient surface, such as either black or white. In addition, we plan to use a binocular eye tracker to measure observers' vergence eye movements.

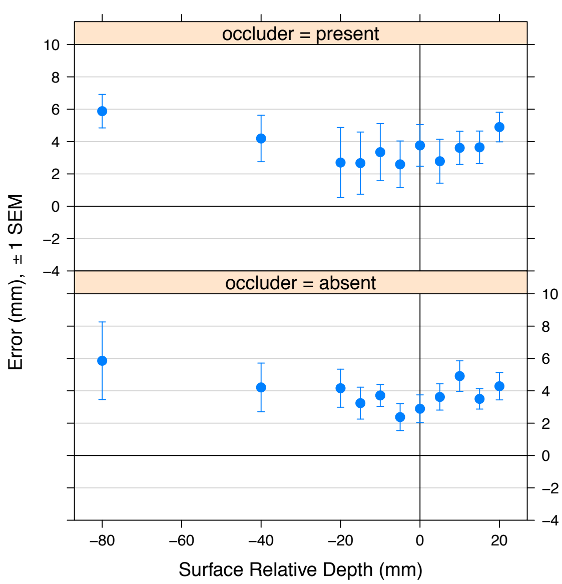

Figure 2: Our results, in terms of error by occluder condition.

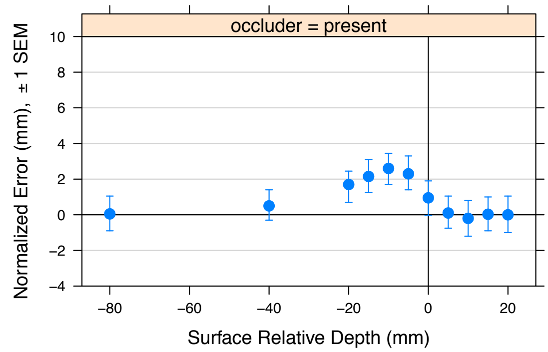

Figure 3: The results of Edwards et al. [2].

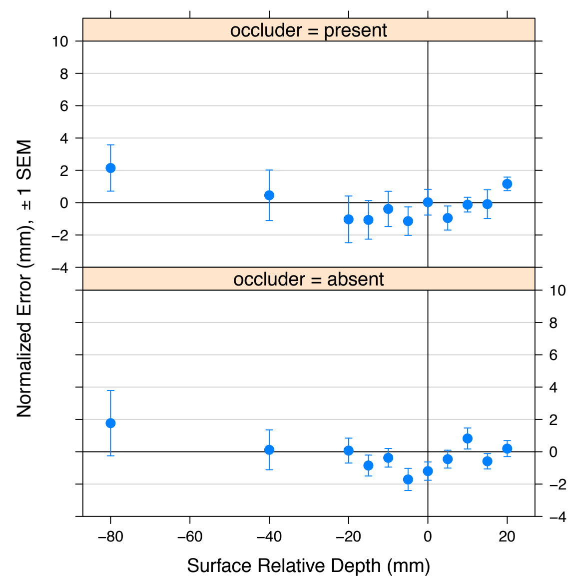

Figure 4: Our results, with error normalized using the method of Edwards et al. [2].

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