A Method for Measuring the Perceived Location of Virtual Content in Optical See Through Augmented Reality

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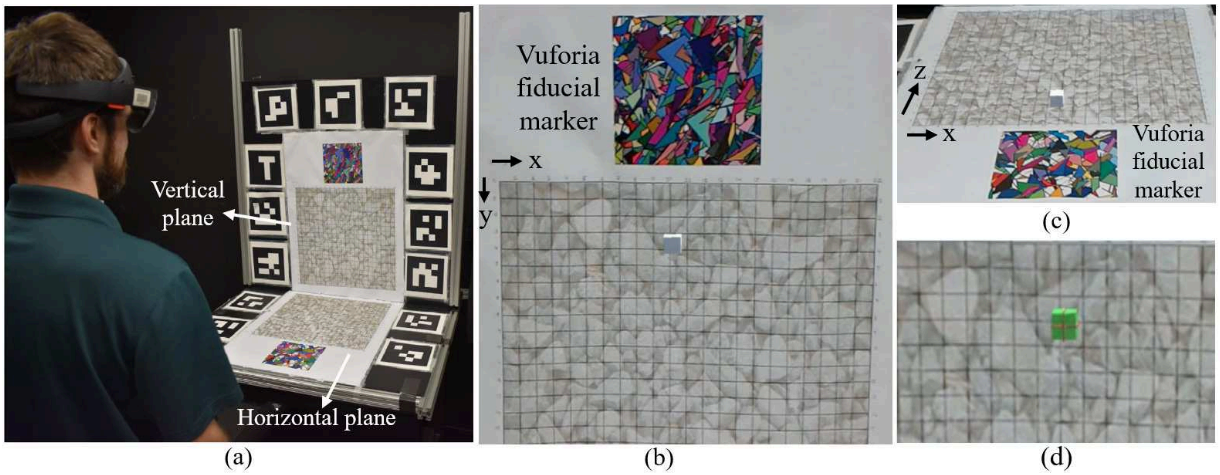

Figure 1: (a) Experimental participant, viewing the horizontal and vertical plane. (b) Participant verbalizes the perceived grid location of a virtual cube on the vertical plane. (c) A virtual cube on the horizontal plane. (d) An alternative virtual cube design.

Abstract

For optical, see-through augmented reality (AR), a new method for measuring the perceived three-dimensional location of a small virtual object is presented, where participants verbally report the virtual object's location relative to both a horizontal and vertical grid. The method is tested with a Microsoft HoloLens AR display, and examines two different virtual object designs, whether turning in a circle between reported object locations disrupts HoloLens tracking, and whether accuracy errors found with a HoloLens display might be due to systematic errors that are restricted to that particular display. Turning in a circle did not disrupt HoloLens tracking, and a second HoloLens did not suggest systematic errors restricted to a specific display. The proposed method could measure the perceived location of a virtual object to a precision of $\sim$1 mm.

Index Terms: Augmented Reality—Depth Perception—Human-subject experiment—Virtual Object Location;

1 Introduction

A long-standing goal of optical see-through (OST) augmented reality (AR) is that virtual objects are perceived to be located at intended positions. A central challenge is *measuring* perceived location; such measurements require a perceptual task that can be quantified into a real world position. Perceived depth has often been measured (Jones et al. [1]), using a variety of measurement methods, but depth only measures one dimension of location. This work proposes a new method for measuring the perceived location of virtual objects, in all three dimensions. The method is adopted from Moser et al. [2], where it was originally used to measure the effectiveness of OST head-mounted AR display calibration methods.

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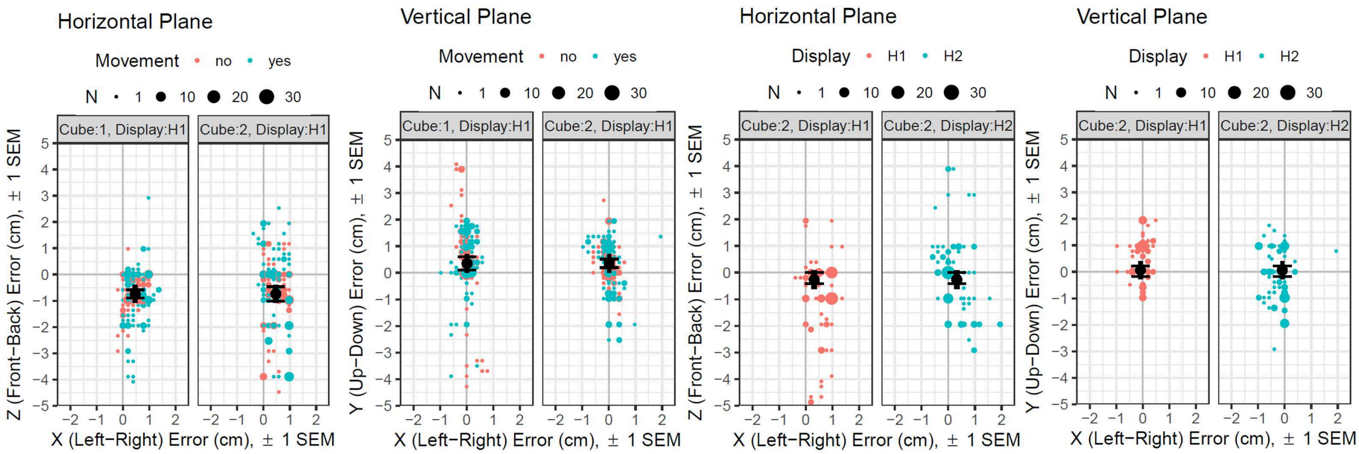
This is an author version preprint. The final version is available as: Farzana Alam Khan, Veera Venkata Ram Murali Krishna Rao Muvva, Dennis Wu, Mohammed Safayet Arefin, Nate Phillips, J. Edward Swan II, "A Method for Measuring the Perceived Location of Virtual Content in Optical See-Through Augmented Reality", *IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops* (VRW), Lisbon, Portugal, March 27–April 3, 2021, pages 657–658, DOI: 10.1109/VRW52623.2021.00211.

2 Measurement Method and Experimental Task

As shown in Figure 1a, the participant views a horizontal and a vertical plane, each marked with a 22 by 22 cell grid. Together the grids mark out space in the X (left-right), Y (up-down), and Z (front-back) dimensions, with the horizontal plane in XZ and the vertical plane in XY. Grid cells measure 1.95 cm by 1.95 cm. In each trial, the participant sees a cube rendered within a first-generation Microsoft HoloLens display; either a white cube (cube 1, Figure 1b, c) or a green cube with red bisecting lines (cube 2; Figure 1d). The participant's task is to indicate the perceived grid location of the center of the cube, estimated to the nearest tenth; e.g., a perceived location might be reported as "the center is at 14.2 along X, and 9.6 along Y."

To measure the perceived location, the AR display must be very carefully calibrated to the grid; the display's internal, virtual grid must precisely match the location and size of the real-world grid. With the HoloLens, this task was difficult; a central technical challenge was accurately aligning a HoloLens *anchor point* to a specific real-world location. As shown in Figure 1a and b, Vuforia optical tracking was used to center a virtual cube within the Vuforia fiducial marker. When the participant reported that the cube was properly centered, Vuforia tracking was switched off, and the cube's location was updated using the built-in HoloLens tracking.



(a) (b) (c) (d)

Figure 2: The results of two experiments. (a) and (b) show the result for the first experiment, for the horizontal (a) and vertical (b) planes. The error of perceived locations are shown as dots, with dot size indicating the number of times each error occurred. Dot color indicates whether participants moved in a circle between reporting cube locations. The facets indicate whether the first cube design (cube 1; figure 1b) or second cube design (cube 2; figure 1d) was used. The black dot indicates the overall error, and standard error bars indicate precision in each dimension. (c) and (d) show the results for the second experiment, for the horizontal (c) and vertical (d) planes. Here, both color and facet indicate which of two identical HoloLens displays was used, HoloLens H1 or H2.

Participants stood in front of the experimental table (see Figure 1a), and performed the Vuforia alignment procedure. Then, participants observed a sequence of ten random cube locations, and verbally reported the location of each cube. For every experimental condition, this was repeated for both the horizontal and vertical plane.

3 First Experiment

The first experiment (Figure 2a, b) examined two questions: whether one of two different cube designs (cube: 1, 2; Figure 1b and d) would be perceived more accurately, and whether turning in a circle between each cube location would disrupt HoloLens tracking (movement: yes), as compared to standing still (movement: no). 24 subjects participated; 12 saw cube 1 and the other 12 saw cube 2.

For the horizontal plane, for both cube designs (Figure 2a), X errors had high precision ($\sim$1 mm SEM), but were not accurate, exhibiting a rightward bias of $\sim$5 mm. Z errors showed less precision ($\sim$5 mm SEM), and were not accurate, exhibiting a bias of $\sim$7 mm closer than intended (see Figure 2b). This underestimation replicates that found in previous studies, such as Jones et al. [1]. For the vertical plane, for both cube designs (Figure 2b), X errors had high precision ($\sim$1 mm SEM), and were accurate, with no measurable bias. Y errors were less precise ($\sim$5 mm SEM), and not accurate, exhibiting an upward bias of $\sim$4 mm.

Overall, the cube design made no difference, and participants were just as accurate when they moved in a circle between each trial as when they stood still. While the depth underestimation in Z was expected, the rightward bias on the horizontal plane and the upward bias on the vertical plane could not be explained. We hypothesized that the HoloLens might be exhibiting a systematic error, perhaps caused by the display's optics being slightly out of alignment.

4 Second Experiment

To examine whether a particular HoloLens might exhibit systematic error, the second experiment (Figure 2c and d) compared the first HoloLens (H1) and a second, otherwise identical HoloLens (H2). The cube 2 design was used, and participants stood still. 14 experimental subjects participated and experienced both HoloLenses in a within-subjects design.

The HoloLens used made no difference, either in the horizontal or the vertical plane, which indicates that the unexplained findings from the first experiment were not due to systematic errors occurring in a single HoloLens. Overall the precision was similar to the first experiment. However, the errors improved: for the horizontal plane the rightward bias reduced to $\sim$4 mm, and the underestimation to $\sim$3 mm. For the vertical plane, Y errors were accurate, but there was a leftward bias of $\sim$1 mm. The reasons for the changing bias could not be satisfactorily explained, but unavoidable differences for the second experiment include being conducted in a different location by a different experimenter, and running a HoloLens operating system that was being continuously upgraded, and therefore modified.

5 Conclusion

Although the experiments could not fully explain the reasons for the accuracy errors, the proposed measurement method could measure the perceived location of a 1.95 cm virtual object to a precision of $\sim$1 mm. The measurement method promises to be generally useful.

Acknowledgments

This material is based upon work supported by the National Science Foundation, under awards IIS-1320909, to J. E. Swan II, and IIS-1937565, to J. E. Swan II and Cindy Bethel.

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