Evaluating the Effectiveness of Visual Guidance for Out-of-View Object Localization using Mixed Reality Head-Mounted Displays

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a) 3D Arrow b) 3D Radar c) EyeSee360

Figure 1: Screenshots of three selected visual guidance techniques displaying out-of-view objects in a Mixed Reality environment.

Abstract

Navigating and interacting effectively with virtual content in Mixed Reality (MR) environments poses significant challenges, particularly when localizing objects outside the observer's field of view (FoV). While existing MR approaches can provide visual information to guide the user's attention towards these objects, their efficacy has predominantly been measured through task completion times or the efficacy in their localization. In this work, we explore the effectiveness of visualization techniques used to convey information to the users of this technology in situations that require quick reaction times. A user study involving 24 participants served to investigate the responsiveness of participants when performing search and object identification tasks. Results from this study show that visualization techniques influence user responsiveness, contributing to better understanding how these strategies impact perception and task efficiency.

Index Terms: Human computer interaction (HCI)——Mixed / augmented reality; —User studies; —Visualization techniques

1 Introduction

The development of Mixed Reality (MR) technologies allows users to interact with physical and digital content in a unified space. Although the use of Head-Mounted Displays (HMDs) contributes to the direct observation of real and digital content, their limited field-of-view (FoV) often restricts the peripheral rendering of virtual content, depriving users of important visual cues. To address this limitation, techniques like *3D Radar* [1], *3D Arrow* [4], and *EyeSee360* [3], have been proposed to guide users' attention in MR environments. The effectiveness of these techniques has primarily been tested by task completion times. While task completion time is a critical indicator of efficiency, it does not fully capture user responsiveness with these techniques.

In this work, we aim to bridge this gap by measuring Just Noticeable Differences (JNDs) to reveal the perceptual thresholds at which each technique effectively conveys spatial information. Thus, we conducted a user study involving 24 participants to investigate how different techniques influence user responsiveness.

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2 Selection of Visualization Techniques

To investigate users' responsiveness in localizing objects outside their FoV, we selected three established visualization techniques known for their capacity to communicate spatial information regarding objects located outside the user's field of view.

3D Arrow. Displays a single arrow positioned at the center of the user interface that points towards virtual objects. The visualization is simplified to show only one arrow at a time, without color differentiation or length scaling, as only one out-of-view object is presented at a time and all objects are equidistant. This design keeps it straightforward and allows users to focus on identifying the direction of objects (Fig. 1a).

3D Radar. Features green concentric circles in front of the user, a central triangle for the user's position, and a light-blue cone indicating the FoV. Objects are shown as 3D spheres with 2D circles on the radar plane for horizontal location, with color-coded vertical positioning: red for above eye level and blue for below. A line connects each 3D sphere to its 2D circle to aid in spatial correlation (Fig. 1b).

EyeSee360. A grid system that compresses 3D spatial information onto a 2D plane, with an inner rectangle depicting the user's FoV and the surrounding area representing space beyond immediate vision. Dotted lines indicate 45° sections of the user's view, while horizontal and vertical lines show objects' altitude and direction. Objects within the FoV are shown inside the inner rectangle, and those outside are mapped accurately based on their angular position (Fig. 1c).

3 User Interface Modalities

To investigate the effectiveness of the visualization techniques under different interaction paradigms, we also included two modalities of user interfaces:

Dynamic. This user interface dynamically followed the participant's head movements, ensuring that the virtual prompts would remain within the participant's view. This modality was designed to simulate a continuous interaction scenario where users can always see the UI regardless of the orientation of their head.

Static. In this modality, the user interface remained fixed at its initial spawn position. As a result of this feature, participants could only see the virtual prompts when looking directly forward at the initial position, mimicking scenarios where users must return their focus to a specific location to receive visual guidance.

4 Responsiveness to Visual Stimuli

Just Noticeable Difference (JND) is a critical concept in perceptual psychology used to identify the smallest detectable difference in sensory input that a user can consistently recognize. In our work, this attribute determines the threshold at which participants can react and identify out-of-view objects using the proposed visualization techniques, offering a quantitative basis for evaluating each technique's effectiveness. We use the staircase method to determine JND, which offers a dynamic and adaptive way to measure perceptual thresholds. This method adjusts the difficulty of tasks based on real-time performance feedback, where the adaptive mechanism is crucial for pinpointing the exact perceptual limit at which changes in visualization become noticeable to participants [2].

5 User Study

To investigate user responsiveness to visualization techniques for locating objects outside the FoV, we developed a system where users were asked to complete a series of tasks. Twenty-four unpaid volunteers (6 female and 18 male), aged between 23 and 28 with a mean age of 24.6 ± 1.6 years, took part in the study.

Experimental Variables. The *UI Modality* and *Visualization Technique* served as our independent variables, while the *JND* computed using the staircase method served as our dependent variable.

Task Description. Participants underwent eye calibration with the HoloLens 2 and completed an interactive tutorial to familiarize themselves with the headset and a clicker. Following the tutorial, they performed tasks to locate and interact with virtual objects outside their FoV across eight rounds, split into two sessions. The first round of the first session and the last round of the second session served as ground truth (G.T.) with no visualization. The remaining rounds used the three techniques with two modalities, assigned in a Latin Matrix order. Objects were placed in four predetermined sequences and rotated systematically across the rounds to ensure diverse task scenarios (Fig. 2).

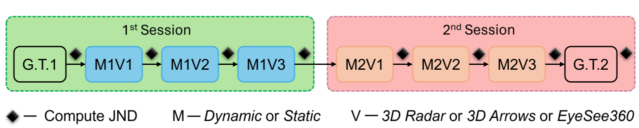

Figure 2: Participants completed two trial sessions using the UI Modalities: *Dynamic* or *Static*. Every session included a ground truth round without visual assistance (G.T.) and three rounds with Visualization Techniques: *3D Radar*, *3D Arrow*, and *EyeSee360*.

Object Placement. Virtual objects were positioned along an arch-like trajectory above and in front of the participant's FoV to resemble scenarios where users must locate items outside their immediate visual range. The objects were consistently spaced along a predefined arch that spanned from the participant's direct left to their direct right, arcing slightly overhead. This configuration ensured standardized search difficulty across trials (Fig. 3).

6 Results

Visualization Techniques. To identify statistically significant differences between *Visualization Techniques*, we first used Shapiro-Wilk tests ($\alpha = 0.05$) to check for normal distribution. Results from this test showed that the data collected did not follow a normal distribution. A subsequent Friedman test showed statistically significant

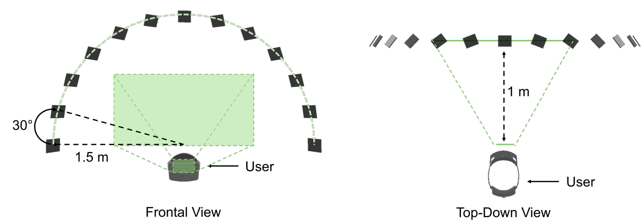

Figure 3: The experimental setup demonstrating the arch-like placement of target objects. A green square is used to depict the HMD's FoV. Target objects arch is positioned outside the user's visual field.

differences among the three techniques ($\chi^2 = 11.44,\ p = 0.0032$). A Post-hoc Dunn-Sidàk test revealed faster response times for *3D Arrow* compared to *EyeSee360* ($p = 0.0383$) (Fig. 4).

User Interface Modalities. To identify statistically significant differences between *Visualization Techniques*, we first used Shapiro-Wilk tests ($\alpha = 0.05$) to check for normal distribution. Results from this test showed that the data collected did not follow a normal distribution. A subsequent Mann-Whitney U test revealed no statistically significant difference between the modalities ($U = 2483.5,\ p = 0.6659$), with both modalities showing a median JND of 1.54 *sec* ($Dynamic:\ IQR = 0.31;\ Static:\ IQR = 0.39$) (Fig. 4).

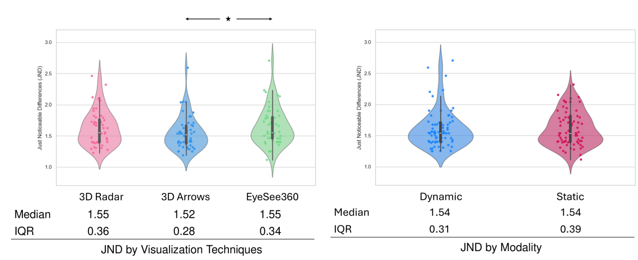

Figure 4: JND scores grouped by *Visualization Technique* (left) and *User Interface Modality* (right). Statistically significant differences ($p < 0.05$) are represented with a $\star$.

7 Conclusion

This study systematically evaluated user responsiveness in MR environments using visualization techniques for locating out-of-view objects. Our analysis using Just Noticeable Differences and NASA TLX scores indicated that *3D Arrow* provided better performance in quick identification tasks. Each technique, however, has unique advantages: *3D Radar* is effective for direction-distance encoding, and *EyeSee360* enhances panoramic awareness. These findings offer valuable design guidelines for developers to choose appropriate visualization methods based on specific application needs.

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