Improving Search Time Performance for Locating Out-of-View Objects in Augmented Reality

Uwe Gruenefeld
OFFIS - Institute for IT
Oldenburg, Germany
uwe.gruenfeld@offis.de

Lars Prädel
OFFIS - Institute for IT
Oldenburg, Germany
lars.praedel@offis.de

Wilko Heuten
OFFIS - Institute for IT
Oldenburg, Germany
wilko.heuten@offis.de

ABSTRACT

Locating virtual objects (e.g., holograms) in head-mounted Augmented Reality (AR) can be an exhausting and frustrating task. This is mostly due to the limited field of view of current AR devices, which amplify the problem of objects receding from view. In previous work, EyeSee360 was developed to address this problem by visualizing the locations of multiple out-of-view objects. However, on small field of view devices such as the Hololens, EyeSee360 adds a lot of visual clutter that may negatively affect user performance. In this work, we compare three variants of EyeSee360 with different levels of information (assistance) to evaluate in how far they add visual clutter and thereby negatively affect search time performance. Our results show that variants of EyeSee360 with less assistance result into faster search times.

CCS CONCEPTS

• **Human-centered computing → Mixed / augmented reality**; *User studies*; *Visualization techniques.*

KEYWORDS

out-of-view, off-screen, augmented reality, user study

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1 INTRODUCTION

Augmented Reality (AR) devices allow a user to alternate the perceived reality by overlaying digital information onto the real world [1]. Therefore, AR technology fundamentally changes the way we interact with technology. Instead of physical screens that are placed at fixed positions, we can interact with virtual content all around us. However, with the limited field of view of current AR devices (e.g., Hololens[1]), this virtual content often recedes from the user's view. This is problematic, because it turns locating virtual objects into an exhausting and frustrating task.

To address the problem of virtual objects receding from view, different visualization techniques have been developed [3, 16, 18]. One of those techniques is EyeSee360, proposed by Gruenefeld et al. [10]. The technique allows one to visualize multiple out-of-view objects at the same time (it has been tested with up to 11 objects without showing any performance decrease in participants). Furthermore, EyeSee360 has been compared to most of the state-of-the-art techniques and was found to result in the best search time performance, lowest workload and highest usability [4, 10, 11]. However, especially on small field of view devices, EyeSee360 as it is currently used, introduces a lot of visual clutter to the screen in the form of additional information (assistance). We hypothesize that this additional information interferes with the perception of other content and may lead to less optimal search time performance. Further, in the original work, three different variants of EyeSee360 [10] were proposed, each offering different levels of assistance information, but were never compared to each other in terms of search time performance.

In this work, we aim to improve the search time performance for locating out-of-view objects in Augmented Reality. We compare three variants of EyeSee360 with different levels of visual information (assistance) in a laboratory user study. Thereby, we want to investigate the influence of more information (assistance) but also more visual clutter on the search time performance. Our results contribute to a better understanding of the effect of visual clutter and assistance onto search times for locating objects out of view. Further,

[1]Hololens version 1 has a field of view of 30° horizontal and 17° vertical.

our results show which variant of EyeSee360 is the best for out-of-view object search tasks.

2 RELATED WORK

Extending the field of view. The problem of objects receding from view is amplified when a head-mounted device (HMD) further limits the human field of view (FOV). To address this problem, Xiao et al. [19] and Gruenefeld et al. [13] suggested extending the FOV of those devices with additional LEDs. Their results show that additional LEDs have a positive effect on the perceived immersion [19] and allow cueing of direction towards objects out of view without adding visual clutter to the existing screen [12]. However, while this approach is suitable for guiding towards virtual objects distributed 360° around the user, the number of objects that can be presented simultaneously is limited. Furthermore, additional hardware is required to implement these techniques.

Off-screen visualization techniques. Just as objects recede from view in current HMDs, content can also recede from small-screen devices such as smartphones. Therefore, researchers have developed various off-screen visualization techniques to show the location of off-screen content. Those techniques can be classified into three main approaches: Contextual views, Focus+context, and Overview+detail [7, 14]. Contextual views (e.g., arrows pointing into off-screen space [5]) and Focus+context (e.g., fisheye-views that convey a distorted view [17]) both overlay the screen borders with contextual information, while Overview+detail shows a miniature map of the surrounding area. Previous work has shown that miniature maps come with the disadvantage of increased cognitive load required to mentally integrate all views [7]. On the contrary, Contextual views such as Halo [2], Wedge [14], and Arrow [6] do not have this disadvantage and were shown to perform best for the visualization of off-screen objects on small-screen devices [5, 15]. However, all those techniques have been developed for handheld 2D displays, and therefore need some adjustments to visualize the locations of out-of-view objects in HMDs.

Out-of-view visualization techniques. In previous work, Gruenefeld et al. [9] adapted Arrow, Halo, and Wedge to head-mounted Augmented Reality to visualize multiple out-of-view objects all at once. Their results showed that all of these techniques are applicable for head-mounted devices, but their approach was limited to 90 degrees in front of the user. Therefore, they developed HaloAR and WedgeAR, which make use of 3D shapes to guide to out-of-view objects [8]. However, the 3D shapes add visual clutter to the screen and are not well suited for small field-of-view devices (e.g., Hololens) or the visualization of many objects at the same time. To visualize multiple out-of-view objects at the same time without addding too much clutter, a new visualization technique called EyeSee360 was proposed [10]. EyeSee360 uses a radar-like visualization to display out-of-view objects. The authors compared the technique to Arrow, Halo, and Wedge, and showed that EyeSee360 resulted in the highest usability and best user performance. Recently, Bork et al. compared EyeSee360 to five other techniques and found significantly lower completion times and better usability when using EyeSee360 [4]. However, EyeSee360 adds visual clutter to the screen, especially for devices with smaller fields of view. Therefore, we want to investigate whether the amount of visual information present in EyeSee360 can be reduced while at the same time improving users' search time performance.

3 EYESEE360

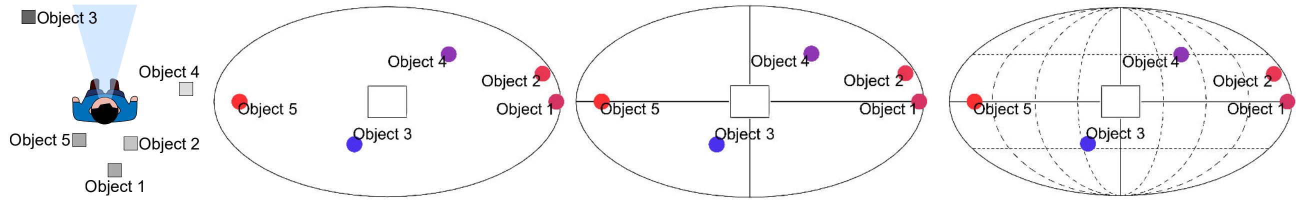
In this work, we aim to improve search time performance of the out-of-view visualization technique EyeSee360 [10]. We chose EyeSee360 because it supports multiple out-of-view objects and encodes their direction and distance relatively to the user in head-mounted Augmented Reality devices. Furthermore, compared to other techniques, EyeSee360 shows the lowest direction estimation error and the fastest search times for objects distributed 360° around the user [4, 10, 11]. EyeSee360 concentrates information about out-of-view objects onto a grid system in the user's periphery (see Figure 1). This grid system compresses 3D position information onto a single 2D plane. The inner rectangle of EyeSee360 represents the FOV of the user, and the area outside the rectangle represents the area outside of the user's view. However, EyeSee360 supports three different variants. The different variants of EyeSee360 offer different levels of assistance for locating objects out of view. The first variant offers no assistance (see Figure 1b), the second variant shows vertical and horizontal zero lines (see Figure 1c), and the third variant shows additional dotted lines representing 45° sections of the user's view. The three variants of EyeSee360 have not been evaluated against each other with regard to search performance. However, we hypothesize that the variant with all helplines offers too much unnecessary information and adds visual clutter to the screen, especially on devices with smaller fields-of-view. We think this results in higher search times and therefore, we will compare the three variants in our first user study.

4 USER STUDY

In this study, we compare the different variants of EyeSee360.

Study design

To evaluate the performance of different variants of EyeSee360 for visualization of objects out of view, we conducted a within-subjects controlled laboratory study in Augmented Reality with the Microsoft HoloLens. During the study, participants were asked to search for objects that are out of view.



(a) Example scene. **(b) No helplines.** **(c) Zero helplines.** **(d) All helplines.**

Figure 1: Out-of-view visualization techniques for virtual objects in example scene. (a) illustration explaining relative positions (bird's eye view); (b-d) user view through Hololens without built-in RGB camera image for better readability (each visualization fits the device screen 1:1). ***Best seen in color.***

Our independent variable was the variant level (no helplines vs. zero helplines vs. all helplines). We used quantitative methods to evaluate user performance, taking search time and subjective Likert-items as our dependent variables.

For this study, we asked: **(RQ) In how far does the visual clutter added by the different variants of EyeSee360 influence search time performance?**

- H_1 We expect the EyeSee360 variants with no helplines and zero helplines to result in faster search time performance because they add less visual clutter and are therefore less distracting.

Apparatus

We set up an empty office space (3 x 3 meter) with darkened windows and an artificial light source to control the brightness throughout the experiment (around 500 lux). Our experiment and all variants of EyeSee360 are implemented in Unity3D[2], a 3D game development platform, and the Microsoft Hololens[3], a head-mounted AR device.

Procedure

At the start of the study, participants received an introduction to the Hololens. After, we started testing the different variants of EyeSee360. Each of the three variants of EyeSee360 was tested in one block. All blocks were counter-balanced, using a balanced Latin square design. For each block, we had two test trials and ten measured trials. In each trial, five virtual objects were randomly placed 360 degrees around the user but not in view (see Figure 1a for an example). Each virtual object was assigned a label, starting with "Object" plus a random number from one to five. On-screen text informed the participant which of the five objects to search for. The participant had to search for the virtual object by moving their head into the direction of the object. When the virtual object appeared in view, the trial was successfully finished. We stored the ten randomly generated positions of the first block and used them in different orders for the other two conditions to ensure the search times would be comparable. After each block, participants were asked to answer two questions regarding performance and distraction. At the end, participants were asked for their favorite variant and filled out a demographics questionnaire. Each participant took approximately 25 minutes to finish the experiment.

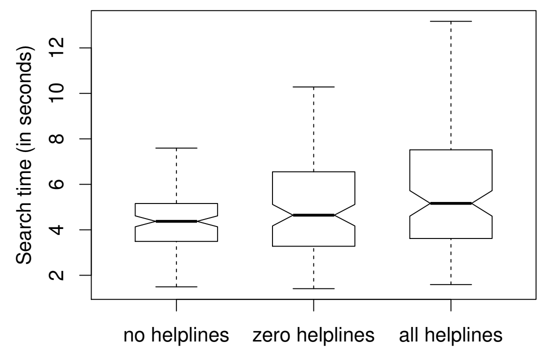


Figure 2: Boxplot of search times for different variants of EyeSee360 for out-of-view object visualization.

Participants

We recruited 12 volunteer participants (5 female), aged between 25 and 54 years (M=35.75, SD=10.38). None suffered from color vision impairments, 8 had normal vision, and 4 had corrected-to-normal vision. We asked the participants to rate their experience with Augmented Reality on a 5 point likert scale. The participants stated that they had limited experience (Md=2, IQR=1.5).

Results

Search time performance. For the first task, we consider the effects of one factor (variant) on search time to locate out-of-view objects. The mean search times for variant are: no helplines=4.51s (SD=1.45s), zero helplines=4.89s (SD=2.08s), and all helplines=6.02s (SD=3.36s). The search times are compared in Figure 2.

[2]www.unity3d.com, last retrieved July 10, 2019
[3]www.microsoft.com/hololens, last retrieved July 10, 2019

A Shapiro-Wilk-Test showed that our data is not normally distributed ($p < 0.001$), and thereafter we ran a Friedman test that revealed a significant effect of out-of-view visualization on search time ($\chi^2(2)$=7.27, p=0.026, N=12). A post-hoc test using Wilcoxon Signed-rank with Bonferroni-Holm correction showed significant differences between some of the conditions (see Table 1). All helplines has significantly higher search times than zero helplines and no helplines.

Comparison	P-value	r-value
No helplines vs. zero helplines	0.142	0.10
No helplines vs. all helplines	< 0.001	0.26
Zero helplines vs. all helplines	0.001	0.21

Table 1: Pairwise comparisons of Variants of EyeSee360 (r-values report the calculated effect sizes).

Likert-scale questionnaire. After each condition, we asked the participants to answer two questions with 5-point Likert-scale items (1=strongly disagree, 5=strongly agree). The results are shown in Figure 3. Participants stated that they could quickly locate the out-of-view object for all variants: no helplines=4 (IQR=1), zero helplines=4 (IQR=0), and all helplines=4 (IQR=1). Further, participants stated that they did not get distracted by the visualization for most of the variants: no helplines=1 (IQR=1.25), zero helplines=2 (IQR=1.25), and all helplines=3 (IQR=2.25).

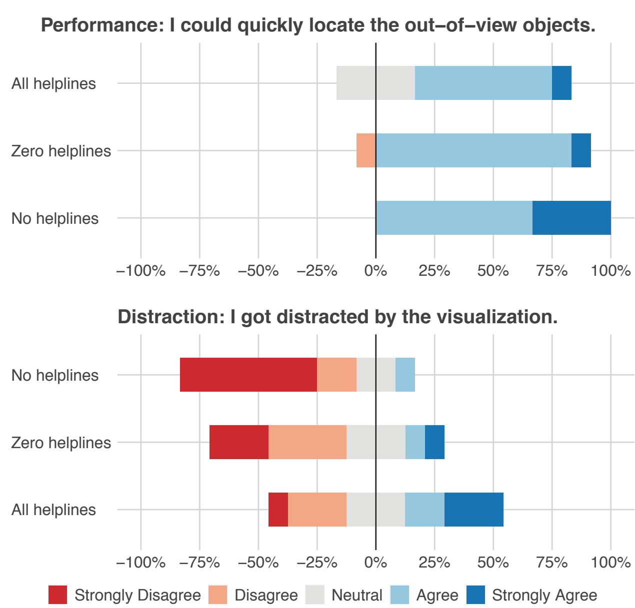


Figure 3: Results from 5-point Likert-item questionnaires.

Overall, nine participants stated that they preferred no helplines and three stated that they preferred zero helplines.

Discussion

Search time performance. We observed better search times for EyeSee360 than was reported in the original work [10]. We think this is due to the fact that no click was required to prove that the out-of-view object had been found. Additionally, our experiment used the Hololens instead of a Google Cardboard. From our results, we saw that no helplines and zero helplines worked significantly faster than all helplines. Therefore, we can accept our hypothesis H_1. We found no significant difference between no helplines and zero helplines. However, the subjective results show that participants preferred no helplines and stated that this variant has the least visual clutter.

Direction estimation. In some situations it may be enough to understand the location of a virtual object, while it is not needing to look at the object itself (e.g., when looking for some free space to place new virtual objects). We argue that, in those situations, the variant with all helplines may be more efficient because it gives additional information about the exact locations of those objects.

Visualization on demand. Our results show that the EyeSee360 variant with the least visual clutter performs best in terms of search time performance. However, for small field of view HMDs, there is still a lot of visual information overlaying virtual and real objects, which can interfere when users interact with it. We recommend using EyeSee360 on demand. Like a task manager that gives one an overview of all active tasks, the visualization could work as an location manager that gives one an overview of the locations of all virtual objects.

Limitations. For small field of view HMDs, there is still a lot of visual information overlaying virtual and real objects, which can interfere when users interact with it. For example, EyeSee360 encodes the precise location of an out-of-view object, although the general direction in which a user needs to turn his head might be sufficient.

5 CONCLUSION

In this paper, we compared three different variants of EyeSee360 in terms of search time performance. Our results show that the variants with less visual clutter (no helplines, zero helplines) perform significantly better than the variant with the most visual clutter (all helplines). Even though there were no performance differences between the variants no helplines and zero helplines, participants preferred the variant with no helplines in most of the cases. For the best experience and to reduce visual clutter on small field of view HMDs, we recommend to show the visualization technique only when users need to search for objects out of view.

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