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Birds vs. Fish: Visualizing Out-Of-View Objects in Augmented Reality using 3D Minimaps

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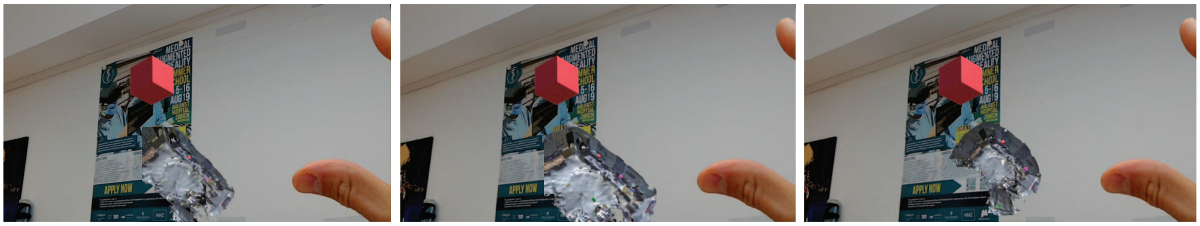

Figure 1: We compare three different minimap visualizations for displaying out-of-view objects in head-mounted display-based Augmented Reality: top-down bird's-eye view minimap (left), tilted bird's-eye view minimap (center), and our newly proposed stereographic fisheye minimap (right).

Abstract

Despite recent technological advanced in Augmented Reality (AR), the majority of state-of-the-art head-mounted displays (HMDs) still suffers from a limited field of view. Hence, there is a high probability that virtual objects are located outside of the user's view. Several approaches to mitigate the problem of out-of-view objects have been proposed in the past by using visualization techniques to guide the user's attention towards such objects. However, none of these techniques provides any context about the real environment. Current state-of-the-art HMDs are equipped with various sensors to create a 3D map of the environment. In this work, we leverage such 3D reconstructions and developed a set of different 3D minimap visualizations for conveying information about out-of-view objects in AR. We propose a novel kind of minimap using stereographic fisheye projection and compare it to more traditional, bird's-eye view minimaps. Preliminary results show that our stereographic fisheye minimap offers a set of distinct advantages over bird's-eye view minimaps that facilitate the localization of virtual objects in AR environments.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Mixed / Augmented Reality; Human-centered computing—Visualization—Visualization design and evaluation methods

1 Introduction

Augmented Reality (AR) environments contain virtual objects that are displayed to the user in conjunction with the real world [5]. Such environments can potentially be very complex and comprise a large number of virtual objects at various locations, e.g. maintenance tasks in a large factory environment. Due to the small field of view (FoV) of current head-mounted displays (HMDs), many of these objects will be outside of the user's view. Therefore, providing positional information about virtual objects can improve scene understanding and enable quick navigation as well as targeted object searches. Traditionally, conveying information about the location of virtual objects in AR environments has been done with abstract visual guidance techniques. A recent user study compared six of these visualizations and proposed a novel 3D Radar for locating static virtual objects in HMD-based AR [2]. This techniques also proved to be very efficient for moving virtual objects [3]. However, all abstract visualizations inherently do not provide any context about the real environment. Another category of related work that naturally contains real-world information are minimaps, also known as worlds in miniature. In the context of AR, they were first proposed by Bell et al. in 2002 [1]. Today's state-of-the-art HMDs are equipped with several sensors that generate a 3D reconstruction of the scene using spatial mapping techniques. In this work, we compare three different visualization techniques for displaying such 3D reconstructions as minimaps. Two traditional bird's-eye minimaps are compared to our novel stereographic fisheye minimap, which uses stereographic projection to map the area of a 180° hemisphere onto a circular 2D image plane [4]. In the rest of this paper, we provide a short overview of the two different minimap types (bird's-eye view and stereographic fisheye view) and present the results of a preliminary user study which compared their efficacy for locating out-of-view objects in HMD-based AR.

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2 Bird's-Eye View Minimaps

Minimaps are most commonly known from computer and video games, especially in genres such as real-time strategy and massively multiplayer online role-playing games (MMORPGs). They facilitate the orientation of players within the game world and vary depending on the level of detail that is displayed. In most scenarios, they present a top-down 2D view of the game world, including the player's position as well as the location of objects of interest. To create a bird's-eye view minimap in the context of HMD-based AR, the 3D reconstruction of the environment generated using various sensors that are integrated into the HMD for spatial mapping purposes can be employed. A perspective virtual camera with a specific FoV is placed at a certain distance above the 3D scene facing downwards. Movements of the user directly correspond to movements of the virtual camera. Tilted bird's-eye views can be easily achieved by slightly rotating the virtual camera. Both the position of the user and the positions of virtual objects can be integrated into the minimap via proxy icons. In this paper, a white triangle and small proxy representation of the objects are employed. While offering an undistorted view of the scene, the absolute area that can be mapped with a

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bird's-eye view minimap is smaller than with a stereographic fisheye minimap due to the different projection mechanisms. A particular shortcoming of bird's-eye view minimaps are cut-offs at the edges of the scene, especially for large, non-square reconstructions. The only way to avoid this is to move the virtual camera up, which can severely limit the overall resolution of the minimap.

3 Stereographic Fisheye Minimap

Fisheye minimaps can be obtained by simply replacing the projective camera that is used for bird's-eye view minimaps with a fisheye camera. Such fisheye cameras use fisheye lenses with extremely high angles of view to map the viewing sphere to an image plane and produce wide panoramic or hemispherical images. As a result, fisheye minimaps contain barrel distortions such that straight lines are bent during the mapping process. Several different types of fisheye projections exist that trade off the amount and type of distortion. Among those, the most popular fisheye projections are the equidistant projection, orthographic projection, and stereoscopic projection [4]. The latter is known as the conformal form of a fisheye projection such that angles are better preserved and barrel distortion is less obvious. For Cartesian coordinates (x,y,z) on a sphere and (X,Y) on the image plane, the projection process as well as its inverse can be formulated as follows:

$$(X,Y) = \left(\frac{x}{1-z}, \frac{y}{1-z}\right), \tag{1}$$

$$(x,y,z) = \left(\frac{2X}{1+X^2+Y^2}, \frac{2Y}{1+X^2+Y^2}, \frac{-1+X^2+Y^2}{1+X^2+Y^2}\right). \tag{2}$$

In this work, we employ the above formulas to generate stereographic fisheye minimaps that project the area of a 180° hemisphere onto a circular 2D image plane. Due to the fact that the overall area of this hemisphere is significantly larger than the area of the viewing frustum used during the projection process for bird's-eye view minimaps, the absolute area that can be mapped with a stereographic fisheye minimap is much larger. While the resolution decreases at the edges of the minimap, no cut-offs will occur with our stereographic fisheye minimap and the entire 3D reconstruction including all virtual objects will be seen.

4 Preliminary User Study

We conducted a preliminary user study to investigate the potential of our three different minimap visualizations for conveying information about out-of-view objects in AR. Following a short introductory overview of the three minimaps, participants were asked to use the Microsoft HoloLens to collect (via HoloLens clicker) five virtual objects in an office environment as quick as possible. All virtual objects were abstract representations of 3D shapes (cubes, spheres, and cylinders) and were randomly positioned around the user. Small proxy icons corresponding to these shapes were displayed in all three minimaps, c.f. Figure 1. We employed a pre-computed 3D reconstruction of the scene and manually registered the real and virtual environments. A total of six participants (5 male, 1 female) with a mean age of 28.17±3.54 years took part in the experiment. All of them were unpaid post-graduate student volunteers without color deficiencies. A 6×6 balanced Latin square matrix was employed for randomizing the type of minimap visualization across study participants to eliminate order effects. To capture performance, we measured the time participants required for successfully collecting all five virtual objects in the scene. Additionally, they were asked to fill out a System Usability Scale (SUS) survey for each of the three minimap visualizations and optionally provide free form feedback.

5 Results

Participants achieved the lowest mean completion times using the stereographic fisheye minimap (20.83±3.98*s*), followed by the tilted bird's-eye view minimap (23.43±7.04*s*) and the top-down bird's-eye view minimap (25.41±10.03*s*). Similar results were obtained for the SUS questionnaire. While all three minimaps achieved high average SUS scores, participants gave the highest scores to the stereographic fisheye minimap (88.33±10.57), followed again by the tilted bird's-eye view minimap (85.83±5.16) and the top-down bird's-eye view minimap (75.83±10.33). In terms of user feedback, three participants mentioned that the stereographic fisheye minimap is excellent for understanding the height of virtual objects due to the relative size differences of the proxy icons in the minimap, while this information is difficult to convey using the traditional top-down bird's-eye view minimap. One participant explicitly stated that the tilted bird's-eye view minimap is worse than the stereographic fisheye minimap for understanding the parts of the scene behind the user, while another participant did not find any significant difference between all three minimaps.

6 Discussion & Future Work

In our preliminary user study, we were able to demonstrate the potential of minimap visualizations for locating out-of-view objects in AR environments. Our proposed stereographic fisheye minimap achieved both the lowest completion times as well as the highest user preference ratings, showing benefits over more traditional bird's-eye view minimaps. Interestingly, participants exploited the perspective distortions of the stereographic fisheye minimap to better understand relative size differences between proxy icons for determining the height of virtual objects in the scene. In future work, we would like to verify these findings in a larger user study and to compare our stereographic fisheye minimap to established visualization techniques for locating out-of-view objects in AR [2]. Additionally, we would like to investigate the behavior of participants when using the minimap visualizations in more detail. By tracking the eye gaze of the user, we would like to find out whether these minimaps allow the user to quickly obtain an understanding of the location of a virtual object, or whether a continuous look-and-verify process is necessary.

7 Conclusion

In this work, we presented a novel stereographic fisheye minimap visualization for conveying information about out-of-view objects in AR environments. We compared it to two different bird's-eye view minimaps in a preliminary user study during an object collection task. Participants achieved the lowest mean task completion times using the stereographic fisheye minimap, demonstrating its potential for providing the user with a concise overview of an AR environment.

References

[1] B. Bell, T. Höllerer, and S. Feiner. An annotated situation-awareness aid for augmented reality. In *Proceedings of the 15th annual ACM symposium on User interface software and technology*, pp. 213–216. ACM, 2002.

[2] F. Bork, C. Schnelzer, U. Eck, and N. Navab. Towards efficient visual guidance in limited field-of-view head-mounted displays. *IEEE transactions on visualization and computer graphics*, 24(11):2983–2992, 2018.

[3] U. Gruenefeld, I. Koethe, D. Lange, S. Weiss, and W. Heuten. Comparing techniques for visualizing moving out-of-view objects in head-mounted virtual reality. In *26th IEEE Conference on Virtual Reality and 3D User Interfaces (IEEE VR)*. IEEE, 03 2019.

[4] T. J. Herbert. Area projections of fisheye photographic lenses. *Agricultural and Forest Meteorology*, 39(2-3):215–223, 1987.

[5] P. Milgram and F. Kishino. A taxonomy of mixed reality visual displays. *IEICE TRANSACTIONS on Information and Systems*, 77(12):1321–1329, 1994.