Challenges and Opportunities for Head-Worn AR Use in Wide-Area Environments

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Abstract

Head-worn Augmented Reality (AR) technologies are advancing toward ergonomic designs suitable for continuous, on-the-move use, and many current devices such as Microsoft's HoloLens 2 and the Magic Leap 2 enable untethered use in large environments. This presents an opportunity for AR research to move outside the lab, and in this position paper we discuss our research on AR use in large environments (both outdoors and indoors) while performing search tasks. The findings from four user studies provide insights into potential benefits and costs of AR use during locomotion as well as considerations for the design of AR annotations for task guidance.

Keywords

Augmented Reality, Locomotion, Navigation, Perception

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1 Background and Experience

Our research focuses on investigating user behavior and perception when using AR in mobile contexts, and identifying considerations for the design of AR-on-the-move. Recent advances in head-worn AR technology have made AR smart glasses increasingly feasible as a primary mode of information consumption in the future. There is still limited knowledge, however, about the impact of using such devices in the wild and considerations for the design of on-the-go AR interfaces. We therefore examine how users perceive and interact with them in large environments that necessitate natural locomotion and interaction.

The research discussed in this position paper is a part of the first author's PhD dissertation [4], and was carried out in close collaboration with the other authors. We have conducted four wide-area user studies in both outdoor and indoor environments, with a total of 120 participants walking around these environments using the AR headset for up to one hour. In each study, subjects completed a treasure hunt task where they searched for gems in environments that were augmented with both virtual and physical objects. We compared the use of different types of navigation guidance to support the search task. Factors such as environmental lighting and cognitive demand were also studied in the same experimental framework, and our findings indicate that these factors influence user behavior and subjective experience when using AR on-the-move, even if they do not directly impact performance in the primary task.

Overall, these experiments have highlighted key challenges for always-on AR use in large and dynamic environments as well as valuable directions for future research, which we discuss in the rest of this paper.

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2 Methodology

Our research has focused on empirical methods to study AR use while navigating large environments, with a series of four user studies in wide-area AR environments indoors and outdoors [2, 3, 5, 6]. All experiments were conducted using Microsoft's HoloLens 2 headset, which was the most suitable device for outdoor use and offered the most reliable wide-area tracking at the time the research was conducted. Participants performed a gem search task in all four experiments, which was chosen as a representative task for a broad range of everyday usage scenarios that would require scanning one's surroundings and walking around the environment to interact with objects. Factors such as environmental lighting, cognitive demand, and tangibility of objects (both target and non-target) were systematically varied in different experiments, as these are likely to vary in real-world AR-on-the-move scenarios and it is therefore important to understand their impact on users' task performance, experience and attention to the environment.

We also examined the potential for world-anchored spatial annotations (3D arrows) to support search and navigation in head-worn AR, comparing them with screen-anchored navigation aids that display navigation guidance on a two-dimensional canvas (we used an on-screen radar and a horizontal compass inspired by the Context Compass [9]). Quantitative analysis of task performance metrics, behavioral metrics and participant ratings of experience offered insights into the influence of our factors of interest on AR use in mobile contexts. We also collected free-form responses in the post-experiment experience surveys that offered insight into participant strategies and preferences, and modeled attention to the environment using recall of objects as a conservative metric of attention [1].

3 Reflections

Our research thus far has highlighted some key challenges and opportunities for the design of head-worn AR interfaces for use in everyday mobile contexts, which we discuss here.

3.1 Attentional Biases due to Visual Disparities between Virtual and Physical Content

Most current head-worn AR devices present perceptible differences between virtual and physical content as rendered on the displays, due to factors such as display fidelity, environment lighting, and, in the case of video see-through AR, the quality of the pass-through video. We observed increased attention to virtual objects in the environment compared to physical objects when the search targets were virtual, suggesting that the perceptible differences can lead to attention being selectively guided based on the user's expectations about the target modality (i.e., virtual). Self-reported comfort was also influenced by environment lighting and relative salience of virtual and physical content, indicating that there is an additional cost to switching between virtual and physical content. In everyday AR usage scenarios, especially when walking in the real world, an increased focus on virtual content could cause users to ignore important points of interest in the real world, and potentially raise safety concerns (especially in crowded and dynamic environments).

While it is likely that technological advancements will minimize the visual disparity between virtual and physical content, it is also important to consider whether the goal really is to make virtual content indistinguishable from the real world. Achieving photorealism may certainly be feasible in the near future, but AR by definition is grounded in the real world (unlike Augmented Virtuality) and it is therefore important for users to remain aware of what is real and what is not in most usage scenarios. This attentional bias can be reduced by balancing the visual and semantic saliency of virtual and physical content, and attention can be intentionally directed by highlighting content in the less salient virtuality if an imbalance is unavoidable. To achieve this, it is important to identify and model the various factors that influence user attention in mobile AR contexts, so that AR application designers can account for (and shield against) attentional biases when creating interfaces for users on-the-move.

3.2 The Tradeoff Between Spatially Located and On-Screen AR Guidance

A key advantage of AR over most current information consumption technology is its ability to display annotations in a spatially relevant manner, bringing information from a 2D screen into the real world. Head-worn AR, in particular, allows users to view these annotations simultaneously with the real environment rather than switching between viewing a screen and the surroundings. This was also reflected in the results from our user studies, with participants preferring the world-anchored navigation aid over the screen anchored ones. However, despite early performance benefits for the arrows, they became less useful when fewer targets remained and participants needed to walk larger distances in the environment to spot them. In contrast, the screen-anchored aids were always visible to participants and enabled a more consistent search strategy over the course of the experimental trial.

This highlights a tradeoff between world-anchored and screen-anchored AR guidance: screen-anchored guidance allows for constant access and a comprehensive overview of the information, at the cost of spatial detail and ease of interpretation. Presenting users with a combination of the two could offer the best advantage from the perspective of information consumption. However, this may also lead to overdependence on the AR tools [8] — even if the tool use results in sub-optimal outcomes [7] — and therefore exacerbate the attentional biases discussed earlier in this paper.

A potential solution to this challenge would be to create adaptive AR interfaces that control the amount and nature of AR information visible at any point in time based on the user's current context, to enable limited virtual clutter when the user is in motion and/or needs to focus on their surroundings and offer more annotation support when task performance is the priority. Alternatively, offering users a convenient way to customize their view of different aspects of the AR interface could encourage them to modify the density and appearance of the AR annotations based on their needs, which will perhaps be more accurate to the user's needs and preferences than context models with limited information.

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