Exposing Blind Spots in XR Accessibility With Simulated Vision Impairments

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1 Motivation

One in four people in the United States of America has some form of disability [8]. Yet this large portion of the population is unable to use extended reality (XR) head-mounted displays (HMDs) due to their inaccessible designs. Both head-worn augmented reality (AR) displays like the Microsoft HoloLens and virtual reality (VR) displays like the Oculus Rift fall under the umbrella of XR HMD products. Accessibility groups, like XR Access [14], have recently emerged to disseminate best known practices for developing accessible applications in extended reality. However, best practices for accessibility in immersive XR HMDs are still a nascent area of research.

Because XR HMDs are not yet a mature or widespread technology—developers, designers, and researchers alike have the rare opportunity to make immersive XR accessible from the outset [7]. A barrier to this goal is that most software developers and designers do not know how to make their applications accessible, and they often do not have access to user testers with disabilities to evaluate their products.

My dissertation research will create and evaluate the efficacy of a testbed that will give developers the ability to design better XR experiences for those with vision disabilities, whom account for 4.6% of the U.S. population [8]. I will create an eye-tracked, data-driven visual impairment simulation with flexible input parameters that allows people to experience visual impairments firsthand. Furthermore, I will conduct a robust evaluation of the system with low vision patients, those with simulated low vision, and those with normal vision.

1.1 Visual Impairments

The visual impairments expressed by low vision, in which vision is impaired to the degree that it cannot be corrected with glasses alone, are often the result of a *scotoma*—or a blind spot in one's visual field. Scotomas vary in size, intensity, number, and placement within a person's visual field. As such, low vision conditions are heterogeneous and vary widely between conditions and even between patients with the same condition. Two of the most common types of visual field loss that can affect people's vision are: central and peripheral field loss. An example of simulated peripheral vision loss, which may be caused by glaucoma or retinal detachment, can be seen in Figure 1. Low vision conditions interfere with one's ability to interpret visual information, making everyday tasks like reading, driving, or walking down the street challenging. Tasks like driving may even become dangerous.

1.2 Disability Simulations

If developers are to design accessible products that people with disabilities can use, then they must understand how affected populations interact with their surroundings. Disability simulations allow individuals to experience what it is like to have a specific impairment. These simulations are not only informative for product and application design, but they can also help caregivers or medical professionals better understand the needs of those whom they care for.

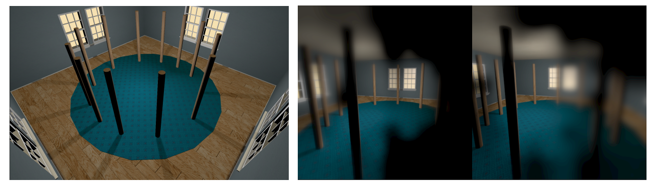

Figure 1: An overhead view of a virtual environment (left) and the environment as viewed stereoscopically by someone with simulated peripheral field loss (right)

Extended reality (XR) provides a particularly unique opportunity for disability simulation. Within XR people may experience firsthand how specific disabilities, like visual impairments, affect the strategies that one employs to interact with their surroundings. Some immersive low vision simulations already exist. However, most are based on simplified symptoms of eye diseases [12] and are unable to produce the irregular scotomas that individuals experience in reality. Even fewer of these simulations have been implemented with eye tracking [6, 13]. Yet the biggest obstacle for the adoption of immersive low vision simulations for design may be that there are no rigorous evaluations of their efficacy. In short, there are no complete, empirical studies that evaluate the ability of low vision simulations to replicate the impairments of those with low vision. This dearth of evaluations is likely due in part to the low latency demands of eye-trackers for effectively simulating low vision and to the difficulty of recruiting a sufficient number of people with visual impairments for system evaluations. As a result, most researchers have either only been able to conduct preliminary analyses [12, 6] or they have focused on applying their simulation to applications [13].

2 Project Framework

2.1 Research Objectives

Accessible design allows a large portion of the population, which would otherwise be neglected, to have access to products. However, not all product development teams have access to disabled test users for feedback. Reliable disability simulations may allow these teams to better design their products for accessibility, especially in the absence of real user testers.

My dissertation research presents an immersive, low vision simulation testbed to evaluate how design decisions affect user experience for those with visual deficits. This testbed uses a data-driven approach to empower XR developers to design for low vision individuals—even when they do not have access to real low vision test users. I will validate the testbed by analyzing behavioral responses across real low vision patients, simulated low vision patients, and normally-sighted individuals.

I will also demonstrate how to employ this testbed to evaluate accessibility by conducting user studies with both normally-sighted and simulated low vision participants to assess how specific rendering techniques affect spatial perception in XR. By the end of my dissertation research, I will have generated developer guidelines that improve spatial perception for both normally-sighted and low vision users in XR. And I will create a testbed for future investigations into how design decisions affect those with low vision in XR.

2.2 Vision Disability Simulation

My immersive simulation will map data from visual field tests, such as Humphrey or Goldmann, to calibrated blur and opacity maps in a stereoscopic head-mounted display (HMD). By employing HMDs equipped with eye trackers, I may map foveal deficits correctly to the foveal regions of a user's vision. The field of view of these devices is limited, so I am unable to model far peripheral field deficits. User-specified scotomas and blur fields can also easily be mapped. An example of the simulator output using patient data is shown in Figure 1.

How to best render scotomas for simulation is an active area of research [9]. However, the simulation of central vision loss is particularly challenging since intrasaccadic perception might occur [5], which would result in a misalignment between the simulated field and fovea. Misalignment could allow "peeking" at the percepts that are supposed to be masked. To prevent this effect, a low vision simulation that attempts to mask central vision should have an overall latency of 25 ms or less; higher latencies can be tolerated for peripheral field loss [10]. This overall latency is independent of the display update rate but instead derives from the time between eye movement event and display event. Recent work on commodity-level head-mounted displays suggests that system latency remains the primary concern but that commodity eyetrackers perform well at simulating peripheral field loss [11]. The low vision simulator proposed in this grant will be built on equipment that has significantly lower overall latencies than those tested in Sipatchin et al. [11]. If necessary, the field of foveated rendering has developed fast gaze prediction techniques [4] that can be used to further reduce latencies.

2.3 System Evaluation

There is little published research validating the ecological validity of immersive low vision simulations. My primary evaluation will be conducted within virtual reality (VR) for experimental control. I intend to thoroughly assess my system by observing behavioral responses across three groups: people with low vision, people with simulated low vision, and people with normal vision. Low vision participants will be recruited through Vanderbilt University Medical Center. All three groups will undergo a training period to acclimate to the VR environment. A training period is particularly important for those in the simulated low vision group, since people with low vision develop compensatory techniques over time to successfully navigate their environment.

2.4 XR Design Testbed

After the initial evaluation, I intend to extend the testbed to encompass both video see-through and optical-see through augmented reality HMDs. The HoloLens 2 is of particular interest for low vision simulation since it provides an unobstructed view of the real world outside of any augmentations. This feature makes visual impairment simulation within the HoloLens desirable for the evaluation for physical products. I will additionally make the simulation publicly accessible for other developers and researchers to use. For a design case study, I will evaluate the effects of non-photorealistic rendering techniques on perception in XR, which is motivated by my prior work in which I found that non-photorealistic renderings of cast shadows improved surface contact perception in immersive augmented reality displays [2, 3].

3 Conclusions

Although many consider extended reality to be one of the next major computing platforms, current head-mounted displays do not easily accommodate for consumers with disabilities—a population that constitutes one fourth of the U.S. population. Robust toolkits for enhancing accessibility in XR for people with low vision like those presented by Zhao et al. [15] are rare. Effective disability simulations, like the system proposed in the current work, may allow accessible design tools to be developed more rapidly and iteratively, especially for groups without ready access to user testers with disabilities. My simulation, when extended to immersive augmented reality, can even inform the accessible design of physical products. Given my prior research findings in which high contrast shading was demonstrated to improve spatial perception [2, 3], I hope to extend my research to enhance depth perception for both normally-sighted individuals [1] and those with low vision.

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