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XREye: Simulating Visual Impairments in Eye-Tracked XR

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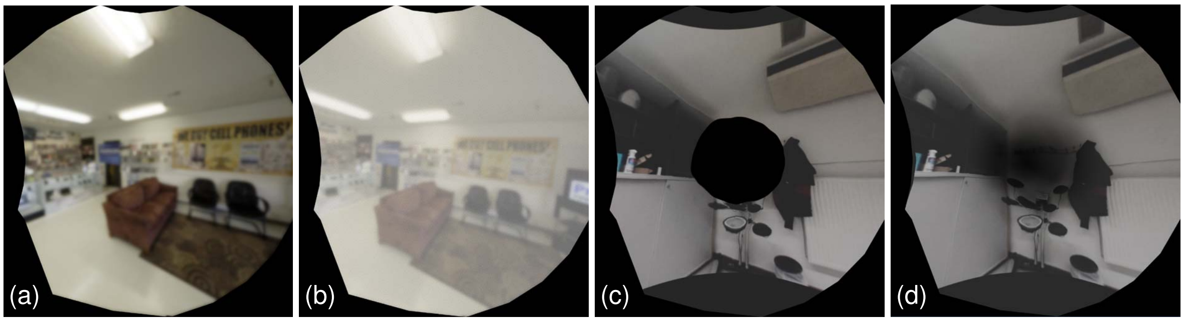

Figure 1: Simulation of (a) refractive errors (myopia) and (b) cornea disease when viewing 360° image in VR HWD, (c) dry and (d) wet age-related macular degeneration in video–see-through AR HWD.

Abstract

Many people suffer from visual impairments, which can be difficult for patients to describe and others to visualize. To aid in understanding what people with visual impairments experience, we demonstrate a set of medically informed simulations in eye-tracked XR of several common conditions that affect visual perception: refractive errors (myopia, hyperopia, and presbyopia), cornea disease, and age-related macular degeneration (wet and dry).

Index Terms: Computing methodologies—Computer Graphics—Graphics systems and interfaces—Perception; Applied computing—Life and medical sciences—Health informatics

1 Introduction

Many people are affected by visual impairments, which are estimated to affect up to 1.3 billion people worldwide [11]. Some impairments, such as refractive errors, are very common, and easy to correct with glasses or contact lenses. Other eye diseases, such as age-related macular degeneration (AMD), have a sustained impact on visual function and can lead to central vision loss [7]. It can be difficult for people with healthy eyes to understand how the world looks to a person with a visual impairment. Textual descriptions, reports from patients, 2D images, or 3D simulations are often insufficient. People, whether relatives of people with eye diseases or medical personnel, could benefit from realistic, immersive simulations of visual impairments to increase their understanding and empathy. Such simulations could also aid in designing everyday objects, architectural planning, or developing standards to increase accessibility of public spaces. To address these goals, we present eye-tracked XR simulations of three common conditions that affect visual perception: refractive errors (myopia, hyperopia, and presbyopia), cornea disease, and AMD (wet and dry). Our simulations are informed by expert knowledge from ophthalmologists, as well as reports from patients with these conditions.

We modified an earlier system we developed [3, 4] to simulate a wider range of visual impairments, employing efficient post-processing effects that run in real-time. Since some symptoms affect only parts of the visual field, we use eye tracking to implement gaze-dependent effects. Because eye-disease symptoms can vary greatly from one person to another, it was crucial to make the simulations as adjustable as possible to support a wide range of characteristics of the involved symptoms. In our demo, participants wearing a head-worn display (HWD) experience the visual impairments in VR, video-see-through AR, or when viewing 360° images.

While there have been previous attempts to simulate visual impairments, they were limited in their realism, immersiveness, and/or adjustability. 2D images viewed on desktop displays [1] and physical goggles with special lenses [12] have been used to recreate the effects of eye diseases and educate people about how these impairments affect perception, but have limited field of view and immersion. Lewis et al. [5, 6], Werfel et al. [10], and Väyrynen et al. [9] developed VR simulations of visual impairments, but they did not support adjusting individual symptoms to change the severity and characteristics of the simulated impairments. Commercially available smartphone apps that simulate visual impairments (e.g., the Novartis ViaOpta Simulator [8]) have only a small field of view, and present the same image to both eyes. None of the above-mentioned approaches use eye tracking to simulate gaze-dependent effects. Jones and Ometto [2] recently implemented eye tracking for their HWD-based simulations of visual impairment symptoms, achieving near real-time rendering. We take their approach one step further and simulate complex eye diseases, such as AMD, comprising multiple symptoms, with eye tracking, in real time, making it possible to use these simulations in VR or AR HWDs, while minimizing the risk of VR sickness.

We introduce the first medically informed AR/VR simulation of common eye diseases using an eye-tracked AR/VR HWD. In addition, we modified our earlier framework [3,4] to make it easy to extend with further visual impairment simulations, already providing functionality to steer gaze-dependent effects with the eye tracker,

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seamlessly switch between VR, AR or 360° image viewing, and expose adjustable parameters to modify the simulation at runtime.

2 Visual Impairment Simulations

Our visual impairment simulations run in VR or video–see-through AR and can also be experienced when viewing 360° images, using an HTC Vive Pro HWD with a Pupil Labs 200Hz binocular eye tracker add-on. Participants trying our demo will experience our simulated visual impairments while exploring a virtual kitchen in VR, looking at their actual surroundings in AR, or viewing HDR 360° images, and can compare different levels of severity of symptoms when parameters are modified at runtime. We developed the following visual impairment simulations.

2.1 Refractive Errors: Myopia, Hyperopia, Presbyopia

Myopia (also known as near-sightedness or short-sightedness) causes blurry vision in the distance, while people still have good near vision [7]. **Hyperopia** causes blurred vision of near objects, while far objects can appear clear [7], similar to blurry vision caused by **Presbyopia**, which is due to aging and a reduction of accommodation abilities of the eyes [7].

For video–see-through AR and 360° images, we simulate the reduced visual acuity caused by refractive errors as a Gaussian blur over the image. This approximates the reduced perception of short-sighted people well, although neglecting that very close objects, right in front of a person's face, should be rendered sharp. (This will be added in AR in future work using the information from the depth camera.) Our VR simulation already takes the distance of objects into account and uses a depth-of-field effect, as described by Krösl et al. [3], which can be used to simulate all three of the above.

2.2 Cornea Disease

The transparent front layer of the eye is known as the cornea. Different conditions can affect the cornea and therefore the vision of a person, such as injuries, allergies, inflammation (keratitis) that causes fogging or a swelling of the cornea, or material build-ups in the cornea (corneal dystrophies), each affecting vision differently [7].

We try to replicate the vision of a patient with cornea disease, who described it as "looking through opal glass," by reducing the contrast of the image and applying a slight color shift (as described by Krösl et al. [4]), and then using a high-frequency noise texture, softened by interpolation with a white color image to create opal glass material. We can then interpolate between this material and the contrast-reduced and color-shifted image. All interpolation weights and colors are adjustable via parameters to allow fine-tuning of the simulation, in order to create different depictions of corneal diseases, according to patient descriptions or expert knowledge from ophthalmologists.

2.3 Age-Related Macular Degeneration

AMD does not cause total blindness, but the reduction or loss of central vision can have a high impact on perception and make tasks such as reading, cleaning, cooking or recognizing faces, challenging [7]. There are two main types: dry AMD and wet AMD. Symptoms affect the center of the field of view and include blurry vision, reduced brightness, distorted vision, and loss of central vision.

We simulate **wet AMD** by combining a distortion, radial desaturation, contrast reduction and semi-transparent texture to darken the central field of vision. First, we distort UV coordinates with the use of a water texture to create random distortions and then add multiple overlapping, parameterized circular distortions, which cause inward or outward bulges. A radial desaturation creates a washed-out image in the center of the field of view. To achieve this, a greyscale version of the image is created by calculating the luminosity of the pixels. Then the original image is interpolated with this greyscale image, weighted by a radial gradient exponential. We use the same contrast reduction as for cornea disease and add a circular gradient texture (colored grey) via alpha-blending. All parameters controlling the extent and characteristic of each of these effects are adjustable.

We simulate **dry AMD** in a similar fashion (with slightly modified parameter values), but instead of blending a grey gradient texture on top, the central loss of vision, caused by failing photoreceptors in the macular area, is simulated with a black texture, with clear edges, drawn over the central area of the field of view.

3 Conclusions and Future Work

We developed a new set of real-time eye-tracked AR/VR simulations of visual impairments and described the system components used to create them. Moving forward, we will conduct a user study to evaluate the authenticity of these simulations, with people with normal and impaired vision. Further, we will explore simulating other types of visual impairments, including cataracts and an improved approach to presbyopia.

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