Simulating Vision Impairments in VR and AR

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Figure 1: Our cataract simulations demonstrate how to combine different symptoms to create whole eye disease patterns. The original (a) image is blurred, simulating reduced visual acuity (b). The contrast is reduced (c) and a color shift (d) is applied. Dark shadows (e), caused by a clouded lens, are added and a bloom effect (f) simulates an increased sensitivity to light.

ABSTRACT

1.3 billion people worldwide are affected by vision impairments, according to the World Health Organization. However, vision impairments are hardly ever taken into account when we design our cities, buildings, emergency signposting, or lighting systems. With this research, we want to develop realistic, medically based simulations of eye diseases in VR and AR, which allow calibrating vision impairments to the same level for different users. This allows us to conduct user studies with participants with normal sight and graphically simulated vision impairments, to determine the effects of these impairments on perception, and to investigate lighting concepts under impaired vision conditions. This thesis will, for the first time, provide methods for architects and designers to evaluate their designs for accessibility and to develop lighting systems that can enhance the perception of people with vision impairments.

CCS CONCEPTS

• **Human-centered computing → User studies**; **Virtual reality**; *Mixed / augmented reality*; • **Computing methodologies → Perception**; • **Applied computing** → *Health informatics.*

KEYWORDS

vision impairments, cataracts, virtual reality, augmented reality, user study

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1 INTRODUCTION AND RELATED WORK

Vision impairments like cataract, diabetic retinopathy, glaucoma, age-related macular degeneration or myodesopsia are widely distributed among elderly people. They are also a major health risk as one of the main factors for falling in elderly people, resulting in serious injuries like fractures or brain injuries. One way to reduce these risks, which affect a globally aging world population, is to take the needs of elderly people into account when designing their everyday environment. However, designers and architects currently lack the tools to adapt their design concepts to special needs, for example in homes for the elderly or schools for kids with vision impairments. We believe that virtual reality (VR) and augmented reality (AR) offer a unique opportunity to create new methodologies for taking accessibility into account in the design phase, in particular through simulation.

So far, vision impairments have been simulated as modified 2D [2, 3] images or using specifically modified simulation goggles [10]. The drawback of 2D images is their static nature. While goggles allow users to look at their environment, the impact of vision impairment cannot be set to different levels of severity or different impairments. 3D simulations of vision impairments provide more flexibility, but lack a higher level of immersion for the user. Recently, immersive VR simulations have been developed [7] in order to raise awareness and empathy [9] or for demonstrative or educational purposes. AR has also been explored for vision impairment simulations for accessibility inspection tasks [1]. These simulations are mostly based on photos from the National Eye Institute and not on medical tests. More complex simulations created from perimetry exam data of real patients [4] are already a first step to increase the realism of vision impairment simulations, but in order to use such VR simulations to conduct user studies and take measurements, a baseline has to be established, taking hardware constraints and the actual vision capabilities of users into account. Developing complex, medically grounded simulations of vision impairments and a methodology to evaluate designs for accessibility are the scientific challenges we want to address in this thesis.

2 RESEARCH APPROACH

The goal of this thesis is to provide architects and designers with tools to take into account vision impairments in their designs, i.e., conduct user studies, take precise measurements, evaluate their concepts for different vision impairments and develop new lighting systems adapted to vision impairments. In order to reach this goal, we target each of the following research questions with one project:

Q1: *How can medical eyesight tests be adapted to create VR simulations that can be used to evaluate and quantify the effects of vision impairments on visual perception?*

Q2: *How can different symptoms of eye diseases, such as cataracts, be simulated and combined to form complex disease patterns?*

Q3: *What impact do different lighting systems have on the perception of people with vision impairments?*

To investigate and quantify the effects of vision impairments on perception, we need to conduct user studies with a large number of participants who all share exactly the same kind of vision impairment and same characteristics and severity of symptoms in order to be able to statistically evaluate the results. However, it is cumbersome to find such a sample group of participants, or almost impossible, since the severity and characteristics of symptoms are very subjective and can often not be assessed very precisely. This makes user studies with people with vision impairments infeasible. Our innovative solution to this problem is to conduct user studies with people with normal sight and just graphically simulate the vision impairment in VR. Since different levels of visual acuity above a certain threshold are categorized as "normal sight", and since the vision capabilities of users as well as hardware constraints of VR headsets (like the resolution of the displays) affect the experienced vision in VR, these factors have to be taken into account in order to guarantee similar vision conditions for all user study participants.

In our **first project** [5], targeted at research question *Q1*, we developed a simulation of reduced visual acuity (VA) to evaluate the maximum recognition distances of escape-route signs for people with vision impairments, taking the actual VA of users and hardware constraints into account and calibrating the simulation for all users to the same level of reduced VA. This allows us to conduct user studies with people with VAs in a range classified as normal sight and just graphically simulate the vision impairment.

In our **second project** *ICthroughVR* [6], we targeted research question *Q2*. Following the findings from our previous work [5], we developed more calibration methods for different symptoms, such as contrast loss, based on medical eyesight tests. By using eye-tracking technology, we were able to also simulate gaze-dependent effects. We then combined different symptoms (see Figure 1) to simulate eye disease patterns, which for the first time allows creating realistic simulations of complex eye diseases, which can be used to evaluate architectural designs or VR-solutions for accessibility.

Our **third project** targets research question *Q3*. We are currently working on improving our cataract simulation and adapting it for the use in AR. We plan to run a user study with cataract patients who already had cataract surgery on one eye, but not on the other. Through this study we will be able to evaluate the realism of our simulation and obtain parameter values for each symptom that create the most realistic impression of cataract vision, according to the user-study participants. Finally, we will use our AR simulation to test different lighting conditions in AR and investigate their impact on perception under cataract vision.

3 POTENTIAL IMPACT

Related work [8] on simulating vision impairments for the use of architects and designers mostly just provides possibilities for qualitative analyses of design concepts. Through these simulations, architects and designers get an idea of how people with vision impairments perceive their designs. There are no solutions that offer possibilities for quantitative analyses or accurate simulations of complex eye diseases. Our research will close this gap and provide realistic, medically grounded simulations that can be used for user studies and yield data for statistic evaluations. In order to simulate gaze-dependent effects, we use cutting-edge eye-tracking hardware and work on improving existing eye-tracking algorithms to develop approaches that are fast enough for gaze-dependent real-time interaction or renderings, which could also be very useful for other applications that use eye tracking. Furthermore, although this thesis focuses on cataract simulations, our research also provides the basis for other vision impairment simulations, which can be built upon the methodology presented in this thesis. Finally, this thesis will provide new insights about perception in VR and AR that could inform future research projects in this field.

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