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Developing a User-Centered Accessible Virtual Reality Video Environment for Severe Visual Disabilities

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Abstract

We address a timely issue of accessibility for visual information through the means of videos. Using emerging technologies (Head Mounted Virtual Reality Displays) and a user-centred design approach, we provide people with severe visual disabilities with a bespoke platform for accessing and viewing videos. We report on newly created test methods for measuring acuity within virtual spaces and reactions of impaired individuals, which informed our platform's design, to inform similar designs and allow testing and refinement for ecological and external validity. A prototype software for accessible virtual reality video viewing is presented, with a subsequent user evaluation to test the software, and a newer virtual reality head mounted display to determine usability while measuring how visually impaired users utilize elements in a virtual environment. We give guidance, based on empirical evidence, and advocate that although VR technologies are currently primarily targeted at a generic audience (gaming and entertainment), they can and should be further developed as assistive tools that enable independent living and increase the quality of life for those with disabilities, and specifically severe visual impairments.

Keywords

Virtual Reality, VR, Visual Disabilities, Video, Viewing, Accessibility

Introduction

Virtual Reality (VR) has experienced a resurgence, aided by its improving affordability, increased range of software, and hardware capabilities now matching user experiences needed for adoption. Head mounted displays (HMDs) are prevalent over similar VR technologies (Antycip; Horan et al.) due to their portability, immersion, and price (Oculus).

Mainstream focus of commercial VR headsets is entertainment, and although some work towards areas such as training (Barad; Elliman et al.) or therapy (Psious) exists, the technology is still at the research and development stage in regards to accessibility, missing mainstream adoption into consumer accessibility communities. HMDs are now advanced enough to be used as accessibility tools, enabling individuals with visual disabilities to live more independent lives through experiences otherwise restricted to them (Lee). An activity that our visually impaired participants desire greatly is the capability to watch TV again, being able to view videos comfortably.

Despite modern improvements, studies show that video player accessibility is still problematic for the elderly, who are the most likely to suffer from visual impairments (Villena et al.). Although there are existing ways to enhance video for impairments (Fullerton and Peli), the devices themselves (e.g. monitors, mobile) limit feasibility and effectiveness, with many impairments still restricting access to video.

The work presented in this paper, focuses on:

1) Creating a methodology and “benchmark” for assessing visual acuity within HMDs for visually disabled people with regards to viewing video content.
2) Presenting and assessing the usability of a VR HMD based platform for viewing videos, targeted at our visually disabled users with a follow up user evaluation.

Related Works

There are various types of HMDs today, most either video see-through (VST), or optical see-through (OST). VST devices (Massof and Rickman; Massof et al.) typically function by displaying a video feed to the user's eyes via an HMD, while OST devices (Microsoft; Google) overlay digital visuals over natural sight. Our work focuses on VST devices as they allow greater control over the visual feed via camera mounts, not relying as heavily on natural vision. Despite VST improvements, they still share many shortcomings of past devices (Harper et al.), and motion sickness is still problematic (LaViola Jr).

Research has been conducted combining VR and AR through reading live video feeds via camera mounts placed on VR devices (Zhao et al. 2015, 2016). Adaptability between multiple visual enhancements was praised by participants, and increased performances when compared to typical assistive tools, highlighting their suitability as visual aid tools.

There have been some attempts (Deahl; Relumino; GiveVision) at product releases for visual aiding headwear integrated with sight enhancing technology (eSight), although expensive costs and limited availability stagnate their adoption and accessibility to the public, a concern shared previously by Wolffsohn and Peterson, and a contrast to VR headsets today which have lowered their prices. Rather than expensive specialist devices, a cheaper VR headset could be purchased with accessibility software setup to assist with tasks. Reviews have shown that electronic vision aid devices are preferred and more effective than traditional optical devices, and that older CCTV attempts have shown increased performance in reading, yet there are too few studies to form strong conclusions (Jutai et al.; Moshtael et al.; Harper et al.). Looking at the conclusions of older research (Everingham et al. 1998, 2003; Peli et al. 1991, 1994) combined with VR today (Hwang et al.) could be the next step in accessibility for the visually impaired.

Discussion

Participant Selection & Test Environments

Prior to development of our specialist software, a preliminary test was conducted to inform us on how visually impaired users would observe and perform within a virtual environment. Our study selected 9 participants that were classed as “Low Vision” (Corn and Lusk) and were all supported in their day to day lives due to the level of their visual disability in various ways. The type of condition did not matter if each participant fell into this LV category. Generally, these participants were older adults either middle aged or older, as is the typical age bracket with most severe visual impairments.

To understand the different visual elements of playing video within a 3D space, and what might affect these, a set of measure-able variables were defined that could be fed into the development of our software. Following discussions with an optometrist, we devised 10 test variables that would allow us to cover different visual aspects within a 3D space. These were Color, Location, Speed, Contrasting Movement, Distance/Depth, Detail, Contrast, Size, Brightness, and Distinction. As the way VR devices display imagery is unique and differs from both natural vision and standard 2D screens, utilizing an existing test could yield inequitable results, prompting us to design our own methods to test these variables.

These developed tests allowed us to observe how LV users might utilize an HMD and its environments, what is beneficial to them, and what limitations are present and could be addressed in further developments. This feedback fed directly into the development of the subsequent video player as design considerations were made based on our participant's reactions. Tests presented here are designed to cover one or more of our original variables listed above.

Object Tracking

This first test was designed to examine the user's ability to identify and track a simplistic object within VR. The user follows a green sphere while facing directly forward, testing their perception at differing horizontal and vertical positions, as well as distance as the sphere travels further away and back again (see fig. 1). This allows us to determine any damaged visual cones.

Results showed that 5 users with damaged visual cones could only see portions of the sphere and that vertical tracking was easier than horizontal. Background colors blended with the sphere, but its color could still be determined and was easiest next to white. All but 1 user could fully track the sphere to the end, with 1 losing vision beyond 15m ranges temporarily.

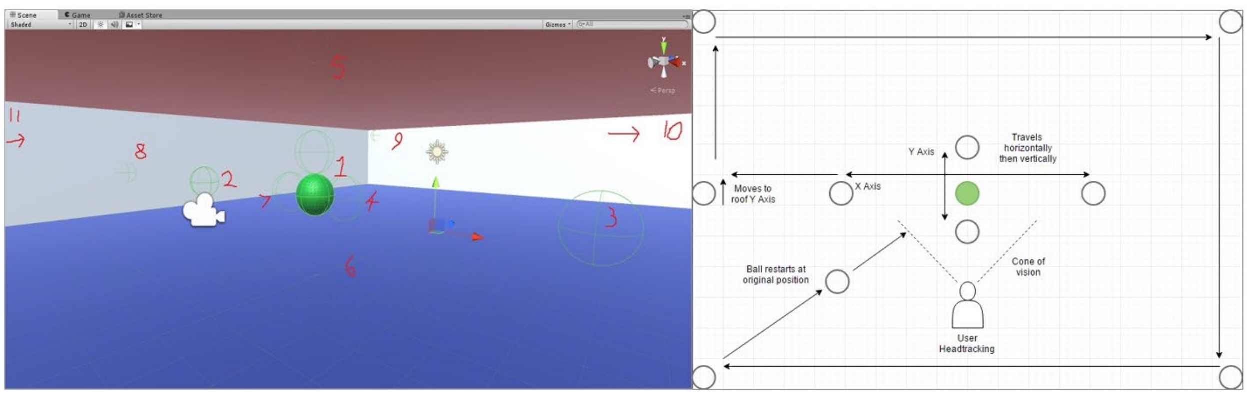

Fig. 1. The left image shows the Unity scene of the Object tracking test, and the right image the wireframe diagram of the sphere's movement pattern.

Movement

This test was designed to gauge the perception of users differentiating between multiple visual elements with varying levels of movement, simulating visual noise. Multiple objects move in front of the user while they attempt to identify them, count them, describe their movement, and list objects in order of speed (see fig. 2).

Results showed that 2 users struggled with identifying colors, 1 struggled with counting all objects due to limited vision cones, and 1 struggled with distinguishing between varying speeds. Remaining users accurately identified between fastest and slowest objects. Those that struggled were distracted by visual noise, with 1 seeing static objects as moving.

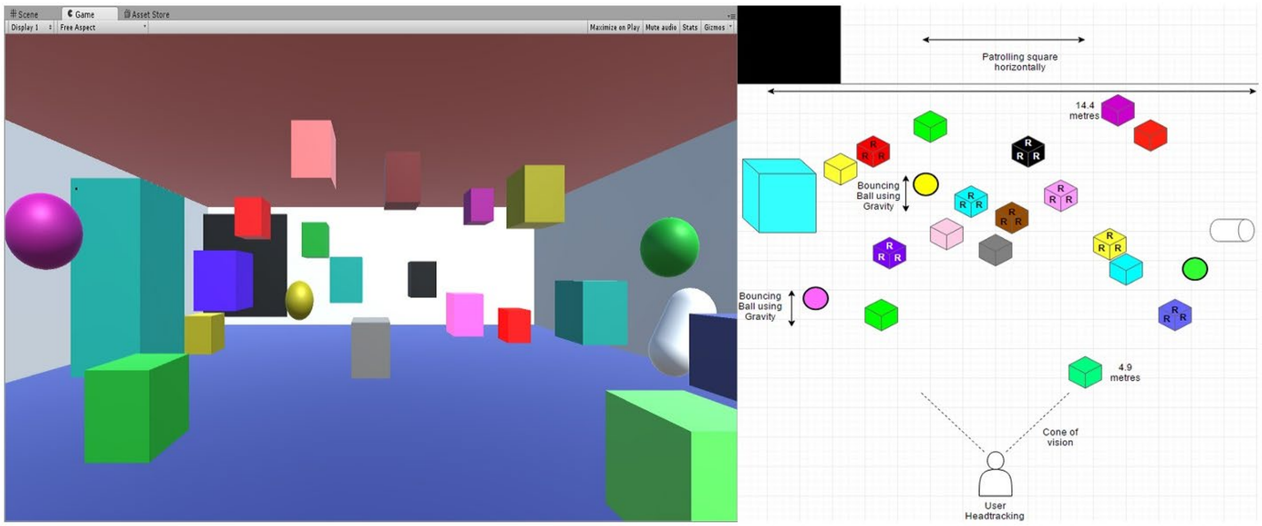

Fig. 2. The left image shows the Unity scene of the Movement test, and the right image the wireframe diagram of each object's characteristics.

Gaze Ability

This test was designed to observe cognitive ability within VR with simple task solving, and the ability of users suffering from central vision loss, such as AMD (Age-related macular degeneration). Red arrows direct the user to subsequent arrows changing green once a central hit scan is detected, until an entire sequence has been followed (see fig. 3). Collision can be calibrated to compensate to the degree of central vision missing.

Results showed that all users but 1 could complete the full test's sequence. This user struggled due to central vision loss, particularly identifying arrows placed higher up. 2 users required central vision calibration to complete the test, benefitting them afterwards. 1 user observed the arrows as moving, despite being static.

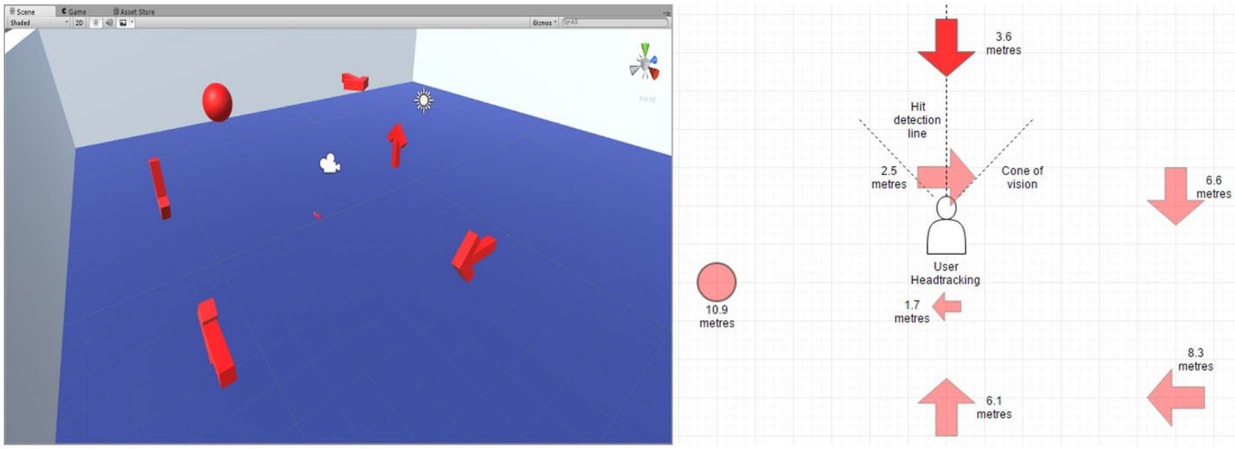

Fig. 3. The left image shows the Unity scene of the Gaze test, and the right image the wireframe diagram of each arrow's location.

Distance Color

This test was designed to examine the user's ability to detect and correctly identify color over varying distances. Four green 3.3753 m cubes of different colors were presented at 3.9m from the user, and after each attempt of identifying each color these cubes move a further 2m distance, changing color until every sequence is completed (see fig. 4).

Results showed that 2 users struggled with colors, with 1 unable to see color and beyond 17.5m from one eye. One user's perception was affected by which side of their head a cube was at. As expected, distance affected the accuracy of color detection, particularly those with central vision loss, highlighting the need for control over distances.

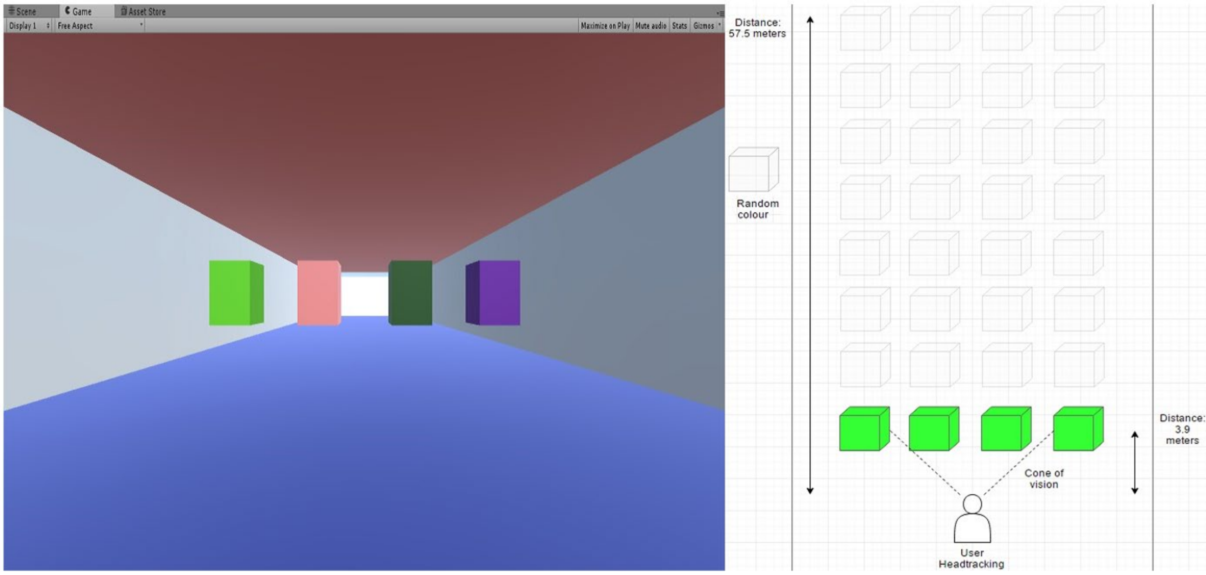

Fig. 4. The left image shows the Unity scene of the Distance test, and the right image the wireframe diagram of the scene.

Size Detection

This test was designed to gauge the user's ability to identify dimensions in nearly identical shapes. 4x5 rows of red cuboids were displayed, some perfect cubes, some distorted by an axis or entirely scaled, with the user asked to identify and spot out irregular cubes and describe any differences they could perceive (see fig. 5).

Results showed that no user could fully complete the test sequence, and 1 user could not detect any size differences. One user described cuboids as wobbly and blurry and could not see differences until highlighted to them. Exaggerated objects were best detected, and VR development should ensure elements are contrasting and clearly defined for accessibility.

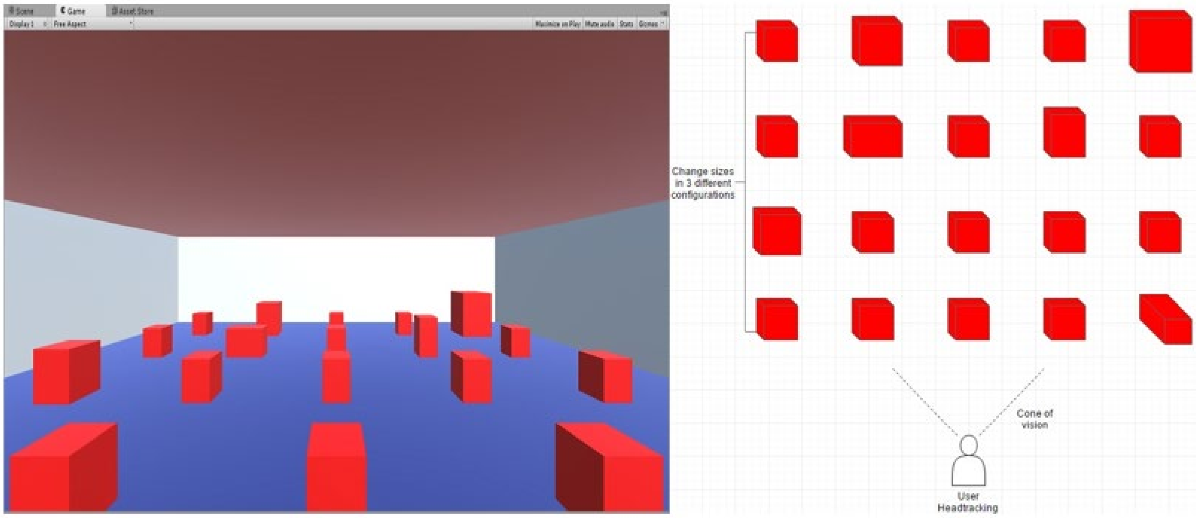

Fig. 5. The left image shows the Unity scene of the Size test, and the right image the wireframe diagram of each cube's size.

Depth Perception

A final test was designed to gauge depth of perception as a participant reported having stereo-blindness. The first half of the test has the user examine a 3D and 2D circle and determine the difference in a 3D space, while the second half has the user look at several pillars distances behind each other at longer distances while describing their perception of depth (see fig. 6).

Results showed that 6 users could correctly perceive depth, 2 were unsure and struggled describing, and 1 could not at all. One user commented that their depth has been long gone, and they were able to correctly observe it again through the headset, but we could not replicate these same results with any other participant.

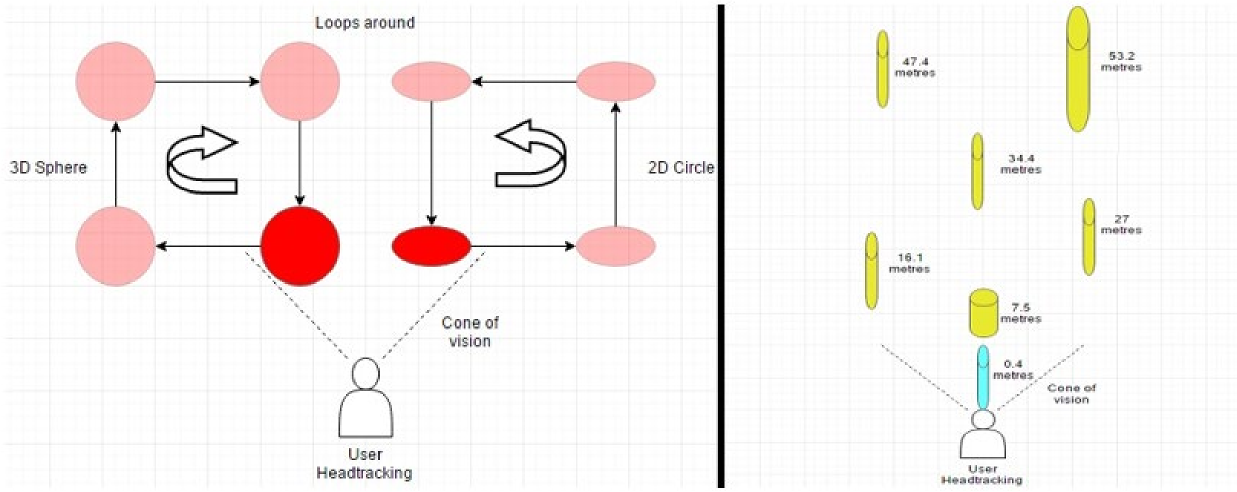

Fig. 6. The left image shows the wireframe diagram of the first part of the Depth test, and the right image the wireframe diagram of the second part.

Summary

Findings showed that color accuracy was manipulated by both visual noise and distance, vertical tracking was easier for tracking an object, but worse for finding an object for AMD sufferers, color accuracy degraded near 17m distances, size differences between near identical objects were difficult to perceive, and that depth perception might be affected within VR but limited results were produced. It is worth noting that the tested headset produces clearer visuals when looking at the center of the lenses, which is a limitation. Reactions from participants were very positive, with most suggesting they could not perform these tasks without the headset. This gives us a framework for what impaired users are capable of within a VR headset, informing future developments towards VR accessibility, such as our software.

Software Prototype & User Evaluation

Following the preliminary test, a VR video player was developed based on participant results and feedback using the Unity engine and tested via a Pimax 5K Plus VR headset (Pimax). Our findings highlighted that control over distance and placement (such as elevation to compensate for vision cones) would improve the viewing capabilities of visually impaired users. Contrasting colors, visual noise, and distinguished elements are also key and can be emphasized within a digital environment, showing the benefits of a VR system. The application allows users to select and setup their own 3D virtual living environment and view videos that can be manipulated with several enhancements and size adjustments. Using motion controllers, users watched videos within the 3D environment which could be customized for both preference and accessibility, such as enabling virtual lights from specific directions or torches, or to place and re-position both the video and the environment. 2D, 3D, and 360-degree video formats are supported, and can be embedded from external websites. The user can resize the video player by stretching it (see fig. 3 (left)). The video player can be moved around freely and frozen virtually grabbing and releasing it via motion controllers. Curvature of the screen can be adjusted to assist with viewing angles. The light and color levels of the video can be adjusted for accessibility needs. Overall brightness and contrast of the video, or of the entire environment, can be adjusted to assist with clarity and to aid specific conditions such as photosensitivity. Specific color adjustments can be made to help with conditions such as color-blindness (see fig. 7 (right)). Most options are also available through voice commands spoken via an embedded microphone into the VR headset, thus requiring less dexterity from the user.

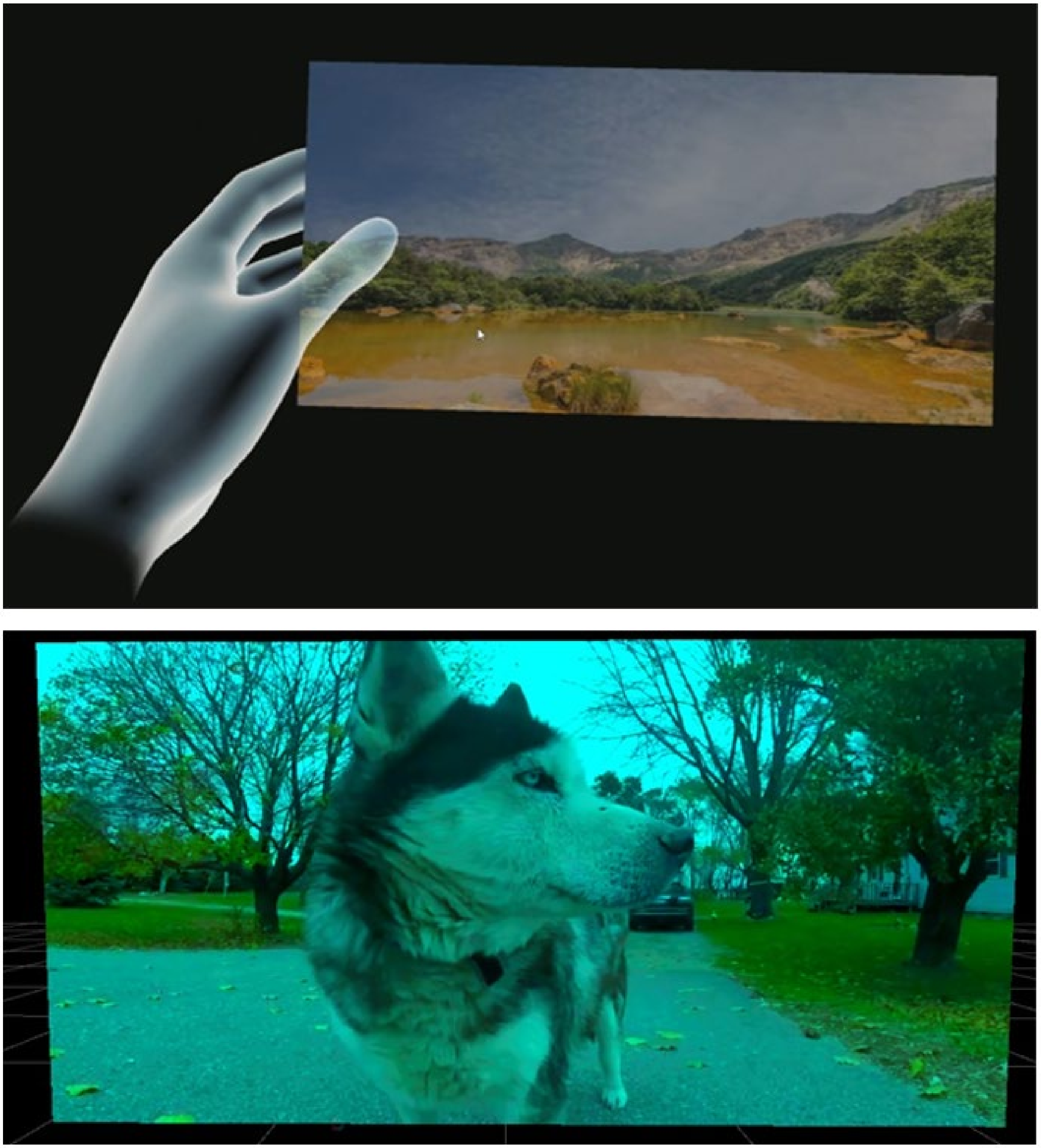

Fig. 7. (Top) A video shrunk to the user's hand in our prototype; (Bottom) A video with colors adjusted to compensate for Protanopia color-blindness.

The environment can be manipulated using the motion controllers to grab, re-arrange, and place objects. Configurations are saved and loaded, and the user can choose how complex or simple the environment is to increase immersion factors, or to reduce visual noise (see fig. 8).

Fig. 8. An example bedroom environment configuration.

After the prototype software was developed, a second study was conducted trialing a further 11 participants still classed as Low Vision. We recorded configurations each participant selected while using the video player, notably their **contrast**, **brightness**, **distance**, **video size**, and **rotation settings**, asking for their preferred preferences. A follow up interview and questionnaire was conducted for feedback.

Results showed that 7 users preferred an increased brightness, while 4 were sensitive to light with 3 of these preferring brightness unchanged, and 1 the brightness reduced. Seven preferred an increased contrast, with six of these by a significant amount and one only minor. Three preferred no changes, and one reduced contrast levels. Average distance for preferred viewing was 0.63m, with 3 preferring 0.3-0.4m ranges and 3 preferring 0.78-0.84m ranges. Ten users kept the video size at its default 60x30cm at 0.5m distance, while one increased this by 20%. Similarly, users did not make significant changes to the video rotation, while 1 rotated it 20 degrees upwards and placed it 120 degrees forward to the right of their vision.

In summary, participants displayed an affinity towards the ability to adjust the brightness and contrast dynamically themselves. Participants expressed the biggest improvement to visual clarity in manipulating brightness, and to a lesser extent the contrast. The preferred location for the video player was left close to its default position (0.5m away from eye level).

Observational and verbal feedback from our test group showed that natural real-world interactions via motion and voice controls were understandable and preferred by impaired users. Participants quickly understood and enjoyed interactions by gripping triggers via HTC Vive Wands (HTC) to move objects. Participants expressed they would utilize an accessibility headset daily if it were lighter and more comfortable to wear.

Conclusions

In this paper we successfully developed user-informed accessibility work in VR to enable persons with disabilities to watch videos, or to improve their video watching experience, as part of increasing their independent living capabilities. The presented tests give us a greater clarity of what visually impaired users are capable of within VR environments, and their level of perception amongst tested variables. This type of study is important, as current top commercial VR headsets are not designed with the visually impaired in mind, yet the technology could greatly enhance their lives. These findings were then used as the foundation of our bespoke highly adaptable VR video viewer. This video viewer designed for accessibility is the first of its kind and aims to highlight and promote the potential for using VR technology as accessibility tools.

Feedback from our user evaluation highlighted that the ability to re-position virtual objects dynamically via motion controls was very well received by impaired users, as details such as modifying viewing angles to combat damaged visual cones effortlessly allowed for easier viewing. Our evaluation validated the usefulness and usability of such a device combined with specialist software, as well as where improvements could be made. Our participants gave us a baseline for what settings persons with severe visual impairments would use to view and operate a video player within a VR environment, and what aspects that affect their acuity. Our research showed that video elements were perceived well with persons of severe visual impairments, and flagged some concerns with field of view limitations, (particularly those with AMD) and brightness settings being a concern.

In future works we aim to develop the software further by integrating live video with enhancements via camera mounts and compare performance to natural vision.

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