Exploring the Prospects of Virtual Reality for the Visually Impaired

Literature survey briefly exploring the potential of Virtual Reality as a novel interface for assistive technology, drawing on current research and exploring their impact on empowering accessibility and fostering empathy.

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Virtual Reality (VR) although mostly associated with visual phenomena and primarily described as a mediated abstraction of reality perceived visually, is often touted as a democratizing way to access new worlds and experiences [6]. This has led VR systems to be even used as assistive technology for visually impaired users through interaction modalities that surpass visual renderings. The inclusive approaches to accommodate non-sighted users not only promote accessibility as a means to appropriate VR systems to cater to a larger audience but also for sighted users providing a medium to educate themselves to experience and understand the perspective of their non-sighted counterparts. This survey reflects on the current research on how VR systems have been explored to benefit the affordances of visually impaired users, points out key areas of concern in terms of accessibility, and generalizes the challenges when trying to use VR as a tool for empathy.

1 INTRODUCTION

Virtual Reality (VR) technology has traditionally been associated with visual experiences and for most, it simulates spatial information through stereoscopic rendering presented through a Head Mounted Display (HMD) [12]. However, other sensory feedback mechanisms such as audio and haptics that constitute a more immersive VR experience have not been thoroughly leveraged. Thus, if the dominance of visuals in VR can be extricated through sensory substitution [14], it can be used as a capable assistive technology for visually impaired users. Current research focuses on achieving this through the creation of a soundscape in the virtual world [14] as well as through telepresence [8] which proposes an avenue for multimodal interactions with VR representations.

Accessibility in VR for non-sighted users is a usability concern that traditional VR systems have been trying to patch in order to establish a more inclusive experience. However, considerations at a later stage of the system design life cycle have proven to produce sub-par fixes to these usability concerns. Thus, the design process should inherently promote key inclusions to make the VR experience more accessible for non-sighted users as it helps even sighted users during situational disabilities [7], analogous to how a rising tide raises all boats [14]. Fostering empathy for a disability through the use of VR is an effective means of communicating a perspective of another individual’s situation; however, challenges arising from misrepresentations of blindness simulations, lack of personal experience, and presence of misconceptions have led to fostering causal empathy and not long-term perspective shifts.

2 VR FOR THE VISUALLY IMPAIRED

The visual sensory bandwidth exceeds the bandwidth of haptics and hearing by far and therefore enables faster and more interactive types of locomotion [12]; however, related work in VR for users with visual impairments and/or low vision have mostly examined navigation techniques in indoor spaces with less focus on video spatial renderings and more on spatialized audio and texture mimicry through vibrotactile feedback mechanisms. Niklas Elmqvist in his article [14] terms this approach as *sensory substitution* which in the case of non-sighted users implies visualization only through the two practical options - touch or sound. Moreover, the article talks about shifting the idea of visual representation to spatial representations through the creation of a *soundscape* where the user exhibits navigational expertise through a mental map using echolocation and kinesthetic feedback from a cane tip and ambient environmental sounds in a simulated environment [14].

Microsoft Research’s Canetroller [11] is an example that demonstrated how rendering virtual objects haptically, including simulating materials’ properties and textures, could enable users who were completely blind to successfully navigate and understand virtual scenes when paired with a novel haptic controller that mimicked the interaction of a white cane [7]. A successor to this study [1] employed a multiple degrees-of-freedom cane enabling users to adapt the controller to their preferred techniques and grip along with a three-axis brake mechanism to emulate large shaped virtual objects. Additionally, as three-dimensional rendering, the main channel of information used in current virtual reality is unavailable to people who are blind, new haptic rendering technologies capable of detecting and displaying surface roughness in Telepresence [8] can also be explored as a means to convey virtual 3D objects to people who cannot see [7].

2.1 Generating Design Space for Visually Impaired VR Users

Jain et al. [9] in their research on sound accessibility in VR for Deaf and hard of hearing (DHH) users suggest a morphological search-based design space of input devices and information visualization. The design space includes both syntactic and semantic dimensions for sounds, visuals, and haptics. However, since the review concentrates on visually impaired users, vocabularies encompassing sound and haptic have been explained as viz.

2.1.1 Sound Vocabulary.

The taxonomy of sound vocabulary covers two dimensions: source and intent. The “source” is the origin of the sound (e.g., from a character or an object) which is further categorized as *localized* and *nonlocalized* depending upon the sound emanating from an actual object/character in the VR world or from those playing in the background. The “intent” on the other hand is the impact of a sound on the users’ experience that increases realism and/or conveys critical information.

Table 1: Jain et al. [9] categories of localized and non-localized sound sources

Sound source	**Category**	**Description**
Speech	Localized	Spatially positioned speech of a character
	Non-localized	Ambient speech of a narrator
Objects	Inanimate	Sounds from non-living objects
	Animate	Non-speech sounds from living beings
Interaction	-	Sounds from the interaction between multiple objects
Ambient	Point	Spatialized ambient sounds that belong to the VR world
	Surrounding	Non-spatialized ambient sounds
System	Notification	Sounds of critical alerts of specific events
	Music	Background music

Table 2: Jain et al. [9] categories of sound intents

Sound intent for	Description
Conveying critical information	All sounds that are critical for progression in an app
Increasing realism	Ambient or object sounds that increase immersion
Rhythm or movement	Sounds that correlate to or enhance a particular user/object/actional movement
Generating an affective state	Emotional sounds with varying level intonations
Aesthetics or decoration	Non-critical sounds that increase the beauty
Non-critical interaction	Interaction sounds that are not critical to game progression

2.1.2 Haptics Vocabulary.

The taxonomy of the haptics vocabulary is articulated as having three feedback dimensions depending upon the delivery, location, and qualitative elements. The first dimension is the *haptic form facto*r which describes the device on which the haptic feedback is delivered. It encompasses a range of delivery mechanisms ranging from traditional VR controllers to non-conventional and emerging haptics-based commodity devices. The second dimension is the location of the body on which the haptic feedback is delivered called the *haptic feedback location* which includes prominent localized areas of palms, arms, torso, head-mounted, and legs. Finally, the *haptics elements* constitute three primary quality factors of a realistic haptic experience, namely (i) Intensity (amplitude/strength), (ii) Timbre (sharpness/pitch), and (iii) Rhythm (beats/interval between feedbacks).

3 ACCESSIBILITY CONUNDRUMS IN VR

One of the key principles of Human-Computer Interaction is Iterative Design where usability concerns are incorporated from the start to make informed design decisions throughout the design process. Unfortunately, in practice, fixes for usability concerns perceived as affecting small populations (such as people with disabilities) are often tackled on at the end of the software design lifecycle, resulting in sub-par user experiences [7]. Accessibility has thus far not been a primary consideration during the development of mainstream VR systems. Mammot et al. introduce the concept of *situational disability* [7] where a normal user can become disabled at certain instances (e.g. When the hands are occupied holding groceries and unable to do any other task) thus emphasizing the concept of considering accessibility as a core part of a VR system’s design process. Although contemporary commercial VR systems seem deficit in incorporating accessible mediums for a large diaspora of disabled users, in this literature review, the accessibility concerns are bluntly aimed towards the visually impaired population.

3.1 Visual Dependency

VR experiences heavily rely on visual stimuli, making them inherently challenging for individuals with visual impairments. The immersive nature of VR relies on visual graphics, spatial awareness, and visual cues, which can create significant barriers for those who are blind or have low vision. Lack of visual information limits their ability to perceive and interact with the virtual environment. VR environments can be disorienting, especially without visual cues for navigation and orientation. Visually impaired individuals may struggle to understand the layout, identify objects, or navigate within the virtual space. Developing effective auditory or haptic navigation aids and spatial awareness techniques is essential to provide a sense of direction and orientation [3].

3.2 Lack of non-visual feedback

VR typically lacks alternative modalities or non-visual feedback to compensate for the absence of visual cues. While some VR applications may include audio cues, haptic feedback, or speech synthesis, their implementation is often limited, inconsistent, or insufficiently utilized. Providing meaningful and comprehensive non-visual feedback becomes crucial to conveying information and enabling participation for visually impaired users [2][12].

3.3 Key Areas of Accessibility Concerns in VR

Existing literature points out overlapping themes of concern for accessibility in VR for visually impaired users that revolve around standards of content, interaction modality, and device usability. The papers used in this review that highlight these areas are congruently grouped up in the following Table 3.

Table 3: Tabular representation of literature sharing congruent areas of accessibility concerns in VR

Paper	**Content Accessibility**	**Interaction Accessibility**	**Device Accessibility**
Mamott et al. [7]	✓	✓	✓
Jain et al. [9]	✓		
Philips et al. [6]	✓	✓	✓
Elmqvist et al. [14]	✓	✓	
Williams et al. [3]			✓
Zhao et al. [11]	✓		
Kreimeier et al. [12]		✓	

3.3.1 Content Accessibility.

One of the key challenges in traditional VR systems is to appropriate representations as per users' abilities. For many assistive VR systems targeting non-sighted users, the audio information conveyed by most VR content is not enough to fill in for the visual cues that seeing users experience. This is mainly due to the lack of definition of metadata necessary to allow multimodal representations [7]. Attempts to establish a standard representation of these data include transforming visual representations into spatial representations through the process of sensory representations [14] along with introducing metadata that encodes objects' haptic properties, such as their materials and textures, for creating realistic haptic renderings [7].

3.3.2 Interaction Accessibility.

VR has the potential to create a "level playing field," providing spaces in which all users may be equal in their capabilities. Due to this very reason, it is necessary that VR systems and their representations account for end-user diversity within their design to be comfortable for and usable by a large audience. Thus, for the interaction in VR to be inclusive, two main areas of focus comprise accessible inputs and user interfaces [7]. The input in VR systems is typically through hand-held and one-size-fits-all controllers that assume users have an articulate range of motion. Unlike interaction with stationary or mobile devices, this implicit dictation of users' input actions offers limited to no support for direct input apart from 3D controller motions in mid-air. Thus, there is an opportunity to design VR interfaces to support direct 3D input as well as input through alternative modalities, such as voice and gaze [7].

3.3.3 Device Accessibility.

VR hardware typically makes many assumptions about users' abilities which can lead to accessibility problems [7] more specifically when the challenges are due to motor skills [6]. The physical interfaces of VR systems, such as controllers and head-mounted displays, may not be designed with accessibility in mind and often rely on visual feedback or complex button configurations, making them challenging to use for individuals with visual impairments. Incremental changes in the design of this hardware that aim to reduce the number of individual components and introduce more flexible and ergonomic types of equipment prioritizing non-visual interaction methods are necessary to ensure equal access to VR experiences [3][7].

4 VR FOR FOSTERING EMPATHY

VR is often revered as an effective means of promoting empathy as the system enables the simulation of an actual experience for people to better understand the perils and perspectives of another individual's situation. For simulations that focus on users experiencing a disability, the primary agenda is to foster some kind of empathetic concern and desire to help accommodate people belonging to the group. However, current literature suggests that such kind of disability simulation comes short in one way or another, misleading realities of a disability which can contribute to paternalistic discrimination [13]. Moreover, empathy that is fostered through these simulations is found to arouse compassionate feelings but not necessarily encourage users to imagine other peoples' perspectives [15].

4.1 Challenges in VR blindness simulations

In terms of disability simulation concerning vision, no ample research has been conducted that highlights the significant implications of post-simulation empathy. However, the present literature on studies concerning VR simulating blindness simulation presents the following challenges.

4.1.1 Lack of Personal Experience

VR experiences aimed at fostering empathy for blind individuals require sighted users to understand and embody the perspective of blindness. However, sighted individuals naturally lack personal experience and understanding of the daily challenges faced by blind people. This knowledge gap can make it difficult to develop accurate and meaningful VR simulations that effectively convey the actual blind experience. Studies [15][16] have shown that following the simulations, empathetic concern (warmth) toward disabled people increased with certain boundary conditions to this effect; however, attitudes about interacting did not improve. Moreover, in some conditions, VR was no more effective at increasing empathy than less technologically advanced empathy interventions such as reading about others and imagining their experiences [15].

4.1.2 Misrepresenting Visual Impairment.

Creating a realistic representation of visual impairment in VR poses a challenge. Blindness is not merely the absence of vision; it encompasses a range of visual impairments with different degrees and types of vision loss. Designing visual effects or simulations that accurately depict various types of blindness is a complex task that requires careful consideration that can also mislead people about blindness because it highlights the initial trauma of becoming blind rather than the realities of being blind [13].

4.1.3 Stereotypes and Misconceptions.

When designing VR experiences to foster empathy, it is crucial to avoid reinforcing stereotypes or perpetuating misconceptions about blindness [3]. Misrepresenting blind individuals as helpless or dependent can undermine the goal of promoting empathy and understanding. Redmond et al. [16] found that with a number of participants in disability simulations, most of the participants felt more confused, embarrassed, helpless, and more vulnerable to becoming disabled themselves compared to baseline which in itself contradicts the idea of empathy generation.

5 CONCLUSION

This monograph briefly underscores the promising role of VR to inclusively accommodate visually impaired users, explores the underlying accessibility concerns in terms of content, interaction, and devices, and highlights key challenges while trying to foster empathetic concerns. By leveraging sensory modalities beyond visuals, such as audio and haptics, VR can create inclusive and immersive experiences. Incorporating accessibility considerations early in the design process is crucial to ensure a more accessible VR environment for both non-sighted and situational disabled users. However, challenges related to misrepresentations, lack of personal experience, and misconceptions must be addressed to facilitate genuine and enduring empathy. Collaborative efforts with visually impaired individuals are vital for accurate representations and meaningful perspective shifts. In summary, VR holds substantial potential for enhancing accessibility and empathy, necessitating further research and collaboration to optimize its impact on the visually impaired community.

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