Accessible by Design: An Opportunity for Virtual Reality

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Abstract

Too often, the accessibility of technology to people with disabilities is an afterthought (if it is considered at all); post-hoc or third-party patches to accessibility, while better than no solution, are less optimal than interface designs that consider ability-based concerns from the start [31]. Virtual Reality (VR) technologies are at a crucial point of near-maturity, with emerging, but not yet widespread, commercialization; as such, VR technologies have an opportunity to integrate accessibility as a fundamental, developing cross-industry standards and guidelines to ensure high-quality, inclusive experiences that could revolutionize the power and reach of this medium. In this position paper, we discuss the needs, opportunities, and challenges of creating accessible VR.

Keywords: Virtual Reality, Mixed Reality, accessibility.

Index Terms: K.4.2 [Computers and Society]: Social Issues – Assistive Technologies

1 Introduction

Iterative design is a key principle of HCI (human-computer interaction), wherein usability considerations are incorporated from the start of the design process. Systems are periodically tested with users as part of the development process, resulting in iterative improvements to the design and usability until the system is ready to deploy to end-users. Unfortunately, in practice, fixes for usability concerns perceived as affecting small populations (such as people with disabilities) are often tacked on at the end of the software design lifecycle, resulting in sub-par user experiences [31].

However, considering accessibility as a core part of a system's iterative design process is valuable not only for the more than a billion people worldwide who have some type of disability [32], but for *all* users, since everyone experiences *situational disabilities* dependent on their context (e.g., a person holding groceries is unable to use their arms for other tasks, a person in a loud room may have difficulty hearing, etc.) [24].

Virtual Reality (VR) technologies are at a key crossroads in their development, with costs and form-factors placing them just at the cusp of widespread commercial feasibility. Accessibility has not thus far been a consideration in the development of mainstream VR systems; Zhao et al. found in a study of Unity developers that none had ever considered accessibility, nor been given any guidance by their employer on any accessibility guidelines to which their applications should adhere [36].

Additionally, there is currently debate about the applicability of the Americans with Disabilities Act (ADA) to various categories of digital media (e.g., [3]), and it is quite likely that within the next few years there may be increased legal requirements around digital accessibility, including for VR; there is an opportunity for our community to lead by defining these standards, rather than playing catch-up in the face of punitive actions.

In this position paper, we describe five key areas of accessibility for the VR community to consider: the accessibility of VR content, the accessibility of interaction techniques, device/hardware accessibility, inclusive user representations within VR environments, and accessibility-focused application areas for VR. We argue that the VR community should seize this moment in time (while devices and standards are still evolving) to include accessibility considerations in VR systems, in order to create a more usable and inclusive technological future for users of all abilities.

2 Content Accessibility

Many media forms have agreed-upon standards and/or guidelines for making content accessible. For instance, closed-caption file formats allow embedding of captions in online videos that can be shown or hidden depending on a user's preferences (i.e., someone who is deaf may choose to reveal the captions), and the alternative text ("alt text") field in HTML and other document formats allows the specification of an image description that can be read aloud to a user who is accessing content via a screen reader (i.e., someone who is blind). Currently, VR lacks agreed-upon methods for making content accessible; the ability to render content in alternative modalities (e.g., sound to text in the closed captioning example, imagery to audio in the alt text example) would be an important first step to enabling VR content accessibility.

Some prior works have begun to explore the value of metadata in VR for more inclusive representations of content. Microsoft Research's Canetroller [35] 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. 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 such as ShapeDisplay devices are being explored as a means to convey virtual 3D objects to people who cannot see [25]. Microsoft Research's SeeingVR toolkit [36] was the first system with the ability to add metadata analogous to alt text into VR scenes, allowing objects to be described and text to be read aloud to people with vision disabilities.

An open challenge is for the VR community to agree upon and define the metadata necessary to allow multimodal representations of VR content so that an appropriate representation can be chosen based on a user's abilities. Once the community can agree on what data would be sufficient for such rendering, then we can move toward agreed-upon standards for representing these data. For instance, as proposed by SeeingVR [36], it seems reasonable that the inclusion of alt text descriptors for all objects in a VR scene should be included in such a standard. Including metadata with transcribed text for audio content, as well as imagery or other visual

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representations of non-speech audio used in VR scenes, is likely important for rendering information accessibly to people who are deaf or hard-of-hearing. Metadata that encodes objects' haptic properties, such as their materials and textures, will be important for creating realistic haptic renderings for people with limited vision. The addition of such metadata also has great potential for a large range of applications that can benefit the general audience of virtual reality users, such as adapting content for temporary or situational impairments, creating "spectator interfaces" that log or describe VR content to non-primary users, etc.

Desktop and mobile device operating systems currently offer users a range of accessibility options that can be applied post-hoc to any application running on-device, such as the ability to magnify text content, enlarge fonts, invert colors, or change control-display ratios. The ability to apply similar accessibility updates to any VR world will be necessary for ensuring broad access; SeeingVR [36] demonstrated how many common vision-related accessibility settings (e.g., magnification, contrast adjustments, etc.) can be applied to virtual scenes; developing standards that all VR developers can adhere to in order to allow accessibility settings to apply universally across any VR application is another important topic for the community to consider.

3 Interaction Accessibility

Because VR technologies extend the capabilities and realism of computing far beyond today's desktop interfaces (e.g., through extremely high resolution, ever-increasing field of view, 3D presentation of visual and auditory content, haptic sensation, etc.), they present both opportunities and barriers. On the positive side, VR has the potential to create a "level playing field," providing spaces in which all users may be equal in their capabilities, or even in which all users may experience "superpowers" such as the ability to fly. On the other hand, VR extends the use of users' physical input and output beyond any previous medium; this constant evolution toward increased fidelity of input and output in VR may amplify differences among users' abilities; for instance, a person with a limited field of view may have sufficient visual angle to consume information on a tablet, but may require special accommodation to effectively consume a 110 degree HMD's contents. VR must account for end-user diversity within its design to be comfortable for and usable by a large audience.

3.1 Accessible Input

Users typically provide input to current VR systems through hand-held, one-size-fits-all controllers. Such controllers commonly assume that users have one or both hands available for use with full articulation of fingers, wrists, and arms. Controllers thereby implicitly dictate what input actions users can perform and how they need to perform them, as many VR titles require large, coordinated, and precise upper-body movements to control interactions. All of this can exclude individuals who may have limited mobility or weakness, or who may not have the expected complement of limbs or digits to produce the gross and fine motor skills needed to perform direct manipulation tasks in VR, such as precisely selecting, dragging, rotating, and scaling virtual objects. For many people with upper-body motor limitations, these actions may be difficult to perform, may cause fatigue, or may result in frustrating experiences while using VR.

Advances in VR hardware could help alleviate some of these issues, by providing alternative means of support for HMDs, and adaptations for controllers (e.g., the Xbox Adaptive Controller [33]). Unlike interaction with stationary or mobile devices (e.g., tablets), many VR applications offer limited to no support for direct input apart from 3D controller motions in mid-air. This aggravates fatigue and ergonomic concerns, which affect all users and may particularly impair the usability of VR for older adults and people with mobility limitations.

Alternative sensors from which VR applications can infer user input can help make interfaces more accessible, including motion, eye gaze, and audio sensors already built into current VR headsets. Unlike the direct input from controllers, such sensor input must be interpreted by VR systems, creating ambiguity and possibly interfering with fluid interaction. For example, voice interaction is a possible solution for some users with upper-body motor limitations, but it should not be considered a solution for all users, as many people with motor-impairing conditions such as cerebral palsy and Parkinson's disease may have dysarthria, making it difficult for automatic speech recognition systems to understand them. Further, considering how to make voice control usable for dense, complex, 3D VR scenes remains an open challenge.

3.2 VR User Interfaces

Further complicating matters, VR applications often present users with 3D user interfaces whose additional spatial component can already hamper easy use for able-bodied users and is often less accessible than traditional 2D user interfaces on desktop and mobile systems to begin with. Studying user behavior to inform the design of accessible interaction techniques has been useful in developing more accessible interaction techniques for desktop and mobile computing systems. For example, understanding the pointing performance of people with tremor [13] led to the development of the Steady Clicks pointing facilitation techniques [25]. Conducting similar formative studies on the accessibility of current VR systems to people with a range of abilities is important for understanding the status quo and envisioning how to move beyond it.

We see an opportunity to design VR interfaces to support direct 3D input as well as input through alternative modalities, such as voice and gaze. Since VR applications often contain 3D interfaces, voice- and gaze-based interaction is not straightforward and needs to be incorporated into the design process of each application—not just retrofitted to existing designs as is common in 2D GUIs. Researchers have previously investigated how to construct usable interaction techniques in VR and other 3D graphics environments [2][4][20], but these investigations have largely ignored people with upper-body motor limitations.

There is also the opportunity to discover if existing solutions for desktop and mobile systems would provide accessibility benefits for VR systems. Although the affordances and input devices for these platforms differ, the key insights of these accessible interaction techniques may be transferrable to VR. For example, interaction techniques that provide additional stability and control by relaxing the need for precise pointing [1][30] could make virtual targets easier to select by increasing their size in motor space.

4 Device Accessibility

VR hardware typically makes many assumptions about users' abilities that can lead to accessibility problems. For example, most head-mounted displays (HMDs) require significant head and shoulder strength, as well as the ability to execute a large range of motion and may also be problematic for people who wear assistive devices on the face such as eyeglasses, hearing aids, or cochlear implants. Headset cables and surrounding tracking systems create an infrastructure that requires setup and calibration before use and impedes mobility while experiencing VR. Even the ability to put on such equipment requires substantial strength, range of motion, and dexterity (e.g., being able to reach to tighten a headset with a knob located on the back of the head).

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The most recent generation of VR headsets aims to reduce the number of hardware components, such as by integrating outside-in tracking into the headset. This mobile tracking approach makes VR systems faster to use out of the box but may not reliably detect accessibility features inside real-world environments, such as tactile guides or small haptic features.

Flexible design is also becoming more common in VR hardware, which is an encouraging trend for accessibility – for instance, many HMDs now allow the user to specify the distance between the eyes or between the eyes and the display in order to optimize the experience. Further, the VR industry has begun to make applications more flexible to different types of hardware, enabling backwards compatibility of older applications as new generations of HMDs and controllers emerge (e.g., SteamVR's action mapping interface [26]); this flexibility is an excellent example of a framework that may particularly benefit accessibility, i.e., by supporting novel or customized controllers used by particular populations. In the future, customizable hardware may become increasingly common; for instance, the ability to incorporate prescription lenses into headsets and/or to create custom optics may benefit end-users with low vision.

Improved ergonomics of equipment may increase accessibility (as well as improve broader public perceptions around the aesthetics and practicality of VR hardware); on the flip side, it may be that future VR (as well as AR) systems could also be integrated directly with access technology. For instance, headsets might be built directly into glasses already used to address vision impairments, or controls might be built directly into assistive devices such as wheelchairs or canes (e.g., taking inspiration from Carrington et al.'s notion of "Chairables" [6]).

5 Inclusive Representations

User representations will have implications on people's ability to engage with the virtual world. In particular, VR affords the opportunity to control and embody virtual avatars that have characteristics that might differ from a user's physical traits. The physical appearance of avatars varies based on the application, with some avatars appearing as superheroes, giant robots, or humanoids with large heads and small bodies. As VR applications become more diverse, evolving from primarily games to more social and professional applications, there is a need to have more diverse representations of avatars for people with disabilities. What avatars users decide to control or embody depends on numerous factors, such as the application and task users are engaged with [12], as well as users' personal preferences [8]. Researchers have previously investigated how certain user groups, such as older adults [5], choose and customize avatars, but it remains unclear what preferences people with disabilities have regarding avatar choice.

Avatars in VR should be as diverse as the population of users who can control them. Providing avatars with diverse physical characteristics, such as avatars who use wheelchairs, avatars with white canes, and avatars with hearing aids, would give users with disabilities the option to choose if they want to control or embody avatars that resemble their physical appearance. Look-alike avatars have been shown to increase self-representation through brain electrophysiological traces [11]. Therefore, it is important that people with disabilities are given the option to choose, rather than having the designers of VR applications decide for them.

In addition to the appearance of the avatar, users might want to alter the way their avatar moves to more closely resemble their movements in the real world. For example, a user with an atypical gait might want their avatar to possess a similar gait while walking in a virtual environment. Alternatively, they might want the avatar to be able to reach further than they would be able to in the real world [15], especially if the user has motor impairments [14][19].

Of course, people with disabilities may decide not to choose an avatar that resembles their physical appearance. How and why users customize their avatars is highly dependent on the context, and users should have the option to change the appearance of their avatars based on these contexts. For example, a user in a social VR application might want to have one avatar representation when interacting with friends but a different representation when interacting with strangers. There might be numerous privacy and security concerns that influence users' decisions when choosing and customizing avatars, so it is important to provide users some control over how their avatars are presented to other users.

6 Application Diversity

Making VR accessible not only ensures that people with a wide range of abilities will be able to use and enjoy the categories of VR that are of emerging commercial importance (e.g., gaming and entertainment applications [29], productivity tools, education), but also opens the door to new application areas related to skill-development, rehabilitation, and other special needs of people with disabilities. For example, the development of a novel haptic device and tactile representations of virtual scenes allowed Orientation and Mobility (O&M) instructors (professionals who train people with vision impairments to navigate without sight) to envision the potential of VR for O&M training [35]. Examples might include allowing a person who is blind to practice a dangerous situation such as crossing a busy intersection virtually before trying it in the wild, allowing practice with navigating a particular location such as a train station in a foreign country before travelling there, or allowing practice with novel environments such as navigating in snow when environmental conditions aren't suitable in the real world. VR tools could also enable people who are blind to preview a new route or locale in the comfort of their home before attempting it for the first time [23]. Further, VR could support compelling travel experiences for people who are homebound [7].

VR also has potential therapeutic applications. VR can democratize rehabilitation for people who have restricted motor abilities, since with VR devices they can practice and perform their physical therapy at home and be monitored remotely [10][18]. VR may also enable therapies similar to the Mirror Box [21][22], where a limb that is absent or motion-restricted (i.e., due to amputation, paraplegia, or ictus) can be felt as functional by observing the healthy counter-limb as seen in a mirror; this type of therapy has been shown to reduce phantom pain and reorganize pathways to increase recovery [34]. Other applications that may be well-suited to VR include Gestalt therapies in which a patient might provide self-compassion [9] or self-counseling [17] to themselves through a variable time-space inside VR.

VR also has the potential to improve existing digital tasks by virtualizing them. For example, performing productivity tasks on traditional desktop and mobile UIs can be frustrating for people with low vision who rely on screen magnifier tools, which require frequent panning [27]. However, traditional computing devices can be replaced with a VR experience in which a user can interact with completely virtual monitors that can have whatever sizing properties best suit a user's abilities, such as a monitor that is far wider than would be possible in the physical world (e.g., [16]).

7 Conclusion

Ensuring that VR systems are designed with accessibility in mind is important not only to ensure technology equity for people with

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disabilities, but also to create a more flexible, adaptive, and inclusive technology ecosystem that will benefit all users. In this position paper, we have highlighted five key considerations for accessible VR: content accessibility, interaction accessibility, device accessibility, inclusive representations, and application diversity. We believe that the time has come for the VR community to discuss these important issues, while the technology is still malleable; we look forward to taking part in that discussion.

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