CeeUI - Accessible Virtual Reality for the Blind and Visually Impaired: Challenges and Opportunities

Daniel Lange
OFFIS - Institute for IT
Oldenburg, Germany
daniel.lange@offis.de

Wilko Heuten
OFFIS - Institute for IT
Oldenburg, Germany
wilko.heuten@offis.de

Mazen Salous
OFFIS - Institute for IT
Oldenburg, Germany
mazen.salous@offis.de

Larbi Abdenebaoui
OFFIS - Institute for IT
Oldenburg, Germany
larbi.abdenebaoui@offis.de

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Abstract
Virtual reality (VR), as a primarily visual medium, is not accessible or difficult to access for people with visual impairments (PVIs). However, current developments in VR, such as shared persistent virtual environments, as often described in the context of the metaverse, offer unique opportunities for PVIs. For this reason, it is necessary to think about how to make these technologies more accessible. This paper discusses the challenges PVIs face while shopping in a supermarket, how immersive online shopping in a shared persistent virtual environment could make shopping easier, and how voice assistants (VAs) can help make VR technologies more accessible.

Author Keywords
virtual reality; conversational user interfaces; voice assistants; visually impaired; accessibility

CCS Concepts
•**Human-centered computing** $\rightarrow$ **Human computer interaction (HCI);** *Accessibility;* Accessibility technologies;

Introduction
Currently, there is much discussion about how shared persistent virtual environments (SPVEs), as described in metaverse [15] concepts, can change and improve our everyday life in the future. From virtual doctor's visits to immersive

online collaboration at work and online shopping experiences to experiencing virtual leisure and culture activities alone or with friends [17]. Access to this type of experience is provided by, among other things, virtual reality (VR) technologies such as head-mounted displays. As predominantly visual media based on screen technology, a natural barrier exists for people with visual impairments (PVIs) who rely primarily on tactile and auditory output technologies.

Input and interaction with virtual worlds in VR are typically done with tracked controllers. Visual skills are mostly mandatory for locomotion by walking or teleporting and for navigation in a virtual environment. However, research on voice assistants (VAs) shows these interactions can also be performed via speech. VAs enable PVIs to interact with technical devices without vision [5] and can help them find their way around their environment [8, 4]. Two use cases that are also relevant in VR. A VA could help orient in three-dimensional space and help building a mental image of the environment. It could also assist with navigation or reading descriptive text aloud.

There is much research about using Augmented Reality (AR) technologies to help people in their daily lives [13, 19, 10, 20] but little about how to give them access to the VR content that sighted people use. Therefore, the goals of this paper are to a) raise awareness of what opportunities PVIs have in PSVEs, b) raise awareness of the problems PVIs have with current VR technology and its operation, and c) show how vital VAs are for accessibility and at what points it can support.

Opportunities for the Visually Impaired

People with visual impairments often suffer disadvantages in their mental and physical health, working conditions, and social interactions [7]. PVIs often suffer from anxiety, such as the fear of moving in their environment. Everyday activities such as shopping at a supermarket, walking on a sidewalk, taking the bus to work, or crossing the street become hard and sometimes dangerous challenges. Even for people who walk with the help of a cane, there are dangers, such as other passers-by, electric scooters standing around, and broken sidewalks. Not all cities invest in accessibility and install guidance systems for the blind, and not all traffic lights have audible signals yet [18].

Barriers for the visually impaired while shopping in supermarkets

Although there has been much research about assistive devices for PVIs, such as smartphone apps [5] and smart canes [9], shopping in a supermarket remains a significant obstacle [11].

In order to shop successfully, the person must be able to form a mental image of the environment. Without vision, only hearing and the sense of touch remain, for example, via a cane for the blind. However, a supermarket is not a static environment but a dynamic one where other people are also active, complicating getting to know the environment. People cross paths, music plays, and other people talk, so tools such as echolocation cannot be used. If building a mental image of the surroundings is challenging, then orientation and navigation without aids are virtually impossible.

A modern supermarket has different ways of presenting and storing products. Baskets, open shelves, shelves with sliding glass doors, shelves with hinged glass doors, open chests, closed chests, or products stacked on pallets, to name a few. In order to identify products, they must not only be found but also removed from the appropriate shelf. PVIs rely much more on their sense of touch and hearing than sighted people. The sense of touch can help identify the correct varieties of products, such as fruit or vegetables. With packaged products, this is more difficult because, for example, the different varieties of canned soup feel the same.

There are aids for this, such as smartphone apps that can read out descriptive texts on the back of products or identify products via the barcode [16] or image processing [12] and output information held in front of them. However, the camera must be correctly aligned with the product, text or barcode, which can be difficult, even with tactile feedback, and it is not reliable, because the design of the product can change at any time. Additionally the products must be touched for this to happen, which can be considered particularly uncomfortable during pandemics.

PVIs are thus very susceptible to changes on the shelves they know and frequent regularly and they need support understanding the entire range of new varieties and products. They cannot easily perceive what products are next to familiar products, which also applies to visual advertising.

In summary, building a mental map, navigating the supermarket, and being at risk from walking into other people or obstacles are among the significant challenges, as are finding and identifying familiar and new products, reading descriptive text, and accessing visual advertising. An immersive shopping experience in VR could enable a more pleasant shopping experience for PVIs.

Online Shopping in shared persistent virtual environments as an opportunity

Shopping in a SPVE, or the metaverse is a rapidly growing area [3]. The first metaverse shopping mall, called "Island Shopping Mall" [6], opened last year, where it is possible to browse stores and products and buy them, just like in a real shopping mall. Alone or collaboratively with friends. A realistic shopping experience in a virtual environment. Transferring the problems that PVIs face when shopping in the real world to such a virtual environment creates many approaches for potential solutions.

Shopping in an SPVE could be feel more natural than in a browser-based online store. There is a three-dimensional environment with shelves and products to interact with. Realistic room-filling soundscapes could be created for PVIs to increase the sense of immersion. PVIs could move around the virtual supermarket without risking injury from obstacles or walking into other people. They could build a mental image of the environment at their leisure. Unlike in the physical world, the layout of the virtual building is accessible as data that could be experienced via tactile or haptic devices. The system also knows where in the building the user is at any given time and could assist with navigation.

In the virtual environment, descriptions of each object could be read aloud via interaction without the user having to search for a barcode with another device first. In addition, the system knows where the objects they are looking for are located, or if something changed about the layout of the shelves. The system could also provide information about which products are nearby or if there are any new products. Products would also no longer need to be physically touched to examine them, and visual advertising boards could be found and read aloud by the system.

In summary, a virtual shopping center in an SPVE could solve many problems by having all objects known to the system, from layout to products, locations, and where the user is. In addition, appropriate interfaces and interactions could provide easy access to this information, including for people with impairments. However, to offer these possibilities to PVIs, there are still some challenges to be solved: Accessible hardware and new forms of interaction.

Challenges in terms of Accessibility and how to solve them with CUIs

Even though SPVEs offer many possibilities, the current focus in designing these virtual environments is on replicating and extending reality. The replication aspect is a problem because blind people have challenges in physical environments, and these problems are first transferred to the virtual world. Therefore, the question arises of how the advantages of virtual worlds, such as the rich data and the available descriptions, can be used to favor accessibility. Therefore we want to discuss challenges that need solving to enable accessibility.

Although there are efforts to define uniform accessibility guidelines for head-mounted displays [1], there is still a lack of consensus and implementation on the part of manufacturers [2]. For example, it is still difficult for PVIs to set up a head-mounted display [14]. The menus need to be customizable enough or have a screen reader. They are operated via controllers whose interaction concept has been optimized for sighted people. For PVIs, it is often difficult to understand where precisely the pointer of a controller is pointing and whether they are currently pointing to a button that can be pressed since haptic feedback is sometimes missing. At this point, conversational user interfaces (CUIs) like voice assistants are essential for accessible interactions. PVIs could ask the system which buttons are available and instruct the system to press a button via voice command. Alternatively, the entire setup process could be implemented using a VA, which could be switched on to assist with complicated steps.

Another obstacle is locomotion or movement within the virtual environment. With the help of a VA, the user could be actively supported in creating a mental image of the environment. The user could ask the VA about the premises and get descriptions of how the shopping center is structured, what areas are there, and where they are located. The user could also ask what is in front of or next to him. How the shelves are set up, what products are on the shelves and ask for information about the products. The VA could also help move around within the premises, using teleportation points accessed by voice command.

The combination of a virtual environment, rich data, descriptions about the environment and voice assistants seems essential for accessible VR-enabled devices.

Conclusion

SPVEs can be a real opportunity to break down barriers and give people with impairments access to previously difficult experiences. The example of shopping in a mall shows that everyday activities are often a real challenge for PVIs and that VR technologies used in SPVE can help make these experiences accessible through novel interactions and augmentations. CUIs, especially voice assistants, seem an essential technology to accessibility regarding VR technology and, thus, the virtual worlds to be experienced through them.

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