

aVRness: Leveraging Augmented Virtuality to Increase Real-World Awareness in VR for People with Physical Disabilities

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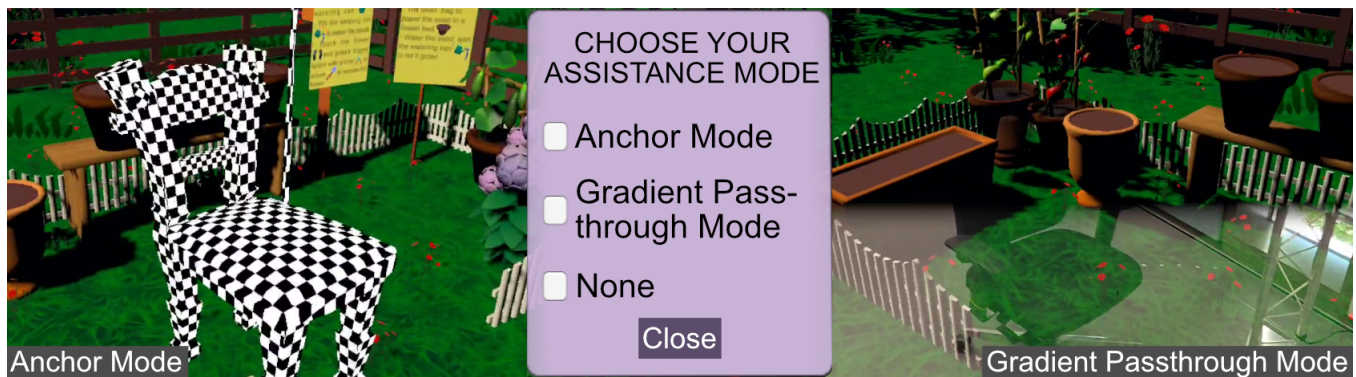


Figure 1: With aVRness, users can choose between displaying real-world objects through fitting placeholders (Anchor Mode), or a faded view of the real world (Gradient Passthrough Mode) to increase their safety and avoid collisions during VR locomotion.

Abstract

Virtual Reality (VR) promises to fully immerse users. However, when engaging in real-world locomotion, immersion can be an access barrier for users with physical disability, who may require greater awareness of real-world surroundings. In this work, we present *aVRness*, a prototype of two Augmented Virtuality (AV) techniques that we co-designed with two persons with physical disability to increase safety when standing and walking in VR: the *Anchor Mode* allows the depiction of static real-world objects such as chairs or tables in VR to support collision avoidance. While using the *Gradient Passthrough Mode*, users can partially observe the real-world, e.g., floor characteristics. Both modes are integrated in *Gardenia*, a slow-paced VR gardening experience.

Keywords

Virtual Reality, Accessibility

1 Introduction and Background

Virtual Reality (VR) promises immersion in virtual worlds with interactions entailing the whole body, and applications are already spanning from serious use [26, 32] to entertainment [27, 28]. However, the body-centricity of VR interactions also led to a wide range of accessibility concerns as demands are placed on users' bodies [10, 22]. **In the context of physical disabilities, multiple barriers to VR have been identified**, and the research community is actively working on design recommendations for accessible VR [3, 9, 14, 23]. For example, common challenges are linked to locomotion techniques, i.e., methods that allow moving in the virtual world, and improvements for both seated use [2, 7–9, 12] as well as during standing and walking [5, 19] are of interest for academic research. In particular, the work of Creed et al. [2] pointed out

concerns around real-world awareness and proprioception of not only people with physical disabilities but also of neurodivergent users, and investigations of natural walking in virtual environments by Ferdous et al. [5, 6] have shown that the lack of peripheral vision and visible cues negatively impact the gait of persons with balance impairments. Here, it has been demonstrated that visual feedback methods can be used to increase gait and stand stability [17, 18]. However, it appears that industrial practitioners rarely offer alternatives to standard locomotion methods (e.g., free-roam or joystick-based approaches) and thus fail to address the need for adaptations to personal needs [1]. For example, Meta [20] only recommends offering sedentary locomotion techniques (e.g., seated use and joystick-based locomotion) as an alternative to natural walking locomotion to VR designers. This is also rooted in the lack of adaptable safety mechanisms for free-roam locomotion. Current implementations of the so-called Guardian (Meta Quest) or Chaperone (HTC Vive) systems only notify users of the boundaries of play areas but do not account for room characteristics, e.g., obstacles such as carpets, within these areas. With people with physical disabilities’ demand for natural interaction [30], **accessible locomotion input paradigms, and especially novel safety systems that offer alternatives to complete immersion are needed.**

This could include visual real-world feedback, such as depicting the floor when looking down or highlighting real-world objects in the vicinity. Notably, there is a body of work that has explored augmented virtuality (AV) techniques for collision avoidance. Hereby, AV refers to a type of mixed reality (MR) displays, where real objects (e.g., walls, tables, chairs, ...) are added to a virtual world, contrary to the other widely known MR technique of augmented reality (AR), where virtual objects are added to real environments (c.f. Milgram et al. [21]’s reality-virtuality continuum). For example, Wozniak et al. [31] used the Kinect 2 depth-imaging sensor to extract bounding boxes of objects in front of an HTC Vive VR system and alerted immersed users of potential collisions through different visual metaphors. Likewise, Hartmann et al. [13] created an overlay of the physical environment as a static scan made either with a Kinect 2 or using dynamic data of an RGB-D camera equipped onto the Head-Mounted Display (HMD). However, both approaches relied on external hardware, which is no longer necessary in current state-of-the-art VR systems with good external HMD cameras. For instance, Huang et al. [15] used the HTC Vive Pro depth scan to create a static mesh of the physical environment and superimposed it in a custom game environment after post-processing. Additionally, using native VR camera output was also suggested for other applications where awareness of the real-world was necessary, for example, in Wang et al. [29]’s *RealityLens*, that allowed users to create spherical areas, in which the pass-through camera output got rendered on top of virtual worlds, e.g., to keep keyboard and mouse visible during VR meetings.

In our demo, we explore AV techniques to increase the safety of free-roam locomotion for people with physical disability, focusing on disabilities that affect standing and/or walking. We present two AV modes developed in dialogue with two people with physical disabilities. The first mode allows locating static real-world objects in virtual environments to enable collision avoidance and spontaneous propping up on real-world objects (anchor mode, see Section 2.2). The second mode allows nuanced

immersion by observing the real-world under a horizon, which enables users to perceive floor characteristics (gradient passthrough mode, see Section 2.3). We embedded both modes in a custom-built virtual environment called Gardenia that features slow-paced gardening gameplay elements and facilitates exploration of those modes. In the following, we detail our design process, the two AV modes, and the virtual environment (Section 2). We close with a conclusion and an outlook on future work (Section 3).

2 aVRness: Augmented Virtuality for Increased Real-World Awareness

Here, we will give an overview of our design and development process and the two AV modes, and conclude with a description of the Gardenia environment.

2.1 Design and Development Process

We co-designed aVRness with two people with physical disabilities (one woman, one man, 51 and 26 years old) for whom safety while moving in VR was a concern. Both persons had lived experience navigating spaces with and without crutches due to a lower limb prosthesis (P1) and a physical disability affecting the lower limbs (P2). P1 also had previous hands-on experience with VR. With our co-design approach, we wanted to involve them as experts in our design process. Similar approaches have already been used to explore accessibility challenges for VR users in wheelchairs [24], or in the context of developing prototypes and applications for specific user groups such as people who are blind or have low vision [4]. We divided our co-design process into three different phases: (1) An ideation phase in dialogue with the participants, (2) an implementation phase, and (3) an exploration phase, where both participants could try the prototype under our guidance in our VR lab. In the ideation phase, we met with each participant to discuss different ideas and approaches to making them feel safe when walking or standing during VR use. For example, when reflecting on prior VR experience, P1 told us that *"when I look down [in the real world], I can always see the real floor beneath me. That was totally gone [in VR]... That makes you feel cautious"*. Likewise, P2 also commented that being able to observe floor characteristics can lead to a feeling of safety, as *"whether I'm more likely to get stuck or stumble, that can make a difference"*. As a result, we decided on two different AV modes for implementation that either incorporated the feedback regarding real-world objects (Section 2.2) or floor visibility (Section 2.3) with the Meta Quest 3 as target platform using Unity. We also implemented a dedicated test environment called Gardenia (see Section 2.4). In the exploration phase, P1 tested the prototype under our guidance in our VR lab. Due to practical constraints, P2 only watched video recordings. The first impression showed that both modes seemed to increase a subjective feeling of safety, and P2 expressed that *"[both modes] would give me the confidence to move freely in VR"*. While P1 could use the anchor mode to navigate around chairs and a small table that we placed in the play area, P1 preferred the gradient passthrough mode: *"I really saw the real world and knew exactly, okay, that's the table, because I saw it. And that made it easier for me to recognise it, to actually see the real object. That was good"*.

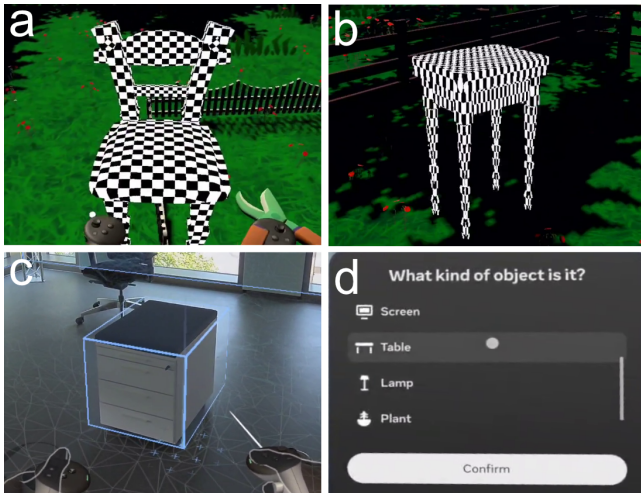


Figure 2: The anchor mode allows users to display static object-fitting placeholders in virtual worlds for collision avoidance, e.g., a chair (a) or table (b). Objects must be registered using Meta’s space setup (c) and labeled (d) accordingly.

2.2 Augmentation Option 1: Anchor Mode

With the anchor mode (Figure 2), users can highlight static real-world objects within the virtual environment, e.g., a chair or table that protrude into the play area. The depiction of real-world objects can prevent collisions and allows users to prop themselves up or sit down without exiting VR. For object detection, we utilized Meta’s Mixed Reality Utility Kit¹, which allows creating and exposing so-called "scene anchors" -individual elements attached with geometric and semantic information- to applications. For example, there could be a scene anchor of label *chair* at a fixed position in the room and a scene anchor marking a wall. The user must set these scene anchors in advance using Meta Quest 3’s space setup (Settings > Environment Setup > Space Setup). For this, users have to visually mark and verify the position and boundaries of individual objects within the setup process and add a respective label (see Figure 2c and d). Afterwards, all scene anchors are part of the static environmental definition of Meta. However, this also means that not the real objects are tracked but their location at setup time, which can lead to differences in spatial alignment if the real objects were moved from their initial location, which could pose a safety hazard in itself. In the context of this demo, we use the spatial anchors for our virtual environment to automatically add virtual representations of the actual objects at static locations (see Figure 2b). This approach extends Wozniak et al. [31]’s *placeholder metaphor*, in which stationary, the virtual scene fitting objects (in their case: trees) are used to visualize obstacles. However, by using appropriate representations and checkered surfaces, users can visually differentiate between virtual and real objects and know which real-world object an obstacle is.

¹<https://developers.meta.com/horizon/documentation/unity/unity-mr-utility-kit-overview/>

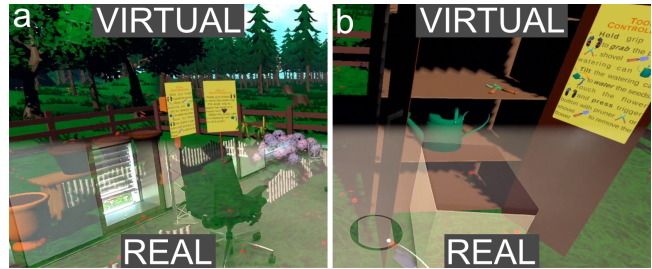


Figure 3: The gradient passthrough mode allows simultaneously observing the real and virtual world. The increased real-world awareness can be used for collision avoidance and allows interactions with real-world objects, e.g., a chair (a) or office roll container (b), without prior setup or exiting VR.

2.3 Augmentation Option 2: Gradient Passthrough Mode

The gradient passthrough mode (Figure 3) overlays the real world on top of the lower portion (choosable, max. 50%) of the view of the virtual environment using the external cameras of the Quest 3. This increases the real-world awareness of users at the cost of immersion. They can see a part of the real world around them and can again rely on peripheral vision as a contributor to stable gait (cf. Ferdous et al. [6]). Compared to the anchor mode, they can also avoid collisions, even with small objects, and there is no need for prior setup. For example, with the gradient passthrough mode, users can adapt their footing to avoid tripping on carpet edges or individual cables. Additionally, objects in the vicinity can be identified and interacted with (e.g., sitting down on a chair or rearranging a cable) without exiting VR. We based our implementation on Meta’s Mixed Reality Passthrough API² and attached a passthrough plane to the camera rig in Unity. Thus, the passthrough plane follows a user’s head movement and ensures that the real world is always visible on screen. We also added a shader to smooth the transition between the real and virtual world using height-dependent transparency values from 0% to 100% to avoid a clean-cut edge in the middle of the view.

2.4 Experience Prototype: Gardenia

We created Gardenia (Figure 4), a gardening experience, to allow users to explore the previously described augmentation modes in a slow-paced VR scene. Users can move around a garden and use gardening tools to plant, water, and harvest flowers. A dedicated menu allows users to change the augmentation mode (anchor, gradient passthrough, or no augmentation) at any time. Gardenia features a large closet containing gardening tools and several round and rectangular garden beds within a small, fenced-in area. Users interact by using the Quest 3 controllers and walking around the play area. A typical workflow (also see Figure 4b) is as follows: (1) Taking the seed bag out of the closet, and pouring out a random flower seed above a garden bed. (2) Watering the planted seed by pouring water out of the watering can. (3) Waiting for a few seconds until the flower has fully grown. (4) Harvesting the flower using the

²<https://developers.meta.com/horizon/documentation/unity/unity-passthrough>

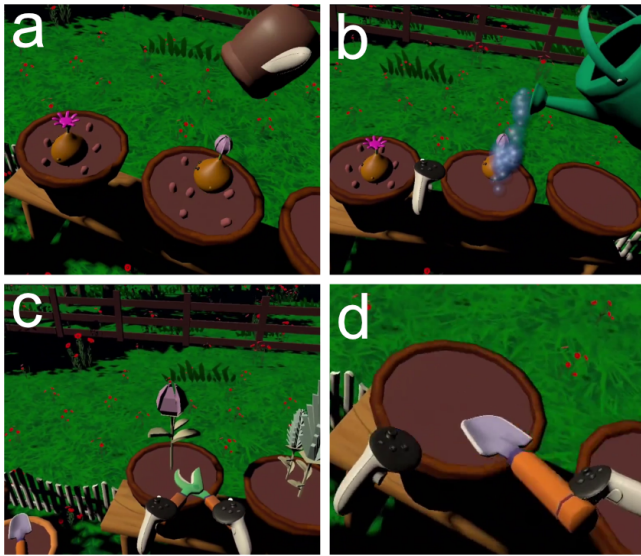


Figure 4: Gardenia is a gardening experience in which users can plant (a), water (b), harvest (c), and unearth (d) flowers while using the augmentation modes or complete immersion.

gardening scissors. (5) Unearthing the flower roots with the small shovel to prepare the garden bed for the next seed.

3 Conclusion and Future Work

Our work is a first exploration of augmented virtuality techniques to increase real-world awareness in VR to increase accessibility for people with physical disabilities. Through the implementation of two different augmentation modes (see Sections 2.2 and 2.3), we show that it is already possible to build upon techniques offered by the current generation of VR systems to cater to individual locomotion safety concerns. Both modes have the potential to increase safety compared to full immersion by augmenting the virtual world with static objects or adding real-world views. Thereby, we contribute an exploration of how intentionally reducing immersion can be leveraged as an avenue to potentially increase VR safety, an aspect that is not just relevant for people with physical disability, but also extends to other audiences, e.g., neurodivergent people [2]. Future work should empirically explore how the modes presented in this demo affect user safety, and whether they have implications for VR experience, e.g., whether they negatively impact the sense of presence (cf. Slater [25] and Wolf et al. [30]) or the sense of embodiment (cf. Kilteni et al. [16] and Guy et al. [11]) in the context of possibly two overlaying but bodily representations with the gradient passthrough mode. With this demo, we hope to spark discussion around real-world awareness during VR use and invite visitors and researchers to reflect on how we can design such supportive systems.

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