Towards Designing Echolocation Interfaces for Inclusive Virtual Gaming Environments

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Figure 1: Exploring echolocation interfaces in VR through audio-driven navigation and a sonar-based environmental probe.

Abstract

Virtual reality (VR) systems often rely only on continuous visual rendering. This standard can create functional barriers and limit alternative interactive paradigms. We present a VR game designed to explore how an echolocation interface can be designed to deliver an accessible gaming experience for everyone. The game restricts continuous visual output and casts the player as a superhero navigating via spatial audio and a triggered radar action. This work prompts critical questions regarding the development of better echolocation interfaces to advance inclusive design in VR.

CCS Concepts

• **Human-centered computing → Accessibility technologies**; *Virtual reality*; *User interface design*; Auditory feedback.

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Demo at Graphics Interface 2026 (GI '26), Waterloo, ON, Canada

ACM ISBN 978-x-xxxx-xxxx-x/YYYY/MM
https://doi.org/10.1145/nnnnnnn.nnnnnnn

Keywords

Virtual Reality, Accessibility, Echolocation, Spatial Audio, Inclusive Design, Blind and Low Vision, Cross-Modal Interaction

ACM Reference Format:
Masir Javed, Rachit Ranabhat, Tarang Rana, Raafay Sheikh, Muhammad Minhajuddin, and Somang Nam. 2026. Towards Designing Echolocation Interfaces for Inclusive Virtual Gaming Environments. In *Proceedings of Demo at Graphics Interface 2026 (GI '26).* ACM, New York, NY, USA, 3 pages. https://doi.org/10.1145/nnnnnnn.nnnnnnn

1 Introduction

Virtual Reality (VR) systems primarily focus on visual interfaces. This dependency creates navigation barriers for Blind and Low Vision (BLV) players.

Many gaming interfaces often consider accessibility as secondary or an afterthought, which is likely to disconnect immersion in the gaming experience [1]. Yet, previous works have made attempts to design a game interface for BLV players by exploring audio as the primary interface. A paper showed that an action role-playing game can be made fully playable through audio cues without compromising its core loop [5]. A player agency for BLV gamers in VR could be achieved by allowing them to actively probe their surroundings through a thumbstick-driven audio survey and improve mental-map accuracy over menu-based descriptions [3, 6]. The navigation in VR could also use a hardware solution such as a haptic cane controller that combines physical resistance, vibrotactile feedback, and 3D spatial audio to simulate white cane interactions [7]; the design space of auditory representations of objects and behaviours in VR [4]; and simulated reflections in virtual space to support mental maps [2].

We present a game prototype that removes default visual output to explore potential options for the accessible VR gaming interface. The motivation for this design is to raise awareness among game designers regarding the importance of accessible interfaces and their benefits. Forcing players to navigate without continuous vision can highlight the practical need for robust echolocation tools. Consequently, this work was initiated to answer the following research question in the future: *How do cross-modal audiovisual mechanics, designed primarily for entertainment engagement, function as universal design elements to lower navigation barriers for low vision players in VR?*

Our work aims to explore multi-modality to promote an accessible VR gaming interface through the design of embedded audio-driven navigation, and to ask whether the same techniques can serve as universal game design elements.

2 System Overview

The system is built in Unity for a head-mounted display with stereo headphones and two tracked controllers, optimized for the Meta Quest 3. Continuous geometry, lighting, and texture are suppressed in the headset view, so players cannot rely on sustained visual rendering. Navigation instead happens through a continuous spatial audio layer, supplemented by a player-triggered sonar pulse that briefly exposes nearby geometry. The two channels are coupled to the same scene representation so that what the player hears and what the sonar reveals refer to the same underlying objects.

Each interactive object, non-player character, and environmental hazard carries a spatialized audio source. Sources are rendered through a head-related transfer function so that direction and elevation are encoded binaurally, and distance is encoded through attenuation and low-pass filtering. Surfaces between the player and a source apply additional occlusion filtering, so a sound heard through a wall reads differently from the same sound heard through an open doorway. The cue set distinguishes object categories: idle ambient loops mark fixed features such as doorways and corridors, repeating event sounds mark interactive items, and dynamic sources mark moving agents. Hazards use a distinct low-frequency motif that intensifies as the player approaches, allowing avoidance to be driven by sound alone. Falloff curves are tuned per category so that hazards remain audible at longer ranges than ambient features, and category-specific timbre keeps simultaneous sources separable when several are active in the same room.

Players navigate by listening and turning. Head rotation rebalances binaural cues in real time, allowing a player to localize a source by orienting toward it until the cue is centred between the ears. Locomotion uses thumbstick movement with snap turning, and approach is verified by attenuation change rather than vision: a source that grows louder and brighter in its high-frequency content indicates the player is closing distance, while a source that dims and dulls indicates drift. Interactive objects respond to controller proximity with a localized confirmation cue, so action does not require visual acquisition. Successful interactions trigger a short positive-toned response, while invalid actions produce a flatter cue, giving the player feedback on the outcome of an attempt without breaking the audio-first interaction loop.

The sonar pulse complements this layer for moments where audio alone is ambiguous, such as resolving a corner, confirming the layout of a cluttered room, or distinguishing two sources that overlap in direction. The pulse is modelled as an expanding radial scan from the player's head position. When the player activates the radar action, the scan radius increases over time according to:

$$R(t) = \min(v_s t, R_{\max}) \tag{1}$$

where $R(t)$ is the current sonar pulse radius, v_s is the scan speed, and $R_{\max}$ is the maximum scan distance.

In our implementation, $v_s = 12$ units per second and $R_{\max} = 25$ units. As the wavefront expands, any scene geometry it intersects is temporarily rendered as a wireframe outline, with edges drawn at the moment of intersection rather than all at once, so the player perceives the room being filled in directionally as the pulse travels outward. After reaching its maximum range, the pulse remains briefly visible for an afterglow period before fading out, creating a temporary spatial impression of the surrounding environment. A synchronized audio sweep travels with the wavefront, so the pulse remains informative when the player is facing away from a reflecting surface, and the sweep is also panned binaurally so that off-axis returns can be heard from the correct direction. A cooldown prevents the trigger from being held to keep the world continuously visible, which preserves the audio layer as the primary channel and frames the sonar as a deliberate sensing action rather than a substitute for vision. The cooldown duration was tuned so that the player has enough uninterrupted listening time between pulses to update their mental model from the audio cues, rather than treating the sonar as a continuous flashlight.

3 Future Work

Future work will evaluate this game with players and game designers as a demonstration tool. We will organize user study sessions to assess how this constrained interface impacts the design methodologies and the player experience. Exposing creators to these cross-modal mechanics aims to stimulate direct discourse regarding the importance of accessible gaming. The primary objective is to equip game designers with practical frameworks to implement echolocation interfaces and prioritize universal design in future VR games.

Acknowledgments

We would like to thank the National Centre of Excellence for Immersive Technology for their support.

References

[1] Ronny Andrade, Melissa J. Rogerson, Jenny Waycott, Steven Baker, and Frank Vetere. 2019. Playing Blind: Revealing the World of Gamers with Visual Impairment. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19)*. Association for Computing Machinery, 1–14. doi:10.1145/3290605.3300346

[2] Ronny Andrade, Jenny Waycott, Steven Baker, and Frank Vetere. 2021. Echolocation as a Means for People with Visual Impairment (PVI) to Acquire Spatial

Knowledge of Virtual Space. *ACM Transactions on Accessible Computing* 14, 1 (2021). doi:10.1145/3448273

[3] F. Apavou, T. Bouchara, and P. Bourdot. 2025. AVA: An Audio-Based Virtual Aiming System for Accessible VR Shooting Games. In *2025 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)*. 1172–1173. doi:10.1109/VRW66409.2025.00232

[4] Joao Guerreiro, Yoonha Kim, Rodrigo Nogueira, Sang Ah Chung, Andre Rodrigues, and Uran Oh. 2023. The Design Space of the Auditory Representation of Objects and Their Behaviours in Virtual Reality for Blind People. *IEEE Transactions on Visualization and Computer Graphics* 29, 5 (2023), 2552–2562. doi:10.1109/TVCG.2023.3244443

[5] Masaki Matsuo, Takahiro Miura, Masatsugu Sakajiri, Junji Onishi, and Tsukasa Ono. 2016. ShadowRine: Accessible Game for Blind Users, and Accessible Action RPG for Visually Impaired Gamers. In *2016 IEEE International Conference on Systems, Man, and Cybernetics (SMC)*. 002826–002827. doi:10.1109/SMC.2016.7844667

[6] Vishnu Nair, Jay L. Karp, Samuel Silverman, Mohar Kalra, Hollis Lehv, Faria Jamil, and Brian A. Smith. 2021. NavStick: Making Video Games Blind-Accessible via the Ability to Look Around. In *The 34th Annual ACM Symposium on User Interface Software and Technology (UIST '21)*. Association for Computing Machinery, 538–551. doi:10.1145/3472749.3474768

[7] Yuhang Zhao, Cynthia L. Bennett, Hrvoje Benko, Edward Cutrell, Christian Holz, Meredith Ringel Morris, and Mike Sinclair. 2018. Enabling People with Visual Impairments to Navigate Virtual Reality with a Haptic and Auditory Cane Simulation. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. Association for Computing Machinery, 1–14. doi:10.1145/3173574.3173690

Received 1 May 2026; revised 20 May 2009; accepted 5 June 2026