Spatial Audio for Ski Simulation with Visually Impaired Users in Dynamic Environments

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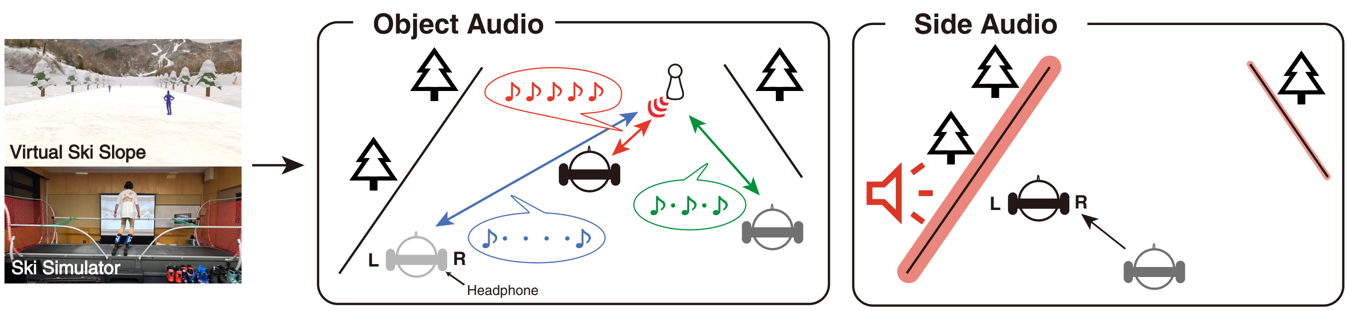

Figure 1: Our system enables users to avoid obstacles with two types of spatial audio. Object Audio conveys the direction of an obstacle through spatial positioning and its distance through the interval between sounds. Side Audio indicates the course boundaries, with the volume increasing from the direction of the boundary as the user approaches it.

CCS Concepts

• **Human-centered computing → Accessibility systems and tools**.

Keywords

blind skiing, visual impairment, ski simulator, spatial audio

ACM Reference Format:
Yuta Taguchi, Toshihiro Hirano, Masaki Kuribayashi, Yichen Peng, Erwin Wu, Hideki Koike, and Shigeo Morishima. 2025. Spatial Audio for Ski Simulation with Visually Impaired Users in Dynamic Environments. In *SIGGRAPH Asia 2025 Posters (SA Posters '25), December 15-18, 2025*. ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3757374.3771466

SA Posters '25, Hong Kong, Hong Kong

ACM ISBN 979-8-4007-2134-2/2025/12
https://doi.org/10.1145/3757374.3771466

1 Introduction

Skiing is an activity that people with visual impairments (PVI) enjoy with the help of sighted guides who ski near them and give voice commands. Thus, researchers have developed systems such as one that uses multimodal feedback [Haladjian et al. 2017] for facilitating their verbal communication. Nonetheless, as there are limited numbers of experienced sighted guides available, opportunities for PVI to enjoy skiing remain limited. Recently, researchers have explored ski simulators as a way to make skiing practice more accessible for PVI throughout the season. The initial work introduced audio feedback to guide users along predetermined paths [Miura et al. 2023], followed by SlopeNav [Hirano et al. 2025], which generates adaptive paths to avoid obstacles using real-time images.

However, as previous systems were designed to handle only static obstacles, they cannot be applied to realistic scenarios with dynamic obstacles such as other skiers or snowboarders. While SlopeNav generates adaptive paths, the path could be updated frequently in a dynamic environment. Such repeated updates can lead to inconsistencies in the audio feedback. This can confuse users and make it difficult to follow the route.

To address dynamic scenarios, we propose a system that conveys obstacle locations and course edges through continuous spatial audio. This allows users to intuitively perceive hazards. By shifting from path guidance to spatial awareness, the system avoids confusion from frequent path updates like the previous approach.

We conducted a pilot study with six sighted participants to compare SlopeNav with our proposed system. We show our preliminary evidence that our system improves upon the previous method in dynamic environments and reduces overall workload.

2 Implementation

We developed our system using Unity and a commercially available ski simulator. As shown in Figure. 1, to convey positions of both static and dynamic obstacles, we prepared two types of sounds:

Object Audio: Spatial audio, implemented using the head-related transfer function, is employed to indicate the position of obstacles located within 8 m ahead. Each obstacle is represented by a simple sinusoidal sound. As the user approaches an obstacle, the sound increases in frequency and volume. When the obstacles get within 2 m, the pitch is additionally raised to convey imminent risk.

Side Audio: To indicate the edge of the course, a continuous sinusoidal sound is emitted from the direction of the nearest side of the slope within 5 m. Its amplitude increases as the user approaches the side. The pitch of this sound is designed to be clearly different from that of Object Audio to make a clear distinction.

In essence, any emitted sound signals danger and users only need to move away from it.

3 Pilot Study

To obtain an initial design probe and evaluate the effectiveness of our spatial audio approach compared with the previous path following method, we conducted a pilot study with six sighted participants from our institution (six males, mean age = 22.33, standard deviation = 0.94). Participants practiced the ski simulator for 20 minutes under each condition: with SlopeNav and with our proposed method. After the practice, participants completed three courses.

(1) C_{Static}: 10 static obstacles were placed randomly at 10±2 meter intervals.
(2) $C_{Dynamic}$: 10 dynamic obstacles (*i.e.,* skiing people) appeared every 10±2 meters in front. For realism, the obstacles moved in two patterns: skiers moving in a zigzag pattern to make S-shaped turns, and skiers moving in a straight line to descend directly.
(3) C_{Real}: 10 obstacles, which are either static or dynamic, were placed or appeared in front at random intervals of 10±2 meters. Additionally, virtual skiers occasionally overtook the participant from behind on either the left or right, automatically avoiding collisions. These overtaking skiers were introduced to make sudden system feedback, simulating more challenging and realistic skiing scenarios.

Finally, a post-interview was conducted to gather qualitative feedback, along with the NASA-TLX, an established subjective workload (measuring mental demand, physical demand, etc.) assessment item. Each session lasted approximately 90 minutes.

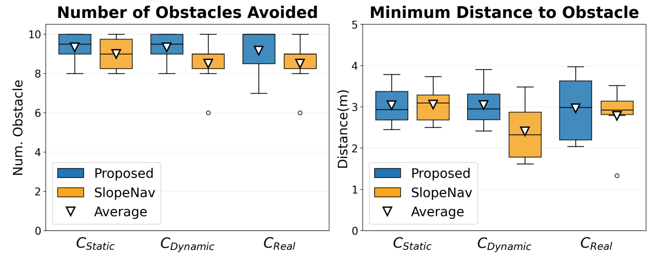

Figure 2: Box plot of the number of obstacles avoided and the average minimum distance to obstacles.

4 Results

Figure. 2 shows participants' skiing performance, measured by the number of obstacles avoided and the average minimum distance to obstacles [Hirano et al. 2025]. The proposed method demonstrated a slight improvement over SlopeNav in terms of the average number of obstacles avoided across all conditions. While the minimum distance to obstacles was similar in C_{Static} and C_{Real} conditions for boths methods, in $C_{Dynamic}$, the proposed method clearly outperformed SlopeNav in $C_{Dynamic}$. These results indicate that while SlopeNav struggles to adapt to dynamic obstacles, the proposed method can effectively handle them. Also, SlopeNav scored 6.32 in NASA-TLX on average, whereas the proposed method scored 4.79, suggesting that the proposed method imposed a lower workload.

In the post-interview, two participants commented that knowing the positions of obstacles with our approach allowed them to ski with a sense of reassurance. However, five participants mentioned that when multiple obstacles were present, sounds from many directions caused confusion. One participant requested a different type of feedback, noting that when an overtaking obstacle suddenly began sounding from the side, it was startling.

5 Conclusion and Future Work

This paper introduces a system that leverages spatial audio to notify users of obstacle locations. A pilot study with sighted participants was conducted to demonstrate its effectiveness and to serve as an initial design probe. While rigorous statistical testing was not feasible due to the small sample size, our findings provide preliminary evidence that the proposed approach improves upon the previous path-following method in dynamic environments and reduces overall workload. Based on participant feedback, we found that when multiple obstacles are present nearby, it is important to design a feedback system that dynamically adjusts and filters which obstacles are conveyed, prioritizing them according to their risk level. It is also necessary to design distinct feedback for skiers who are overtaking the user from behind. Finally, we plan to conduct a study with many actual PVI for evaluation and further feedback design.

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