Proceedings of ICLLCD 2026 Symposium: Intelligent Media for Cultural Bridge: Forum on Global-Local Communication
DOI: 10.54254/2753-7064/2026.BJ33619

The Expression and Intervention Simulation of Underwater Noise Impact Based on VR Particle Soundscapes: From Noise Visualization to Participatory Strategy Development

Yuquan Yan

Department of Art, Guangdong University of Foreign Studies, Guangzhou, China
yanyuquan823@gmail.com

Abstract. This study focuses on the underwater noise pressure endured by the Yangtze River finless porpoises in the context of shipping and coastal human activities, and explores how virtual reality can transform "invisible and difficult-to-perceive" noise pollution into perceptible visual and interactive experiences. The research objective is to construct a soundscapes expression framework based on typical noise sources and spatial characteristics of the Yangtze River, and in VR, create a set of visual grammar centered on a particle system using "medium distortion + particle density + frequency band layering form"; finally, design a strategy module to conduct interactive reasoning, and provide real-time feedback on noise distribution and ecological pressure indicators changes. The noise visualization method and participatory reasoning prototype enable the audience to intuitively understand noise intensity, spatial aggregation, and frequency band differences, and through strategy selection and combination, observe noise changes and form comparisons and scheme outputs. This is applicable to science popularization exhibitions, environmental education, and issue communication, helping the audience move from perceiving the problem to understanding its underlying mechanisms and trade-offs.

Keywords: Virtual reality, underwater noise visualization, particle system, frequency band layering, participatory intervention simulation

1. Introduction

Underwater noise pollution is a typical "invisible environmental stress", whose intensity, propagation and superposition process are difficult to observe with the naked eye and are also hard for the public to intuitively understand [1, 2]. Against the backdrop of dense shipping and frequent engineering activities along the riverbank, the continuous superposition of ship and construction noise and its spatial aggregation characteristics may interfere with the positioning, communication, foraging and habitat behavior of finless porpoises [2-4]. Recent related research has mainly advanced along three paths: first, conducting measurements and impact assessments on specific noise sources, such as discussing the acoustic characteristics of engineering noise like pile driving and its potential impact on finless porpoises; second, focusing on the underwater noise characteristics generated by human activities such as channel improvement and assessing their

DOI: 10.54254/2753-7064/2026.BJ33619

possible impact on finless porpoises and the mitigation directions; third, discussing the relationship between shipping activities and the habitat of finless porpoises from the perspective of shipping pressure, and proposing the necessity of reducing conflicts through shipping management and spatial planning [3-5]. At the same time, passive acoustic monitoring is used to obtain information on the presence of finless porpoises and acoustic activities on a larger scale, providing a data basis for understanding the relationship between "noise environment - animal response" [6].

However, these achievements are mostly presented in the form of text, spectrograms or static charts, with high expression thresholds and difficult to simultaneously present the spatial propagation and aggregation of noise, frequency band differences and the trade-off relationship of different intervention strategies [2-4]. Virtual reality technology has advantages in expressing complex systems, establishing spatial intuition and supporting interactive reasoning. Relevant studies have shown that non-fiction VR narratives and underwater VR experiences can enhance the audience's understanding of complex issues and their sense of presence, and soundscapes research also shows that the subjective evaluation results of the virtual environment are comparable to those of the real environment, providing a methodological basis for presenting and discussing acoustic issues in immersive scenarios [7-9]. At the same time, VR education research emphasizes the introduction of observable interactive processes and feedback evidence in immersive environments, which helps to improve the interpretability of learning and understanding [10, 11]. Based on the current research status, this study proposes a "particle soundscapes + participatory reasoning" expression framework, presenting the noise intensity and spatial hotspots in VR through particle density and medium disturbance, and expressing the low/middle/high frequency differences in a hierarchical form, thereby reducing the threshold for spectral interpretation [3, 4]. At the interaction level, strategy modules (such as speed limits, time division, channel avoidance and ecological buffer) are introduced for intervention simulation, and Before/After comparisons and solution cards are output to present the "strategy - cost - improvement" relationship [5, 9, 10]. This study aims to construct a readable underwater noise visual grammar and design a participatory noise intervention simulation mechanism, allowing viewers to observe noise changes through strategy combinations and obtain interpretable comparison outputs [3-5].

2. Design method

This study takes "noise visualization - spatial deformation" as the conceptual starting point. It regards underwater noise as a pressure field acting on the water medium, and takes the spatial characteristics of the Yangtze River channel - "long and narrow, strong reflection, and the shoreline and bridge piers are prone to acoustic aggregation" as the expression basis. Therefore, the noise is presented in the scene as a soundscenic phenomenon with obvious spatial non-uniformity. At the same time, the noise pressure endured by the finless porpoises is not a simple linear relationship of "louder", but more closely resembles a comprehensive pressure composed of exposure intensity, frequency band structure, and duration. To reduce the understanding threshold of traditional spectrograms for non-professional viewers, the research adopts a three-layer visual strategy centered on the particle system. Firstly, through water body refraction, wave stretching, and spatial distortion, the propagation direction and aggregation trend of noise are expressed, emphasizing the readability of noise as a spatial phenomenon; Secondly, the noise intensity is mapped by particle density and instability, making the accumulation effect at bridge areas, shorelines, and when cargo ships pass, etc., presented intuitively; Finally, the frequency band differences are translated into particle form differences, making low frequencies present as thick and slow, oppressive masses, mid-frequencies as layered flows with overlapping ripples and continuous fluctuations, and high frequencies as fine

DOI: 10.54254/2753-7064/2026.BJ33619

and sharp, pointed noise dots that flash rapidly, so that the audience can distinguish different noise types without understanding the professional spectrogram. On this basis, the prototype constructs a participatory closed-loop process of "noise manifestation - strategy deduction - comparison output", as shown in Figure 1, where when the audience enters the VR river scene, they first see the particle soundscenic manifestation. The system then identifies the main noise sources and provides two information paths. The audience can either click on the noise source to enter the interactive deduction, or view the introduction of the noise source to establish background understanding; When the audience clicks on the noise source and enters the strategy deduction stage, they can select and combine intervention strategies such as speed limits, time division, channel avoidance, and ecological buffer/waterweed planting from the module library, and the system updates the soundscenic in real time and synchronously displays the travel time, diversion degree, and implementation difficulty on the upper left corner, while simultaneously displaying the satisfaction of underwater organisms and providing an entry point for further viewing "underwater organisms affected by noise". To avoid the strategy being understood as an uncostly "magic button", the strategy is combined with the implementation of measures such as speed limits, time division, channel avoidance, and ecological buffer/waterweed planting. The system updates the soundscenic in real time and synchronously displays the simplified cost dimensions such as travel time, diversion degree, and implementation difficulty. At the same time, it also displays the satisfaction of underwater organisms and provides an entry point for further viewing "underwater organisms affected by noise". This approach avoids the strategy being perceived as a one-way viewing experience and instead promotes an interpretable and repeatable participatory understanding process.

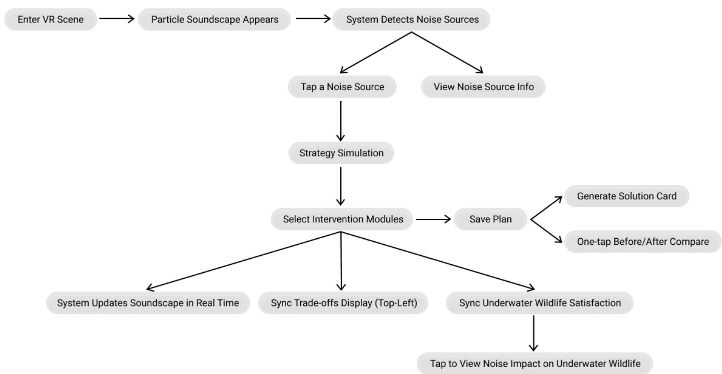

Figure 1. Flowchart (picture credit: original)

3. Expected outcome

As shown in Figure 2, the final presentation of this study is centered around the VR interactive prototype. After the audience enters the river scene, the underwater noise is visualized in the form of a particle sound scene, and the intervention simulation options can be triggered by clicking on the noise source. Specifically, as shown in Figure 3, users can directly click on the ship and select strategy modules such as "speed limit", "time division", and "channel avoidance". The system then updates the distribution and propagation form of the noise particles and simultaneously displays the cost dimensions (such as the distance of detour, delay, cost changes, and the reduction in the amplitude of the combined low-frequency noise and peak) on the upper left corner of the interface,

DOI: 10.54254/2753-7064/2026.BJ33619

thereby transforming the governance process into an interpretable trade-off process. In addition to shipping strategies, as shown in Figure 4, users can also trigger "planting water grass" and other ecological buffer schemes. The system then displays the cost dimensions such as coverage area, effectiveness time, maintenance cost, and impact on navigation, while presenting the effect feedback of noise reduction buffering and improvement of habitat quality, enabling ecological intervention and shipping management to be compared and understood within the same interactive framework.

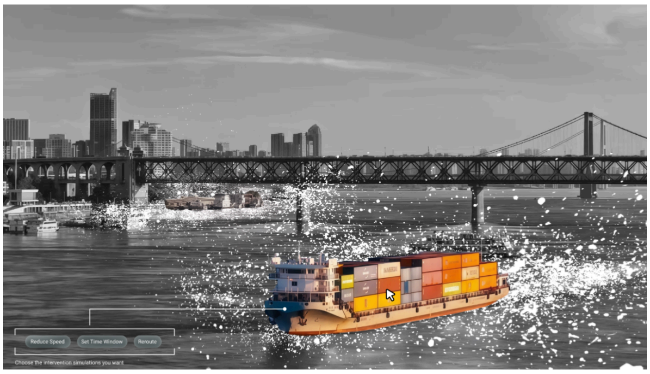

Figure 2. Example of the VR underwater noise particle sound scene and the interactive interface for strategy intervention (picture credit: original)

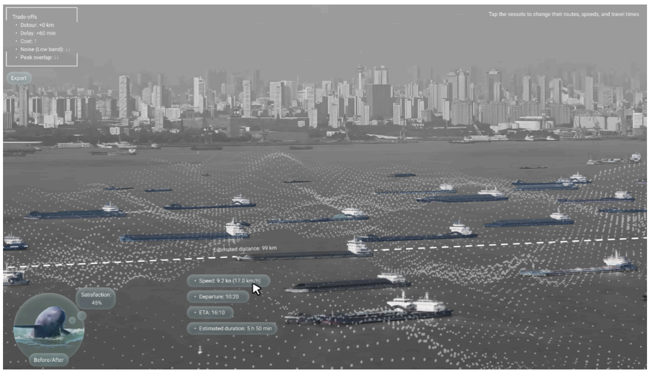

Figure 3. Example of synchronous display of ship strategy module (speed limit/time division/channel avoidance) and cost dimension (picture credit: original)

Figure 4. Example of ecological buffer (planting water plants) intervention and cost dimension, as well as satisfaction feedback (picture credit: original)

DOI: 10.54254/2753-7064/2026.BJ33619

In order to make the results reproducible and communicable, as shown in Figure 5, the system supports one-click Before/After comparison and the generation of "solution cards", outputting strategies, improvements and costs in a unified template, and can be exported as screenshots or short video clips for presentation and reporting. Besides the prototype itself, this study will also summarize a set of reusable visual grammar rules, namely the noise expression system of "media distortion - particle density - frequency band shape", to provide a consistent visual language for the subsequent extension to other water area noise issues.

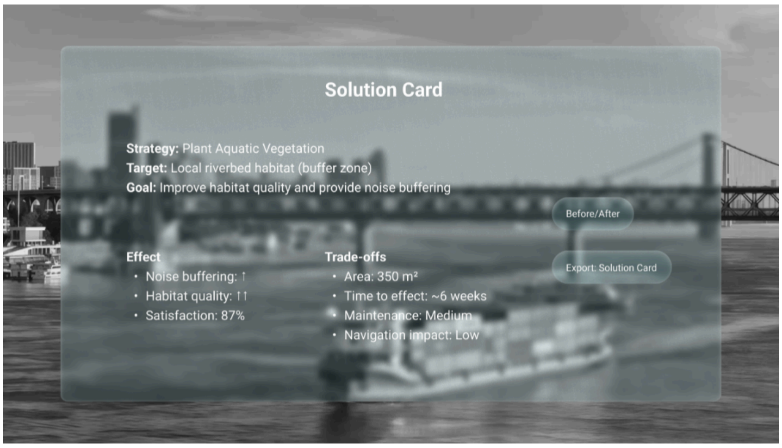

Figure 5. Example of the output template for the scheme card and the one-click comparison function of "Before/After" (picture credit: original)

Based on the above achievements, the application scenarios of this research mainly focus on public science popularization, environmental education and issue communication. At the scientific popularization level, the particle soundscapes transform noise from an abstract concept into intuitive spatial evidence; at the educational level, strategy reasoning and cost display help learners understand that intervention is not a single answer but a multi-objective trade-off; at the communication level, Before/After and solution cards output provide an "evidence interface" for non-professional audiences to have a common discussion, enabling people from different backgrounds to conduct more specific discussions and reach consensus on strategy combinations and costs.

4. Conclusion

This study focused on the issue of underwater noise in the Yangtze River and proposed and implemented a VR-based prototype of "particle soundscapes visualization + participatory intervention simulation", aiming to translate the invisible and difficult-to-understand noise pollution into a visually readable language with spatiality, and through strategic reasoning, enable the experiencers to understand the trade-off relationship of "strategy - cost - improvement". The study constructed a visual grammar of "medium deformation - particle density - frequency band stratification form" to present the noise propagation trend, hotspot aggregation, and differences in low/middle/high frequencies; at the same time, it designed intervention modules such as speed limit, time division, channel avoidance, and ecological buffer, supporting Before/After one-click comparison and scheme card output, making the results repeatable and communicable. The research conclusion indicates that shifting the expression of noise from static charts to immersive spatial evidence and introducing interpretable interactive loops helps to lower the understanding threshold

DOI: 10.54254/2753-7064/2026.BJ33619

and improve the efficiency of issue communication. The main challenges in the research process came from two aspects: technologically, there was a trade-off between the real acoustic modeling of noise, the real-time performance of the particle system, and the stability of multi-strategy superimposed feedback; environmentally, the Yangtze River scene was complex and the data sources were scattered, resulting in the need to repeatedly calibrate parameter settings and visual mapping between scientific credibility and understandability. In the future, more reliable noise data and basic acoustic models will be introduced, the frequency band and indicator system will be improved, and more real scenarios and role constraints (such as shipping efficiency and ecological protection negotiation) will be added. Through user testing to evaluate the understandability and decision support effect, the application value of the prototype in science popularization exhibitions and cross-party communication will be enhanced.

References

[1] Wang, Z. T., Akamatsu, T., Duan, P. X. et al, (2020) Underwater noise pollution in China's Yangtze River critically endangers Yangtze finless porpoises (Neophocaena asiaeorientalis asiaeorientalis) Environmental Pollution.
[2] Wang, Z. T., Duan, P. X., Akamatsu, T. et al, (2021) Riverside underwater noise pollution threaten porpoises and fish along the middle and lower reaches of the Yangtze River Ecotoxicology and Environmental Safety.
[3] Shi, W. J., Wang, Z. T., Fang, L. et al, (2015) Preliminary Study on the Impact of Piling Waterborne Noise on Yangtze River Finless Porpoises Acta Hydrobiologica Sinica.
[4] Ju, T., Zhang, T. Z., Wang, Z. T. et al, (2017) Characteristics of Stone-Throwing Noise and Its Possible Impact on Yangtze River Finless Porpoises Acoustical Technology.
[5] Mei, Z. G., Han, Y., Turvey, S. T. et al, (2021) Mitigating the effect of shipping on freshwater cetaceans: The case study of the Yangtze finless porpoise Biological Conservation.
[6] Dong, L. J., Wang, D., Wang, K. X. et al, (2011) Passive acoustic survey of Yangtze finless porpoises using a cargo ship as a moving platform J. Acoust. Soc. Am.
[7] Bédard, P., (2023) Closing the Gap: Storytelling in Nonfiction Virtual Reality Canadian Journal of Film Studies.
[8] Fauville, G., Voşki, A., Mado, M. et al, (2024) Underwater virtual reality for marine education and ocean literacy: technological and psychological potentials Environmental Education Research.
[9] Yang, M., Heimes, A., Vorländer, M., Schulte-Fortkamp, B., (2024) Comparison of subjective evaluations in virtual and real environments for soundscape research The Journal of the Acoustical Society of America.
[10] Yang, Q., Huang, Y., Wang, R., Xu, G., (2024) Exploration of Eye-Tracking Data Collection and Visualization Methods in Virtual Reality Educational Environments SSRN.
[11] Georgiou, Y., Tsivitanidou, O., Ioannou, A., (2021) Learning experience design with immersive virtual reality in physics education Educational Technology Research and Development.