SOUNDSCAPE EVALUATION IN THE VIRTUAL REALITY: TOOLS FOR THE CREATION OF SOUNDSCAPE STUDIES

PRESENTED AT THE 2022 INTERNATIONAL CONFERENCE ON AUDIO FOR VIRTUAL AND AUGMENTED REALITY (AVAR 2022)

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August 15, 2022

ABSTRACT

Communicating the impact of decisions in the management of environmental noise presents several significant challenges, requiring non-experts to rationalize changes to the environment through the comparison of metrics that can be difficult to relate to tangible outcomes. Virtual reality technologies provide a platform for the auralization and visualization of environments, providing the opportunity to experience the impact of changes to the environment through a virtual representation before decisions are made. This paper presents The Virtual Reality Soundscape Evaluation Framework, a set of tools for performing environment evaluation experiments in virtual reality.

Keywords Soundscape · Environmental Noise · Virtual Reality

1 Introduction

Environmental noise is a critical pollutant that contributes to an estimated 12000 premature deaths and 48000 new cases of ischemic heart disease each year in the European region [1]. Environmental noise management is a key aspect to modern infrastructure projects, directly impacting the quality of life for local communities. One of the challenges in the management of environmental noise is the communication of the estimated impact of noise on local communities, and an adjacent challenge is the collection of subjective data that reflects how people perceive the quality of an environment. Auralization can be an invaluable tool in environmental noise management, informing non-experts with subjective information that can complement the objective figures used to quantify environmental noise [2, 3]. Auralization is defined by Kleiner as the process of rendering a sound field to simulate the listening experience in a given space [4].

Though environmental noise management policies in the European region put an emphasis on minimizing the average level of key noise sources [5], researchers have identified that this strategy does not always result in an improved quality of life [6]. Alternative strategies for environmental noise management include the study of soundscape, analogous to the acoustic landscape, as a multidisciplinary holistic approach to the curation of sound as a resource in the context of the environment [7, 8]. Soundscape is defined in the soundscape standards as the "*acoustic environment as perceived or experienced and/or understood by a person or people, in context*" [9]. Within the soundscape paradigm, researchers have developed several standardized methodologies for the evaluation of soundscapes. Virtual and augmented reality (VR) technologies can be used as a vehicle for the immersive presentation of auralizations in the context of environmental

*Corresponding Author. Preprint version. Original version to be found on: http://www.aes.org/e-lib/browse.cfm?elib=21843.

noise evaluation, taking advantage of the interactive nature of VR application to execute soundscape evaluation methodologies. This paper discusses a use-case for VR technologies in the context of soundscape evaluation. The paper first discusses some of the motivations behind the use of VR in environmental noise evaluation from the perspective of soundscape studies. This includes a discussion of some of the challenges associated with using VR and spatial audio technologies in the context of soundscape evaluation. Finally, the paper presents a framework for the development of soundscape evaluation applications in VR, centred around a description of the use of the framework in a listening experiment.

2 Motivation

Motivated by increased evidence of the impact of environmental noise [10], European governments were given a mandate by the European Commission to manage environmental noise through the enactment of the Environmental Noise Directive (END) [5]. This mandate has motivated the development of procedures and technologies for the assessment and mitigation of environmental noise [11]. Beyond the environmental noise management processes described in the END, large infrastructure projects in UK are required to follow a process of public consultation [12, 13, 14] which can be used to gather feedback from those who might be affected. Auralization can be used in these consultations to represent what an environment might sound like under different circumstances, giving developers an opportunity to gather feedback on proposed projects ahead of implementation, and minimizing the complexity of the information that is presented [15, 3, 2].

Though the END has been integrated into the native policy of many EU member states, researchers have argued that the approach to environmental noise management described in the END is reactionary in nature, and does not necessarily result in an improved quality of life. Instead it is suggested that further aspects including the subjective impression of the environment are important factors in determining instances where environmental noise is problematic [8, 6]. To this end, researchers have continued to develop the soundscape paradigm, resulting in a standardized definition of soundscape and a framework for the study soundscapes [9, 16]. This framework identifies several methodologies that should be included in a complete soundscape study, and that the resulting subjective data should be complemented with further perceptually motivated objective measures. The standards identify that at least one of three methodologies should be included in a complete soundscape study. These three methodologies include a sound walk, a survey and a guided interview [16]. Any of these three methods can be performed either with a group of participants or on an individual basis. All three methodologies involve having participants experience an environment and then respond by identifying the subjective qualities of the environment, following a protocol as described in the standard.

Soundscape researchers have often performed soundscape studies in existing places. However, performing studies in-situ may not always be practical, particularly if researchers wish to perform studies of environments that don't exist, or are subject to significant change. Though performing studies in a laboratory setting can have several advantages related to experimental control and repeatability, several significant challenges are present. One such challenge is the reduced ecological validity of the experimental condition. Bronfenbrenner defines ecological validity as "the extent to which the environment experienced by the subjects in a scientific investigation has the properties it is supposed or assumed to have by the investigator" [17]. Researchers have identified that the degree of spatial information present in the reproduction of the soundscapes can have a direct impact on the cognitive representation of the events that occur within the recording [18]. In the same experiments the researchers identified that the visual environment present during listening tests had an influence on the perception of the soundscapes, remarking that a neutral visual environment and spatial immersion are important to ensure ecological validity.

VR systems including spatial audio have advanced significantly in the last decade, and researchers have begun exploring how they can be used in environmental noise and soundscape evaluation [19]. An obvious benefit to utilizing VR technologies include the ability to perform cross-modal environment evaluation including visualization and spatial sound reproduction [20]. It has been found that subjective results from soundscape evaluation utilizing several different spatial audio reproduction methods were not significantly different from in-situ evaluations, but differences in spatial quality were found between the different spatial audio reproduction methods [21]. This reinforces the importance of using a high quality spatial audio reproduction system as identified by by Guastavino *et al.* [18]. Researchers have recently reviewed processes that can be used to validate the ecological validity of immersive VR systems in the evaluation of urban environments, finding several measures that can be used for this purpose [22]. Xu *et al.* also identified that head mounted display technology might be more beneficial for studies focused on personalized reproduction, and projection based surround systems may be more appropriate for studies that include group participation. Puyana-Romero *et al.* implemented a multi-platform system for the evaluation of soundscapes, covering several different modalities of spatial reproduction for the purposes of smart soundscape studies [23]. The authors found that there were no significant differences in subjective estimates of soundscapes between the modalities, and they further identified that a key challenge in maintaining the system was the disparity in the quality of spatial audio reproduction across the three modalities.

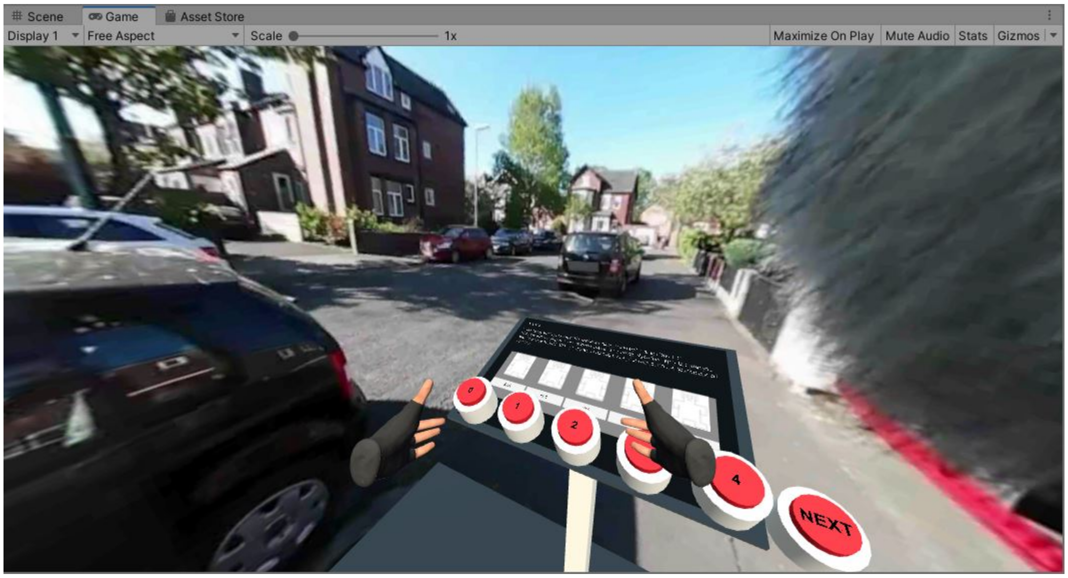

Figure 1: An implementation of a soundscape evaluation experiment as seen through the view of the software development environment. This view would be stereoscopically rendered for a participant wearing a head mounted display system. The view shows the visual stimuli of a 3D still image of a quiet street. The diegetic user interface presented to the participant is also visible, showing a section of the questionnaire and the buttons that participants can use to respond to the questionnaire. Finally the participant hand models are visible.

Though research into the use of VR systems in environment evaluation is in its infancy, large engineering organisations have begun to deploy the systems in large consultation schemes. Arup deployed virtual reality soundbooths as part of the consultation for new works being proposed to one of the primary UK airports [24]. Arup identified that the VR booths were intended to communicate what the proposed building works involved and how they would effect the local community.

3 Framework

To study aspects of the use of VR in soundscape evaluation, the authors have developed the virtual reality soundscape evaluation framework (VRSEF). The framework is intended to ease the creation of soundscape evaluation experiments, and is in use in ongoing research. An example of an experiment that uses this framework is presented in Figure 1. In the experiment participants experience successive soundscapes which are paired with 360 still images that are presented via a head mounted display. This figure shows an example of a diegetic user interface that is presented as part of the game world used in the experiment. This has the benefit of keeping the participants immersed in the environment while performing the survey. Participants perform a survey using the virtual tactile interface for each soundscape, with questions presented on the user interface. The experiment is being performed using the Meta Quest 2 VR head mounted display, and was developed using the Unity game engine and the VR Interaction Framework assets [25, 26, 27]. The Meta Quest 2 was the chosen headset because it is inexpensive, widely available and is supported by a suite of software integration plugins that work with several game engines. Using a VR headset in the experiment has the benefit of keeping the experiment apparatus self contained, improving the repeatability and reliability while minimizing the cost of the apparatus. Unity was used because it includes native support for several VR systems, and has a licensing framework appropriate for academic use. The VR Interaction Framework is an inexpensive asset pack for Unity that includes a suite of tools and scripts which ease the VR application development process [27]. The survey is configured to perform a modified version of the Method A survey described in ISO/TS 12913-2 soundscape standards [16]. The survey is a questionnaire that includes sections for sound source identification, and several ordinal categorical questions related to the participants perception of the qualities of the environment.

The stimuli used in the experiment are excerpts from the EigenScape dataset of Ambisonic recordings and 360 videos[28]. The visualizations used in the experiment are 360 still images of the environment that were taken as the soundscapes were being recorded. The visualisations are rendered as equirectangular projections that are mapped onto to skybox of the game world, giving participants an impression of the surrounding visual environment. The only

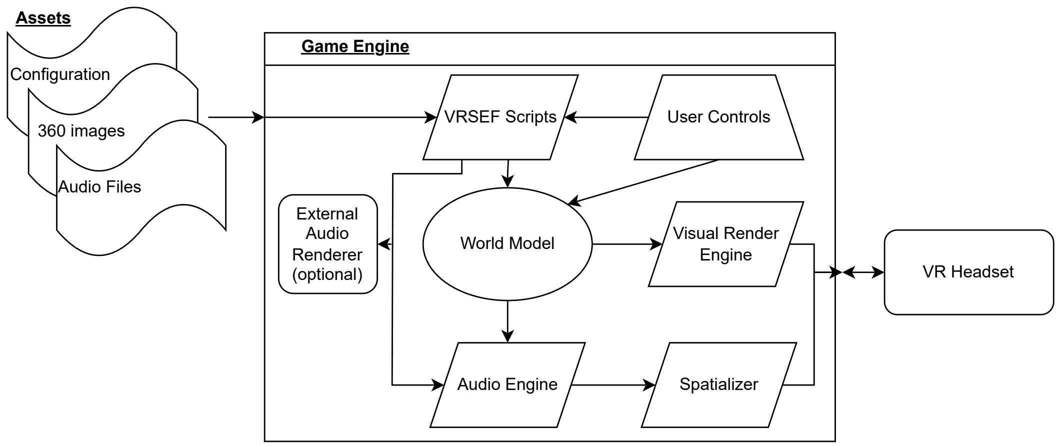

Figure 2: A high level block diagram overview of the components of the VR soundscape evaluation system. The game engine binary encapsulates various elements of the software system, including several scripted objects that are used to control the game world and the progression of the experiment. Several assets are included in the system that are external to the core application binary, represented on the left of the block diagram. The VR Headset hardware referenced on the right hand of the diagram interfaces with the binary, providing feedback and control information to the application.

geometry being rendered in each scene includes the participants' hand models, and the survey apparatus, resulting in very fast graphical rendering times.

The auralizations include up to third-order Ambisonic recordings that are rendered using the Wwise audio middleware [29]. Wwise was chosen because it includes native support for higher order Ambisonic rendering, and includes support for Android devices including the Meta Quest2. The audio stream is rendered binaurally for participants using the Resonance Audio Renderer plugin for Wwise that includes support for up to third-order Ambisonic audio streams[30].

Figure 2 presents a block diagram of the software system that is used in the experiment described above. As represented in Figure 2, the game engine compiles a binary application and a set of resource files that are deployed to the VR headset, including the 360 images as textures, and the Ambisonic audio files as part of the Wwise soundbank for the project.

Figure 3 presents a block diagram of the software objects that automate progress through the experiment.

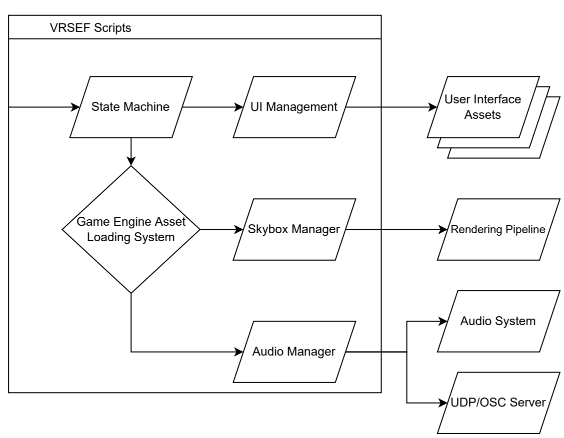

Figure 3: A block diagram of the connection between the singleton objects included in the scripts of the virtual reality soundscape evaluation framework. The state machine directs several manager objects, setting the experiment stimuli and controlling the user interface elements presented to the participant. Where necessary, the game engine resource loading mechanism is used to read assets into the experiment. External input is used to trigger the state machine using the game engine callback architecture.

The scripts associated with the framework include several singleton objects that manage different parts of the system. A state machine organises the experiment procedure, and the configuration files in the assets are used to set up the state machine. As the participant is guided through the experiment procedure, the state machine interfaces with several singleton objects that control different aspects of the VR system. These include an audio manager that interfaces with the system's audio engine, and a user interface manager that presents visual information to the participant. Due to this modular architecture, the framework can be modified to support different audio systems and UI elements. This flexibility reflects the findings of previous research that has suggested loudspeaker rendering may be preferential in situations where verbal discussion is desirable, which is likely to be important when performing a group guided interview as part of a soundscape evaluation [19].

4 Summary

Evaluation and consultation are important steps in the management of environmental noise, and auralization can be used for several purposes including qualitative assessment in the consultation phase of a large infrastructure project. Using any one of several survey modalities can yield similar results with respect to the affective quality of an environment in a soundscape assessment, but the choice of spatial audio reproduction system has an influence on how the environment is cognitively processed. Soundscape assessment can provide a useful framework on which to perform listener-centric subjective evaluations of environments including environmental noise. VR systems including spatial audio can provide a convenient vehicle for the assessment of soundscapes and environmental noise. The Virtual Reality Soundscape Evaluation Framework has been presented, forming the basis for performing soundscape evaluation using virtual reality systems such as head mounted displays. The framework is under active development and experimental validation is ongoing. The development of such frameworks will highlight potential applications of virtual and augmented reality systems, promoting further development and improving the quality of environment evaluation procedures. The framework will be distributed via GitHub [31]. Reference to bibliography file.

5 Acknowledgments

This project is supported by the University of York Department of Electronic Engineering through the EPSRC doctoral training studentship: reference number EP/R513386/1. For the purpose of open access, the authors have applied a Creative Commons Attribution $CCBY$ licence to any Author Accepted Manuscript version arising. Audiokinetic Inc and Unity Technologies kindly provided non-commercial licences for research purposes as part of this research project.

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