SOUNDSCAPE RESEARCH IN VR

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RESUMEN

El enfoque del "Soundscape" supuso un avance muy importante en la evaluación del ruido ambiental. Los datos obtenidos son mucho más significativos que los puros datos de medición, ya que se tiene en cuenta la respuesta humana al entorno de varias maneras, incluido el contexto multimodal, conductual, cultural y estacional. Si estos escenarios complejos se simulan en Realidad Virtual (RV), existen oportunidades para estudiar las respuestas humanas de forma reproducible, pero se plantean grandes retos en lo que respecta a la precisión de la visualización y la auralización y a la validez ecológica al transferir las impresiones perceptivas a la situación de laboratorio.

ABSTRACT

The Soundscape approach created a very important progress in environmental noise assessment. The data obtained are much more significant than pure measurement data, since the human response to the environment is taken into consideration in several ways, including the multimodal, behavioural, cultural and seasonal context. If these complex scenarios are simulated in Virtual Reality (VR), there are opportunities to study the human responses in a reproducible way but there are severe challenges as concerns the accuracy of the visualization and auralization and the ecological validity of transferring the perceptual impression to the laboratory situation.

Palabras Clave— Environmental sound, audio-visual simulation, auralization, Virtual Reality.

1. INTRODUCTION

The auralization of environmental sound offers versatile potential for the elucidation of sound immission and, thus, also makes an innovative contribution to research on noise effects. In addition to technical investigations into the principles of the sound generation and sound propagation, perception experiments and their transferability to other experimental environments are the core of the Soundscape approach [1, 2, 3]. Established methods for the investigation of soundscapes are described in ISO/TS 12913-2 [4]. They are often used in soundwalks on-site (for example [5]). With auralization and VR technology, the core idea is to make acoustic scenes audible in virtual environments on the basis of separately adjustable source, propagation and receiver models as well as spatial reproduction formats [6]. The hypothesis is that soundwalks could be done in the laboratory under more controlled experimental conditions. To this end, the freely available auralization software Virtual Acoustics (VA) is being continuously developed at the Institute of Hearing Technology and Acoustics (IHTA) at RWTH Aachen University. For direct demonstration of the acoustic effects of noise control measures, auralisations enable realistic and cost-effective comparisons for options in decision-making planning processes.

In this paper, we discuss the workflow of creating Soundscapes in VR, and we present application examples.

2. AURALIZATION WORKFLOW

2.1. Creation of audio-visual models

The creation of a digital twin for soundscape studies has particular prerequisites for both the audio and visual models. This distinction emerges from the different physical behavior of light and sound phenomena, and how they interact with the built environment. However, it is very important to understand the differences for the modelling process in a common framework [7]. Firstly, two different geometrical models need to be built: one for the sound propagation, another for the light propagation. The features of the visual model have no influence on the acoustic model except that both models have the same dimensions and are referenced to

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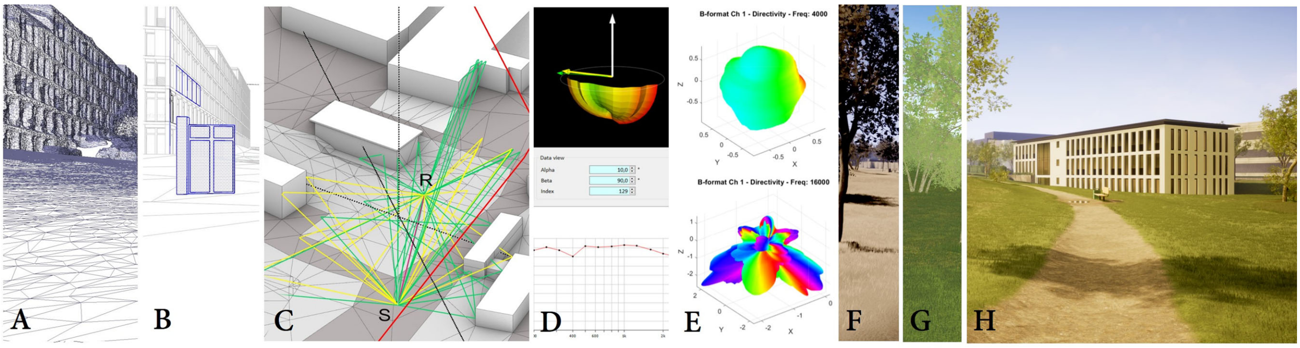

Figure 1. Modelling workflow example: A) photogrammetry; B) visual geometry; C) acoustic geometry and sound propagation paths; D) sound source directivity characterization; E) 1st HOA receiver characterization; F) light sources and shadows calculation; G) visual materials definition; H) Final audio-visual model of IHTApark [9]

the same origin point and orientation in their coordinate systems.

To prepare the models, three main modules determine the whole modelling chain. Firstly, the source model: algorithms for determination of the properties of sound sources and light sources (for example [8]). They will be defined separately and attending to the most salient acoustic and visual effects (see section 2.2). Audio and visual source models only will share location and orientation between models. Secondly, the propagation model will determine the transmission from the sources through the environment. The preparation of the propagation model presents several challenges and important modelling decisions to be taken into account. For example, the level of detail in the geometry definition greatly varies between both modalities. Whereas visual modelling needs geometrical detail of a few centimeters within 5 meters around the receiver, the acoustic model will need polygon dimensions equivalent to half of the lowest audible wavelength (between 0.5 to 1 meter). The geometrical models are complemented with material definitions, which include important features, such as absorption, reflection or scattering. The propagation acoustic models can be built after the detailed visual one by simplification of geometries [7], or both independently based on a common ground, like a photogrammetric capture [9]). Finally, the receiver or reproduction model includes listeners and viewers, which share the same location and orientation. All the effects calculated from the sources, through established reproduction methods such as headphones, loudspeakers, head-mounted displays, monitors, or combinations of them.

2.2. Simulation

Acoustic simulation models are very well developed. The main difference between models are their applicability in terms of uncertainty and computational efficiency for a) indoor vs. outdoor environments, b) low vs. high frequencies. Furthermore, source movements such as in the case of vehicle sound sources are a decisive factor for inclusion or exclusion of computational methods. For outdoor sound propagation, specific challenges are source movements, atmospheric propagation effects (meteorological conditions), acoustic boundary conditions of building façades (diffraction, scattering), and the ground effect for sound reflection at grazing incidence [10].

In contrast to room acoustic modelling, however, some features of outdoor sound propagation are relaxing the computational effort. While room-acoustic impulse responses contain a rapidly increasingly reflection density, the impulse responses in outdoor scenarios are rather sparse. For this reason, the propagation effects can be processed more efficiently path by path by using filters with variable delay lines (VDL), as illustrated in fig. 2.

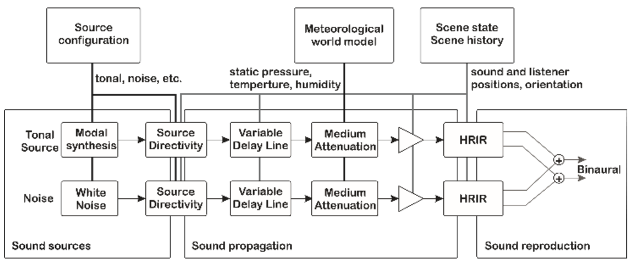

Figure 2. Real-time simulation of outdoor sound propagation with audio-visual VR scene and illustration of the noise footprint on the ground (after [6])

The temporal features such as the propagation delays and corresponding 3D filters must be created for the direct sound and for each reflection/diffraction/scattering path between the source and the receiver. Accordingly, ray tracing and image sources and all other numerical methods yielding energy and delays of propagation paths are candidates to determine the physical behaviour of sound in a virtual scenario. The simulation is used to predict transmission paths from a source to a receiver in an environmental situation, which is entirely based on digital input data. This is basically identical with the situation in indoor scenarios.

2.3. 3D sound reproduction

Virtual acoustics is requires 3D audio technology. The fundamentals of 3D audio - spatial hearing - begin with the consideration of the sound incidence at the listener's head and torso from various directions. This part can be described by filters as well, using the well-known Head-Related Transfer Functions (HRTFs) in the frequency domain and Head-Related Impulse Responses (HRIRs) in the time domain, see fig. 2. HRTFs are specific for the angles of sound incidence, and they are specific for each individual person [11].

Loudspeaker arrays may serve as alternatives to binaural headphone reproduction. The sound field can also be reproduced within a certain area of listener's "sweet spot". Loudspeakers arranged around the sweet spot then serve as an amplitude- and phase-controlled array to reproduce a spatially distributed incident sound field, for example using Higher-order Ambisonics (HOA).

3. APPLICATION EXAMPLE

3.1. IHTApark

The VR framework "VA" [12] has been tested extensively in the case study "IHTApark", a digital twin of a real environment monitored with acoustic and visual recordings, as well as weather indicators. The real laboratory is located nearby the Institute for Hearing Technology and Acoustics, at the geographical coordinates of 50.78054, 6.06628 (https://goo.gl/maps/yrGkUtfLeLHMLNF46) [13].

Figure 3 Virtual Soundwalk at the IHTApark using headphones and VR glasses. The participant is asked to make use of virtual GUIs to describe and rate the different scenarios.

The digital twin has been under development since its creation during the COVID-19 pandemic, and it is a common platform where the main urban acoustic simulation features have been or are being implemented: sound propagation, several sources, source directivities, receiver HRTFs, HOA output, surface material absorption, surface scattering, edge diffraction, atmospheric propagation effects, real-time simulation, etc. Additionally, the visual simulation includes material reflection, diffusion and albedo, different levels of geometry detail, sun and sky lights, atmospheric propagation effects, vegetation and terrain meshes, etc. in three different weather configurations: summer, rainy and winter [9].

Such simulations are being used to unfold how different population groups perceive and describe urban soundscapes, see fig. 3. In order to achieve that, the Individual Vocabulary Profiling (IVP) technique [14] allows participants describing the simulated soundwalks with their own words ensuring that the reproducibility of the environment is the same. With this, several research questions can be investigated. For example, how several descriptive words are rated much more consistent over environments than others, especially those describing dynamic variations of the environments investigated by using psychoacoustic metrics [15].

4. CONCLUSION

The workflow of acoustic simulation, auralization and visualization of urban scenarios is complex and requires careful consideration of CAD model design and acoustic parameter settings. While the propagation models are quite advanced, input data often lack precision with regards to absolute references. Relative differences in the environment such as weather conditions or interventions in the built environment can well be investigated in listening experiments or soundwalks.

It was presented a case study at the IHTApark model. The VR framework is modular, enabling the work in packages and compatible formats. The results are also accessible in online channels such as Youtube. This way, soundwalks can be performed online, if it is ensured that the technology for audio-visual reproduction at the user's end is calibrated.

The datasets generated for this study can be found in the Open Science repository under the following permanent links:

IHTApark in ZENODO:
https://doi.org/10.5281/zenodo.4629759
IHTApark in GITHUB: https://git.rwth-aachen.de/ihta
Example auralizations can be found here:
https://www.akustik.rwth-aachen.de/go/id/dzhe/lidx/1

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