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RENDERING COMPLEX ACOUSTIC SCENES FOR PERCEPTION EXPERIMENTS

Lukas Aspöck* **Michael Vorländer** **Janina Fels**

Institute for Hearing Technology and Acoustics, RWTH Aachen University, Germany

ABSTRACT

The open-source software Virtual Acoustics is a real-time auralization framework primarily designed for scientific research. It is based on a highly modular concept that allows users to combine various audio rendering and reproduction options. Typical experiments range from simple scenes, such as a single sound source in free-field conditions for fundamental psychoacoustic research, to complex real-world scenarios involving multiple moving sound sources within a room acoustical environment. While the software has reached a robust state and has been applied in numerous experiments, selecting the appropriate configuration — and input data — for each new experiment remains a crucial and challenging aspect of experimental design. For binaural reproduction, for instance, this involves considerations such as whether or not to apply headphone equalization, whether individual HRTFs should be used, and in the case of dynamic complex room scenes, which parts of the scene should be updated in real-time. This work presents the software framework and discusses its application in perception experiments, accompanied by examples from various recently conducted research studies.

Keywords: *listening experiments, virtual acoustics, simulation, auralization*

**Corresponding author*: *las@akustik.rwth-aachen.de.*

1. INTRODUCTION & MOTIVATION

Listening experiments have always been a part of academic research in the fields of acoustics. In times, when technical equipment was not available, not affordable or less flexible than today, researchers often used their own ears as a measurement device [1]. While today, many acoustic phenomena can be rather easily detected and analysed using advanced measurement technology, well-designed listening experiments are still a very important part of acoustics research, especially for gaining more understanding of how humans acoustically perceived their environment.

In order to control the acoustic presentation to participants in experiments, acoustic stimuli are typically reproduced in a hearing booth. In traditional psychoacoustic research, stimuli are often recorded signals and/or synthesized or processed signals (e.g., narrow-band filtered noise) [2]. The acoustics of everyday situations in our lives (e.g., in a restaurant), however, consist of a variety of sound sources that interact with each other and their environment in complex ways. Recordings of such complex scenes can be used for perception experiments, but lack the possibility to control or modify the scenario once it has been recorded. This is especially critical for situations, where listeners move, e.g., turning the head when being in a conversation with multiple partners or riding a bicycle in noisy urban environment. Using sound propagation simulation in combination with individually recorded (anechoic) source signals allows the creation of arbitrary virtual scenes, which can be carefully controlled and applied in listening experiments.

To provide a tool to create and control such complex acoustic scenes, the real-time auralization framework called *Virtual Acoustics* (VA) [3] was implemented in the last 10 to 15 years. This software is briefly introduced in this work, along with some examples of research studies, for which VA was used to render acoustic scenes in listening experiments.

2. THE VIRTUAL ACOUSTICS SOFTWARE

Virtual Acoustics (VA) is an open-source real-time auralization framework for scientific research providing a range of rendering and reproduction modules, as well as various interfaces for experiments and demonstrations. Figure 1 shows an overview of the software's concept. An acoustic scene can be defined and controlled via included interfaces (e.g., for MATLAB [4] or the game engine Unity), and rendered and reproduced by a selection of modules (based on either *ASIO* or *Portaudio* driver). The rendering can be configured sound source specific, e.g., a target speaker could be rendered fully in real-time using the *RoomAcoustics* renderer, while for background sources, a static FIR convolution is applied.

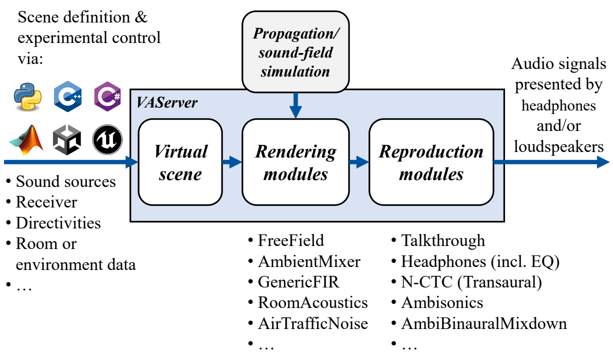

Figure 1. Brief overview of the *Virtual Acoustics* software concept including examples of interfaces, rendering and reproduction modules.

Detailed information and documentation, the access to the code-repository as well as the downloads of the binary files can be found on the project's website (`www.virtualacoustics.org`).

3. EXAMPLE STUDIES USING VA

The VA software has been applied both externally and internally at RWTH Aachen University for various (published) listening experiments. These experiments differ with respect to the complexity (e.g., number of sound sources), the applied rendering concepts (free-field vs. room acoustics) and regarding the combination with visual feedback.
In a study by Breuer et al. [5], VA was applied in an experiment to investigate attention in classroom environments. Here, a dynamic binaural synthesis of VA was combined with a VR representation of a classroom, controlled and rendered by the *Unity* environment. A similar technical setup was chosen in a recent study by Ermert et al. [6], with the main difference that the *Unreal Engine* (with additional plug-ins for experimental control) was used. The *Unreal Engine* was also applied in another recent study by Schiller et al. [7], where the *RoomAcoustics* rendering module was chosen to determine and apply binaural room impulse responses (BRIRs) during runtime. The *RoomAcoustics* renderer - in the chosen technical setup of the study - was configured to use the room simulation library RAVEN [8] as a backend. In this experiment, up to four sound sources in a seminar room (BRIR length of 1 s) were rendered simultaneously. The same technical solution, but without providing visual feedback, was also applied in a recent study on listening effort in children and adults [9].

4. DISCUSSION & SUMMARY

This article briefly presented the open-source research software Virtual Acoustics which serves as a rendering and reproduction tool for listening experiments. Various configuration and interfacing options allow to create complex acoustic scenes, also in combination with virtual reality.
While the tool has been tested extensively and applied in various scientific studies, researchers need to be cautious when including highly complex software environments in research studies, especially when interactivity is involved (which is typically the case in VR settings). If extensive real-time calculations are required, it needs to be guaranteed that the experimental environment functions flawlessly for every participant in the experiment (low latencies and no audio dropouts or artifacts should occur). Additionally, the input data (e.g., HRTF data, source directivities, stimuli, room models, ...) has to be validated, properly documented, and, if possible, the corresponding output audio stream of the auralization environment should be logged at least for a reference experimental run.
In general, the amount of real-time processing in an experiment should be reduced to the essential parts. While a full real-time simulation and auralization (six-degrees-of-

freedom, 6DOF) is rarely required (in most experiments, participants are sitting on a chair), a three-degrees-of-freedom (3DOF) situation is typical in numerous listening designs.

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