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AURALIZATION OF DYNAMIC URBAN ENVIRONMENTS INCLUDING DIFFRACTION AND REFLECTION USING "VIRTUAL ACOUSTICS"

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ABSTRACT

The auralization of urban environments poses additional complexities compared to indoor environments. For example, diffraction at the edges of the geometry has a greater influence on the auralization. Furthermore, most urban environments are highly dynamic, e.g. containing fast moving vehicles. Thus, a complex signal processing chain is required in order to consider additional sound propagation phenomena, such as Doppler shifts.

The "Virtual Acoustics" framework uses the concept of geometrical acoustics to auralize such dynamic urban environments. Based on geometric sound paths, sound propagation parameters are derived controlling the digital signal processing elements, e.g. the spherical spreading loss is used as a signal gain. In order to determine higher order diffraction and reflection paths the so called image edge model can be used in a convenient way. Additionally, "Virtual Acoustics" modular interfaces allows the auralization to be based on other simulation models. This allows the framework to be adapted to different auralization scenarios and research questions. How this can be achieved will be presented and discussed in this work.

Keywords: *Auralization, urban environments, diffraction, virtual acoustics*

1. INTRODUCTION

The assessment of urban noise is a subjective task and can be interpreted differently in different disciplines and by different people. For example, a decrease of 6 dB in traffic noise due to a noise barrier can be interpreted by an acoustician. However, the citizen affected by the noise might be unable to interpret this or still be disturbed by it. The auralization of an urban environment can serve as a common ground for evaluating the perceived impact of noise [1, 2]. For time-efficient simulation of the sound propagation, Geometrical Acoustic (GA) models are typically used. This is well established for room acoustic simulations [3]. However, compared to the auralization of indoor environments, the auralization of outdoor scenarios poses different problems. Generally, the sound field is not diffuse but has limited reflections. In many cases, the source is not visible to the receiver, so no direct sound is present. In these scenarios, the diffraction on edges becomes more relevant. Furthermore, many urban environments include fast-moving sources, such as cars. Finally, due to potentially large distances between sources and receivers, air absorption has a significant influence. In order to create a plausible auralization of an urban environment, these factors must be considered [1, 2, 4].

Multiple applications for the auralization of urbane scenarios exist. Viggen *et al.* [4] proposed an urban auralization based on the Nord2000 propagation model [5]. This propagation model also considers reflections and diffraction but only in a simplified way. Pieren [2] and Pieren *et al.* [6] also proposed an urban auralization scheme which includes reflections and diffraction. However, the exact details of the propagation modelling are unknown from the available publications. Georgiou [7] also proposed an auralization scheme for urban scenarios. In this work, *ODEON* was used to simulate the propagation in street canyon's [8]. As Georgiou pointed out, this approach cannot model diffraction or Doppler effects.

This contribution describes the auralization process for urban scenarios using the software Virtual Acoustics

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(VA). Compared to the previously mentioned applications, VA aims to be an open platform with which many different scenarios can be auralized. It is a simulation tool agnostic and could incorporate any propagation phenomena, including Doppler shifts. VA is an ongoing research software project under development for many years. This work will present the newest developments concerning urban sound auralizations with diffraction and reflections. Furthermore, the signal processing steps are presented to simulate the effects mentioned above.

2. VIRTUAL ACOUSTICS (VA)

Virtual Acoustics (VA) is an open-source auralization framework developed at the Institute for Hearing Technology and Acoustics (IHTA) [9]. A schematic overview of its architecture can be found in Figure 1. It uses a client-server architecture, with the auralization performed on the VAServer. This architecture allows controlling the auralization from different client applications called bindings. VA's bindings exist for multiple programming languages, namely C++, C#, Matlab, Python, Unreal Engine 4 and Unity.

Starting point of an auralization is a three-dimensional, virtual scene, which can contain multiple sound sources and a receiver. Each sound source can use a unique source signal or share it with other sources. Sources and receivers can also be assigned a directivity. This could be a Head Related Transfer Function (HRTF) for a binaural auralization for the receiver. In order to model acoustic propagation, the scene also contains parameters for the medium, such as the speed of sound.

The auralization itself is handled in so-called rendering modules. Here, the information from the scene is used to calculate the signal at the receiver. Different types of rendering modules exist. Some perform acoustic simulations others convolve the source signals with a given impulse response. As such, each rendering module is tailored towards a specific use case. The VAServer can be configured to use multiple parallel renderers to auralize complex scenes.

Included in the rendering modules is a spatialisation step. This allows to adapt the output from the rendering to the desired reproduction method. The types include binaural and ambisonics (higher-order) encoding. Vector-Base Amplitude Panning (VBAP) can also be used as the spatialisation type.

After the rendering, the signals are passed to reproduction modules. These are used to spatially reproduce the auralization through a sound card to the user. Similar to the rendering modules, different types exist. Those allow flexible reproduction using different devices. For example, binaural signals can be directly presented via headphones or reproduced using loudspeakers and a CTC algorithm. Similarly, VA allows working with ambisonics-encoded signals.

VA can be used for real-time auralization and offline auralizations. Due to its open-source publishing model, VA can be extended, for example, with other simulation backends or reproductions.

3. RENDERING OF URBAN SCENARIOS

Similar to the concepts in room acoustic simulations, urban sound propagation from sources to the receiver can be combined in a Finite Impulse Response (FIR). For this to work, the simulation has to be based on static ”snapshots” of the environment. However, urban environments are usually highly dynamic, for example, including fast-moving sources. This time-invariant approach can lead to audible artefacts if the simulation cannot be performed fast enough. In addition, this approach cannot include physically accurate Doppler shifts [10]. A time-variant digital signal processing approach can be considered to include the aforementioned effects of dynamic environments. This approach reduces audible artefacts compared to a steady-state FIR design and allows the integration of Doppler effects [1, 10].

The basis of this approach is that acoustic parameters can be determined for each geometric sound path that describes the acoustic propagation path from a source to a receiver. The direction of radiation at the source is known from the propagation path. As a result, the corresponding source directivity spectrum can be determined. From the path length, the spreading loss, the propagation delay and the air absorption spectrum can be derived. Last, the direction of arrival at the receiver position is also known from the propagation path. For example, the directional information can be used for binaural reproduction to determine the correct HRTF spectrum. These parameters can be used in a Digital Signal Processing (DSP) design that models the acoustic propagation for each path separately. Figure 2 shows this concept. The sound field at the receiver can be modelled by superposing all sound paths.

This per-path design also allows the integration of a per-path Variable Delay Line (VDL) (cf. Figure 2). It can be used to handle fast-moving sources and receivers, including Doppler shifts and the propagation delay. It con-

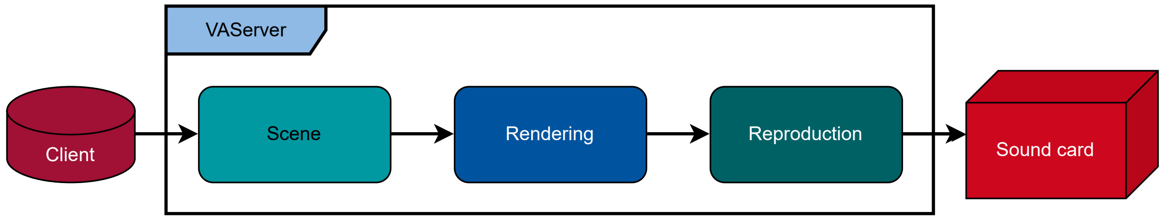

Figure 1. Schematic overview of the auralization process in VA. Through the help of bindings, the VAServer application can be controlled. In the application, a virtual scene can be created, containing multiple sources and a receiver. The scene is then processed through the rendering modules, of which multiple can be used together. The output of the rendering can then be auralized with different reproduction methods such as headphones or CTC.

sists of a buffer for the audio samples of a source. A read cursor retrieves variable numbers of samples from the buffer and interpolates them to the audio block size in order to apply Doppler shifts [10, 11].

For auralizing urban scenarios, VA implements the approach described above in the outdoor noise renderer (cf. Figure 2). Due to the DSP parameter interface of the outdoor noise renderer, it is agnostic to the type utilised path finder algorithm and propagation parameter generator. As such, parameters can be supplied to the renderer by different simulation tools. In this renderer, the concept of the VDL is extended to a Single-Input Multiple-Output Variable Delay Line (SIMO-VDL). This allows having multiple read cursors to feed multiple sound paths from the same source [10]. In order to apply the frequency-dependant parameters, an Infinite Impulse Response (IIR) filter block is utilised. A simple gain block can apply frequency-independent parameters such as the spreading loss.

3.1 Modeling diffraction and reflection

When introducing diffraction and reflections into the GA model, the superposition approach of multiple sources can be extended to cover multiple paths from a source to the receiver. Note, however, that this superposition is a coherent addition as the signal comes from the same source. These propagation paths can include an arbitrary number of diffractions and reflections. Using the aforementioned SIMO-VDL, all paths can also be subject to individual Doppler shifts. The problem is finding these propagation paths containing both diffraction and reflection.

If only reflections are considered, the well-known image source model (also known as the mirror image model) can be used. However, since diffraction is an important part of urban environment auralizations, this has to be considered as well [1]. One pathfinder that can handle sound paths with reflection and diffraction is the image edge model proposed by Erraji *et al.* [12]. Here, the edges of surface boundaries are also mirrored on the surfaces. This allows for determining heterogeneous propagation paths containing both diffraction and reflections. Figure 3 depicts the image edge model in a simplified scenario.

Once the propagation paths for the given urban environment geometry are found, the acoustic parameters can be determined. The propagation paths from the image edge model include information on which surfaces a reflection occurred. Thus, the absorption of the surfaces' material can be represented, e.g. using one-third octave band magnitude spectra. Similarly, diffraction on edges can be interpreted as a filter using the Uniform Theory of Diffraction (UTD) as described in Stienen [1] and Tsingos *et al.* [13]. These parameters can also be applied using the DSP design of the outdoor noise renderer. There exists an already implemented connection for the image edge model for VA's outdoor noise renderer. As a result, the combination of the outdoor noise renderer and the image edge model allows for an efficient auralization of time-varying urban environments.

4. APPLICATIONS AND LIMITATIONS

The presented rendering scheme can auralize dynamic urban scenarios with moving sources and receivers. Complex urban geometries can be considered. These features allow, for example, the auralization of car pass-bys in street canyons or aircraft flyovers [14]. An audio exam-

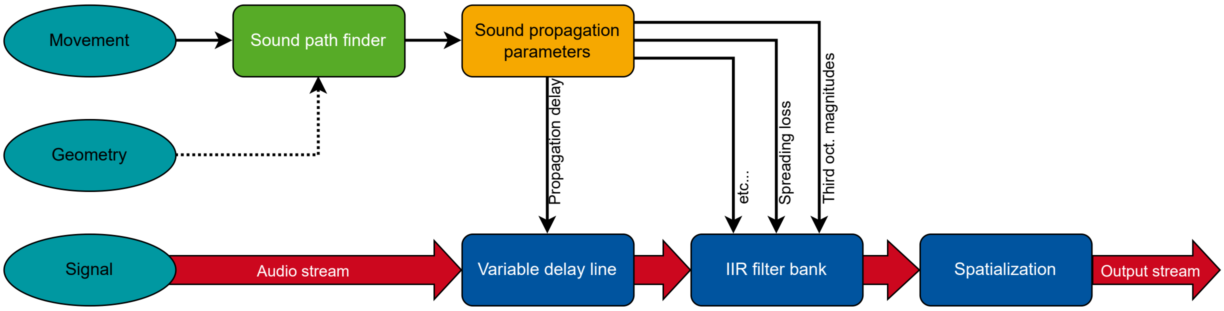

Figure 2. Auralization process using the per-path DSP approach. The input for the auralization is the movement of the source and receiver as well as the source signals. Depending on the utilised sound pathfinder, urban geometry can also be considered. A sound pathfinder takes the information from the movement and possibly the geometry and determines the propagation paths from which the auralization parameters are derived. The audio is fed to the VDL, where the propagation delay of the path is added. Afterwards, the audio stream is passed through an IIR filter bank, where the propagation path parameters are added. Lastly, a spatialisation is performed, which could be a convolution with an HRTF or a HOA encoding.

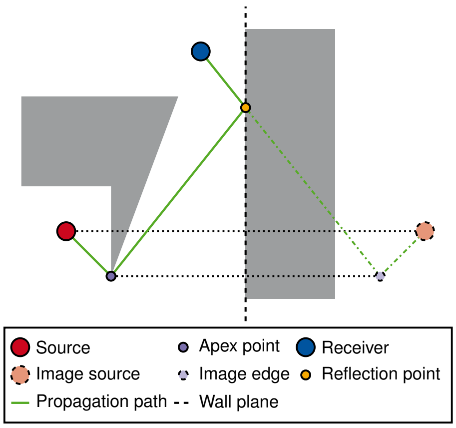

Figure 3. Propagation path determination using the image edge model. Based on [12].

ple of the latter can be found online [1] .

Due to the complexity of the setup, it is currently only possible to use it in an offline rendering context. As a result, user interaction is limited to rotation when using HOA as an output format.

VA is limited to point sources with directivities. However, many urban noise sources can be modelled as line sources. Such noise sources must be approximated using line arrays.

[1] `https://youtu.be/jNWJOKI9sTc`

5. CONCLUSION

This paper introduced the open-source auralization framework Virtual Acoustics (VA), focusing on the auralization of dynamic urban environments. The framework allows auralization based on the image edge model considering higher-order diffraction and reflection. However, its modular design allows using other simulation tools to enable open science.

The results of the image edge model have only been tested on a proof of concept basis. However, they will be validated for more sophisticated urban scenarios using scale model measurements in the future. Also, the presented setup is optimised for specular reflections and cannot consider scattering on surfaces. In ongoing work, it is planned to include these effects in the auralization.

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