Real-Time Sound Insulation Auralization Framework for Virtual Environments for Indoor and Outdoor Sources

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Introduction

Sound is vital for creating a convincing virtual reality (VR) experience, because auditory cues are relevant for the sensation of being present in an actual, physical space. It contributes to the user's sense of immersion. In last decades, the introduction of new building technologies and new powerful sound sources inside and outside the dwellings have contributed to an increased awareness of noise. Along the progress in modelling methods, the development of sound insulation auralization can contribute to studies on noise disturbance and influences in daily live or other situations. Important parts of this development are the technical descriptions and solutions of various auralization methods for simulating sound insulation between adjacent rooms and for facades in virtual reality (VR) environments.

Building acoustics deals with sound transmission of facades and adjacent rooms connected through structural elements of the buildings [1]. To model this in a virtual world, containing all visual and audible objects, we implemented a real-time VR framework, which can be used for audio-visual demonstrations and psychoacoustic experiments with interactive features [2]. We introduce and discuss the basics

Figure 1: Overview over building acoustic auralization framework

of the real-time building acoustic auralization framework such as building acoustics, filter design, real-time convolution and audio rendering, which make the virtual scene more realistic and allow more interaction with the virtual environment. The framework relies on up-to-date methods of building acoustic prediction and enables a perceptually plausible airborne sound insulation auralization. All features are evaluated by investigating both the overall accuracy of filters and the computational performance to maintain a not noticeable delay for the filter update routine. Above all the focus is to pay more attention to the requirements of virtual reality environments including performance issues and to make sure that the audio filters run fast enough in VR systems.

The recent up-to-date work in acoustic virtual reality is available for room acoustical simulations and auralization, implemented in VR environments [1]. To implement a real-time building acoustic auralization framework, two levels of implementation are associated with a universal platform for such kind of advanced VR environments. First, the sound insulation prediction models and building acoustic filter design strategies [3]. Second the filter rendering techniques: such as sound insulation, interpolation, convolution, binaural 3D real-time interactive audio-visual VR technology. Figure 1 shows the general overview of the technical framework. The focus of this paper is on implementation of building acoustics auralization in audio-virtual environments to create immersive and interactive scenes for interactive psychoacoustic experiment such as; work performance under sound insulation conditions.

Building Acoustics Auralization

The sound insulation prediction was introduced by Gerretsen [4] and Vigran [5], based on classical sound insulation theory. Subsequently, the first application of auralization of airborne sound insulation was introduced by Vorländer and Thaden [6]. These filters were used to calculate airborne sound transmission paths from source to receiver placed in simple adjacent rooms of a building and made use of binaural technology for reproduction. This is based on diffuse sound field theory and ISO 12354-1 [7]. Later, Imran et. al. [3,8] developed a real-time airborne sound insulation auralization framework based on [6]. Certain improvements were made by [8,9], such as; source position, its directivity and incident sound intensity on the source room elements, which were calculated based on the sound propagation in the source room.

In the receiver room, the radiating energy from the wall elements is assumed to be transmitted to the receiver by a set of distributed point sources, termed as secondary sources (SS). The reverberation part in both rooms was statistical estimated based on the one-third octave band values of the reverberation time. This is in contrast to common practice of assuming a purely diffuse sound field in the source room for all transmission paths from source to receiver. The extended theory is also applied for the Outdoor sources by neglecting the source room reverberation and considering ISO 12354-3 [7] for the façade sound insulation model. We adopted these models [3,8] for sound insulation rendering and from there we can simulate the binaural audio cues for VR framework.

Audio-Visual Virtual Reality Framework

The latest available models for sound insulation auralization, as mentioned in [3,8] is now integrated into virtual reality framework presented in this paper. To allow a realistic environment in VR, we make use of the professional game and VR engine software Unity [10]. Unity is one of the most demanding game engine and visual rendering software, which is relatively easy to use, compared to other available game engines (i.e. visual rendering tools). However, it contains all necessary tools that are necessary for our purpose. It also supports importing feature for architectural constructions, directly from third-party commercial software such as SketchUp-2017 [11].

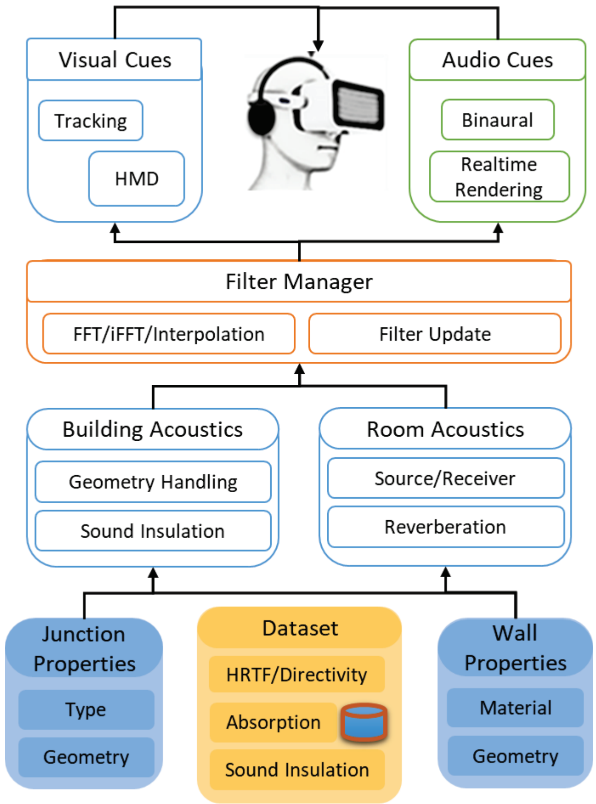

Figure 2: Class diagram auralization process

The building of the Institute of Technical Acoustics (ITA), RWTH Aachen University is designed in a SketchUp-2017 model, which is then imported into Unity. The rest of the graphical features are added into the virtual scene, such as the audio sources, the listener and the camera with interactive features to virtual controllers and the interactive scene (i.e. first-person controller (FPS)). Once the virtual building scene is ready, the rendering process can be initiated. For graphical rendering and interaction in VR there exist many third-party plugins such as Oculus Rift Unity integration plugin [12], or Steam VR plugin [13] etc. with basic audio rendering features such as statistical reverberation and simple room acoustic mixers etc. These auralization features, however, are supporting only free field conditions or generic reverberation, which are not appropriate for specific auralization purposes. Therefore, the sound insulation auralization model described in [3,8] is implemented for audio rendering and auralization into Unity by using its scripting features (e.g. C#). A software framework is described in Figure 2 that includes the selection of materials to room surfaces of the walls, detection of source and receivers' positions, selection of structural properties of the building elements, the filter design and real-time update and the input audio files management and the sound and material properties. The material properties can interactively be assigned to building elements by selecting materials from the database or assigning manual values of absorptions and reflections through graphical user interface in Unity as shown in Figure 3. This process provides the geometric data for calculation of sound insulation metrics. It

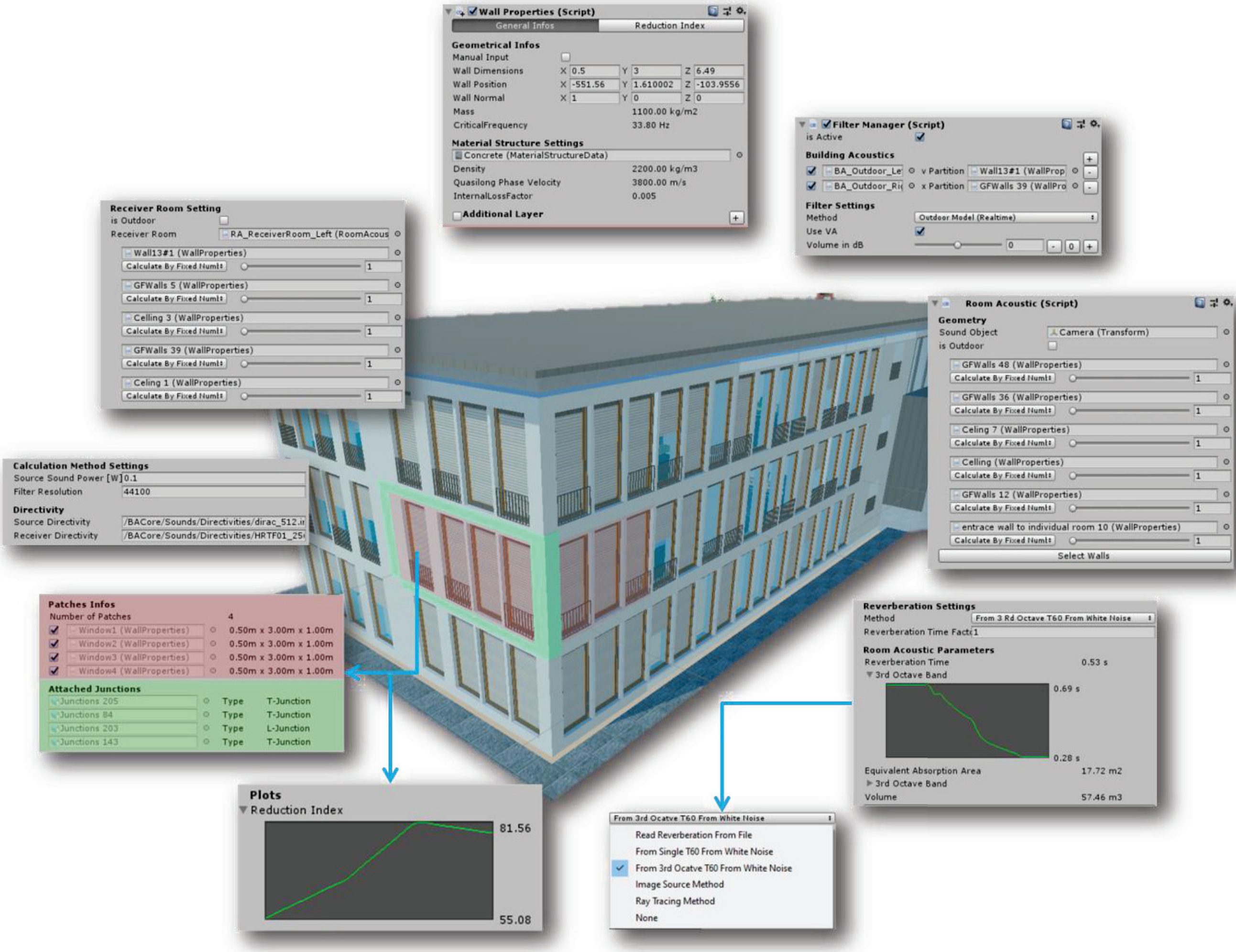

Figure 3: Plugin and software features implemented in in Unity

reproduction. All these features are integrated in the form of plugins. Some of the important plugin and features for the framework are listed below.

- Sound insulation prediction model
- Building acoustic filters (sound transmission)
- Architecture geometry manipulation
- Ray casting
- Real-time source receiver detections and updates
- HRTF database (ITA dummy head recordings)
- FFT and iFFT libraries [14]
- Interpolations
- Convolutions
- Audio filter rendering [13,15]
- Visual rendering (HMD)

These plugins have different functions and are categorized based on their functionalities as described in Figure 2. One category of the plugin automatically detects the building elements with its geometrical information (i.e. dimension) is performed before the auralization process starts and, hence, is required only for initialization of the main framework. The building and room acoustics filters plugin computes all transfer paths from source to the receiver and provides the necessary sound insulation filters for auralization. The filters rendering process applies, Fourier transforms and the real-time convolution operation of these filters to simulate binaural audio cues at receiver end. The sound source and receiver position update, reverberation of the receiving room are the main processes involved in filter management step. The directional cues for binaural signals are then convolved with source signal using real-time add-overlap convolution. This allows us to exchange the filter whenever the source or receiver have moved. This operation is performed with a block size of 256 samples. Normally, the sound file has 24 bit and 44.1 kHz sampling rate. In this way, the whole rendering chain works in real-time and with this, the interactive scenarios can be created in which the source can be moved, and the listener can freely move (turn the head or walk around) in the receiving room.

Real-time Performance

The performance of the framework is evaluated for the real-time updates. Initialization include geometry pre-processing, insulation metric calculation and filter pre-calculations are not included as described in the previous chapter. The real-time process involves updating the source and/or the receiver filter, merge them and transform into time domain. All computations are performed on desktop personal computer featuring an Intel Core i7-7700 CPU @ 3.60 GHz multi-core with 16 GB RAM, Windows 10 (64-bit) operating system. Figure 4 shows the average time over 150 repetitions consumed by just source position updates, just receiver position updates and finally if both positions update in the same frame.

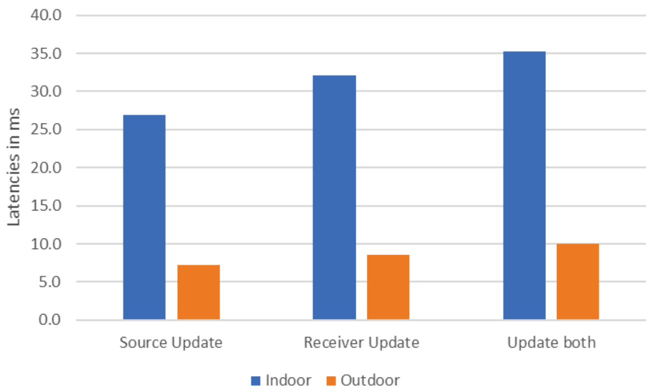

Figure 4: Algorithm latencies (for indoor and outdoor)

Summary

A real-time VR auralization framework is introduced that relies on present up-to-date knowledge of building acoustic simulation techniques. It is implemented in the Unity game engine software. This framework enables several important features along with sound insulation auralization for adjacent rooms and moving outdoor sources against facade. It is intended to use this platform for listening experiments where it allows the test subjects to perform any task of daily life's work or learning under conditions of usual behaviour and movement, creating more realistic noise perception tests in real-time virtual reality environments. Furthermore, in the next version of this framework, sound insulation auralization against outdoor sound source will be incorporated.

References

[1] Vorländer, M. Auralization: fundamentals of acoustics, modelling, simulation, algorithms and acoustic virtual reality. Springer Science & Business Media. (2007).

[2] Imran, M., Vorländer, M., and Schlittmeier, S. J., Audio-video virtual reality environments in building acoustics: An exemplary study reproducing performance results and subjective ratings of a laboratory listening experiment. The Journal of the Acoustical Society of America, 146(3), 2019.

[3] Imran, M., Heimes, A., and Vorländer, M., Real-time building acoustics noise auralization and evaluation of human cognitive performance in virtual reality. In Proceedings of DAGA, 2019, pp: 18-21.

[4] Gerretsen, E. Calculation of the sound transmission between dwellings by partitions and flanking structures. Applied acoustics, 12(6), 413-433 (1979).

[5] Vigran, T. E. Predicting the sound reduction index of finite size specimen by a simplified spatial windowing technique. Journal of Sound and Vibration, 325(3), 507-512 (2009).

[6] Vorländer, M., & Thaden, R. Auralisation of airborne sound insulation in buildings. Acta Acustica united with Acustica, 86(1), 70-76 (2000).

[7] ISO, E. 12354–1: 2017. Building Acoustics, Estimation of Acoustic Performance of Buildings from the Performance of Elements-Part, 1,3.

[8] Imran, M., Heimes, A., and Vorländer, M., Sound insulation auralization filters design for outdoor moving sources. Proceedings of the 23rd International Congress on Acoustics, 9-13 September Aachen, Germany (2019)

[9] Heimes, A., Imran, M., and Vorländer, M. A real-time virtual reality building acoustic auralization framework for psychoacoustic experiments with contextual and interactive. Proceedings of the 23rd International Congress on Acoustics, 9-13 September, Aachen, Germany (2019)

[10] Unity 3D, URL: https://unity.com

[11] SketchUp, URL: https://www.sketchup.com

[12] https://developer.oculus.com/downloads/package/unity-integration/

[13] https://www.steamvr.com/

[14] http://www.fftw.org/

[15] http://virtualacoustics.org/