Perceptual Localization in Virtual Reality Environments of Pass-by Outdoor Sources under Sound Insulation Conditions

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Introduction

Auralization techniques are rapidly attaining importance due to their applications in building acoustics and virtual reality (VR). As an application, sound insulation auralization has become a valuable tool to assess the sound insulation of buildings in terms of investigating how indoor and outdoor noise sources are influencing the daily work and life-routine. The performance of buildings concerning protection against noise exposure is evaluated from technical and human-centred perspectives. The technical oriented evaluation is based on the standard measurement and sound insulation prediction techniques [1,2], whereas the human-centred approach, based on dynamic auralization of virtual reality scenes, is adopted to explore the potential of audio-visual virtual reality to evaluate outdoor noise by building characteristics.

In this paper, we implement a real-time building acoustic rendering framework for façade sound insulation based on ISO 12354-3 [3] and on previous work [4-6] with an extended approach that is used to construct sound insulation filters for binaural sound transmission of moving outdoor sound sources by façade elements. For real-time auralization of complex building façades (i.e. composite façades) to a listener at some place in the building volume, we integrate the façade sound insulation model in VR using Unity software [7] as visual environment rendering tool. This framework allow the users to perform any task of daily life of work under conditions of usual behaviour and movements.

Different background intermittent noise conditions, convolved with sound insulation filters of the façade of a classroom are presented in a VR environment. The perceptual localization capabilities of human under façade sound insulation conditions are evaluated. Therefore, it is intended to create more realistic noise perception tests in real-time virtual reality environments..

Figure 1: Virtual reality building acoustics auralizat1ion environment listening experiment setup [9]

Sound Insulation Model and Auralization

Sound transmission from an outdoor source (e.g. a moving vehicles) into a building is a complex process. The moving sources are directional sound sources with strong low frequency sound characteristics. There exist multiple propagation paths from these sources to several parts of a building including reflections from the ground and other surround buildings. Sound transmission through exterior walls of a building becomes more complicated because of the varying angles of incidence of the source, the multiple transmission paths within the building and the fact that these phenomena all vary greatly with the frequency of the sound source. The procedure for the filter designs of sound levels should cover sound transmission loss of exterior walls, roof constructions, windows, and some doors. The model used in this study is based on [5]. Generally, the exterior walls of common buildings are consist of an assembly of two or more parts or surfaces (e.g. windows etc.), therefore, the idea of segmenting the façade s into finite size patches known as secondary sources (SS) is applied. We consider direct sound transmission paths Dd, through each secondary source because it is assumed that the transmission for each SS is independent from the transmission of the other SS. Therefore, for a direct sound field the sound transmission coefficient of a plane wave depends on the angle of incidence θ, between the direction of propagation of the incident plane wave and the normal to the plane of the exterior elements (i.e. façades). A description of the sound insulation model and filters design procedures are described in [5]. Once the filters for sound insulation are calculated as described in section 2.2 of [5], auralization makes the sound pressure in the receiving room audible at the ears of the listener by an appropriate equipment using reproduction techniques. From an input time signal $s(t)$ and transfer functions (i.e. filters), the time signal at the output of any LTI system can be calculated by means of convolution techniques. Hence, the time signal at a receiver in the room is calculated from the source signal (i.e. a motorbike) and the transfer function from all secondary sources to the listener by convolution. However, the filter length is an important parameter for convolution technique, also in order to fulfil the requirement for approximate time invariance. In the receiving room, the secondary sources located at different positions and orientation relative to the listener's ears, are excited by the sound transmission from the source, therefore, they are required to be perceptually localized to create a spatial impression of listening the room. Hence, it is necessary to consider an auralization with measured or individualized binaural signals by head related impulse responses (HRIR) or corresponding head related transfer function. In our signal processing, the HRTFs of the ITA dummy head are used. Furthermore, to listen the impression of the receiving room, we have simulated impulse responses for the receiving room for each secondary source to the listener position. In addition to the spatial impression, the presentation of signals resulting from building acoustical auralization differs in an important point from other techniques, i.e. the relevance of loudness. When listening to room acoustical auralization, the colouration, the spaciousness or lateral fraction are important but less important is the level. In building acoustical auralization, the level is the most important quantity together with colouration. Therefore, care has to be taken for the reproduction of both the correct absolute level and the relative level between source and receiving room. Since some room situations have level differences of 50 dB and more, care has to be taken for not wasting valuable signal to noise ratio (SNR) in the signal chain. If the absolute level of the sound signals are to be reproduced, a calibration of the replay chain has to be done [6].

Implementation in Virtual Reality

The "Unity" [7] based framework of sound insulation is implemented and evaluated for real-time performance of algorithm. The filters are applied to the façade of a classroom with dimensions 13.5x8.12x3 m. The auralization framework is used for listening experiment in complete VR and real situation of the building of the Institute of Technical Acoustics (ITA), which is selected as a test case for the comparison of real and virtual scenes. The façade of the classroom consists of glass windows, each of thickness 8 mm, 3 m in height and 1 m in width, and are separated by concrete pillars as shown in Figure 1.

Evaluation of the VR Environment: Perceptual Localization of Moving Outdoor Sources

The present experiment used the described VR environment to explore perceptual localization capability of human under façade sound insulation conditions. The audio-visual VR experiment intended to see that whether outdoor moving sound source can perceptually be localized due to frequency-specific façade sound insulation conditions. It aims at finding the correlation between the perceptual localization results of the outdoor moving source in real and virtual environments. The participants worked on a localization task in a real classroom at different positions, hearing the sound conditions via headphones. The same real environment experiment is simulated through VR setting and visualized through HMD. A total of seven participants (5 males and 2 females) took part in experiment and were reported normal hearing. Two auralised versions of sound conditions were included in the experiments, i.e. a motorbike running at 40 km/h from left to right and from right to left in front of the façade.

The experiment was carried out on a personal computer with an Intel Core i7 configuration (16 GB RAM). The visual classroom scene, developed in Unity 3D software with an audio plugin for building acoustics [8], was presented to the participants through Oculus Rift headset, as shown in Figure 1. In the present VR-based experiment, all background sounds were presented binaurally using Sennheiser HD 650 headphones. A Norsonic Type 116 sound level meter was used to measure and calibrated the SPL for each sound condition through RME Fireface UC II sound card to deliver the target SPL to the headphones, placed on an ear simulator (HMS-III, dummy head from HEAD Acoustics). Subjective ratings were measured on a five-point scale.

Results

The data collected in the present real and VR experiments were analysed and compared with each other. The goal was to compare the correct answers from the participants obtained in audio-visually rendered environment (VR) with those found in the real classroom environment.

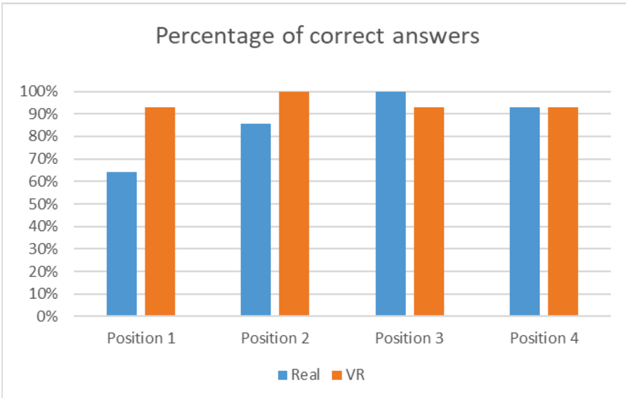

Figure 2: Percentage of correct answers

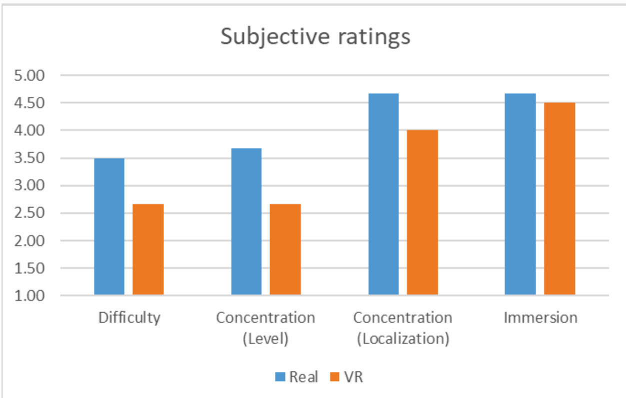

Figure 3: Subjective ratings

In the first step, we tested whether the participants are able to perceptually localize the moving sources under building acoustical conditions in both real as well as virtual environments. Secondly, we compared both results to see if there is apparently a difference between the responses of participants in both environments. Subjective ratings of “difficulty”, “ability to concentrate on level perception”, “effort to localize the source” and “immersion” were measured on a five-point scale for both cases. The results of this experiment are shown in Figure 2 for four different positions in the classroom (position 1 is near the façade and position 4 is in middle of the classroom). Similarly, in the subjective ratings results in Figure 3, we can see similar trend in both environments regarding “difficulty in experiments”, “concentration in level and localization” and “immersion”.

Discussion

The sounds were presented indicating different directions of the motorbike pass-by. In this preliminary test, in all cases, the test subjects could identify the directions significantly above the guessing threshold of 50%. It seems that in positions 2 and 3 this decision is easier than in position 1 (close to the façade) and position 4 (in the middle of the room). Due to the low number of tests, however, this is only a tendency. More test have to follow in order to meet the requirements of statistics. The tendency is visible in the measured scenario as well as in the VR auralization. Nevertheless, the results seem to support the hypothesis that close to the façade (position 1), the main directional information is included on the direct sound of the closest patch, so the sound source is localized just there. In contrast, further away, more patches contribute to the direct sound cluster with varying arrival times, so that the precedence effect and the patch with the earliest arrival time determines the source localization. At position 4, the diffuse field dominates, so that source localization gets more difficult.

Conclusion

From the results of both studies, it seems that VR itself has no significant impact. Therefore, VR can be used as a proper substitution of the real scenario for taking various psychoacoustic tests. The mean correct answers for all four positions are above 80% in both environments, hence, it might be concluded that the perceptual localization of the human under sound insulations is high even though the source itself is visually not present. This study provides initial results of localization of moving outdoor sources which lead us to perform further experiments on cognitive tests to find out the influence of the moving source and other intermittent outdoor noise stimuli on the performance of human beings during their daily work in built environments. In future work, we intend to conduct psychoacoustic experiments with dynamic auralization scenes where the users will be allow to perform any task of daily life of work or learning under conditions of usual behaviour and movement in order to find if moving and intermittent noise effects of passing-by car, ambulance and police sirens etc. have larger distraction effects on attention and work performance than stationary sound sources.

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