Auralization of Urban Environments – Concepts towards New Applications

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Summary

In times of progressive urbanization, a growing section of the human population is exposed to noise pollution. The rising request for mobility enlarges the problem by adding more sound sources to the acoustic environment, e.g. due to public transportation, air traffic, private transport etc. As a consequence, more and more individuals are affected by environmental noise and hence a growing countermovement against large-scale projects can be observed. In order to introduce ways to ease understanding of noise pollution effects, auralization of complex 3D multi-source virtual situations can be of great advantage. The possibility to listen to an acoustic simulation, e.g. of a significant intervention into the infrastructure in a metropolitan area, can be a powerful tool to inform persons affected that is already available in an early project stage. Therefore, auralization represents a preventive measure that can involve non-experts to intuitively experience consequences of urban modification with their hearing sense, and without the need of numbers and figures that are difficult to comprehend. To bring this concept of virtual acoustic reality into existence, some large gaps have to be overcome. This contribution will discuss problems and potential solutions towards new applications of auralization.

PACS no. 43.55.Ka, 43.55.Ev

1. Introduction

The United Nations document that the increasing population worldwide tend to merge towards metropolitan areas [31]. Also, the traffic-related noise pollution in the western part of Europe is portrayed as a health issue with vaulting trend [36, 37]. The progressive urbanization fuels the problematic nature of man-made noise in many ways and can bring nationwide legislative controls to the limits of the possible. A changing urban environment requires further mobility demands on the one hand, and quiet spaces for relaxation within condensed space one the other. Hence, increasing number of passengers in public transport, elevated private vehicle traffic as well as surged air traffic introduces more and more noise sources. Simultaneously, awareness of negative repercussions from noise on health and well-being due to sleep disorder and induced stress counteracts with the abovementioned. This results, among other reasons, in counterforces against urban interventions, for example when extending airport runways.

When sketching the future outline of metropolitan areas, the individual contribution of transportation vehicles to the acoustic environment have to be considered more precisely and with the strong association on human perception. For example, an arbitrary noise source should be investigated in the context of public interest, and its individual signal should be analyzed with respect to the auditory sensation on humans. Evaluating the urban soundscape by means of acoustic annoyance using public surveys can help to identify attitude to certain circumstances [11, 27, 39]. Psychoacoustic rating of the time variant sound field results in a closer perception-related analysis that can be acquired just through measurement and analysis [8, 9]. However, a powerful tool to *predict* the acoustic environment, study effects of particular noise sources and fore'hear' the consequences of infrastructural interventions may be found in the generation of virtual scenarios through computer simulation, namely auralization. The correct

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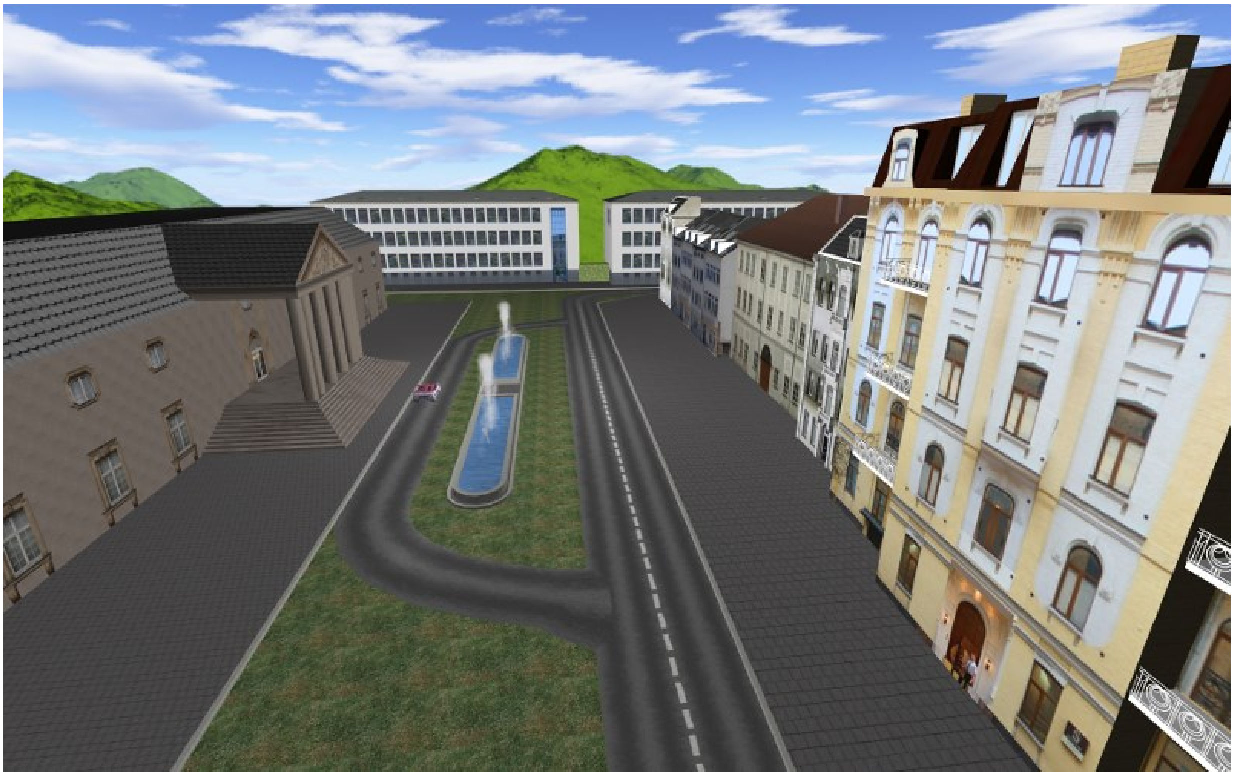

Figure 1: Virtual scenario of a fictive urban environment including a car and two fountains as well as surrounding buildings. Several acoustic boundary conditions can be identified, like building facades, hard and soft ground and pillars occluding the direct sound component

reproduction of the sound field in sensitive urban areas including transient signal pattern and time-variant states of the entities producing the audible sound reveal new approaches to better understand and handle urban noise pollution. Creating auralization applications that produce physically-based acoustic urban environments with high accuracy lead to new fields of noise control engineering and perceptual research.

2. Auralization

Auralization is the process of making acoustic environments virtually audible [12, 32]. It can be separated into the signal generation of a sound source, the propagation of acoustic waves including all physical effects and the reproduction of the sound field at a virtual receiver position for a user or a group.
A common technical implementation assumes that the transmission of sound underlies only linear transformations that do not change over time. Therefore, a linear time invariant system (LTI) can be used to realize the physical processes by a representation of a time domain impulse response or a frequency domain transfer function. The convolution of any given signal containing only the excitation information with the designed filter imprints the acoustic behavior of the environment, including source, propagation and receiver effects. To present the auralization a variety of different techniques exist, of which the binaural reproduction using headphones is an established method that maintains perceptual cues of the auditory system.

2.1 Acoustic simulation

The filter design incorporates simulation processes, which try to determine the circumstances as accurate as required, usually dictated by human perception thresholds. Many simulation techniques exist, which have to be tested carefully for validity in the context of auralization. However, procedures using Geometrical Acoustics can be seen as the leading approaches for large scale environments, for example with the application of indoor room acoustics [7, 12, 13, 19, 22, 25, 33] and outdoor sound propagation, as proposed by ISO 9613-2.

Figure 2: Experts of different disciplines studying the virtual environment with their individual background of expertise in an integrative and intuitive approach using techniques of Virtual Reality

2.2 Outdoor sound propagation

To calculate the sound propagation in outdoor scenarios, special focus has to be laid upon the main physical processes and interaction with objects that are influencing the transmission path from sources to receivers. Basically, a free-field condition can be assumed, that takes certain boundary conditions into account. These components are represented by surfaces of greater extend, like the ground surface and building facades that re depicted in Figure 1. The major contribution to the sound field can be expected from the specular reflection at these boundaries, applying the surface absorption to the reflected energy. The principle of calculation follows the well-known image sound source method, initially introduced by Allen and Berkley [1]. As a second important contribution, the diffracted sound around objects has to be mentioned, especially with regards to urban environments. The broad bandwidth of audible sound and the resulting wavelengths in the lower frequencies bands are large compared to spatial obstacles, hence a significant amount of energy can be observed in the shadow zone [4, 6, 18, 29, 30].

Another influence factor, which has been examined in the past without the concrete background of auralization, is absorption, transmission and scattering of the sound field by vegetation [2, 3, 5, 21, 28, 35, 38]. Despite the positive attitude towards greenery by the public [10], there is a chance that vegetation with certain properties can alter the propagation of acoustic waves in a way that is positively received by human perception, i.e. by damping high frequency components and scattering the waveform.

When regarding long distances and extreme loud noise sources such as high speed trains and airplanes, properties of the propagation medium become a crucial factor to sound propagation and has to be considered for the calculation of attenuation [15].

2.3 Real-time processing

Now, the principle of auralization is partly extended and the constraint of time invariance is loosened to allow for changes of the virtual environment. Still the overall situation is treated as LTI system, but is furthermore sampled in time producing snapshots of a dynamic situation. These snapshots are subsequently triggering simulation processes to

determine the current impulse responses that represent the scene acoustically, and are then smoothly integrated into the convolution engine [24, 34]. This procedure can also be seen as *acoustic rendering* which results in a reactive system, if the simulation recalculation and the filter exchange is efficiently implemented and achieves high update rates. This poses great demands for computational power, efficient algorithms and can usually not be attained without simplification to reduce complexity. This requirement is even more important, if auralization is used within applications of Virtual Reality [26]. Here, one has to take up the challenge of a very low input-to-output latency to account for dynamic user interaction. The entire chain of processing, including motion tracking, audio hardware signal processing, auralization and output reproduction, has to perform within a given time, again dictated by human perception. A key factor hereby is to create the perceptually correct stimulus and adapt for changes rapidly while maintaining physically correct reproduction. Only if these prerequisites are met, real-time auralization can also be used in studies for auditory perception. Assessment of the plausibility can be investigated using the SAQI vocabulary proposed by Lindau and Weinzierl [16, 17].
In terms of urban 3D sound field reproduction, the simulation process does not necessarily have to be recalculated bodily, but depending on the type of modification of the virtual situation. For instance, the direct sound part of the impulse response requires high update rates but it can be expected that the exchange of diffraction filter parts is still not perceivable if updated with lesser rates, as it is known for the diffuse reverberation part in the real-time auralization of indoor scenes [14]. In complete urban scenarios it is clear that many (possibly hundreds) of sound sources must be modeled and their contributions added.

3. Sound source acquisition

The acquisition of sound source signal data presents a problem not to be underestimated if high realism of a virtual environment is requested. For the purpose of quality assessment indoors, a multitude of “dry” sounds are available, that reflect the purpose of a particular space sufficiently to examine the room response appropriately. Examples are anechoic recordings of musical instruments, singing and speech. These signals do not change substantially in a situation with moving source, for instance when auralizing a religious ritual of a choir in a church [20]. In contrast, a large number of audible sound sources in outdoor scenarios are highly depending on a state that can change over a time. Imagine the sound of a regular bus that approaches a stop, opens and closes the doors and then drives off again. To resynthesize this situation correctly and with high sound quality for an arbitrary listener position, either recordings of the bus including all direction during the event has to be captured or the source signal has to be separated and a-priori measurement dataset of the directivity has to be used. In reality both approaches are hard to overcome, and yet offer view dynamics since the modification of the state of the bus (speed, throttling, acceleration, duration of idling) is not possible. In addition, in-situ measurements have to be liberated from influences of the surrounding, as an example the ground effect has to be taken out of the recordings to apply a different ground effect according to the virtual scenario.

Figure 3 Virtual fly-by of an aircraft considering different states of the turbofan jet sound source using synthesized signals only [23]

To overcome the shortcomings in source data acquisition, the signals have to be either fully generated by high quality synthesis [23] or new ways to capture real sounds and manipulate the data accordingly to the source state have to be investigated.

4. Applications

Advances in auralization, and in particular rea-time auralization can contribute to various cross-discipline fields of interest, especially when established for applications of Virtual Reality. Most importantly, the *evaluation of urban environments* can make a large profit when investigating noise pollution including more perception-based

reproduction of acoustic conditions rather than single value numbers and noise contour maps. The conduction in a controlled environment can easy the process of the findings, if a realism of the virtual world is assured that immerses the user into the artificial presentation, hence undergoes the human perception thresholds.
Urban traffic planning and general environmental interventions prediction form another group of applications for a variety of disciplines, where auralization can play a key role to foresee consequences to the public and therefore represents a powerful planning tool.
Psychoacoustic research and audiology can use auralization of urban scenarios to improve general understanding on the *perception of the acoustic environment* with respect to the emotional state of the user. The complex effect of noise induced stress, annoyance, discomfort and so on can largely be investigated under controlled circumstances and can be extended to fully-dynamic reproduction of the real world, for instance via user studies in multimodal Virtual Reality systems, rather than field campaigns. Localization ability, sound source clustering, acoustic spaciousness, immersion, presence, introspection and many more characteristics can be investigated in this context.
The outcomes of the proposed fields of application present new opportunities for noise control engineering, acoustic consulting, public security issues, cultural heritage, urban comfort prediction, quality of life assessment and inclusion of the general public with intuitive presentation of acoustic problems.

5. Conclusion

This paper has presented the principle of auralization within the urban context. The rising demand for more qualified acoustic simulation and presentation of the results that affects a growing number of inhabitants has been described. Problems that have to be overcome were identified by a) accurate acoustic simulation of outdoor noise propagation including reflections, edge diffraction as well as absorption, surface and volume scattering and transmission through vegetation and b) appropriate source signals with a high degree of realism considering dynamic state changes.
Auralization opens up a variety of possible applications that can display current situations and predict future scenarios not only by abstract single number values but also with methods based on psychoacoustic evaluation and audible reproduction. If high quality auralization is achieved that undergoes perceptual thresholds, auralization can be used for auditory studies investigating the received acoustic environment in controlled settings in terms of psychological, demographic, social and cultural research. In addition, real-time auralization enhances Virtual Reality systems founding a basis for further research on human perception of sound in urban environments, such as emotional effects evoked by certain soundscape. Benefits can be expected for a range of applications in the disciplines engineering, urban planning, scientific research and public information.

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