

Augmented Acoustics for Ensembles

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Introduction

The acoustic properties of a room can affect the perception by the musician playing on stage, resulting in a different style of playing [1, 2], especially if one is not used to adapting to different acoustics. In music education, playing an instrument in concert halls typically happens rather in a late stage of training. In order to study the effects of different acoustic environments on playing in an early stage, we previously presented a system for augmented acoustic reality that creates the acoustic impression of concert halls in small practice rooms by adding reverberation to the direct sound [3]. The system employed close-up microphones mounted onto the instrument and acoustically transparent headphones [4] to play back the virtual room while at the same time avoiding attenuation of the direct acoustic path to the musician's ear. It can achieve zero-latency playback on standard PCs, which is important for unimpaired musical playing [5]. Results from the practical application of the system in lessons at a conservatory have been published recently [6]. In some cases, the students reported that headphones and even smallest microphones on the instrument impede the natural movement of the musician.

It can be assumed that freedom of movement is even more important when playing in an ensemble of musicians. Therefore, our further development presented here works with loudspeakers and microphones surrounding the musicians at a larger distance, e.g. close to the walls of the real room, similar as in [7], cf. Fig. 1. Of course, such a system is challenging in terms of stability against feedback and requires corresponding ways to avoid feedback, e.g. by dynamically changing the transfer paths between microphones and loudspeakers.

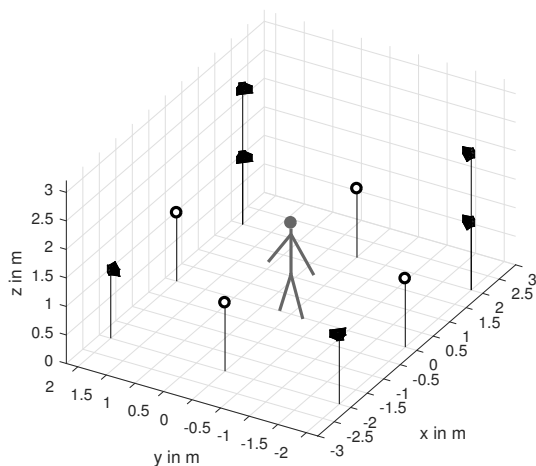


Figure 1: Setup with 4 surrounding microphones (circles) and 6 loudspeakers.

This contribution presents a systems that provides augmented acoustics for ensembles and can be used to study the influence of the room on the interaction between musicians. The system uses surrounding microphones and loudspeakers and requires even less computational resources than the single-user version. First, we present the signal process blocks that create the virtual room acoustics including simple strategies to reduce feedback. Subsequently, results from an evaluation of a practical system are shown. The evaluation comprises the level coverage of the reverberation based on simulations and measurements in the real room, a comparison of the maximum stable gain before feedback with and without our strategies, as well as a preliminary application with different ensembles. Unfortunately, the actual application in lessons with students could not be done due to COVID-19 restrictions. Finally, the contribution is summarized and an outlook to future developments is given.

Signal Processing

The entire signal processing employs 3rd-order Ambisonics [8] and is based on the Augmented Practice-Room App [3]. The following paragraphs describe the particular parts in the block diagram, as depicted in Fig. 2.

Microphone Encoder

The sound of the instruments or singers is captured by multiple surrounding microphones. These signals are summarized in a single virtual source close to the center (1 m, 1 m), however each microphone is encoded with a specific 3rd-order directivity pattern. These directivity patterns ensure that each microphone signal excites the virtual room mainly in the direction that is contrary to the microphone's main lobe in order to avoid feedback.

Early Reflections

The directive virtual source is fed into an image-source model with 40 reflections to only render the position-dependent part [9] that blends into the diffuse, late reverberation at the mixing time [10]. The overall reflection coefficient of the room can be adjusted frequency-dependently and each surface can have an additional broadband attenuation. As no direct sound is rendered, the receiver position is identical to the source position. The time delay of each reflection is reduced by the delay introduced by A/D-, D/A-conversion, processing, and audio buffers to facilitate zero-delay playback. In the case of a reflection arriving earlier, e.g. when a listener is close to a virtual wall, resulting negative delays are clipped to zero. In order to reduce feedback, the reflection pattern is varied over time by rotating the position of the virtual source/receiver counter-clockwise on a circle with 1 m radius at a speed of 0.5 Hz.

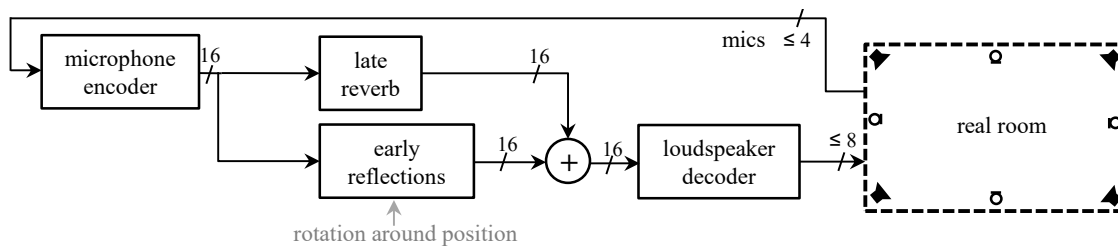


Figure 2: Block diagram showing the signal processing from surrounding microphones to surrounding loudspeakers.

Late Reverb

The encoded microphone signals are then fed into a static 64-channel feed-back-delay network [11, 12] to create the late reverb. A fade-in enables an increased diffuse envelopment [13, 14] and smoother transition into the early room reflections.

Loudspeaker Decoder

Finally, early reflections and late reverberation are summed up and fed into the decoder. The decoder employs the AllRAD approach [15] for maximum flexibility on arbitrary loudspeaker setups.

Evaluation

The evaluation of a practical system took place at *Regieplatz Petersgasse*, a 4.2 m × 6.0 m × 3.2 m studio at our institute. The studio is acoustically treated to a reverberation time of 250 ms in order to fulfill the ITU recommendations [16]. The system consisted of 4 AKG C480B cardioid microphones and 6 Genelec 8020B loudspeakers setup up as shown in Fig. 1. The same 5 virtual rooms as in the previous application for single musicians were employed: a small room, two chamber music halls, a concert hall, and a cathedral [3].

Level Coverage

For practical application, it is important to provide a position-independent level coverage with the virtual room acoustics, so that the musicians can move around freely without experiencing an increase or decrease in the level of the virtual room. Thus, we evaluated the level with which the real source is fed into the virtual room in dependence of its position inside the real room. As a target for plausibility, the level variation should be below 2 dB, which is the just noticeable difference for the direct-to-reverberant energy ratio in the most sensitive case [17]. The simulations under free-field conditions with ideal cardioid microphones (facing to the center of the setup) and source (facing towards positive x-direction) with frequency-independent directivity pattern are shown in Fig. 4 in dependence of the number of microphones. While with a single microphone, the plausible area is small and half-moon-shaped, it covers nearly the entire area for 3 and 4 microphones. Using real cardioid microphones and a Behringer C50A loudspeaker as a source in the studio, Fig. 5 shows a similar or even larger plausible area at low frequencies. At high frequencies, the stronger directivity of the loudspeaker reduces the area, especially when using only one microphone.

Maximum Stable Gain

The maximum stable gain (MSG) before feedback was tested for all 5 virtual rooms using the C50A loudspeaker as a source at the center by increasing the input gain until feedback started. Fig. 3 shows the average values for pink noise, speech, and a clap as excitation signal in relation to the most instable case: omnidirectional encoding of the microphones and no rotation. The directional encoding increases the MSG up to 11 dB, especially for the larger rooms. In the chamber music halls with strong early reflections, a further increase of up to 4 dB is achieved when using the rotation. However, in the small room, there is no further increase, as the rotation brings the virtual source close to the virtual walls.

Practical Application

We tested the same system in 3 groups of musicians from the project team using the 5 virtual rooms in the studio. For the solo guitar, the sound of the ensemble system was reported very natural and similar to the previous system with close-up microphone and headphones. In contrast to the latter, the freedom of movement and the avoiding of addition hardware on the instrument were perceived very comfortable. The small ensemble with guitar, cajon, and 2 percussionists played slower, more staccato and interacted worse in the virtual cathedral. Similarly, the intonation of a 6-people choir was worst in the cathedral. In general, the medium-sized chamber music and concert halls were perceived as most comfortable and supportive when playing in an ensemble.

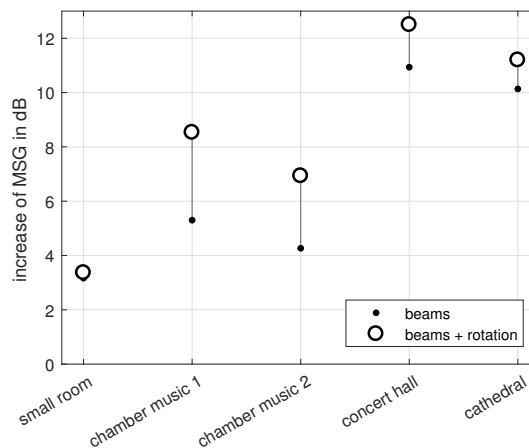


Figure 3: Increase of maximum stable gain (MSG) in different virtual rooms for directional encoding of the microphone signals (beams) with and without rotation around the position in comparison to omnidirectional encoding without rotation.

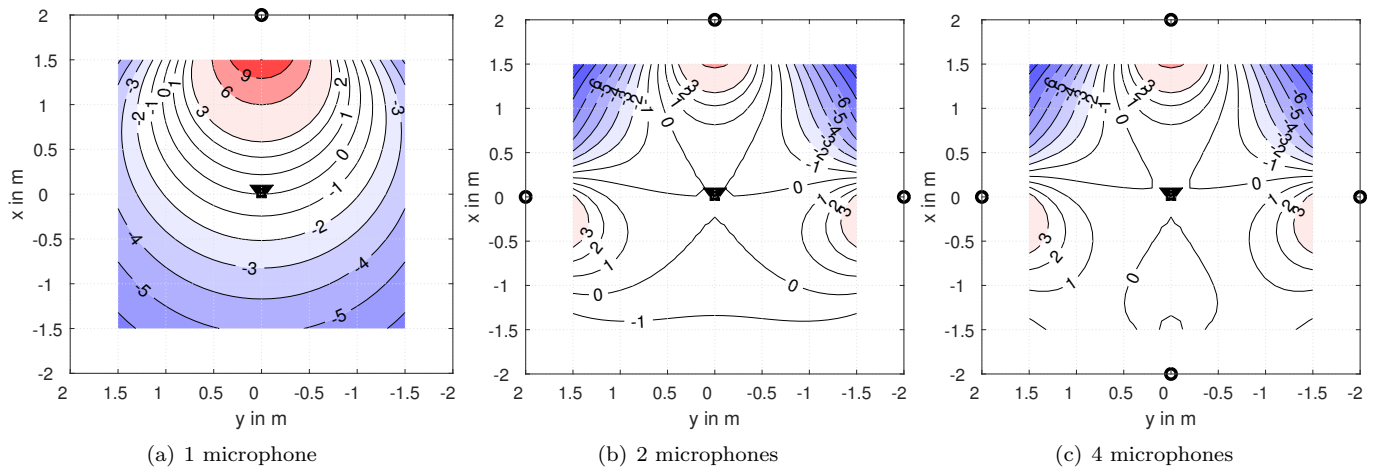


Figure 4: Simulation of position-dependent level of ideal frontal facing cardioid source in the free field recorded by 1, 3, and 4 ideal center-facing cardioid microphones. Levels are equalized to the central source position.

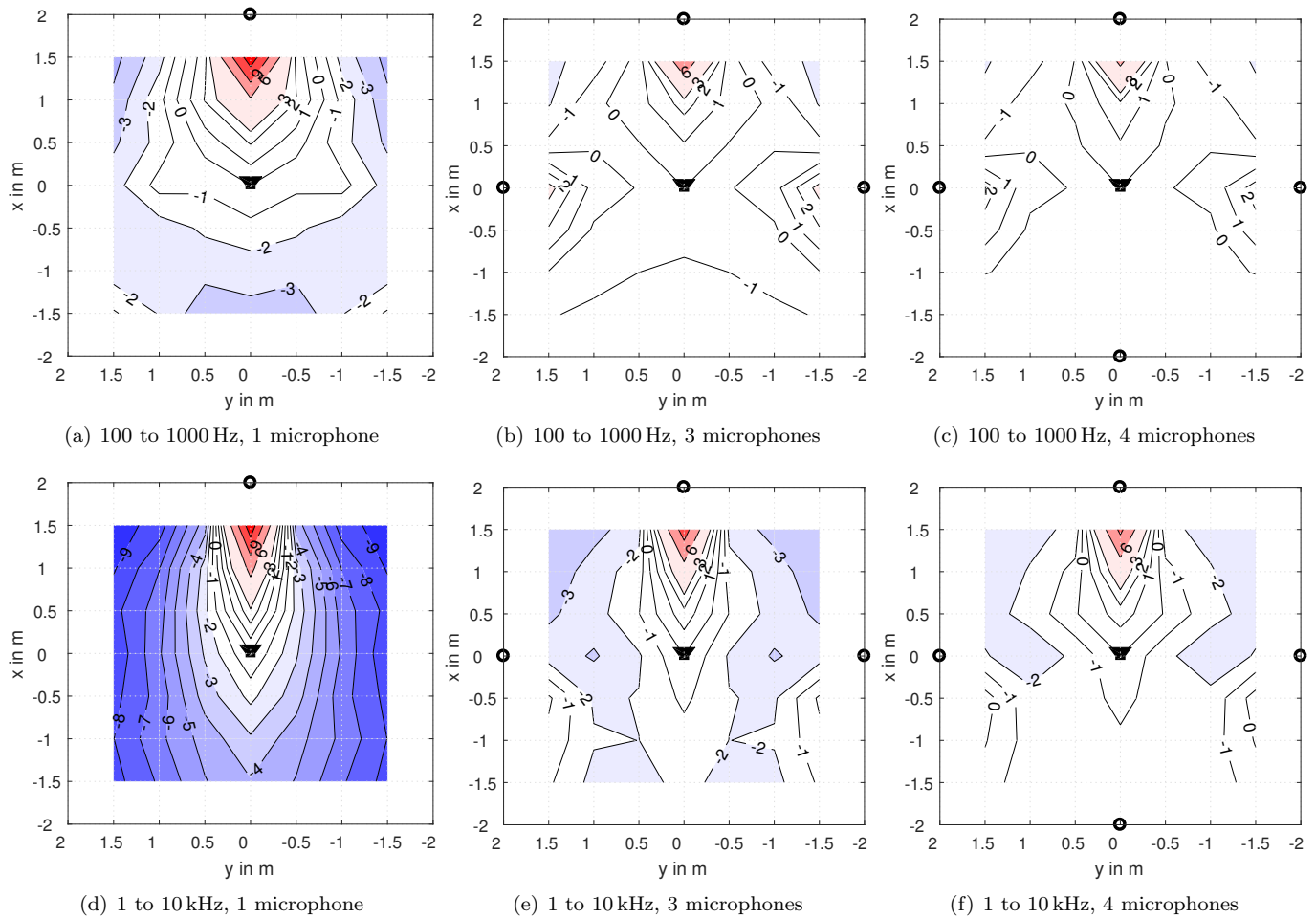


Figure 5: Measurement of position-dependent level of frontal facing C50A loudspeaker in the studio recorded by 1, 3, and 4 center-facing C480B microphones in low and high frequency range. Levels are equalized to the central source position.

Conclusion and Outlook

This paper presented a tool for augmented acoustics that simulates a concert hall inside a small practice room by using surrounding microphones and loudspeakers. The acoustic properties of the virtual room and the position therein can be freely adjusted. The tool runs on standard PCs and is scalable with respect to the number of loudspeakers and microphones. Its main application is for studying musical interaction in ensembles, but it can also be used for single musicians. In the latter use case, the naturalness of the virtual room is comparable to the previously presented single-user version that used close-up microphones and acoustically transparent headphones. The software can be downloaded for free ¹.

An evaluation revealed that the time-variant image-source model and the directional encoding of the microphone signals can strongly increase the maximum stable gain before feedback. Moreover, it could be shown that a practical system with 4 microphones provides a position-independent coverage with the virtual acoustics as long as the musicians stay within around $\frac{3}{4}$ of the microphone radius and face towards the center of the system.

The stability against feedback could further be improved by a different weighting of the microphone encoding, adaptation of the rotation radius to the geometry of the virtual room, a small back-and-forth rotation of entire virtual sound field prior to decoding, and a time-variant feedback delay network. We are also curious about the application of the tool in musical education.

Acknowledgments

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¹<https://apr.iem.sh/downloads/ensemble/>