Room Impulse Responses for Variable Source Radiation Patterns – Part 2: Application

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Motivation

Based on a proposed method to measure room impulse responses with variable source radiation pattern [1] we analyze the applicability of the method in this contribution. Sources of errors are studied theoretically and by means of measured correlation. A small lecturing hall is used for the measurements. A target source is rotated in the room and impulse responses are measured consecutively. These results are used for the comparison of synthesized room impulse responses by using the new method and the radiation pattern of the rotated target source. Finally, room acoustic parameters are calculated for the original and the synthesized impulse responses.

Instrumentation

The spherical loudspeaker array used consists of a midtone dodecahedron loudspeaker developed at the Institute of Technical Acoustics. The single loudspeaker chassis can be driven independently and the radiation pattern of each chassis was measured under free-field conditions in the anechoic chamber with a controlled measurement scan unit. The results were transformed to the spherical harmonic domain. This loudspeaker array was used along with a computerized turntable to allow arbitrary horizontal orientation of the array in the room for measurements as shown in Figure 1. The array was inclined with an angle so that the elevation angles of the single chassis were equally distributed.

Figure 1: Measurement in small lecturing hall with target source (left) and spherical loudspeaker array (right).

The core of the measurement consists of well known impulse response measurements of linear time-invariant (LTI) systems. This assumption holds for most acolyteustical systems in certain limits. A detailed overview of such methods can be found in [5]. Exponentially swept sines (chirps, sweeps) are used as excitation signals and along with proper deconvolution techniques for the signal recorded by the microphones [3]. Furthermore, a time saving approach of using interleaved excitation signals allowing several loudspeaker chassis to run at the same time, but allowing to also perfectly separate the responses is used as proposed by Madjak et. al [4]. The wait time between the sweeps has been set to 2 s to allow decaying of the room impulse response in the noise floor. The used mid-tone dodecahedron loudspeaker developed at the Institute of Technical Acoustics in Aachen did not show significant non-linearities for the given setup.

Detection of time variances

In order to analyze possible time variances room impulse responses were measured consecutively every 90 seconds with a fixed source. The results of the reference loudspeaker are used for a correlation analysis of the impulse responses in time domain. Figure 2 shows this correlation coefficient.

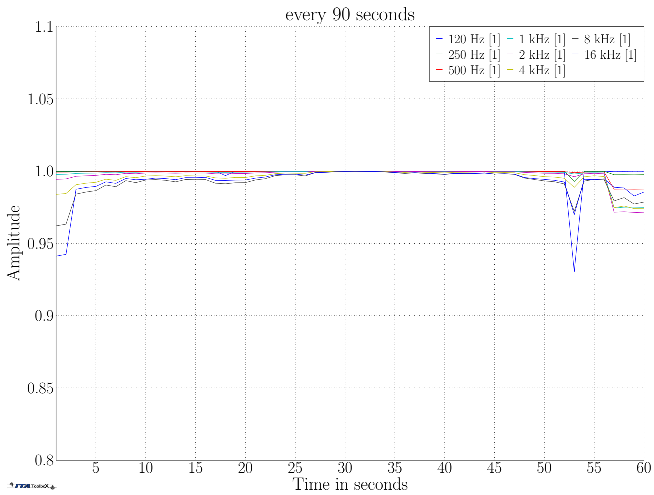

Figure 2: Correlation analysis to detect time variances.

It becomes obvious that the acoustic behavior of the room changes over time. In the beginning, after the personnel has left the room, the changes are strong. This can be explained by the fact that the room still needs some time to completely settle down after objects have moved. In the end at around 1.2 hours the room was shortly entered to study this influence as well. The room can reasonably assumed to be time-invariant for the measurement time of approximately 10 minutes needed for 20 horizontal orientations of the spherical loudspeaker array. The settling time of this room has been empirically found to be approx. 10 minutes. Higher frequencies seem to be more sensitive to time variances.

Results of Synthesis

The theoretical limit towards higher frequencies has been found at approx. 3 kHz. The background cannot be shown in this short paper. The number of orientations used for the array increases the number of available channels. Therefore the results are studied for various numbers of orientation—1 orientation represents 12 channels and 20 orientations represent 240 channels respectively.

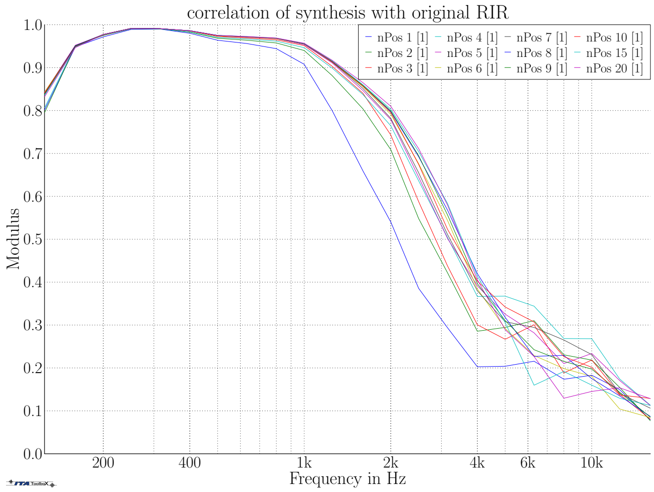

Figure 3: Correlation coefficient in frequency domain for different number of orientations of spherical loudspeaker array.

Increasing the number of orientations increases the applicability towards higher frequencies and also towards more complicated target radiation patterns. Figure 3 illustrates the behavior by using the correlation coefficient over frequency.

As can be seen the correlation coefficient is close to 1 for frequencies below 3 kHz and therefore the synthesized room impulse responses are in good agreement with the originally measured room impulse responses using the target source. The target source has also been rotated by a turntable. In steps of 30 degrees room impulse responses are measured and the clarity index is calculated as a room acoustic parameter being sensitive to the radiation pattern of the source as can be seen in Figure 4. The parameter changes over orientation (blue to red) with a periodicity of 360 degrees corresponding to the radiation pattern of the target loudspeaker.

The method was used to synthesize a rotating target source by using the measured room impulse responses with the spherical loudspeaker array and the rotated radiation pattern of the target source. These results are also shown in the second row of the figure. Up to the octave band around 2 kHz even the room acoustic parameter of the synthesis shows good agreement with the original of the target source. The 4 kHz octave band shows deviations which were expected from the correlation analysis.

Conclusion

Since the method assumes linear time-invariant systems this assumption was studied and a measure to quantify and monitor time variances was used based on measurements with reference loudspeaker on a fixed position. As the main idea of this work was to develop such a measurement method there are still some limitations to overcome in future work. In order to cover the entire audible frequency range from 20 Hz to 20 kHz two modifications seem reasonable: The spherical array should be substituted by high-tone version for the higher frequency range and the vertical resolution of the spherical array has to be increased.

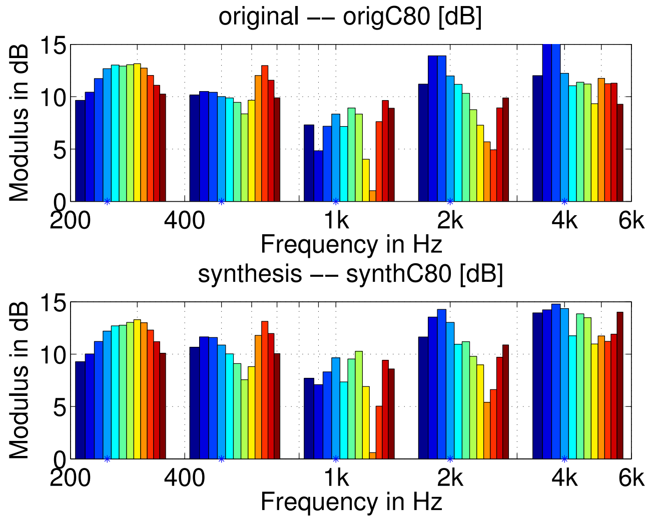

Figure 4: Calculated room acoustic parameter—clarity index C_{80}—for measured and synthesized room impulse responses for different target orientations.

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