Influence of the source's directivity on room impulse responses

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Introduction

Any type of measurement is subject to measurement uncertainties — so are room acoustical measurements. The focus of this work is on the uncertainties of a room impulse response due to different rotational orientations of a dodecahedron loudspeaker. So far there has been research revealing the importance of this matter for different exemplary geometries [4, 6, 5, 3], but a quantitative description of the problem which can be applied for a variety of geometries is still missing. In order to find an exact description of the propagation of uncertainties from the directivity patterns of the loudspeaker to the deviations of the room impulse response (RIR) a modeling function is needed. According to the concepts of GUM [1] this modeling function can also be expressed by a numerical model [7, 2]. The aim of this project is to construct such a model which can then be used in Monte Carlo simulations in order to predict the uncertainties of a measurement.

Measurements

To better understand the physical processes leading to the deviations of measured RIRs, different measurements were conducted. First, the directivities of 3 dodecahedron loudspeaker were determined in a high resolution (1 degree equiangular). Second, these speakers were set up in three different rooms at different positions with a number of microphones distributed throughout the rooms. For each speaker and position two sets of measurements were conducted consisting of 360 (and 72) measurements, whereas the speaker was rotated around its vertical axis in 1 (and 5) degree steps in between the measurements. To ensure constant conditions, 20 min before and during the measurements nobody entered the rooms and the room temperature was kept constant. Rooms under research were a small seminar room (140 m^3), a large auditorium (5800 m^3) as well as a reverberant chamber (120 m^3).

Analysis

In order to be able to model the influences of the speaker's directivity on the RIR it is crucial to be able to pinpoint these influences in a set of RIRs first. To do so, the rotation symmetry of the dodecahedron was used. When rotated around its vertical axis, a dodecahedron speaker shows a threefold rotational symmetry, resulting in repeating patterns after every 120 degree turn. This symmetry also shows in the speaker's directivity above the cut-off frequency (where the speaker's directivity is not omni-directional). Depending on the frequency and the elevation, a latitudal ring (all values with different azimuth but same angle of elevation) of the directivity data shows periodicities of 120, 60, 40 and/or 30 degrees. These periodicities are referred to as *characteristic periodicities* (CPs) of the speaker, since they characterize the speaker (a 90 degree periodicity for example cannot be found in the directivity data).

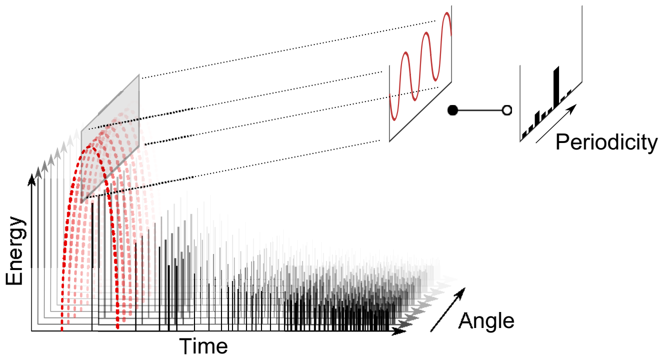

Figure 1: Measured sets of RIRs can be analyzed by an angular Fourier transform in order to detect periodic patterns in the angular signal of an energy bin.

When considering sound propagation in enclosed spaces above the Schröder frequency, a ray model for the propagation of sound can be assumed. For a given room geometry and source-receiver position this implies the existence of certain sound paths leading from the source to the receiver. Whenever the source is rotated, these paths will stay exactly the same while the energy introduced into each of the paths will be scaled according to the directivity of the speaker. In the RIR this assumption results in fixed temporal positions of reflections, but changing amplitudes. The energetic amplitude of each reflection is scaled according to one latitudal ring of the directivity data. Please note that this can be assumed for specular as well as scattered reflections, since scattering is —albeit being treated as of stochastic nature by many ray-tracing algorithms — a deterministic process.

The measured RIRs were band-filtered, segmented into 5 ms bins and an average value for the energy arriving within each segment was calculated. Focusing on one bin, it is possible to read out the variation of the energy within that time interval throughout one complete turn of the loudspeaker (see Fig. 1). The repeating patterns of the speaker's directivity can be found in these *angular signals* (energy over angle). In order to better grasp these patterns, a Fourier transform of the angular signal was performed to achieve a spectrum of periodicities. This processing can be done for each energy bin (time interval) separately. The result of such an analysis can be observed in Fig. 2. It is clearly visible that the 60

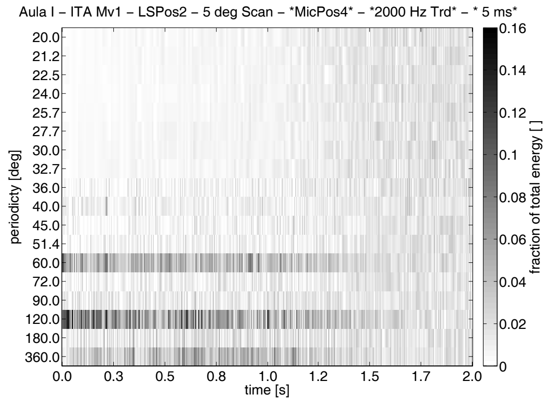

Figure 2: Characteristic periodicities of the source's directivity can be found in the whole RIR. The 360 degree periodicity is due to a slanted speaker-stand and is not of interest here.

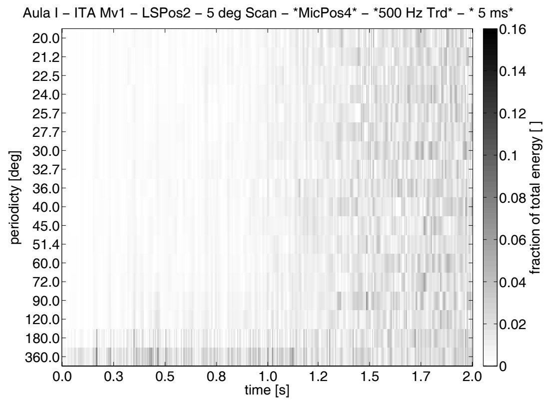

Figure 3: At low frequencies, the speaker's directivity is still omni-directional. No CPs can be observed.

and 120 degree periodicity contain more energy than the rest of the periodicities. At the 2 kHz third-octave band these two periodicities represent the CPs of the speaker used for this particular measurement. Surprisingly, the CPs remain prominent until noise dominates the signal (here at about 1.4 s). Please note that each energy bin is normalized independently, so all periodicities in one bin add up to unity. The long prominence of the CPs could be found in measurements of all three rooms under research independent of source or receiver positions. At frequencies below the cut-off frequency no CPs can be observed (see Fig. 3).

Model

Given the observations described above, a model reproducing the effects of the speakers directivity on a set of RIRs was developed. By the basic input parameters room volume, surface and reverberation time an artificial echogram can be constructed according to statistical reverberation theory. The amplitude of each of the reflections in the echogram is then scaled individually according to the directivity data of a random latitudal ring of the speaker's directivity. Noise is added according to the signal-to-noise ratio of the measurement and the echogram is band filtered. The so obtained set of artificial RIRs can be analyzed in the same way as the measured data. As can be observed in Fig. 4, the temporal developing of the 120 degree periodicity (representative for all CPs) is reproduced very well. While the reproduction of the periodicities validates the model, the generated RIRs can also be used to calculate standard deviations of energies for each segment of the RIR. Thus, the model can be applied according to the concepts of the GUM and measurement uncertainties due to the rotational orientation of the sound source can be predicted.

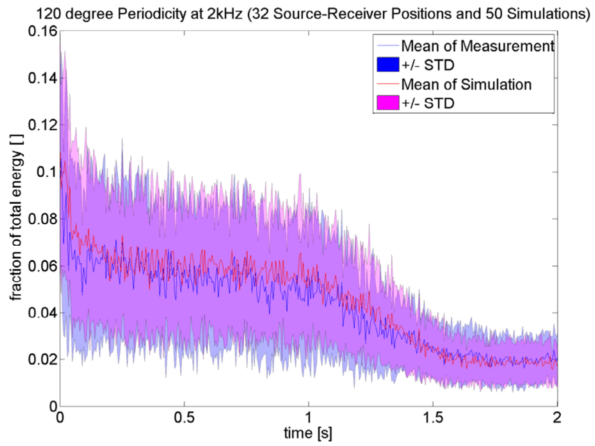

Figure 4: The model can be validated by a comparison of the temporal developing of the 120 degree periodicities.

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