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Database of single-channel and binaural room impulse responses of a 64-channel loudspeaker array

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ABSTRACT
A freely available database of measured single-channel and binaural room impulse responses (RIRs and BRIRs) of a 64-channel loudspeaker array of rectangular shape under varying room acoustical conditions is presented. The RIRs have been measured at three receiver positions for four different absorber configurations. Corresponding BRIRs for head-orientations in the range of $\pm 80^\circ$ in 2° steps with a KEMAR manikin have been captured for a subset of seven combinations of position and absorber configurations. The data is provided in the Spatially Oriented Format for Acoustics (SOFA). It can be used to study the influence of the listening room on multichannel audio reproduction. As an application, RIRs for the synthesis of a sound field by Wave Field Synthesis are shown.

1. INTRODUCTION
The influence of the listening room on audio reproduction is a topic of ongoing research (Toole 2008). Established reproduction techniques such as two-channel stereophonic or 5.1 surround sound are regularly subject to room-in-room situations. New multichannel techniques such as Wave Field Synthesis (WFS) (Berkhout 1988; Spors et al. 2008) require an anechoic environment in theory. Perceptual consequences of the alteration of the sound field by reflections are not fully comprehended. To allow for the study of the influence of the listening room on multichannel audio reproduction, single-channel and binaural room impulse responses (RIRs and BRIRs) of a 64-channel loudspeaker array have been measured. Differing from recently published data (Melchior et al. 2014), impulse responses have been captured for different room configurations by changing the setup of absorptive material in the room. This enables direct comparisons of boundary conditions by binaural synthesis which is not possible for in situ listening tests.

2. MEASUREMENT DETAILS
The measurements have been performed at the Audio Lab of the Institute of Communications Engineering, University of Rostock.

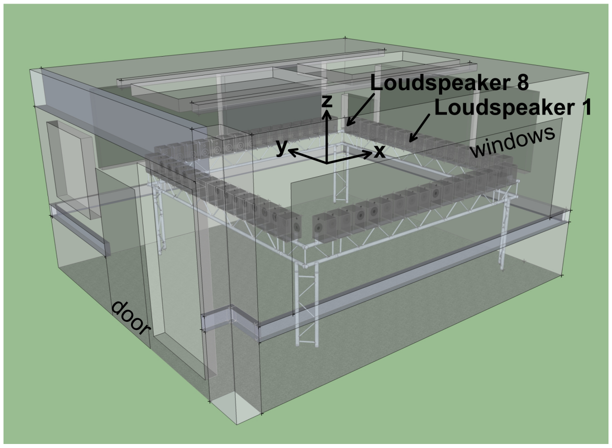

Fig. 1: Loudspeaker array in room with broadband absorbers (grey cuboids) at walls and ceiling, but not in front of the windows. During the measurement, there were additional trusses above the loudspeakers. Coordinate system and loudspeaker numbering are indicated.

Fig. 2: Loudspeaker array in measurement room with additional absorbers in light grey

2.1. Sound field synthesis array

64 loudspeakers Neumann KH 120 A are mounted at ear height on a square truss construction with edge length 4 m, cf. fig. 1. Due to the construction, the loudspeakers are not equidistantly spaced (mean spacing is 23.4 cm). The array is controlled by an RME MADIface USB and two D.O.TEC Andiamo converters.

2.2. Room with different absorber setups

The room (cf. fig. 1) is of shoebox type with floor dimensions $5\,\text{m} \times 5.75\,\text{m}$ and 3 m height. One wall has windows and the door is made of wood. Walls and ceiling are plastered, only the wall with the door is a drywall. The floor is coverd with a thin carpet. The room can be equipped with several broadband absorbers (mbakustik) of 15 cm depth. The absorber configurations have been varied for the measurements:

- no absorbers in the room,
- broadband absorbers at walls and in front of the windows, in total: 15.48 m^2,
- broadband absorbers at walls, ceiling and in front of the windows, in total 20.64 m^2,
- additional absorbers of pyramid-shaped foam with 7 cm depth (total surface area 8 m^2) placed below the broadband absorbers at the walls and in front of the remaining window surfaces.

Broadband absorbers are completely absorptive from 250 Hz and higher according to the manufacturer. The pyramid-shaped foam exhibits an absorption coefficient of at least 0.9 above 600 Hz. The placement of the absorbers can be seen in fig. 1 and fig. 2. The coordinate system of the room and the loudspeaker array is centred at the middle of the truss construction at loudspeaker height as indicated in fig. 1.

2.3. Measurement setup

RIRs and BRIRs have been measured with linear sweeps with bass emphasis of 2^{18} and 2^{17} samples length at a sampling rate of 44.1 kHz for each loudspeaker seperately. This results in an SNR of approx. 65–80 dB. For capturing RIRs, an omnidirectional 1/4” microphone iSEMcon EMX-7150 has been used. BRIRs have been acquired with a KEMAR manikin 45BA with large ears (type KB0065 and KB0066) and G.R.A.S. 40AO pressure microphones. Microphone signals have been fed back to the converters via the microphone amplifier Lake People C360. The head of the manikin was rotated horizontally above the torso from $\pm 80^\circ$ in 2° steps. Angle definitions follow the SOFA convention, cf. section 4.

Additionally, the reverberation time of the room with different absorber setups has been measured with an omnidirectional source Brüel & Kjær 4292-L with Power Amp 2734, positioned at the centre of the room. Eight

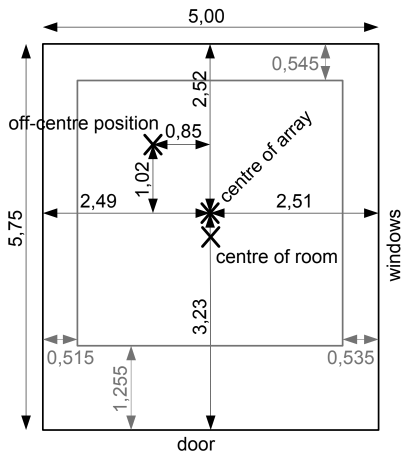

Fig. 3: Loudspeaker array in room (grey lines) and measurement positions, all distances in metres.

room impulse responses with sweep length of 2^{20} samples measured at different positions have been averaged for reverberation time calculation. The results in octave bands are shown in fig. 6 marked with crosses. The exact values can be found as additional information in the database.

The temperature in the room throughout the measurements was between 30–35 °C caused by the 64 active speakers in the small room in summertime.

2.4. Measurement positions

Measured positions are the centre of the array, the centre of the room and an off-centre position as depicted in fig. 3. The direction of view of the KEMAR manikin was towards the wall opposite the door. While RIRs have been measured for all combinations of measurement position and absorber configuration, BRIRs are only available for the combinations given in table 1.

2.5. Data processing

The latency of the measurement chain has been compensated. The frequency responses of the loudspeakers are not compensated, as their directivity patterns are part of the measured system of the loudspeakers in the room.

Subsequent data analysis of the interaural time differences of the BRIRs revealed that the KEMAR manikin had not been accurately positioned during the measurement at the array centre without ceiling absorbers, but had been rotated by $-6°$. Therefore, this dataset has been

Table 1: Measured combinations of receiver positions and absorber configurations for BRIRs

	no absorbers	without ceiling absorbers	all broadband absorbers	additional absorbers
centre of room			×	
centre of array	×	×	×	×
off-centre position	×		×	

shifted to a range from $-74°$ to $86°$, so that the $0°$ data exhibits an ITD of 0 ms.

Inspection of the time of arrival from each loudspeaker to the array centre disclosed that the origin of sound is approximately at the loudspeaker membrane. This has been considered in the coordinates of the loudspeaker positions.

3. APPLICATION OF ACQUIRED DATA

The measured RIRs have been used to synthesise a point source at $\mathbf{x}_{\text{ps}} = (-2.72, 0.09, 0)$ m with WFS. The beginning of the synthesised RIR at the centre of the array (= reference point) with all broadband absorbers installed is shown in fig. 4. The discretisation of the array leads to spatial aliasing artefacts that arrive after the first wave front. Each additional pulse can be attributed to one of the loudspeakers involved in the synthesis. Subsequent energy is due to reflections in the room. Fig. 5 shows the synthesised RIRs for the room configurations without absorbers and with broadband plus additional absorbers. The decay rates differ considerably. Close inspection of the waveform for the setup with additional absorbers reveals an amplitude modulation of 8 Hz in the lower part of the decay. This is caused by a beat of two room modes (60 and 68 Hz). Without absorbers, these room modes are still present, but the beat is concealed by other reflective energy.

For the synthesised RIRs, the reverberation times have been calculated (cf. fig. 6, marked with circles). The reverberation times of the synthesised RIRs do not differ considerably from the mean reverberation time of the room that has been acquired with an omnidirectional source at different positions except for a slight increase at low frequencies.

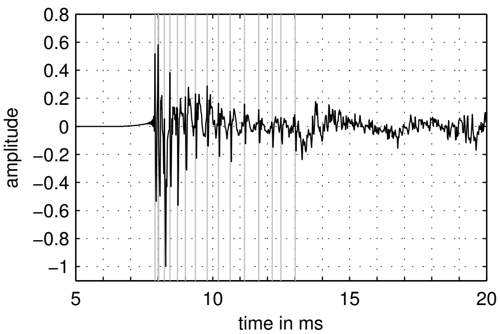

Fig. 4: Synthesised RIR at the centre of the array for a virtual point source by WFS at $\mathbf{x}_{\text{ps}} = (-2.72, 0.09, 0)$ m with all broadband absorbers installed. Grey lines indicate arrival times of spatial aliasing artefacts.

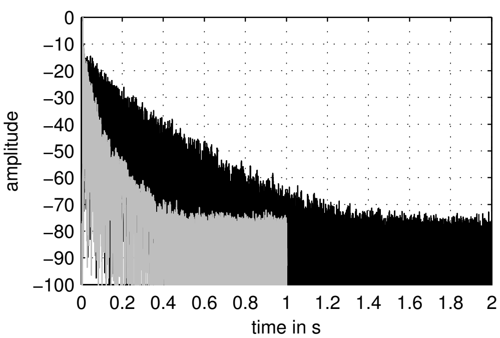

Fig. 5: Synthesised RIRs at the centre of the array for a virtual point source by WFS at $\mathbf{x}_{\text{ps}} = (-2.72, 0.09, 0)$ m. Black: without absorbers at walls or ceiling, grey: with broadband and additional absorbers

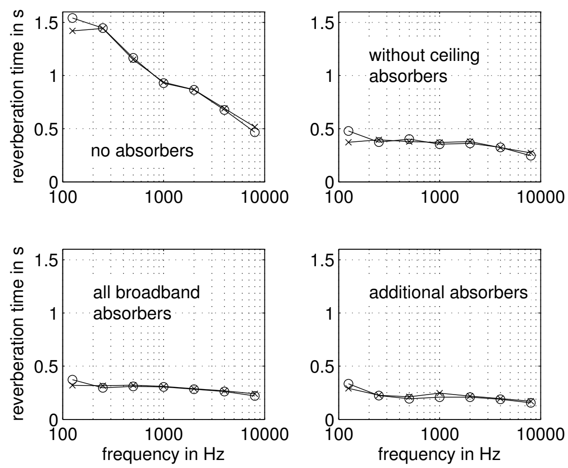

Fig. 6: Reverberation times (RT) in octave bands for different absorber configurations. Crosses: RT obtained with an omnidirectional source, circles: RT for the synthesised room impulse response at the array centre for a WFS point source at $\mathbf{x}_{\text{ps}} = (-2.72, 0.09, 0)$ m.

4. FREE DATABASE

The data is freely available for download as an electronic publication (Erbes et al. 2015) under the *Creative Commons Attribution-NonCommercial-ShareAlike 4.0* license[1]. It is published in the Spatially Oriented Format for Acoustics (SOFA)[2] standardised in (AES69 2015).

5. ACKNOWLEDGMENTS

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[1] `http://creativecommons.org/licenses/by-nc-sa/4.0/`
[2] `http://www.sofaconventions.org`

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