Multiple Model High-Spatial Resolution HRTF Measurements

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Introduction

Head-Related Transfer Functions (HRTF) are impulse responses that describe how the acoustic signal is modified by the head (and upper torso) based on the direction of arrival. These HRTFs are an essential tool for researching spatial hearing and the development of directionally dependant algorithms, e.g. for hearing aids (HA).

Within the Hearing4All Cluster of Excellence, we identified a need to have access to a comprehensive database of HRTFs that a) have high spatial resolution, b) cover as great a range in the vertical direction as possible, c) include multiple head-and-torso simulators (HATS) and d) include measurements from a multi-microphone HA model. To meet these demands, we replicated the basic setup as used by Brinkmann *et al.* [1]. Four different HATS were used, and where possible, the multi-channel hearing aid as used by Kayser *et al.* [2] was fitted to the HATS.

Setup

For capturing the HRTFs, the two-arc-source-positioning (TASP) system shown in Fig. 1 was used in the anechoic chamber of the Carl von Ossietzky University of Oldenburg [3]. This system consists of two Manger W05/1 sound transducers mounted on movable sleds on opposing semicircular arcs. The two arcs form an imperfect circle with roughly 1.7 m radius. Using the sleds, the elevation of the transducers can be changed, and the entire circle can rotate about its vertical axis. The anechoic chamber has a volume of 238 m^3 and a cutoff frequency of 50 Hz.

Sound playback and capture was performed using a RME ADI-8 QS interface connected via MADI to the host computer, enabling sample-synchronous recording of 8 channels. A MATLAB script controlled audio record, playback and the positioning of the TASP system. A sampling rate of 44100 Hz was used. The stimulus used by Brinkmann *et al.* [1] was reused, a sine sweep bandlimited between 100 Hz and 21 kHz. The sweep has a spectral coloration in the form of a low-frequency boost to compensate for the background noise.

Four different HATS were measured, a Brüel&Kjaer Type 4128C (with Brüel&Kjaer Type 4158C and 4159C artificial ears), a HEAD acoustics Type HMSII.2, a KEMAR Type 45BB (with KB0090 and KB0091 artificial ears) and a custom built model from the Signal Processing group at the University of Oldenburg. The HATS are shown in Fig. 2. Of the four HATS, two were fitted with behind the ear (BTE) multichannel hearing aids (HA), as used by Kayser *et al.* [2], type Acuris by Siemens Audiologische Technik GmbH. The HAs are "dummy" hearing aids, with microphones in the original casing but without integrated amplifiers, signal processors or speakers. The microphone signals are routed via cables to external amplifiers. If the HA was fitted, we captured the in-ear signals simultaneous with 6 channels from the HA.

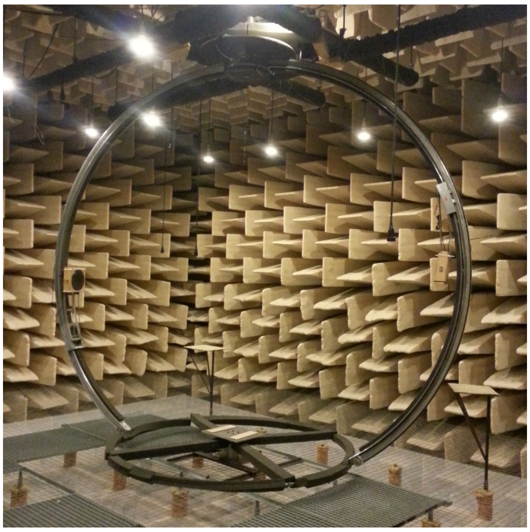

Figure 1: The TASP system in the anechoic chamber of the University of Oldenburg. Note the offset sled mounts, allowing for greater coverage for the vertical positioning of the transducers.

The HATS were placed in the TASP system such that the center point of the TASP coincided as best as possible with the center of the ear canal openings of the HATS. Where possible, we replicated the procedure of [1], using a plumb-line from the "north pole" axle of the TASP system support to center markings on the HATS. The vertical alignment was performed using a Bosch PLC10 self-leveling cross-line laser to align the ear canal opening to the equator of the TASP.

The measurement procedure as described in [1] was modified slightly by reducing the number of pre-sends to 500 and using a modified grid, increasing the number of measurement points around the north pole of the sphere. The modification ensures that for any given direction (with elevation exceeding -65°) a measurement point is available with angular error of no more than 1.41°. The resulting grid contains 12722 points, shown projected onto a unit sphere in Fig. 3. To measure differences in response between the two transducers, the measurement script was modified to record responses from the same direction using both transducers for a small set of elevations but all azimuths. This was done using one HATS (Brüel&Kjaer)

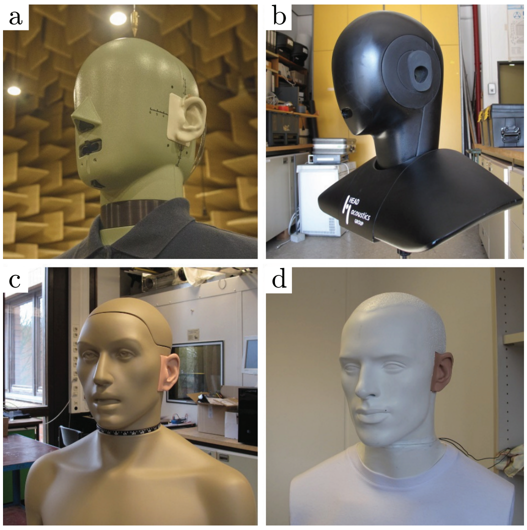

Figure 2: HATS measured for the database. (a) Brüel&Kjaer, (b) HEAD acoustics, (c) KEMAR, (d) custom HATS built by the AG Signal Processing at the University of Oldenburg.

with HA fitted and with free standing reference microphones.

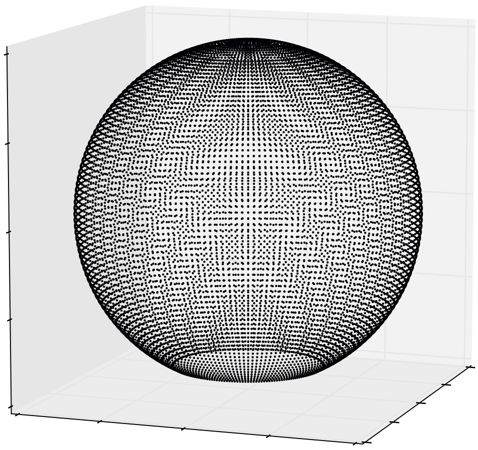

Figure 3: HRTF grid projected onto a unit sphere.

Impulse Response Calculation

To convert the recordings into HRTFs, we used spectral division of the recordings by recordings of the stimulus using freestanding reference microphones. One reference recording per transducer was used. While this cancels out the effect of the speaker, amplifier, and D/A/A/D chain, it does not cancel out the microphone effects. Since a main goal of these measurements was to obtain responses of the HAs, we considered the HA microphone effects to be a part of the desired data.

Observing the transducer overlap region, we saw a consistent difference in the response between the two transducers. From this difference a filter was computed and applied to the measurements to ensure a smooth transition where the switchover occurred.

During the recording we observed temperatures from 20.6°C to 25.5°C, however within each individual HATS recording session the temperature rage was within 2.2°C. The impulse responses are not compensated for possible differences in the speed of sound, but the temperature is stored with each HRTF so the compensation can still be applied if necessary.

The HRTF data was stored into separate data files for each HATS. Even so, the number of measurement points means that each data file is very large (465 MB if 2 channels are used, 1.82 GB if 8 channels are used). To allow for quick access, the HDF5 format was chosen [4], which is supported by several programming languages commonly used in the scientific and engineering communities, including MATLAB, Python, and R. Using this file format, it is generally possible to retrieve individual HRTFs without reading the entire file into memory.

Conclusion and Outlook

The database presented here consists of 4 sets of high-spatial resolution HRTF measurements, two of which include recordings from a multichannel HA. While we are still in the process of evaluating the data in detail, the multichannel HA data has already proven useful in the evaluation of a localisation algorithm. We expect that after comprehensive analysis and documentation of the recorded data, the database will become a valuable tool to researchers in the hearing sciences.

Acknowledgements

This work was performed as part of Project C6.2 "Computational Auditory Scene Analysis for Hearing Devices", within the Hearing4All Cluster of Excellence. The authors would like to thank Fabian Brinkmann for the groundwork and making the code available, Florian Denk and Niklas Grunewald for lending their HATS and assistance therewith, Hendrik Kayser for the HA, and Christoph Scheicht for the construction and operational assistance of the TASP system.

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