Just Noticeable BRIR Grid Resolution for Lateral Head Movements

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Introduction

Dynamic binaural synthesis is based on discrete grids of binaural room impulse response datasets (BRIRs). These are typically one- or two-dimensional, i.e. they account for horizontal and sometimes also vertical rotational head movements of the listener. The angular grid resolution of BRIR datasets is an important factor regarding the quality and plausibility of dynamic binaural auralisations. The perception of spatially discretised head related transfer functions has been investigated with different approaches in recent studies. In [1] HRTFs, interpolated from grids with different resolution were used to simulate stationary and moving sources for a non-moving listener. In [2] HRTFs, manipulated to exhibit only direction dependent spectral differences while keeping the ITD constant were assessed with respect to just noticeable differences. We [3] examined varying spatial discretisations of BRIR datasets independently for horizontal, vertical, and lateral head movements using anechoic and echoic datasets with frontal sound incidence. For lateral head movements this source-receiver configuration was shown to be particularly uncritical due to the lack of varying ITD and ILD cues. Therefore a new listening test was conducted, examining the just audible grid resolution for lateral head movements and a sound source placed above the head in anechoic environment, assuming this to be the most critical case.

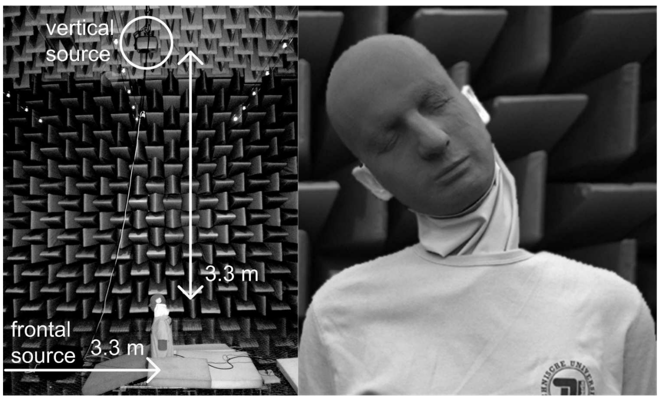

Figure 1: Left: HRTF acquisition setup for a frontal and vertical source in the anechoic chamber of the TU Berlin (left) and FABIAN HATS used with different lateral head orientations (right)

Anechoic binaural impulse response datasets were measured for lateral head rotation with a fine angular resolution of 1° within a ±60°-range using the automatable FABIAN HATS ([4], see Figure 1 right) in the anechoic chamber of the TU Berlin. A small two-way nearfield monitor (Genelec 8030A) was setup directly above, respectively in front of FABIAN (see Figure 1 left) at a distance d = 3.30 m, thus maintaining far field conditions in a frequency range from about 100 Hz to 14 kHz. Figure 2 represents the magnitude spectra of the measured HRTF datasets. For frontal sound incidence (left) the magnitude spectrum is almost independent from angle below 1 kHz. Comb filter effects with angular dependence can be observed above 1 kHz when left ear is moving downward, and shoulder reflections develop. For vertical sound incidence (right) a spectral coloration can be observed starting from 800 Hz at even smaller lateral angles. Within a critical frequency range (2-4 kHz), spectral coloration depending on the angle of head orientation can be noticed. Above 10 kHz, due to head shadowing, a considerable ILD can be observed which is hardly visible at frontal sound incidence (Figure 2 left).

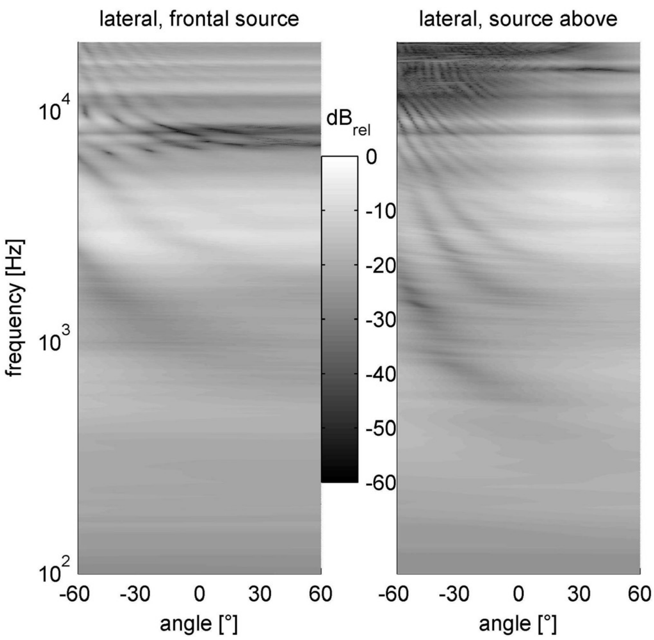

Figure 2: Direction dependent HRTF magnitude spectra for lateral head rotations and frontal sound incidence (left) or sound incidence from above (right). Left ear is shown, negative angles indicate leftward movement, i.e. the ear is approaching the shoulder.

Listening test and results

For auralisation an engine for fast convolution was used ([3],[5]), together with a headphone/amp combination (STAX SRS-202/SRM-252II), linearized in amplitude with an inverse filter, derived from minimizing a mean square error criterion [6], for sound reproduction. A Polhemus FASTRAK was used for tracking the test

subject's lateral head movements. For the purpose of this test the virtual auditory environment (VAE) was set up to operate on HRTFs with a maximum grid resolution of 1°. This resolution could be changed during the adaptive listening test within a range of 1° and 60° in increments of 1°. Inferring from thresholds of the localization blur [7] a resolution of 1° was assumed to be inaudibly fine. The test subject's task was to detect a lower grid resolution when compared directly to the 1° reference resolution. Thresholds were determined within an adaptive 3AFC procedure using 20 trials per condition. As an adaption rule a maximum-likelihood algorithm was used [8]. For consistency with earlier studies, thresholds were tested using a broadband pink noise stimulus and an acoustic guitar stimulus (sample duration 5s) [3]. All of the 20 test subjects (age: 24-40 yrs.) had musical skills and listening test experience.
Since the data were not normally distributed, listening test results are shown as histograms and boxplots (Figure 3). The lowest possible grid resolution of 2° was detected once for pink noise; for guitar a minimum grid resolution of 5° was just audible for two subjects.

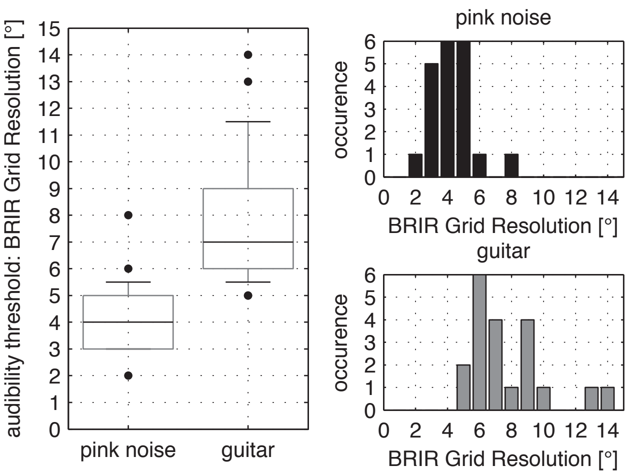

Figure 3: Thresholds of just audible grid resolutions corresponding to lateral head movements. Boxplots show median, inter-quartile range, inter-decile range and extreme values.

Discussion

A listening test on the audibility of discretisation artefacts in dynamic binaural synthesis revealed a high sensitivity of listeners towards a reduced spatial resolution of HRTFs corresponding to lateral head rotations and a sound source above the listener's head. For a pink noise stimulus even a 2° resolution was reliably detected by single listeners. The distribution of just noticeable difference thresholds for lateral grid resolutions (means, variance) is similar to the values found for horizontal and vertical head movements with frontal sound incidence, as shown by [3]. It is particularly remarkable, that no increased sensitivity was indicated for the resolution corresponding to horizontal head movements. As was expected, the thresholds for a sound source above the listener turned out to be much lower than for a frontal source, due to the lack of ITD and ILD variance in the latter case. Together with listening test results from [3] and based on the distribution of thresholds within our test panel we can summarize, that binaural room impulse responses have to be acquired with a grid resolution of 4°, 3°, and 2° for horizontal/vertical/lateral head orientations to make sure that 95% of all listeners will not be able to detect discretisation artefacts (see Table 1).

...was audible for	noise hor/ver/lat1/**lat2**	guitar hor/ver/lat1/**lat2**
50%	6°/5°/16°/**4°**	9°/12°/16°/**7°**
25%	4°/4°/12°/**3°**	7°/9°/12°/**6°**
5%	4°/3°/8°/**2°**	5°/4°/8°/**5°**
0%	2°/1°/3°/**1°**	3°/2°/3°/**4°**

Table 1: Thresholds of just audible grid resolutions for different percentiles of the test panel for horizontal, vertical, lateral head movements with frontal source (lat1, [3]) and lateral head movements with source above the head (**lat2**)

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