SHORT NOTE

A database of Head-Related Transfer Functions in whole directions on upper hemisphere

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1. Introduction

The Head-Related Transfer Function (HRTF) represents the sound pressure at the eardrum of a listener for a specific sound source placed in a free field and thus involves essential information of spatial hearing [1]. HRTF is usually defined as the ratio of the transfer function of the sound propagation path from the sound source to the eardrum of a listener to that from the sound source to the center position of a listener's head in the absence of the listener. HRTFs have been utilized for many applications concerning spatial hearing such as auditory displays [2,3]. However, measurement of HRTFs of a certain subject in whole sound source directions around him/her is very difficult by the following two reasons: 1) The apparatus for such a measurement, including the system for locating the loudspeaker at arbitrary positions and the anechoic environment, may be too costly to construct. 2) The measurement of HRTFs causes temporal and physical burden to the subject. Hence a set of HRTFs in whole sound source directions is not easy to obtain for human subjects. Only two databases are open in public up to now. They are measured by MIT media laboratory [4] and Itakura laboratory [5]. The former database involves the HRTFs in 710 directions measured in an anechoic chamber, but KEMAR dummy head was used for subject. In the latter one, HRTFs of many subjects were archived, whereas each of them was not measured in an anechoic environment.

In this note, a database of Head-Related Transfer Functions (HRTFs) covering whole directions in upper hemisphere measured with human subjects in an anechoic room is provided. Moreover, some comments on the calibration method in the synthesis of those transfer functions

are also briefly mentioned.

2. Measurement of HRTFs

The measurement was carried out in the anechoic room of the Institute of Technology, Shimizu Corporation. Setup of the measurement system is illustrated in Fig. 1. A subject sat on the floor made of glasswool sheets with his head fixed by a small head rest. Sound signal was radiated from a loudspeaker attached to a traverser fixed to the ceiling of the anechoic room. The arm of the traverser can be adjust to an arbitrary angle. This enables the loudspeaker to be positioned at an arbitrary position on the upper hemisphere around the subject. The radius of the sphere is 1.2 m. An Optimized Time Stretched Pulse (OATSP) [6] was used as the sound signal radiated from the loudspeaker. Two small electret microphones were installed to the entrances of the subject's both ears by use of thin metal wires. The outputs from the microphones were amplified by a hand-made amplifier, then A/D-converted and fed to a digital signal processor unit, where the inverse filter of OATSP was convolved with the response to derive the impulse response. Sampling frequency was 44.1 kHz, and the measured responses were time-averaged by eight times per a single measurement point. The rectangular window of 512 points long was applied to each measured response after the deconvolution. The time windowing was positioned so that the sample with the maximum amplitude came around the center of the window while keeping the relative timing/delay among the impulse responses intact. The inverse filter of the loudspeaker was not convolved in this measurement.

HRTFs of three male subjects in whole directions on upper hemisphere were measured. Positions of the sound source are depicted in Fig. 2. As shown in this figure, the interval of azimuthal angle was changed depending on the elevation, which was set at every 10 degrees. The interval of the azimuthal angles at each elevation is summarized in Table 1. As a result, the number of the measurement points was 454. Since the entire measurement would have needed too long time for a subject to sit still, eight to nine rest intervals were inserted during the measurement. It took about four hours per one subject for the measurement of the whole set of HRTFs.

3. Considerations on the HRTFs measured

3.1. HRTFs measured with blocked ear canals

HRTFs described in this note were measured with blocked ear canals [7], i.e., the entrances of the subjects' ears were blocked by rigid earplugs made by an expert (medical doctor) in otolaryngology so as to fit the shape of the entrances of the subjects' ears. Methods for the calibration due to differences in subjects and listening conditions (free-field and headphone listening) were discussed by Møller *et al.* [7,8]. Møller indicated that the HRTFs measured with blocked ear canals reflect less individuality than those measured with open ear canals, which are regarded as a conventional measurement condition. This is because the transfer function from the

Fig. 1 Illustration of measurement system.

Fig. 2 Positions of sound sources where HRTFs are measured (Top view). Quarter of the upper hemisphere is illustrated due to the symmetry of sound source positions.

entrance of an ear to the eardrum, especially the impedance of the eardrum, involves large individual variances, and it makes the calibration of headphone listening condition to free-field listening difficult.

3.2. Calibration of headphone listening condition to free-field listening condition using HRTFs measured with blocked ear canals

To realize an auditory display for headphone listening, sound pressure at the eardrum of a listener must be controlled. To do this, HRTFs must be properly synthesized but the coloration caused by headphones must be calibrated as well. Møller showed that the calibration is easier if HRTFs are

Table 1 Change of interval angle in measurement of HRTFs with elevation angle.

Elevation [deg.]	Interval angle [deg.]	No. of points
0	5	72
10	5	72
20	5	72
30	6	60
40	6	60
50	8	45
60	10	36
70	15	24
80	30	12
90	—	1
Total points		454

measured with blocked ear canals [7]. This is because HRTFs measured with blocked ear canals does not include the transfer function from the entrance of an ear canal to the ear drum. As described above, this transfer function involves large individual variations. If HRTFs are conventionally measured with open ear canals, measured HRTFs are crucially affected by this transfer function. Therefore, an auditory display with HRTFs based on the blocked-ear-canal measurements has a significant advantage when HRTFs of the listener is different from the subject whose HRTFs are synthesized. Please note, however, that of the transfer function for the calibration, i.e. that from the electric input to the headphone to the entrance of the listener's ear, must also be measured to advantage with blocked ear canals. For more detailed discussion, please refer to Møller *et al.* [7–9].

4. Summary

In this note, a database of Head-Related Transfer Functions (HRTFs) of three human subjects covering whole directions on upper hemisphere is provided. Authors hope that this database may contribute to various investigations and applications with regard to spatial hearing and its control. This database may be used for academic purposes, and can be downloaded via the Internet. The URL is <http://www.ais.riec.tohoku.ac.jp/lab/db-hrtf/>.

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