Influence of the ears canals location on spherical head model for the individualized interaural time difference

Sylvain Busson[1], Rozenn Nicol[1], Olivier Warusfel[2]

[1] *France Telecom R&D, 22300 Lannion,France, Email: sylvain.busson@rd.francetelecom.com, rozenn.nicol@rd.francetelecom.com*

[2] *Institut de Recherche et de Coordination Acoustique Musicale, 75004 Paris, France, Email: olivier.warusfel@ircam.fr*

Introduction

Human sound localization is governed by interaural and monaural cues which are embedded by the head related transfert function (HRTF). Measuring HRTF is a time-consuming and expensive task. Furthermore, using non-individual HRTF results in localization blur, intracranial perception and front-back confusion. To avoid measurement of HRTF, physical models which take the transformations of the sound field, generated by the source, by the listeners head, torso and pinnae into account are used. The most simple and widely used model is the spherical head model with centered ears canals. This model provides quite good approximation of human HRTF and analytical formulations of localization cues. The most salient localization cue is the interaural time difference (ITD) mainly for the lateralization of sound sources. Many formulations of the ITD for a sphere are available. Associated with the Woodworth formula [1]:

$$ITD = \frac{a}{c}(\theta + \sin\theta) \qquad (1)$$

where a is the sphere radius, θ is the azimuth angle and c the speed of sound, the Algazi radius well predicts CIPIC subjects ITD [2] [3]. Comparison between constant ITD contours of a sphere (cones of confusion) and a human head shows deviation up to 18% of the maximum value [4]. These deviations are caused by the non spherical shape of the head and the location of the entrance of the ears canals with respect to the center of the head.

In this paper, a new formula is proposed to take the ear displacement into account in the calculation of the spherical head model ITD. As expected, the displacement of the ear canals causes the ITD to vary along a cone of confusion. A psychoacoustic experiment is conducted in order to study to what extent the difference between measured and simulated ITD is audible.

Ear Displacement Formula

Validation

A simple spherical head model ITD formula which takes the ears displacement with respect to the center of the head into account, does not exist. The ear displacement formula (EDF) considers the inner product between both unit right and left ear vectors (Ur, Ul), corresponding to the ears' location, and the unit incident vector of the sound ($Uinc$). Four cases have to be distinguished as the incident plane reach the ears before or after head masking. For example, the formulation in the case of both ear being shadowed is given below :

$$ITD = -\frac{R}{C} * (\arccos(\overrightarrow{Uinc} \cdot \overrightarrow{Ul}) + \arccos(\overrightarrow{Uinc} \cdot \overrightarrow{Ur})) \qquad (2)$$

EDF with no ears' displacement is comparable with elevation dependant Larcher and Jot formula [5]. Figure 1 shows the exact matching of the EDF.

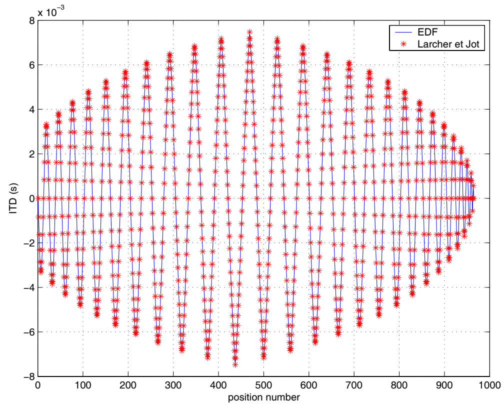

Figure 1: Comparison between EDF and Larcher and Jot Formula

ITD Elevation Dependent Variation

The ear displacement is given by the angular shift to the central position. For exemple, a 10° azimuth and 5° elevation displacement of the ear canal means that the right and left ear locations are 280° azimuth and 5° elevation and 80° azimuth and 5° elevation respectively. Figure 2 shows the ratio between ITD with ears displacement and ITD with ears centered versus elevation for the −60° cone of confusion and several azimuthal ears displacements. The EDF variations compared with constant spherical head ITD are in the same range of the values observed on the ITD estimated from measurement on human subjects [4]. The main effects of ears displacement are : a decrease of the ITD mean value on a cone of confusion and increase of variations and peak values with ears displacement. A least squares minimization procedure could be run to set the optimal ears' displacement giving the best matching. Some deviations remain anyway, probably due to the non-spherical shape of the human head.

Psychoacoustics Experiment

Subjects and Task

In order to examine to what extent the ITD variations along a cone of confusion are audible, an informal psychoacoustic experiment was led with the FTRD subjects [6]. 8 subjects with normal hearing, 5 males and 3 females from 25 to 43 years were tested. The experiment consisted in listening to 40 pairs of sound through headphones. The subjects were asked to determine if they perceive audible differences between the two sounds without a forced choice protocol. Subjects could listen to the sounds as many times as they wanted before

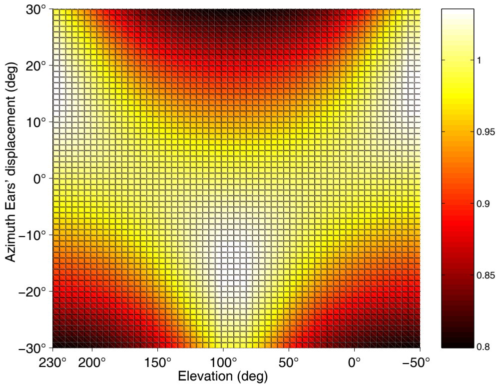

Figure 2: Ratio between ITD with and without ears displacement on the $-60°$ cone of confusion versus elevation with azimuthal ears displacement as parameter

giving their answer. They were further asked to verbalize the differences, if any.

Stimuli

8 sounds locations along 5 different cones of confusion were tested. Each sound of a pair was a white noise convolved with the subject's own HRTFs (except for the subject 8 who listened with another subject HRTFs) over-sampled at 96000 Khz (in order to have 10,4 μs as temporal precision). Implementation of HRTF was made with minimum-phase FIR filter and a pure delay corresponding to the ITD. For one sound, the pure delay was the ITD estimated from the HRTF as in [2] and for the other it was the ITD computed from the spherical-head model with ears centered.

Results

Table 1 indicates that subjects can be divided into two groups : those who perceive none or few differences (Ga Group) and those who perceive differences for half of the presented stimuli (Gb group). Gb contains only experienced subject in listening test.

	S1	S2	S3	S4	S5	S6	S7	S8
Differences	2.5	67.5	50	60	5	47.5	0	10

Table 1: Percentage of discriminate differences

Each Gb subject reported that the audible differences are subtle and required many listenings for the same pair to be discriminate. The verbalization analysis shows that the audible differences source are localization shift and spectral modification. The second difference is quite unexpected because each pair of stimuli was based on the same FIR filters. These results show the ambiguity for the subjects to verbalize a difference in localization. The auditory system can analyze the difference both as a location displacement and a spectral shift. The analysis of the Gb results (see Figure 3) are consistent with those of the former studies in terms of noticeable differences as a function of base line ITD [8] [7]. Moreover, no logical links between ITD differences, or spatial location, and audible differences have been found.

Conclusion

Thanks to EDF, it has been shown that the displacement of the entrance of the ear canals with respect to the center of

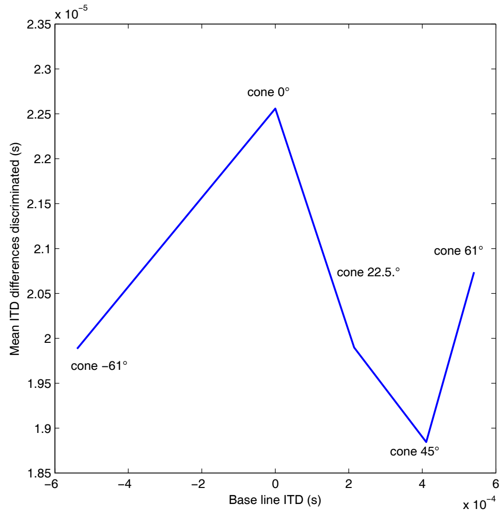

Figure 3: Mean ITD differences discriminated versus constant ITD

the head for the spherical head model causes the ITD to vary with elevation. The results of the psychoacoustic experiment highlights differences between subjects' answers. Further detailed and longer listening tests with a forced choice protocol still have to be conducted to know sharply if ITD variation along a cone of confusion have to be reproduced to obtain a satisfying binaural synthesis with the spherical head model.

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