INTERNATIONAL WORKSHOP
ON THE PRINCIPLES AND APPLICATIONS OF SPATIAL HEARING
NOVEMBER 11-13, 2009, ZAO, MIYAGI, JAPAN

A study on 3D sound image control by two loudspeakers located in the transverse plane

Takashi ISHII, Yohji ISHII, Kazuhiro IIDA*
Chiba Institute of Technology

1 Introduction

The listeners use the Head-Related Transfer Functions (HRTFs) as a cue of sound localization. It is well known that accurate sound localization is accomplished when the listener's own HRTFs are reproduced at his/her ear drum. Some transaural systems, which arrange two loudspeakers in the horizontal plane, have been proposed [1, 2]. The cross-talk cancel filters can be obtained theoretically. The listeners, however, often perceive a sound image at front for the sound with HRTFs for rear direction. This front-back error is caused by the small difference of the listening position.

Morimoto and Ando [3] demonstrated that accurate sound image can be achieved with the transaural system which locates two loudspeakers in the upper transverse plane (T30 in Fig.1), because the HRTFs for such a direction does not have pronounced spectral notches.

In this study, the authors use following two measures to evaluate the pros and cons of the loudspeaker arrangement,

1) flatness of the spectrum of the direct component,

2) the level of the cross-talk components related to that of direct components.

The analysis on the basis of these two measures and sound localization tests were carried out for various loudspeaker arrangements in the transversal plane.

2 Measurements of transfer function between loudspeakers and listener's ears

2.1 Method

The transfer functions between the loudspeakers and the ear canals of subjects were measured in an anechoic chamber. The loudspeakers were located in the horizontal plane and transverse plane (Fig.1). Subjects were three males (IST, ISY, UEO) with normal hearing sensitivity. The subjects were asked to look at front face, however, their heads were not fixed.

2.2 Result

Figure 2 shows the amplitude spectrum of the measured transfer functions. Direct components are relatively flat when loudspeakers are located at near the zenith (T20 and T30) compared with others. Cross-talk component levels are low when loudspeakers located in the lower transverse plane. These results implicit that two loudspeakers located in the transverse plane may bring better 3D sound image control than those in the horizontal plane.

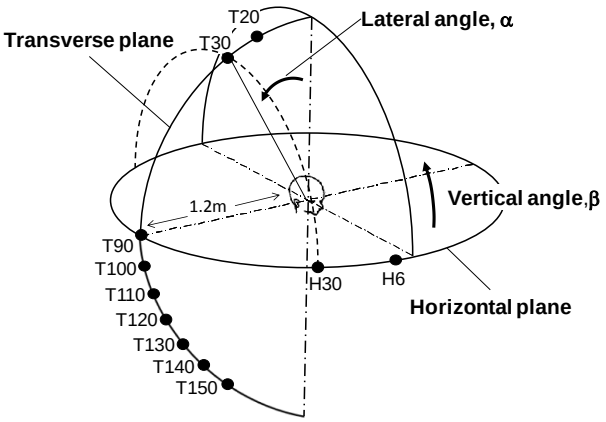

Fig.1 Loudspeakers arrangements in the horizontal plane (H30 and H6) and in the transverse plane (T20 - T150).

* E-mail address: kazuhiro.iida@it-chiba.ac.jp

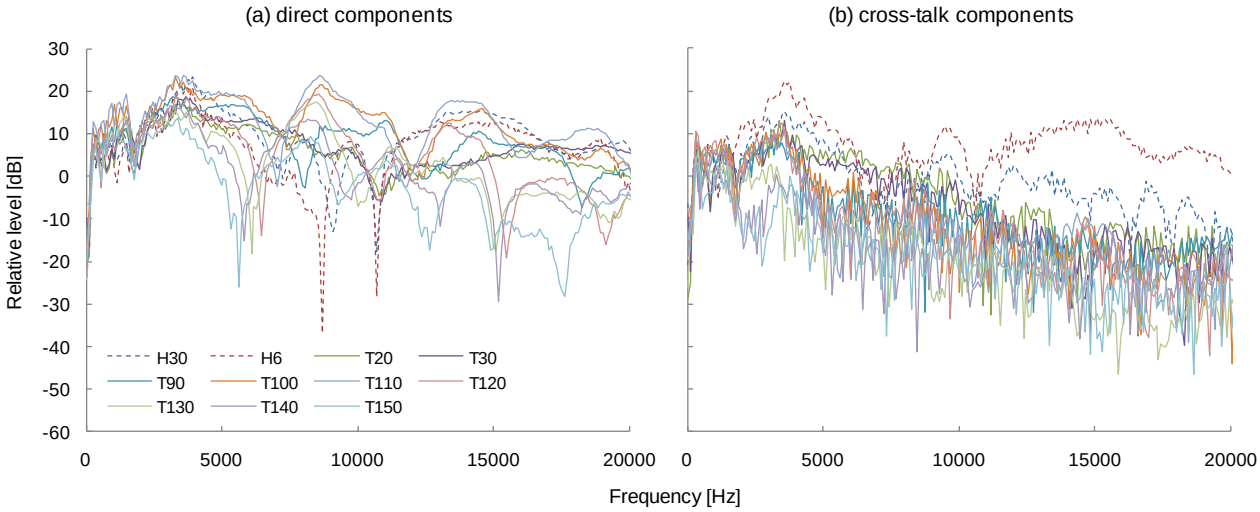

Fig.2 Transfer functions between the loudspeakers and the entrance of the ear canal of a subject. (a) direct components between the left loudspeakers and the left ear, (b) cross-talk components between the left loudspeakers and the right ear.

3 Localization tests

3.1 Method

The localization tests were carried out by the transaural systems using subject's own HRTF and measured transfer functions between loudspeaker and his entrance of the ear. The stimuli were wide band white noise (200-17000 Hz). The sampling frequency was 48000 Hz. Eleven kinds of the loudspeakers arrangements shown in Fig.1 were tested.

The target directions were 12 directions in the horizontal plane (0 - 330 degrees, 30 degrees intervals), and 7 directions in the median plane (0 - 180 degrees, 30 degrees intervals). The experiment was carried out in a darkened anechoic room. Subjects were 3 males who participated as the subjects for the transfer function measurements. The subjects were asked to look at front face, however, their heads were not fixed. The subject's task was to plot the perceived azimuth and elevation on the circle on the response sheet. At the beginning of the localization tests, the transfer functions between the loudspeakers and his entrance of the ear canals were measured again, in order to confirm the difference (reproducibility) of the transfer function, comparing them with those measured in chapter 2.

3.2 Results

Figure 3 and 4 show the responses of the subject IST, whose responses were typical among subjects.

A) In the case when the target directions are on the horizontal plane

For H30 and H6, the front-back error was observed. The subject did not perceive a sound image at the rear. For the transverse plane arrangements, the subject localized a sound image almost at the target directions, except for T20 and T150. Especially, the mean localization error was small (about 10 degrees) for T30, T90, T100, T110, T120, and T130.

B) In the case when the target directions are on the median plane

For H30 and H6, the subjects perceived all the stimuli at forward. For the transverse plane arrangements, the subject localized a sound image almost at the target directions, except for T140 and T150. Among them, T100 and T110 provided relatively small localization error.

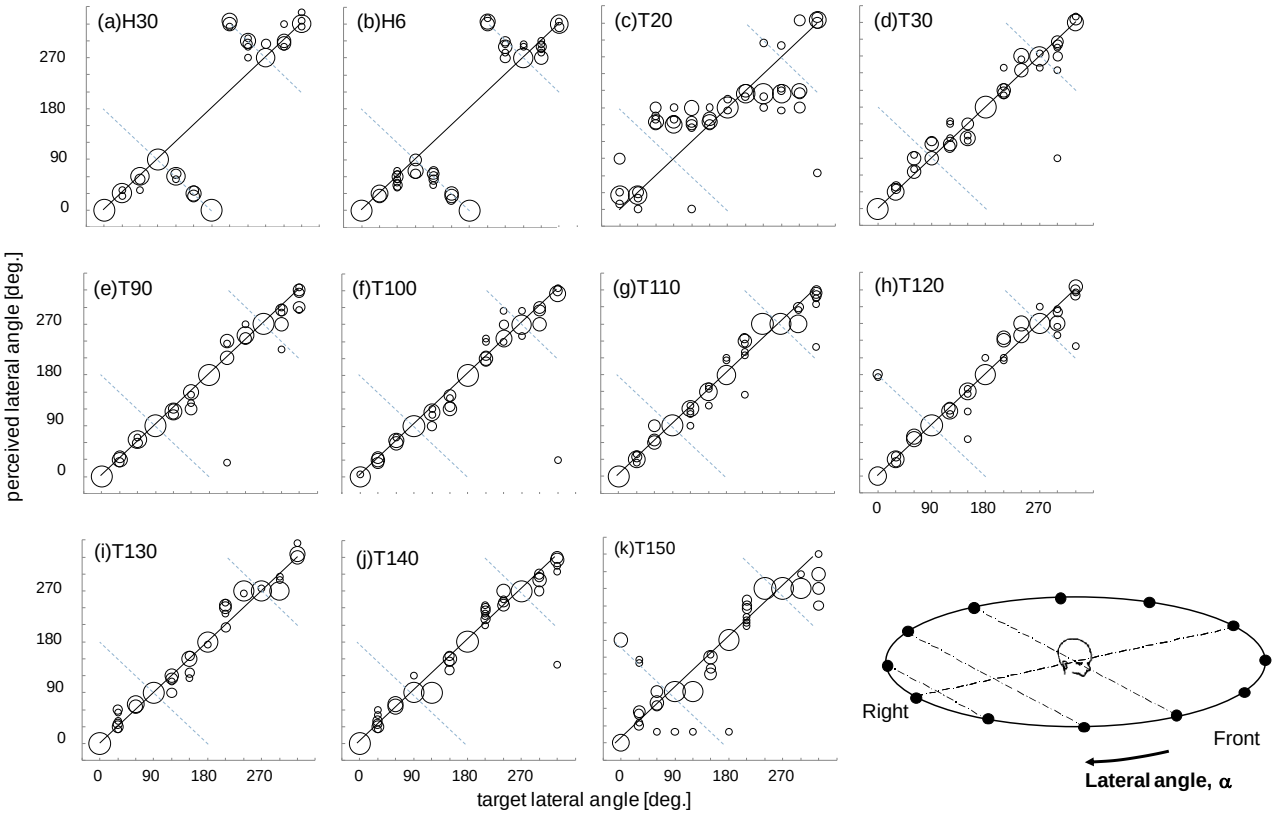

Fig.3 Localization responses for the stimuli in the horizontal plane of subject IST.

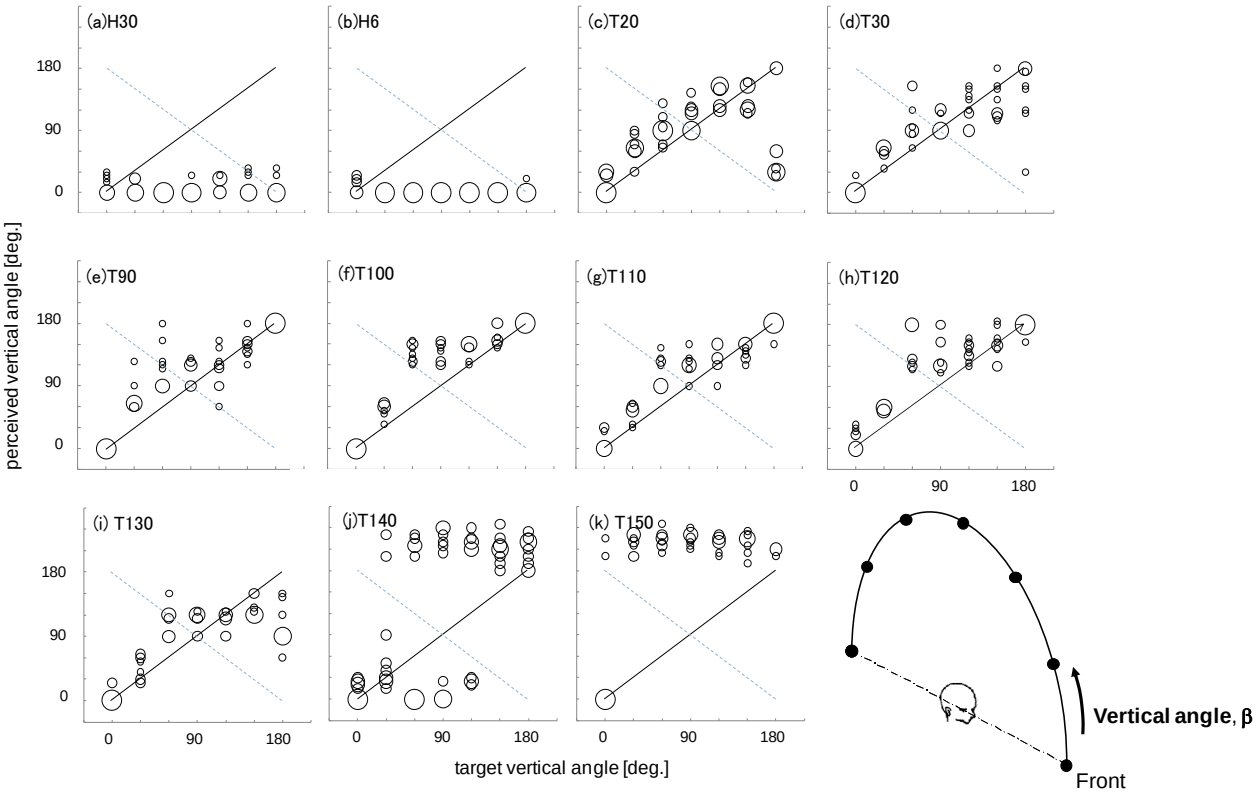

Fig.4 Localization responses for the stimuli in the median plane of subject IST.

4 Discussions

The reason why localization accuracy for the transversal loudspeakers arrangement is better than that for horizontal loudspeakers arrangement is discussed.

Figure 5 (a) shows the spectrum of the signal which is obtained by eq.(1).

$$C(\omega) * C(\omega)^{-1} * HRTF(\omega) \qquad (1),$$

where, $C(\omega)$ is the transfer function between loudspeakers and the entrances of the ear canals of a subject.

The spectrum of the signal is almost same as that of HRTF, since this is the ideal condition, that is, the transfer function is constant.

Figure 5 (b) shows the spectrum of the signal which is obtained by eq.(2).

$$C(\omega)' * C(\omega)^{-1} * HRTF(\omega) \qquad (2),$$

where, $C(\omega)'$ is the transfer function between loudspeakers and the entrances of the ear canals of a subject measured at the localization tests.

Small difference in the listening position causes the remarkable cancellation error for H6. For T100, the significant spectral notches for localization (N1 and N2) [*] are reproduced, although a certain amount of cancellation error was observed.

It could be considered that the transversal loudspeaker arrangement has robust feature to the small difference in the listening position.

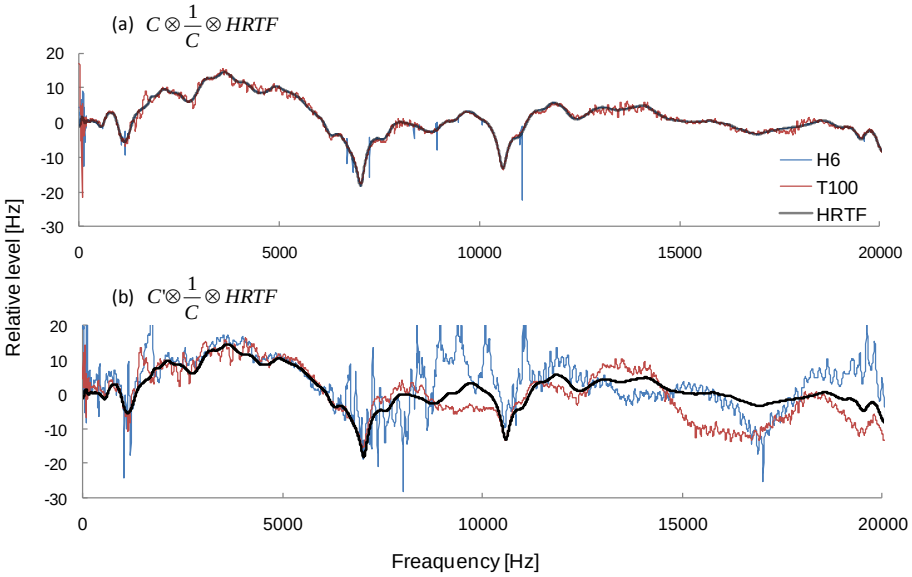

Fig.5 Simulated HRTF by transaural system. (a): transfer function is constant, (b): listening position is changed.

5 Conclusions

The authors examined the accuracy of 3D sound image control by transaural systems for various loudspeaker arrangements in the transverse plane, comparing with ordinary arrangements. The results of the measurements of transfer functions and sound localization tests showed that an accurate sound image control could be achieved by two loudspeakers located in the transverse plane at 100 - 110 degrees.

References

[1] Damaske P "Head-Related Two-Channel Stereophony with Loudspeaker Reproduction," J. Acoust. Soc. Am. 50:1109-1115 (1971).

[2] Kirkeby O, Nelson PA, and Hamada H "Local sound field reproduction using two closely spaced loudspeakers," J. Acoust. Soc. Am., 1973-1981 (1998).

[3] Morimoto M and Ando Y "On the simulation of sound localization," J. Acoust. Soc. Jpn.(E), 1(3): 167-174 (1980).

[4] Iida K, Itoh M, Itagaki A, and Morimoto M "Median plane localization using parametric model of the head-related transfer function based on spectral cues," Applied Acoustics, 68: 835-850 (2007).