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Left-right sound localization outside loudspeaker positions in stereo reproduction with parametric loudspeakers

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ABSTRACT

The parametric loudspeaker is known as a super directional loudspeaker by using nonlinear interaction between ultrasounds. We present some listening test results in stereo reproduction with the parametric loudspeakers. At first, ILDs were used as binaural information. It was confirmed that the sound images reproduced by the parametric loudspeakers were perceptually localized more outside than those by the ordinary loudspeakers. Especially when the ILDs (Interaural Level Differences) were minus or plus infinity, the sound images by the parametric loudspeakers were localized outside the actual position of the loudspeakers, while the images by the ordinary loudspeakers were localized rather slightly inside. It was also confirmed that the sound images by the parametric loudspeakers can be controlled to be localized more explicitly outside by using HRTFs (Head-Related Transfer Functions) instead of ILDs as the binaural information.

Keywords: Parametric loudspeaker, Sound localization, Super-directivity

1. INTRODUCTION

The parametric loudspeaker is known as a super directional loudspeaker based on nonlinear interaction between ultrasounds. The parametric loudspeaker is one of the prominent applications of nonlinear acoustics [1,2]. The main applications of the parametric loudspeaker are monaural reproduction. It is expected that a stereo reproduction using the parametric loudspeakers will lead to enjoy music and make a conversation without other persons' annoyance and trouble.

Recently, it was confirmed that parametric loudspeakers were available to stereo reproduction [3]. It was suggested that binaural information i.e. ILD (Interaural Level Difference) and ITD (Interaural Time Delay) had stronger effect on sound localization than in using ordinary loudspeakers. That is, sound images are localized in the more outside direction [4]. The influence of listener's head in stereo reproduction using parametric loudspeakers is investigated [5]. Interesting characteristics of vertical sound image control with parametric loudspeakers are found [6]. Moreover, an audio system with good reality using the parametric loudspeakers has been investigated.

In this report, the direction of sound localization between with the parametric loudspeakers and with the ordinary loudspeakers, which are set at angle of -30 and +30 degrees, are compared. The ILD is focused on as binaural information. The test method [4] is modified to make clear detailed characteristics. Moreover, in order to pursue the possibility of sound localization explicit outside the right and left loudspeakers, the listening tests are conducted not only with pure ILD but also with HRTFs (Head-Related Transfer Functions). The obtained listening test results are analyzed and discussed.

2. LISTENING TEST I (WITH PURE ILD)

2.1 Test condition

The placement of the listener and the parametric loudspeakers is illustrated in Fig.1. The listening tests are conducted in an anechoic room. A young female and four young males with normal hearing ability attend. The relationship between the right and left loudspeakers and the listening position are vertices of regular triangle with 1.8m length side. Both parametric loudspeakers are placed 0.3 m apart from the wall. The acoustical axis of the right or left parametric loudspeaker is set to the right or left ear of a listener, respectively.

The estimate paper is put on the wall for pointing the direction of sound localization. Meshes of a net are described on the paper. The origin points of x and y are the center and the level of both ears. The ranges of x and y are from -3.8 to +3.8 m and from -50 to +60 cm, respectively. The parametric loudspeaker was shaped as an equilateral hexagon. The inner and outer diameters were 99 mm and 112 mm, respectively.

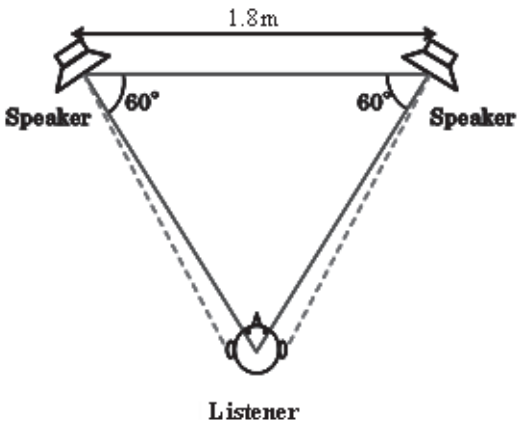

Figure 1 – Loudspeakers and listening positions. The relationship between the right and left loudspeakers and the listening position are vertices of regular triangle with 1.8m length side.

2.2 Test signal

The test signal is pink noise. The ultrasonic wave is modulated by the preprocessed test signal. SSB (Single-sideband) modulation with the lower sideband is used. The level differences of radiated signals between the right and left loudspeakers are $-\infty$, -9, -6, -3, 0, +3, +6, +9 and $+\infty$ dB. The duration of test signal is 5 seconds.

2.3 Test procedure

The listening tests are conducted in the following steps.

1. Before every listening test, a listener listens to some test signals in order to experience the sound localization preliminarily.
2. The listener listens to a set consisted of 45 trials with randomly edited test signals, five times for each of type reproductions.
3. After the listener listens to a test signal, she or he points a position of sound localization on an estimate paper by a laser pointer. Horizontal and vertical angles of sound localization are calculated by the pointed position.

2.4 Test results

The obtained sound localization in the horizontal direction is shown in Fig. 2. The horizontal axis is the level difference between the right and left loudspeakers. The vertical axis is the angle of sound localization in the horizontal direction. Symbols are the mean value and vertical lines indicate the degree of dispersion of data by connecting positive and negative standard deviations are connected. In the both cases of parametric loudspeaker and ordinary loudspeaker, the standard deviations were so small that sound localization was controlled by the ILDs. The directions of sound localization with the parametric loudspeakers were more outside than those with the ordinary loudspeakers. For example, loudspeakers were set at angle of -30 and +30 degrees and ILDs were $-\infty$ and $+\infty$. In using the parametric loudspeakers, the directions of sound localization were outside the loudspeaker. On the other hand, in using the ordinary loudspeakers, those were not outside the loudspeaker but inside. The parametric loudspeaker has such a sharp directivity that a cross talk level and diffraction are smaller than the ordinary loudspeaker has. It is estimated that the substantial ILD with the parametric loudspeakers is larger than those with the ordinary loudspeakers.

The obtained sound localization in the vertical direction is shown in Fig. 3. The horizontal axis is the level difference between the right and left loudspeakers. The vertical axis is the angle of sound localization in the vertical direction. There was small difference between the parametric loudspeaker and the ordinary loudspeaker. It was the same tendency that the directions of sound localization were slightly up in the center direction. The degree was different. The extent of the parametric loudspeaker was twice as much as that of the ordinary loudspeaker.

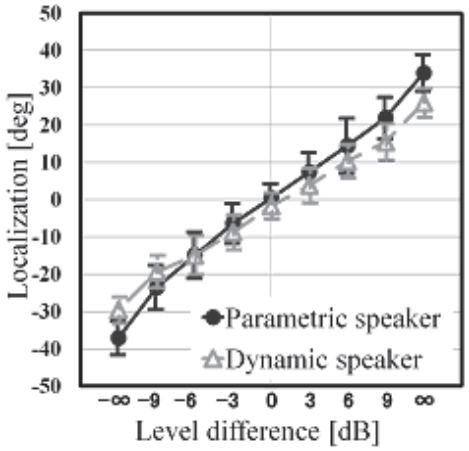

Figure 2 – Sound localization in the horizontal direction. The horizontal axis is the level difference between the right and left loudspeakers. The vertical axis is the angle of sound localization in the horizontal direction.

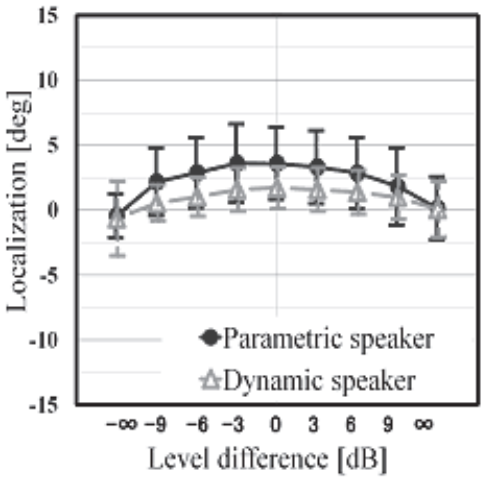

Figure 3 – Sound localization in the vertical direction. The horizontal axis is the level difference between the right and left loudspeakers. The vertical axis is the angle of sound localization in the horizontal direction.

3. LISTENING TEST II (WITH HRTF)

3.1 Test signal

The test condition is the same as in the previous listening test. It is anticipated that the obtained characteristics of the parametric loudspeaker in the previous test probably enable sound localization more outside of loudspeakers. The cross talk of the parametric loudspeaker is so small that the listening situation is probably realized to be similar to the listening by headphones. Therefore, binaural signals are created by convolving pink noise with HRTFs. The HRTFs are provided by MIT [7]. Therefore, in this listening test, individualities of listeners' HRTFs are not considered. The selected directions of the HRTF's sound localization are -90, 0 and +90 degrees. The ultrasonic wave

is modulated by preprocessing the modulated signal. The SSB (Single-sideband) modulation with the lower sideband is used. The duration of test signal is 5 seconds, which is the same as in the previous test.

3.2 Test procedure

The listening tests are conducted in the following steps.

1. Before every listening test, a listener listens to some test signals in order to experience the sound localization preliminarily.

2. The listener listens to a set consisted of 15 trials with randomly edited test signals, five times for each of type reproductions.

3. After the listener listens to a test signal, she or he points a position of sound localization on an estimate paper by a laser pointer. Horizontal and vertical angles of sound localization are calculated by the pointed position.

3.3 Test results

As for reference, angles of sound localization and the standard deviation in the horizontal direction in Fig.2 are picked up in Table 1. The used binaural information was ILDs. The loudspeakers were set at angle of -30 and +30 degrees. The angles the ILDs are $-\infty$ and $+\infty$ are averaged. It is easy to compare between the results of the ordinary and parametric loudspeakers. In using the parametric loudspeakers, the directions of sound localization were outside the loudspeaker. On the other hand, in using the ordinary loudspeakers, those were not outside the loudspeaker but inside. The standard deviations are small enough to distinguish these results between both loudspeakers.

Table 1 – Direction of sound localization in using ILD (∞) as binaural information

Binaural information	Loudspeaker	Direction of sound localization, deg	Standard Deviation, deg
ILD (∞ dB)	Ordinary	27.8	3.5
	Parametric	35.5	4.6

Angles of sound localization in the horizontal direction when the HRTFs were used as binaural information are shown in Table 2. The averaged angles and standard deviations when the directions of HRTFs are -90 and +90 degrees are noted. It is easy to compare between the results of the ordinary and parametric loudspeakers. The standard deviations are small enough to distinguish these results between both loudspeakers. It was confirmed that by using HRTFs of -90 and +90 degrees, the sound images were able to control to localize outside the parametric loudspeakers which were placed at angles of -30 and 30 degrees.

Table 2 – Direction of sound localization in using HRTF (90 deg) as binaural information

Binaural information	Loudspeaker	Direction of sound localization, deg	Standard Deviation, deg
HRTF (90 deg)	Ordinary	26.8	4.1
	Parametric	48.3	6.0

4. CONCLUSIONS

The listening tests in stereo reproduction with the parametric loudspeakers and the ordinary loudspeakers were conducted. These loudspeakers were set at angle of -30 and +30 degrees. The

obtained test results were analyzed and discussed.

It was confirmed that when ILDs were used as binaural information, the directions of sound localization with the parametric loudspeakers were more outside than those with the ordinary loudspeakers. The obtained results were interesting especially when ILDs were $-\infty$ and $+\infty$. In using the parametric loudspeakers, the directions of sound localization were outside of the loudspeaker. On the other hand, in using the ordinary loudspeakers, those were not outside the loudspeaker but inside. Moreover it was confirmed that by using HRTFs of -90 and +90 degrees, the sound images were able to control to localize more outside the parametric loudspeakers.

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