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Stereo reproduction using parametric loudspeakers

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ABSTRACT

We can perceive sound localization in stereo reproduction using ordinary left and right loudspeakers. A parametric loudspeaker is sharp directivity and realizes a spot sound reproduction. In this paper, subjective tests were conducted using parametric loudspeakers and ordinary loudspeakers. It was discussed that we perceived sound localization using parametric loudspeakers in comparison with that using ordinary loudspeakers.

In subjective tests, the listening positions were A, B and C. The listening positions A and B were at the top of equilateral triangle whose other tops were the left and right loudspeakers positions. Lengths of the side were 0.6m and 1.8m, respectively. The listening position C was the just in front of the left loudspeaker and in the left direction of the listening position B. The parametric loudspeaker was an equilateral hexagon. The inner and outer diameters were 99 mm and 112 mm, respectively. The acoustic axis of loudspeaker was set in the direction of an ear of subject. ILD (Interaural Level difference) or ITD (Interaural Time difference) was used as binaural information. The ILDs were -12, -6, 0, +6, and +12 dB. The ITDs were -0.4, -0.2, 0, +0.2 and +0.4 ms. The ILDs and ITDs corresponded to five directions from left, center to right. Signals were 500 Hz, 1 kHz, 2 kHz and 4 kHz pure tones. When listeners listened to stereo signals at the listening position C, the level and time differences of signals between left and right loudspeakers were adjusted taking account of the different distances between from left and right loudspeakers to the listening position C. Three young males listened 10 times in each signal condition in an anechoic room.

Subjective tests showed that listeners perceived correct sound localization at the listening positions A, B and C using the parametric loudspeakers, which was similar to using the ordinary loudspeakers. When signals were 500 Hz and 1 kHz pure tones, both stereo signals with ITD and ILD were effective. However, when signals were 2 kHz and 4 kHz pure tones, stereo signals only with ILD were effective and stereo signals only with ITD were not localized correctly. Listeners reported that the angle of sound localization between left and right direction using the parametric loudspeakers tended to be wider than that using the ordinary loudspeakers. It was confirmed that the parametric loudspeaker were available in an ordinary stereo reproduction and realized a spot stereo reproduction.

1. INTRODUCTION

So far the study of a parametric loudspeaker whose directivity is sharper than that of an ordinary loudspeaker has been promoted. The parametric loudspeaker emits strong amplitude-modulated ultrasound as the primary wave and as the primary wave propagates, the secondary wave generated by a nonlinearity of the air becomes audible [1] [2] [3] .

Recently, the parametric loudspeaker is used at a museum and a plat home of the station to tell messages and announcements to audiences in the limited area. In addition, the applications to auxiliary equipment of the pedestrian crossing and an active voice noise control are studied. Therefore, as a new application of the parametric loudspeaker, we propose an application to stereo reproduction and investigate whether sound localization in stereo reproduction is possible or not.

In stereo reproduction, what we can perceive the correct sound localization is one of the important effects. It is known that we can localize direction of the sound image by using the interaural level difference level (ILD) and the interaural time difference (ITD) that are difference of sounds between left and right ears [6].

We have investigated the characteristics of stereo reproduction using the two parametric loudspeakers by listening tests. In the tests, the parametric loudspeakers were set near a listener. The stereo signal has only ITD or ILD as binaural information. As a result, it was found that the parametric loudspeakers were available for the stereo reproduction because the sound localization was similar to that of the ordinary loudspeakers. It was also confirmed the sound localization by using the ILD was steadier than that by using the ITD [7].

In this paper, subjective tests are conducted using the two parametric loudspeakers or the two ordinary loudspeakers. In subjective tests, the listening positions are three. The first two listening positions are at the top of equilateral triangle whose other tops are the left and right loudspeakers positions. Lengths of the side are different. The last listening position is the just in front of the left loudspeaker. We discuss the characteristics of stereo reproduction using the parametric loud-

speakers in comparison with that using the ordinary loudspeakers. In discussion, the influences of difference of listening positions to the sound localization are included.

2. EXPERIMENTAL METHOD

Figure 1 shows the placement of loudspeakers and listening positions. In subjective tests, the listening positions were A, B and C. The listening positions A and B were at the top of equilateral triangle whose other tops were the left and right loudspeakers positions. Lengths of the side were 0.6m and 1.8m, respectively. The listening position C was the just in front of the left loudspeaker and in the left direction of the listening position B. When listeners listened to stereo signals at the listening position C, the level and time differences of signals between left and right loudspeakers were adjusted taking account of the different distances between from left and right loudspeakers to the listening position C.

The parametric loudspeaker was shaped as an equilateral hexagon as shown in Figure 2. The inner and outer diameters were 99 mm and 112 mm, respectively. Also, the diameter of ordinary loudspeaker was 83 mm in Figure 3. Before starting the listening test, the sound pressure in using each loudspeaker at the listening position was set equally.

The acoustic axis of the loudspeaker was set in the direction of an ear of listener. ILD (Interaural Level difference) or ITD (Interaural Time difference) was used as binaural information. The ILDs were -12, -6, 0, +6, and +12 dB. The ITDs were -0.4, -0.2, 0, +0.2 and +0.4ms. The ITDs and ILDs corresponded to five directions from left, center to right. Signals were 500 Hz, 1 kHz, 2 kHz and 4 kHz pure tones. Three young males listened 10 times in each signal condition in an anechoic room.

The listener sat on a chair at the listening position in the anechoic room. In the listening test, we instructed the listener to keep his posture well, not to move his head and to be always close his eyes in order to shut out the information of the sight.

We conducted a preliminary practice before staring the listing test. Five kinds of signals from a PC were generated at random. The listener answered the direction of the sound localization by selecting a term out of five terms (left, left a little, centre, right a little and right). In analysis, each answer is evaluated as -2, -1, 0, +1 or +2. In the above mentioned condition, three young males participated in the listening tests.

3. EXPERMENTAL RESULTS

Results of the listening test are shown from Figure 4 to Figure 9. Figures 4, 6, 8 and 9 show the results in using the ILD as binaural information. Figures 5 and 7 show the results in using the ITD. The horizontal axis is the direction that sound image should be localized and the vertical axis is the direction that sound image was localized in the listening tests. For example, the +2 and -2 correspond to the right and left assigned positions, respectively. The standard deviations are calculated from thirty test results at each position.

Figure 4 shows the test results of sound localization when binaural information was the ILD and the frequency of sound was 500 Hz. The six characteristics (three kinds of the listening positions and two kinds of loudspeakers) indicated that the sound localization of the parametric loudspeakers was almost the same as that of the ordinary loudspeakers.

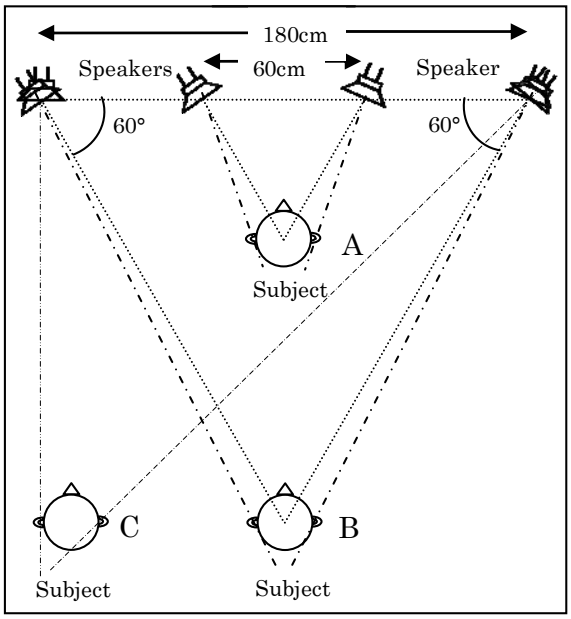

Figure 1. Speaker and listening positions.

Figure2. Parametric loudspeaker.

Figure 3. Ordinary loudspeaker.

Figure 5 shows the test results of sound localization when binaural information was the ITD and the frequency of sound was 500 Hz. Because the values of standard deviation were larger than those using the ILD, the localization of sound image was more difficult than in using the ILD. Comparing the results of parametric loudspeaker with those of the ordinary loudspeaker, the localization of the parametric loud-

speaker tended to be biased to the centre direction. Also, comparing the test result of the ITD with those of the ILD, sound localization of the ITD was unstable and incorrect. That is, the correct sound localization in using the ITD was difficult to perceive.

Figure 6 shows the test results of sound localization when binaural information was the ILD and the frequency of sound was 1 kHz. The values of standard deviation and average value were similar to those in the case of ILD and 500 Hz in Figure 4. When sound image was localized in the direction of the centre, the values of standard deviation in using the parametric loudspeakers were smaller than those in using ordinary loudspeakers. This means that the parametric loudspeaker reproduced the sound image in the direction of the centre more correctly than the ordinary loudspeaker did.

Figure 7 shows the test results of sound localization when binaural information was the ITD and the frequency of sound was 1 kHz. Comparing with the result in the case of ITD and 500 Hz, it is found that the localization of sound image was more difficult. Also, comparing the test result of the ITD with those of the ILD, sound localization of the ITD was more unstable and more incorrect. The degree became worse than in the case of 500Hz. That is, the correct sound localization in the case of ITD became more difficult to perceive.

Figure 8 shows the test results of sound localization when binaural information was the ILD and the frequency of sound was 2 kHz. When we used the parametric loudspeakers, the listeners could not perceive the difference of localization between the sound images that should be localized in the direction of the right a little and the right. This was similar to the case of the left a little and the left. When sound image was localized in the direction of the centre, the values of standard deviation in using the ordinary loudspeakers were larger than in the case of 1 kHz. When we used the parametric loudspeakers, listeners were able to localize the sound image correctly. This is the same as in the case of 500 Hz and 1 kHz.

Figure 9 shows the test results of sound localization when binaural information was the ILD and the frequency of sound was 4 kHz. The tendency of average values was almost the same as the cases of 500 Hz and 1 kHz. When sound image was localized in the direction of the centre, it was found that the parametric loudspeaker was superior to the ordinary loudspeaker in stereo reproduction.

4. DISCUSSION

From the test results in the case of ILD and 500 Hz, the sound localization in the direction of the center in using the parametric loudspeakers was similar to that in using the ordinary loudspeakers. As the frequency increased, the sound localization in the direction of the center in using the parametric loudspeakers was the almost same. However, the sound localization in the direction of the center in using the ordinary loudspeakers became more difficult. Therefore, it was found that the parametric loudspeaker was superior to the ordinary loudspeaker for the sound localization in the direction of the center. The reason is probably that as the listeners reported, the angle of sound localization between left and right direction in using the parametric loudspeakers tended to be wider than that in using the ordinary loudspeakers.

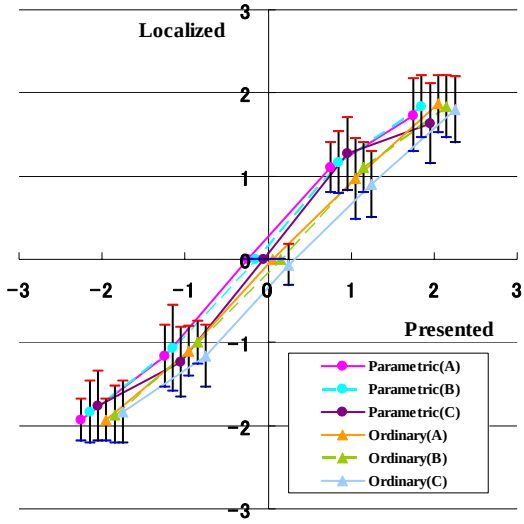

Figure 4. Sound localization in ILD (500 Hz).

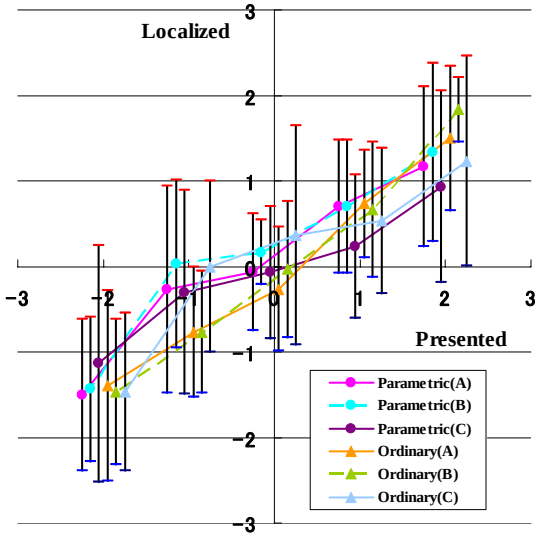

Figure 5. Sound localization in ITD (500 Hz).

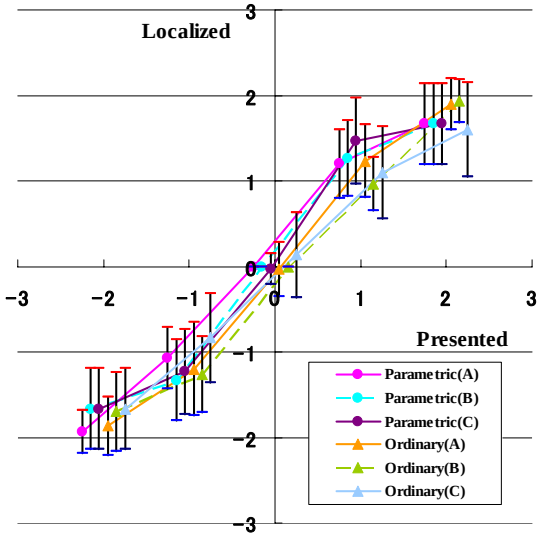

Figure 6. Sound localization in ILD (1 kHz).

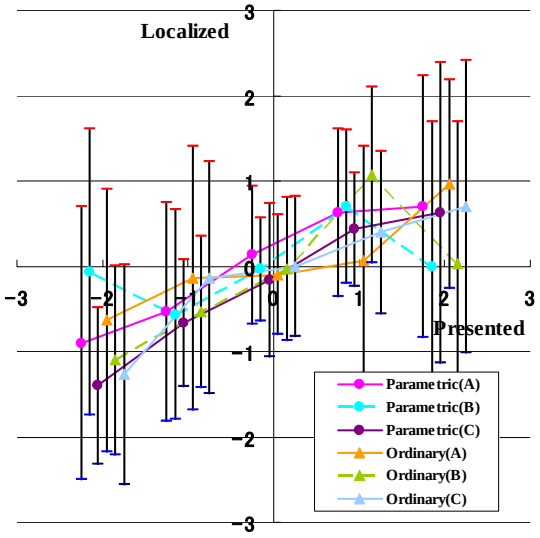

Figure 7. Sound localization in ITD (1 kHz).

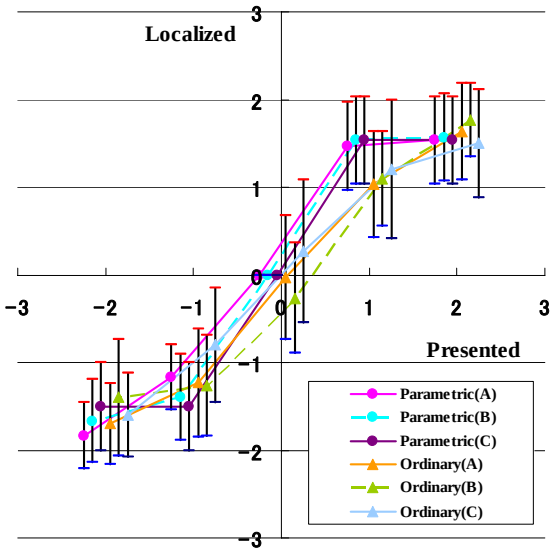

Figure 8. Sound localization in ILD (2 kHz).

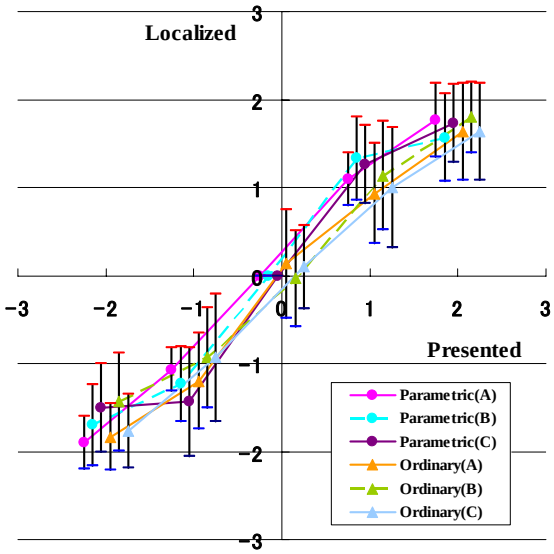

Figure 9. Sound localization in ILD (4 kHz).

5. CONCLUSION

In this paper, subjective tests were conducted using the parametric loudspeakers and the ordinary loudspeakers. It was discussed the sound localization in using the parametric loudspeakers comparing with that in using the ordinary loudspeakers.

(1) When parametric loudspeakers were used, subjective tests showed that listeners at the centre listening positions in the near-field and far-field and the biased listening position in the far-field perceived correct sound localization. This was similar to sound localization in using the ordinary loudspeakers.

(2)When frequency was changed from 500 Hz to 4 kHz in the case of ILD, we can perceive sound localization in stereo reproduction in using the parametric loudspeakers.

(3)Comparing the sound localization of the tests in the case of the ILD with those of the ITD, it was found that sound localization in the case of the ILD was more stable than those of the ITD.

(4)In the case the ITD, when we use the parametric loudspeakers and the ordinary loudspeakers, it was found that sound localization in the case of 500 Hz was easier than that of 1 kHz. The tendency did not depend on the listening positions.

(5) It was found that the parametric loudspeaker was superior to the ordinary loudspeaker for the sound localization in the direction of the center.

In this study, all the listening tests were conducted by using the pure tones. It is known that the sound localizations of pure tones are more difficult than those of noise and audio signal. Therefore, the future works are to conduct listening tests using a noise or an audio signal and to investigate whether these sound localizations are different from the sound localizations of pure tones or not.

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