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Abstract- This paper presents a microphone array design which can be used for capturing a sound selectively and locally at 3-dimensional space. Capturing a sound by microphone array is achieved by addition each signal after fitting each phase. In this method, microphone arrangement has a large effect on the directivity, but it is difficult to calculate optimal microphone arrangement analytically. So we provided many candidates of microphone arrangement, and evaluate a performance of each candidate to obtain optimal microphone arrangement. As a result, we have obtained a high directional quality arrangement that can accept omni-directional in 3-dimensional space.

1. Introduction

We generally use sound level meter when we measure noise level. However, in living space there are many noises, it is difficult that we identify those sound sources with using traditional sound level meter. Therefore, we have proposed combining camera image processing and microphone array consisting of a number of microphones like Fig.1. Microphone array signal processing is a way to capture a sound selectivily and locally in environment there are a lot of sound source. Designing high-performance microphone array improves performance of this entire system.

Capturing a sound by microphone array is achieved by method of Delay and Sum Beam Forming (DSBF). This method is able to capture intended sound to add signal in each microphone after addition delay to each signal. In this processing, high-sensitivity beam is formed in space. Mainlobe is beam extending in a direction of intended sound source, and sidelobe is beam formed by interference involuntarily in a different direction of intended sound source. Fig.2 shows good and bad example of beamforming. If a mainlobe width is thick and a sidelobe gain is high, the noise source is easy to cover high-sensitive area. To capture effectively a intended sound, it is better to form a beam to narrow a mainlobe width and minimize a sidelobe gain.

In DSBF, microphone arrangement has a large effect on the directivity. Fujihara et al.(1) has proposed the method of designing high-performance microphone array. Based on

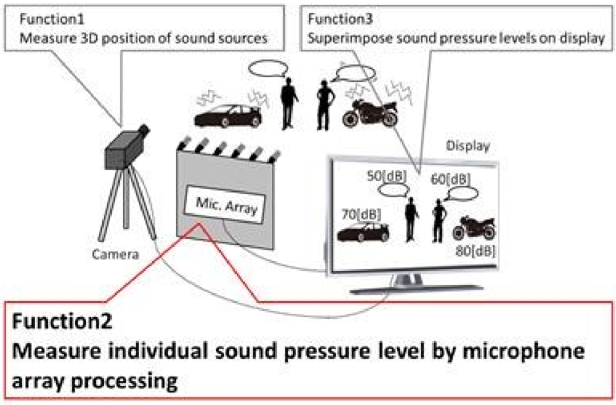

Fig.1 Vizualizing sound pressure distribution

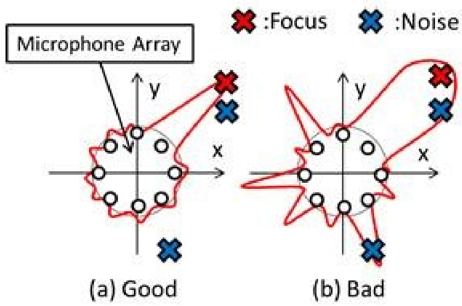

Fig.2 Good and bad cases of beamforming

their method, this paper describes performance of linear, planar, cube and spherical array, and investigating optimal microphone arrangement using beamforming simulation.

2. 3-Dimensional Directivity

2.1 Terms of Obtain 3-Dimensional Directivity

A location there is the desired sound source is called focus. Let $\boldsymbol{L_f} = (L_1, L_2, L_3, \cdots, L_M)$ be a distance vector of between each microphone and focus(F), and let $\boldsymbol{L_c}$ be a distance vector of between each microphone and any location other than a focus(C). If $\boldsymbol{L_C = L_f}$, high-sensitivity beam is formed in not only a direction of focus also point C. In order to form directivity only in a direction of focus, arrangement of each microphone should be 3-dimensional.

Upper part of Fig.3 shows 3-dimensinal sensitivity distribution of linear shape microphone array (element number is 4), and lower part of Fig.3 shows 3-dimensinonal sensitivity distribution of planar shape array (element number is 64). The sensitivity at the focus is 0[dB], and visualize the area of more than -8[dB]. In a linear shape array, point C satisfy $\boldsymbol{L_C = L_f}$ is located on circumference that has an axis laid on microphone array. In a planar shape array, point C satisfy $\boldsymbol{L_C = L_f}$ and focus F are symmetric about the plane laid on microphone array. Therefore high-sensitivity beam is formed in two directions.

Fig.4 shows 3-dimensinal sensitivity distribution of cube shape microphone array (element number is 64). In this case, high-sensitivity beam is formed only in a direction of focus because there is no point C satisfied $\boldsymbol{L_C = L_f}$.

2.2 Shape to Obtain Omni-Directional Directivity

In a particular direction, cube array is not able to form directivity only in a direction of focus. Fig.5 shows the example of comparing cube to sphere array under the terms that frequency of sound is 3000[Hz]. Too high-sensitivity sidelobe is formed in a direction of vertex of cube. In cube array, a direction in forming high-sensitivity beam has a large effect on the directivity pattern. To avoid this, we calculate 3-dimensional sensitivity distribution of spherical shape array, and we confirmed spherical shape array is little affected by a direction than cube shape array.

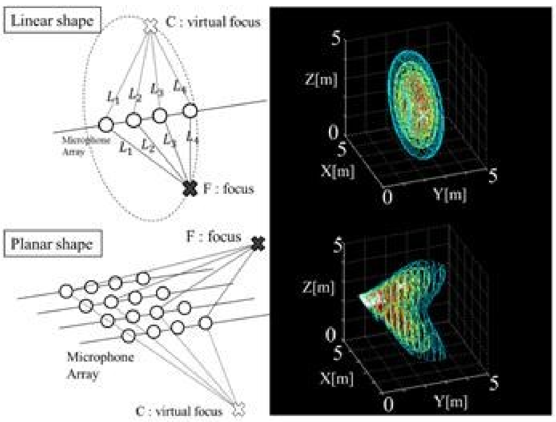

Fig.3 Beam of linear and planar shape array

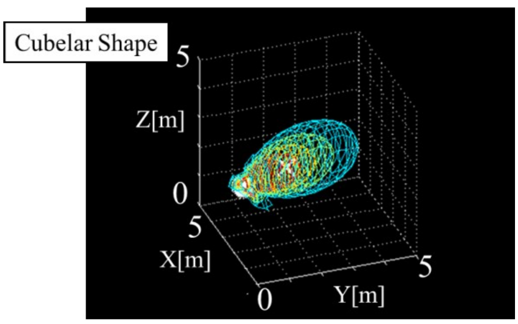

Fig.4 Beam of Cubelar Shape Array

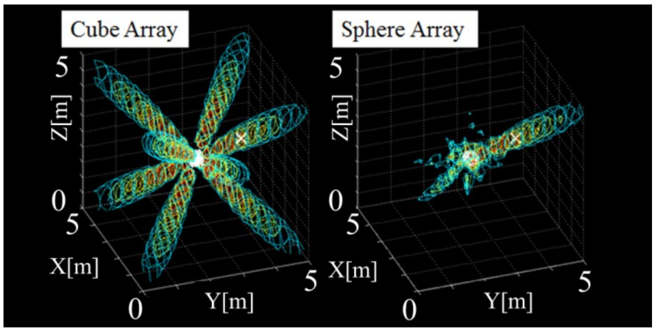

Fig.5 Comparing cube to shape array (3000Hz)

3. Investigation on Optimal Microphone Arrangement

It is difficult to calculate optimal microphone arrangement analytically that is able to narrow a mainlobe and minimize a sidelobe. So we provided many candidates of microphone arrangement, and evaluate a performance of each candidate to obtain optimal microphone arrangement. Based on subsection 2.2, candidates are limited to concentric spherical arrangement in order to downsize the entire microphone array.

3.1 Evaluation Index

In order to evaluate quantitative the mainlobe width and the sidelobe gain of a candidate, we use the following evaluation value.

IMsize : Ratio of the size of the mainlobe area over -12dB to surface area of sphere with radius 1[m] from the center of the microphone array [%]

ISmax : Maximum gain of sidelobes [dB]

We calculated *IMsize* and *ISmax* assuming 7 sine waves from 600[Hz] to 3000[Hz] by 400[Hz] to accept wide-band frequency contain band of human speech, and applied the average of each evaluation value. Due to calculated a sensitivity of focus as 0[dB], *ISmax* is a negative value. There are multiple factors that determine the performance of the microphone array, so we used equation(1) to compare each candidate equally. α and β is population mean value of *IMsize* and *ISmax*, and the smaller value of Eva, the higher the performance of the microphone array.

$$Eva = \frac{IMsize}{\alpha} - \frac{ISmax}{\beta} \tag{1}$$

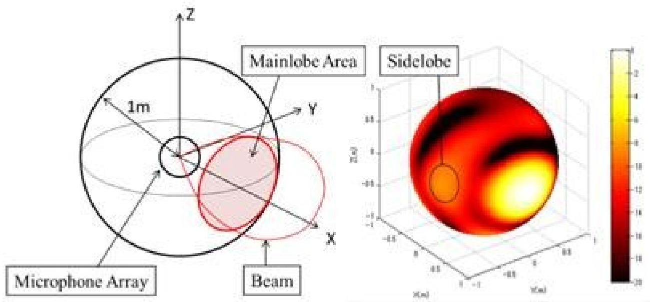

Fig.6 Case of sensitivity distribution

3.2 Method of Setting Arrangement

We simulated by using of 64 microphones in consideration of the limitation of A/D board due to use in implementation. In order to distribute microphones to each concentric sphere, we used the microphone density function[5]. This function determines the number of microphones distributed each concentric sphere when the number of concentric sphere and its radius is determined due to a random value.

$$\rho(r) = \frac{0.328}{cos(\frac{r}{r_{max}})^4} + \frac{0.117}{cos(\frac{r}{r_{max}})^3} - \frac{0.496}{cos(\frac{r}{r_{max}})^2} + \frac{0.117}{cos(\frac{r}{r_{max}})} - 0.122 \qquad (2)$$

Aligning phase in DSBF calculation is considered a projection of microphones to a focus-centered sphere surface. When projected microphones overlap, capturing intended sound become less effective because of causing a little phase difference between these microphones. This method make microphones projected to a focus-centered sphere surface equally. It is necessary to distribute the number of microphone determined according to equation(2) to each concentric sphere. However, it is difficult to distribute the number of microphone determined from random value to each concentric sphere equally. Therefore, we prepared candidates by the following procedure.

1. Microphone arrangement of the outermost sphere is on 50 vertices of a truncated icosahedron.
2. 14 microphones in the outermost sphere are on pair of vertices of regular icosahedron and both ends of line, or pair of vertices of regular hexahedron and regular octahedron. And adequate circumscribed sphere of each solid is calculated according to equation(2).
3. Provides a candidate that solids rotated each other, and examine the performance of the candidate.

In DSBF, if an array size is small, accentuation intended sound of low frequency that has long wavelength become less effective due to causing a little phase difference between these microphones. Meanwhile, if an array size is large, it is difficult to form the directivity in high frequency because of the spatial aliasing. Therefore, in order to obtain optimal array size, we provided candidates that are made to change array size homothetically.

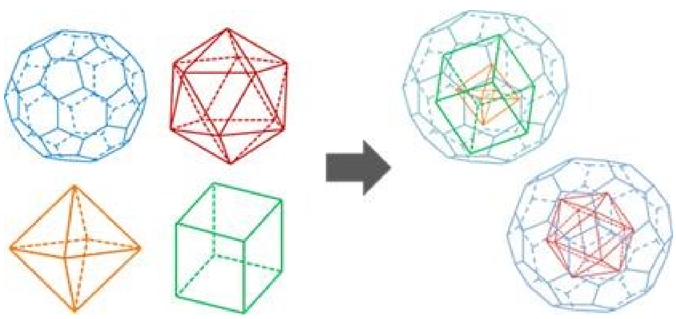

Fig.7 Image of concentrically spherical array

3.3 Simulation to Investigate Optimal Arrangement

We calculated evaluation value of candidates provided by the procedure stated on subsection 3.2. Fig.8 shows its index distribution. Points plotted in blue is evaluation value of candidates consisted of truncated icosahedron, regular icosahedron and both ends of line, and points plotted in magenta is evaluation value of candidates consisted of truncated icosahedron, regular hexahedron and regular octahedron. The range of diameter of array size is 0.30[m] to 0.50[m]. The vertical axis shows a maximum sidelobe gain(*ISmax*), and the horizontal axis shows the frequency average of mainlobe size(*IMsize*). Points of bottom left have better performance.

As a result of the evaluation used equation(1), the best candidate is the arrangement indicated by Fig.9. This arrangement is consisted of truncated icosahedron, regular icosahedron and both ends of line, and the diameter of this array is 0.40[m]. Table1 shows the evaluation value of this arrangement.

Fig.10 shows the direction characteristic curve of optimal arrangement. This figures on the left side means sensitivity distribution on surface of sphere with radius 1[m] from the center of the microphone array, and the figures on the right side are spread its surface of sphere planarly. The vertical axis shows the elevation($\emptyset$), the horizontal axis shows the azimuth(θ), and the focus is $(\theta, \emptyset) = (180°, 0°)$. As a result, we confirmed this array can form directivity with minimizing sidelobe, and obtained optimal microphone arrangement.

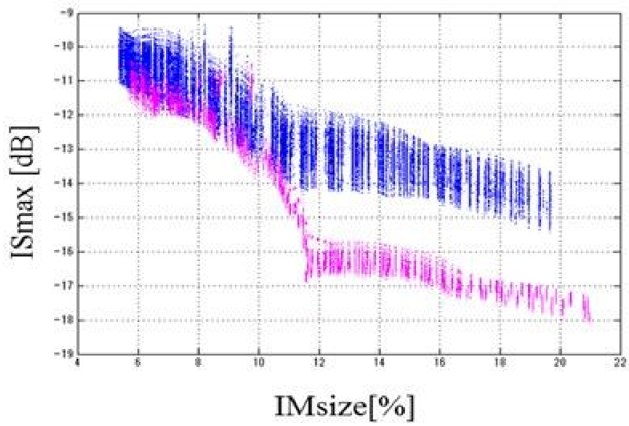

Fig.8 Calculation result

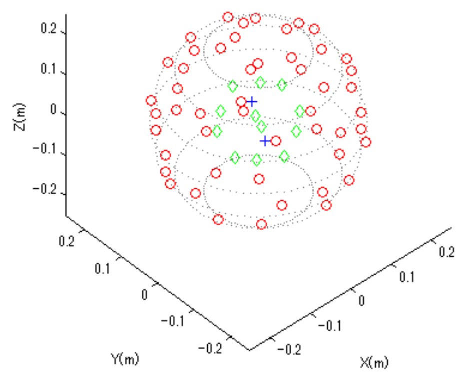

Fig.9 Best arrangement

Table1 Evaluation value

IMsize[%]	ISmax[dB]
11.6	-16.9

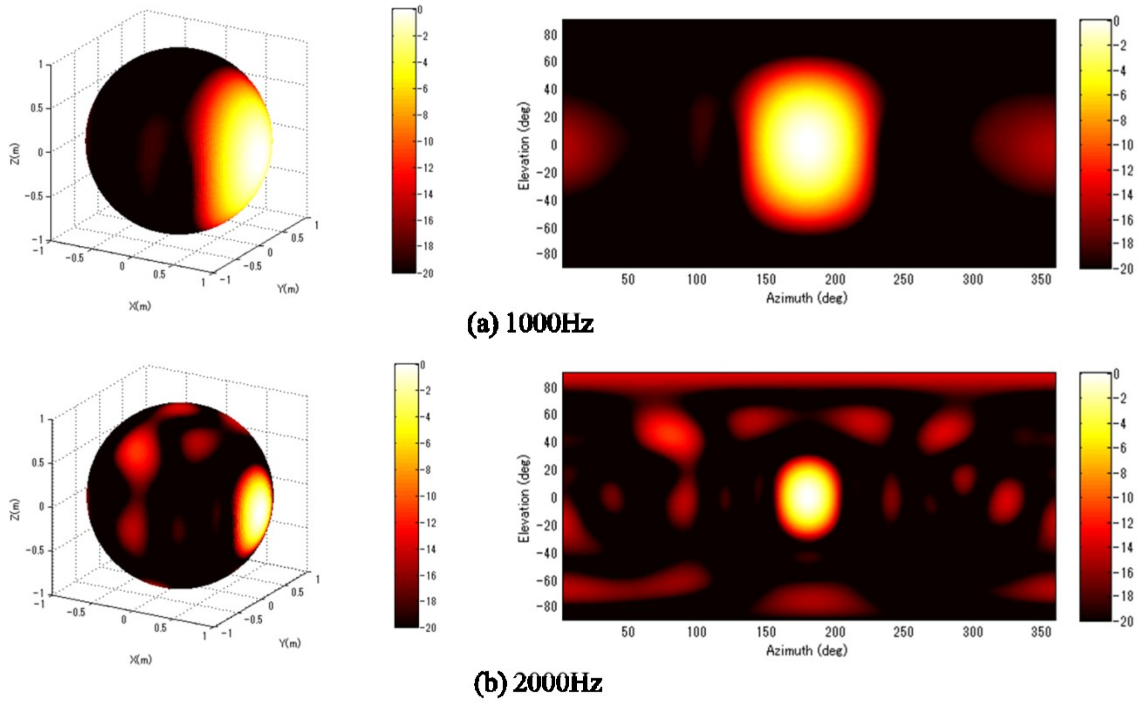

Fig.10 Sensitivity distribution of best arrangement

4. Conclusion

In this study, we investigated terms of microphone arrangement that is been able to obtain 3-dimensional directivity, and investigated optimal microphone arrangement that is able to capture a sound effectively.

Using 3-dimensional beamforming simulation, we confirmed that in order to form directivity only in a direction of focus, arrangement of each microphone should be 3-dimensional. And we confirmed that spherical shape array is little affected by a direction.

Based on the method proposed by Fujihara et al., in order to obtain the optimal concentrically spherical microphone arrangement, we provided many candidates of microphone arrangement consisted of truncated icosahedron, regular icosahedron, regular hexahedron and regular octahedron, and evaluate a performance of each candidate.

As a result, we obtain the microphone arrangement that *IMsize* and *ISmax* indicated performance of the microphone array is 11.6[%] and -16.9[dB].

Acknowledgements

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