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A STUDY OF UTILIZING A HANDY 2-D MICROPHONE ARRAY FOR NOISE SOURCE LOCALIZATION BASED ON THE NEAR-FIELD ACOUSTIC HOLOGRAPHY

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ABSTRACT
The use of handy 2-D microphone array is proposed. This handy array has 8 by 8 microphones, the size of 400 mm square. The real-time measurement system has constructed which consists of this handy array, processing circuits and data acquisition system. This handy array can be moved easily around the objective sound source, so sound source can be localized by Nearfield Acoustic Holography (NAH) with this feature although only a small area of 2-D sound field can be acquired at once. The small measurement aperture, however, causes the truncated error around the edge of the aperture in NAH process. It makes the reconstructed image near the sound source undistinguished. In this report, the optimal shape of filter in spatial wave number domain for the handy array is investigated by simulation.

1 - INTRODUCTION

The sound source localization by the Nearfield Acoustic Holography (NAH) [1] is effective in reducing machinery noise, because the direct treatments for the sound sources are expected to make the noisy machinery silent. The NAH is potentially able to provide the precise images of whole sound field from two-dimensional sound field measurement, but precise image requires a lot of measurement points and a large measurement area, say one hundred by one hundred points, several meters square. Such a measurement condition is not preferable to actual field measurement, because it takes long time and great effort.

So, in this report, the use of handy 2-D microphone array is proposed. The real-time measurement system has constructed, in which the signals of microphones are fed to real-time acquisition system, so transient sound field can not only be grasped, but also measurements at various conditions can be carried out continuously [2].

The small measurement aperture, however, causes the truncated error around the edge of the aperture in NAH process. At low frequency, especially, this error is enhanced at the wide evanescent wave region in NAH process. These problems make the reconstructed image near the sound source undistinguished. Generally, the filter function in the spatial wave number domain is applied to reduce the errors caused by using the finite, discrete measurement aperture. The shape of filter function seems to be decided by experience, or trial and error [3].

In this report, to develop the accuracy of sound source localization by means of small measurement aperture, optimal shape of filter for this handy microphone array is investigated by simulation, and the method for sound source localization with the handy array is proposed.

2 - INVESTIGATION OF APPROPRIATE FILTER FOR SMALL MEASUREMENT APERTURE

2.1 - Simulated condition

Figure 1 shows the configuration of measurement in the simulation and the examples of sound source localization by NAH expressed by contour plots. Before the 2-D FFT in the process of NAH, this

small measurement aperture is expanded to 256 points distribution by means of zero padding around the aperture. By this procedure, the wraparound effect can be avoided [1]. Distance between a point source and measurement aperture, z_{M} is 0.1 m, which is decided in considering the uneven surfaces of real machinery. In this simulation, two types of the location of a point source are considered, as figure 1 shows. Frequency of the sound source is selected from 500 Hz, 1000 Hz or 2000 Hz.
The NAH process is expressed as,

$$p(x, y, z) = \mathrm{F}^{-1}\left[P_{\mathrm{H}}(k_x, k_y, z_{\mathrm{H}}) \cdot \frac{G(k_x, k_y, z)}{G(k_x, k_y, z_{\mathrm{H}})} \cdot W(k_x, k_y)\right] \tag{1}$$

where P_{H} is sound pressure on hologram plane transformed to the spatial wave number domain by 2-D FFT, G is the Green's function, F^{-1} expresses the inverse Fourier transform, p is the reconstructed plane, W is the filter function in spatial wave number domain defined as [3],

$$W(k_x, k_y) = \begin{cases} 1 - \dfrac{\exp\{(k_r/K_c - 1)/\alpha\}}{2}, & k_r \le K_c \\ \dfrac{\exp\{(1 - k_r/K_c)/\alpha\}}{2}, & k_r > K_c \end{cases}, \quad k_r = \sqrt{k_x^2 + k_y^2} \tag{2}$$

where K_c is cut-off wave number, α is the parameter which decides the shape of slope. This filter function is used as elimination of higher component in spatial wave number domain in which the errors caused by finite, discrete aperture are included. In this investigation, two parameters, K_c and α, are varied, and the results of sound source localization are compared.

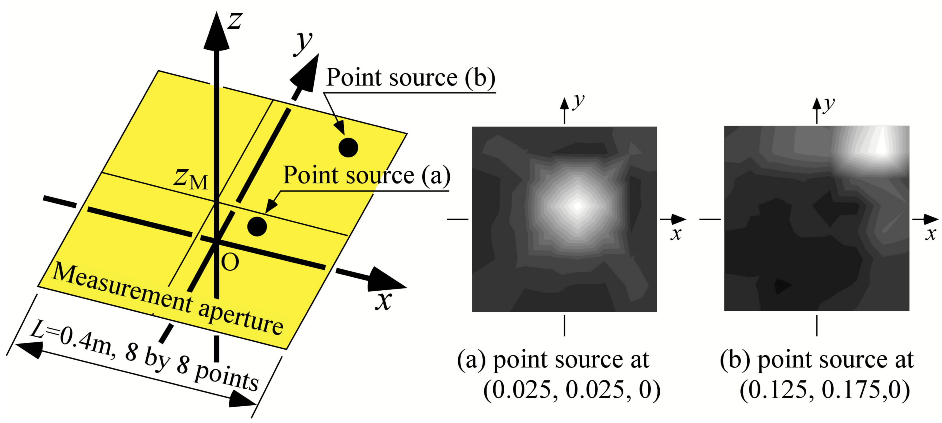

Figure 1: Configuration of simulation and examples of sound source localization.

2.2 - Results

An evaluation value of NAH calculated from the reconstructed distribution at z=0 is introduced here and the results are compared by these evaluation values, which is defined as,

$$ev = \sqrt{\frac{p(k,l)^2}{\dfrac{1}{N-1}\left\{\sum_{i,j}^{N} p(i,j)^2 - p(k,l)^2\right\}}} \tag{3}$$

where $p(i,j)$ is the reconstructed plane, $p(k,l)$ is the magnitude at the nearest point to the source, N is the number of discrete points in reconstructed plane. This means the ratio of the height of the peak appears on the location of sound source to the other distributed values.
Figure 2 shows the variation of evaluation values corresponding to the various filters. The appropriate filters satisfying the both source conditions, (a) and (b), are selected from figure 2 as follows; $K_c = 0.4\pi/d$ and α=0.4 at 500 Hz, $K_c = 0.5\pi/d$ and α=0.2 at 1000 Hz, $K_c = 0.6\pi/d$ and α=0.1 at 2000 Hz, where d is the spacing between measurement points.
The shapes of optimal filters are shown in Figure 3. There is common characteristic that the filter shapes rise in the region of 43 rad/m.

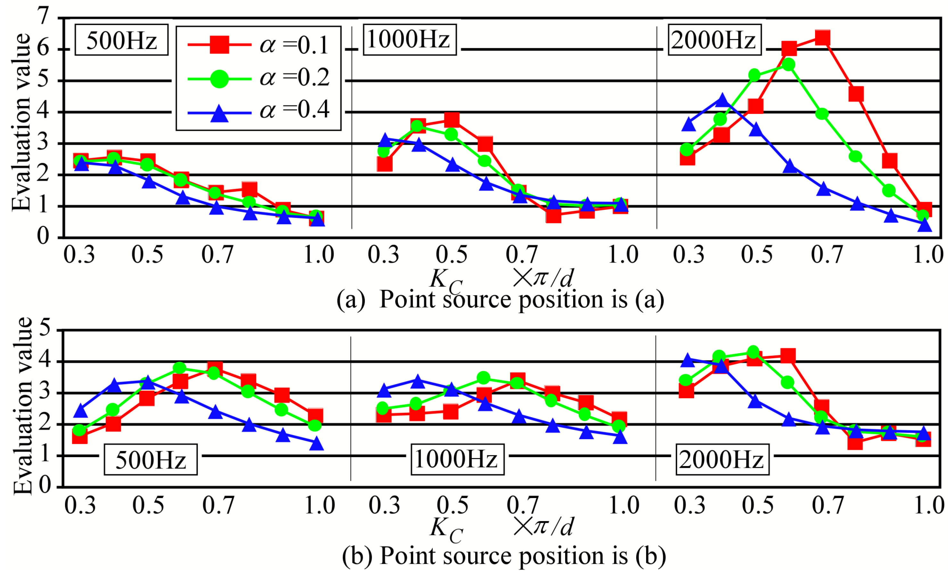

Figure 2: Variation of evaluation values corresponding to the various filters at $z_{\rm M}$=0.1.

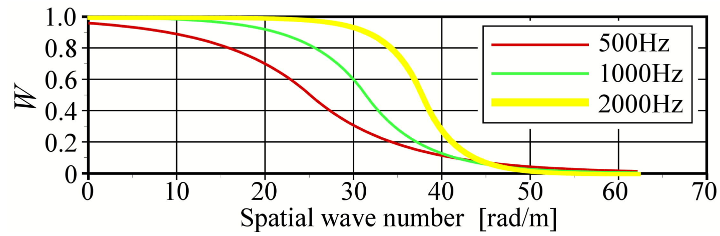

Figure 3: The shapes of optimal filters at $z_{\rm M}$=0.1.

3 - SPATIAL RESOLUTION

One of the features of NAH is high spatial resolution, but the proposed filter shown in figure 3 reduces the spatial resolution to equivalent to a wavelength. Figure 4 shows the results of the localization of adjacent two point sources in phase, in which the filters shown in figure 3 are applied. The distance between the measurement aperture and point sources is 0.1m, and the spacing of two point sources is 0.1 m. In all the results, only one peak is indicated, so two point sources cannot be recognized.

The identification of two point sources can be achieved by approaching the measurement aperture to the sources, and the cut-off wave number of the filter is increased. Figure 5 shows the variation of evaluation value of the localization of adjacent two point sources with the measurement aperture at z=0.05 m. In this condition, the good estimation is provided with higher K_c. Figure 6 shows the results of sound source localization estimated from the measurement aperture at z=0.05 m with the filter of $K_c = \pi/d$, α=0.4 selected from figure 5. Two point sources are recognized at each frequency.

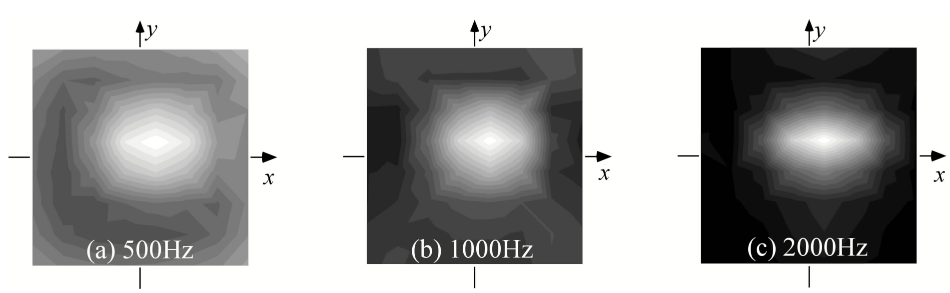

Figure 4: Results of adjacent two point sources localization at $z_{\rm M}$=0.1.

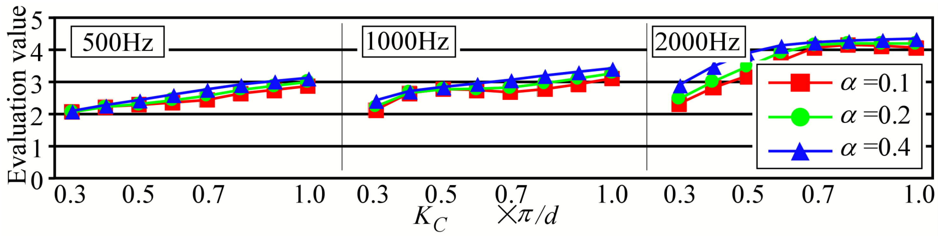

Figure 5: Variation of evaluation values corresponding to the various filters at z_{M}=0.05.

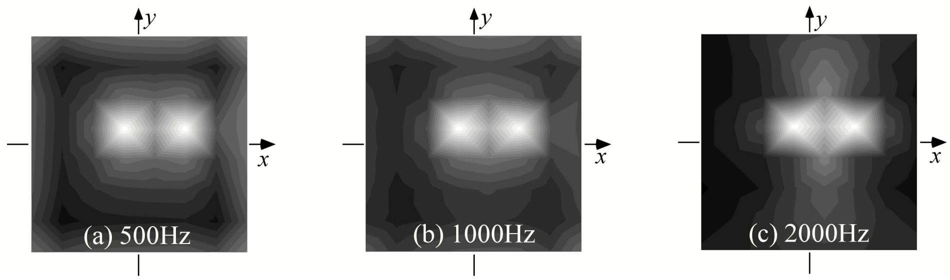

Figure 6: Results of adjacent two point sources localization at z_{M}=0.05.

4 - SUMMARY

The localization of sound sources by NAH can be realized with the handy 2-D microphone array. The small measurement aperture can be applied to the NAH with the optimal filter in spatial wave number domain, whose shape of function is decided at each frequency.

The procedure of sound source localization for the machinery is proposed as follows; at first, the sound source localization is carried out at various view-angles to the target with handy array and simultaneous measurement system, as taking photographs. By the measurements at different angles, the location of sound source in terms of normal direction to the measurement aperture can be specified. After the noteworthy point is specified, the handy array is brought near the point, and the cut-off wave number is increased for high resolution of the NAH, then the sound source localization is carried out for precise image.

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