Development of the Double NAH method

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ABSTRACT

There are several types of sound localization methods. But in sound localization of low frequency noise, all methods do not have enough resolution in reconstructed images. In this paper, the new localization method, Double Nearfield Acoustic Holography method is proposed. This method is converted method of conventional Nearfield Acoustic Holography method, and the purpose of this method is to improve the resolution of low frequency sound localization. In this paper, the theory of proposing method is explained. The several numerical simulations are done to verify the resolution of reconstructed images about sound localization in low frequency. In this paper, some numerical simulation results are explained. As a result, It is verified that the proposing method has better resolution on reconstructed images compared with conventional Nearfield Acoustic Holography method, in sound localization of low frequency sound sources.

1. INTRODUCTION

There are several types of sound localizing method. These methods are used for the noise localization of prototypes of mechanical products, to detect the noise sources. In middle frequency around 1kHz which is most sensitive for the human ears, almost localizing method is effective. In high frequency around 10kHz, the sound localization methods take long time for measurement. We have developed a new localization method, which can measure quickly but have some deterioration in resolution.

In low frequency blow around 100Hz, all localization method do not have enough resolution in reconstructed images. For this purpose, I tried to make new localization method, “Double Nearfield Acoustic Holography (DNAH) method.” This method has doubled measurement planes, and this method is a converted method of the conventional Nearfield Acoustic Holography (NAH) method.

In this paper, the new computation theory of reconstruction analysis of proposing method is explained. And some numerical simulations to verify the preciseness of proposing method are done. In this paper, the simulation results of proposing DNAH method are shown.

2. DOUBLE NEARFIELD ACOUSTIC HOLOGRAPHY (DNAH) METHOD

2.1 Measurement Settings

The conventional NAH method needs measurement of sound field on one measurement plane. This measurement plane is set in the distance of nearfield sound area from the sound sources, the surface of the machine. The figure 1 shows the draft of measurement of NAH method. On the measurement plane, the measurement points, which are the points that the sound pressure is actually measured, are located as mesh pattern. The conventional Acoustic Holography method, the primitive method of acoustic holography, and which is also called as Microphone Array method, also uses single measurement plane configuration.

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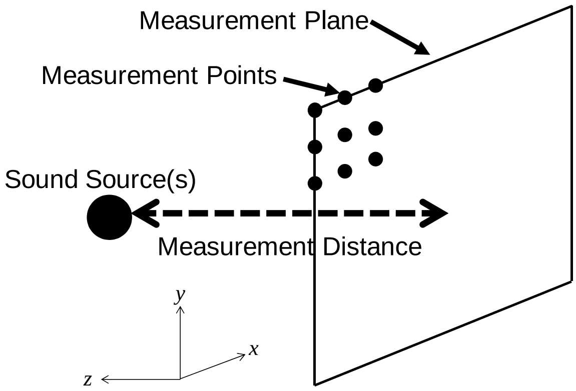

Figure 1 – This is an explanation of measurement of NAH method.

In the proposing DNAH method, the measurement plane is doubled. The figure 2 shows the draft of measurement of DNAH method. On the doubled measurement planes, the measurement points are located as mesh. The sound pressures are measured at measurement points on the front and rear measurement planes.

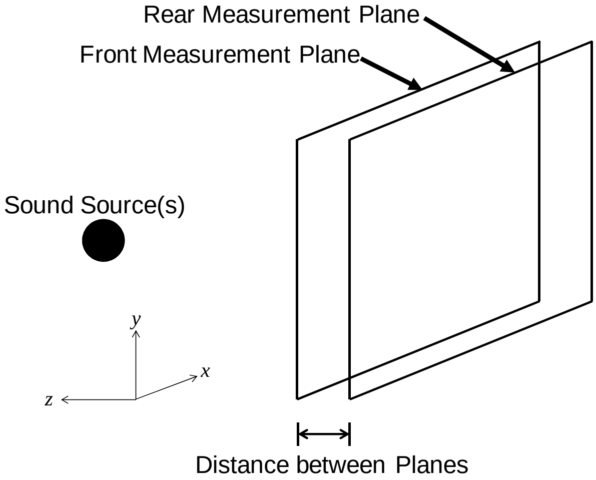

Figure 2 – This is an explanation of measurement of DNAH method.

This style of measurement is possible only by using microphone traverse system, but is not possible by beam forming system.

2.2 Reconstruction Calculation

The reconstruction computation of the original NAH method is explained in figure 3.

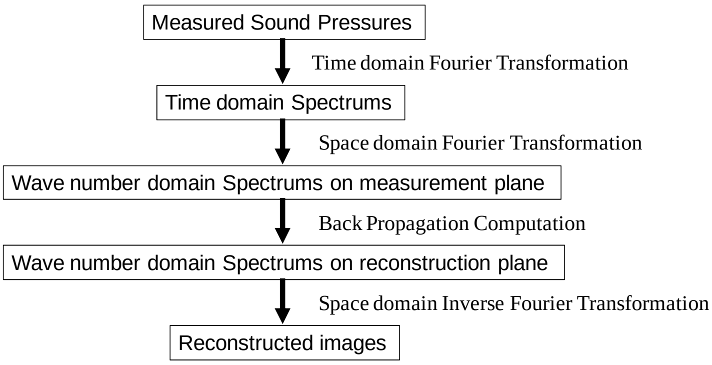

Figure 3 – This is the explanation of computation steps of reconstruction in NAH method.

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In the NAH method, the measured sound pressures are divided into the spectrums of each frequency by time domain Fourier transformation. The following steps of reconstruction are calculated for each spectrum. The next step is the 2 dimensional Fourier transform in the space domain. The result of this transform is 2 dimensional wave number domain spectrums on the measurement plane. From these spectrums, the 2 dimensional wave number domain spectrums on reconstruction plane (i.e. the surface which is estimated as sound sources are exist) are computed by the back propagation computation. The formula of back propagation computation is as follows.

$$G(k_x, k_y, z) = e^{iz\sqrt{k^2 - k_x^2 - k_y^2}} \tag{1}$$

In this equation, z is distance between the measurement plane and reconstruction plane, and k is the wave number of sound of analyzing frequency. The k_x and k_y are the wave number frequency of each direction on the measurement plane. By multiplying G in the equation 1, the wave number domain spectrums on the reconstruction plane is calculated. At last, the sound pressure distribution is calculated by the inverse 2 dimensional space domain inverse Fourier transformation. This distribution is the reconstructed image.

The equation 1 is the equation of the theoretical back propagation. In proposing DNAH method, the actual value of back propagation is computed from the datum difference between front and rear measurement planes. If the $\sqrt{k^2 - k_x^2 - k_y^2}$ in the equation 1 is a positive value, the absolute and argument of complex value G are as follows.

$$|G| = 1 \tag{2}$$

$$\arg(G) = z\sqrt{k^2 - k_x^2 - k_y^2} \tag{3}$$

From equation 2 and 3, it is found that the absolute of G is constant value, 1, and argument of G is proportional to the distance z. In the DNAH method, instead of equation 3, the equation 4 is used.

$$\arg(G) = z\left\{\left(\arg(P_f) - \arg(P_r)\right)/d\right\} = \frac{z}{d}\left\{\arg(P_f) - \arg(P_r)\right\} \tag{4}$$

In this equation, d is the distance between the front and rear measurement planes, and P_f and P_r are the wave number domain spectrums of front and rear measurement planes. In the equation 3, the part of equation, $\sqrt{k^2 - k_x^2 - k_y^2}$ is logical shift rate of phase per z direction. In the DNAH method, the sound field is measured at the two points in z direction. Therefore the “actual” shift can be calculated. The equation 4 is the calculation of it. In this equation, the difference of phase of wave number domain spectrums between front and rear measurement planes, is divided by the distance between the both planes.

If the $\sqrt{k^2 - k_x^2 - k_y^2}$ in the equation 1 is a negative value, the absolute and argument of complex value G are as follows.

$$|G| = e^{-z\sqrt{k_x^2 + k_y^2 - k^2}} \tag{5}$$

$$\arg(G) = 0 \tag{6}$$

In this paper, since the purpose of DNAH is limited for low frequency sound localization, the wave number k becomes small. Therefore the equation 2 and 4 are used for back propagation analysis of the proposing DNAH method. In the figure 4, the computation steps of back propagation analysis in DNAH method is explained.

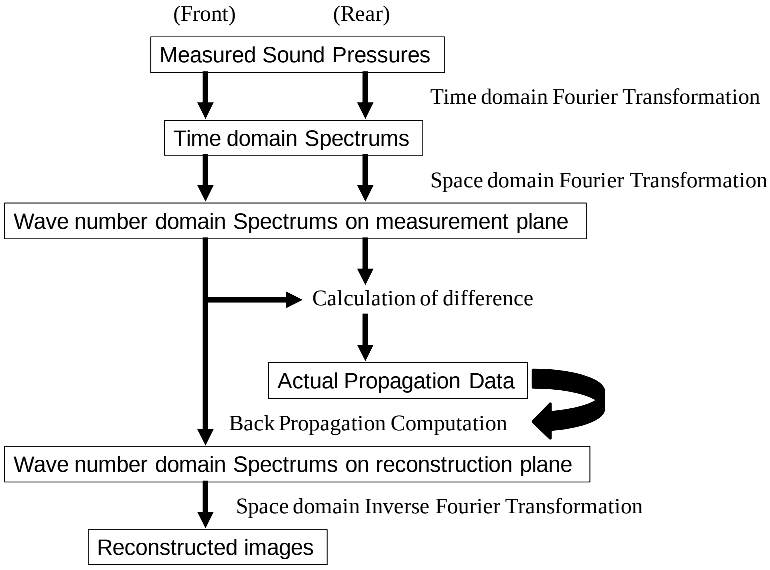


Figure 4 – This is the explanation of computation steps of reconstruction in DNAH method.

3. NUMERICAL SIMULATION

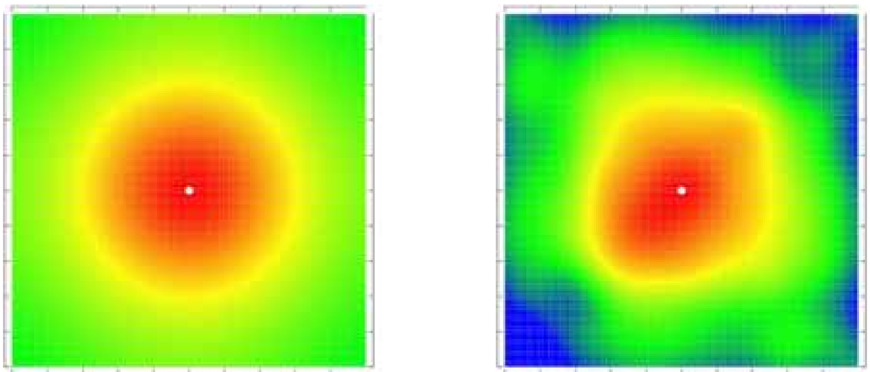
To verify the preciseness of proposing DNAH method, I did some numerical simulations. In this paper, the preciseness in low frequency sound localization is discussed. Low frequency sound, below 100Hz, is quite difficult for sound localization methods because of its long wave length. The numerical simulations are computed for 100Hz or 10Hz point sound source(s), by conventional NAH method and proposing DNAH method. The measurement settings are shown in table 1.

Table 1 – Measurement settings in Numerical simulations

Measurement distancd	0.1m
Distance between Front and Rear Measurement planes	0.2m
Largeness of Measurement plane	[X]1.0m [Y]1.0m
Numbers of Measurement points	[X]11 [Y]11
Pitch of measurement points	[X]0.1m [Y]0.1m
Sound Frequency	100Hz or 10Hz

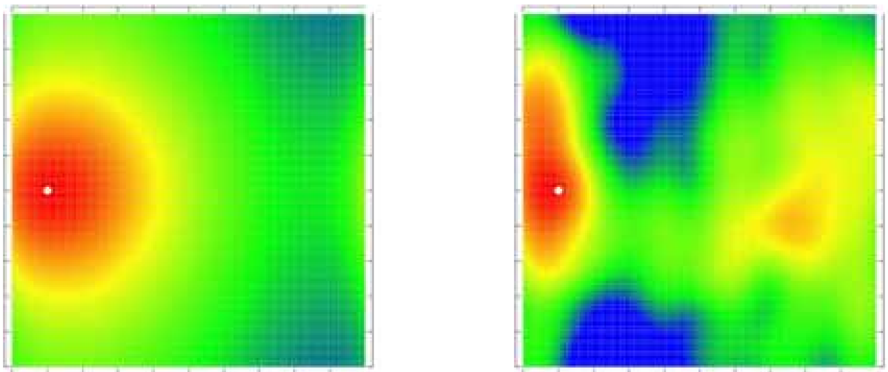
The reconstructed images of results of numerical simulations are shown in following figures. In the images, the white dot(s) is point source location(s). The largeness of reconstructed images are 1m X 1m, and the origins of each axis are set at the left bottom side of each images.

The Figure 5 to 7 are numerical simulation results of 100Hz single point source.



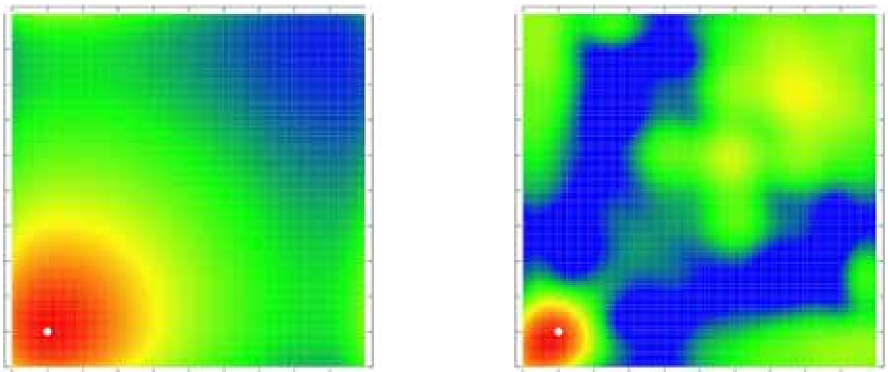
(Conventional NAH method) (Proposing DNAH method)

Figure 5 – The numerical simulation results of single point source located at (0.5,0.5) .



(Conventional NAH method) (Proposing DNAH method)

Figure 6 – The numerical simulation results of single point source located at (0.1,0.5) .

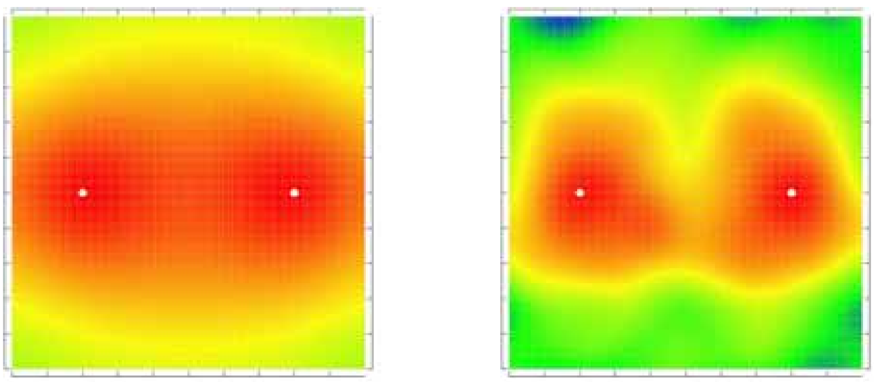


(Conventional NAH method) (Proposing DNAH method)

Figure 7 – The numerical simulation results of single point source located at (0.1,0.1) .

From these figures, the images by proposing DNAH method shows the shrunk image of sound source location compared with the images by NAH method. It means the good resolution of proposing DNAH method.

The figure 8 shows the reconstruction images of 100Hz dual same phase point sources.

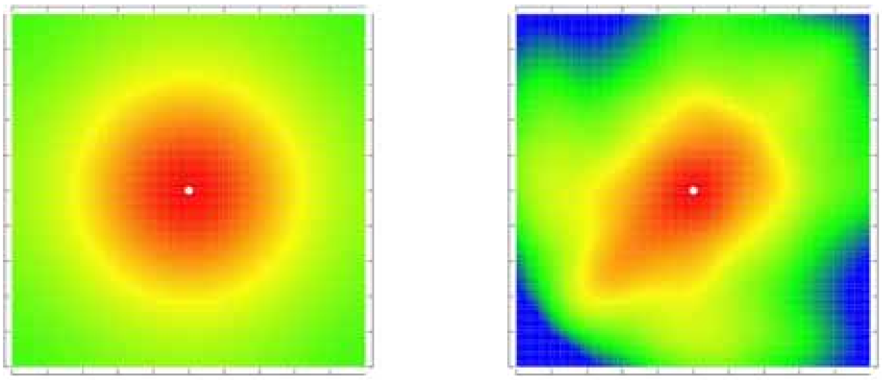


(Conventional NAH method) (Proposing DNAH method)

Figure 8 – The numerical simulation results of dual same phase point sources located at (0.2,0.5) and (0.8,0.5) .

The image by the proposing DNAH method shows the absolutely divided images pointing out the 2 sources location. However the image by conventional NAH method shows the blurry image.

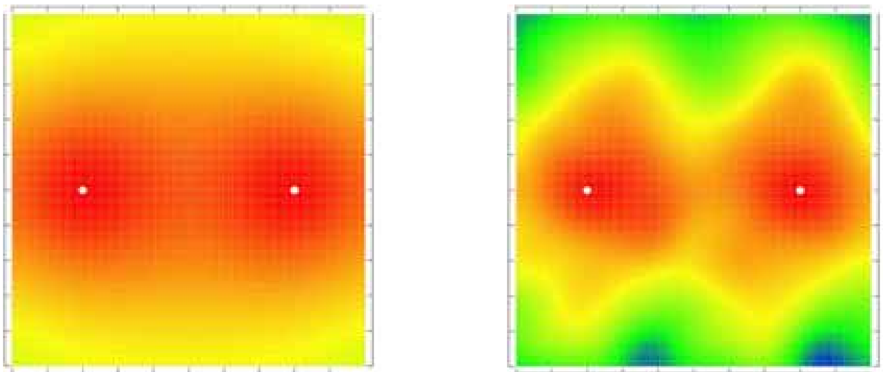
The Figure 9 is numerical simulation results of 10Hz single point source. The 10Hz sound wave is almost lower limit frequency for human auditory. In these figures, the point sound source is located at center of images. The other images corresponding to figure 6 and 7 are omitted in this paper because of same tendency with images of 100Hz.



(Conventional NAH method) (Proposing DNAH method)

Figure 9 – The numerical simulation results of single point source located at (0.5,0.5) .

The figure 10 shows the reconstruction images of 10Hz dual same phase point sources.



(Conventional NAH method) (Proposing DNAH method)

Figure 10 – The numerical simulation results of dual same phase point sources located at (0.2,0.5) and (0.8,0.5) .

From the images in figure 9 and 10, it is also said in 10Hz that the reconstruct image by proposing DNAH method has sharper image than the image by conventional NAH method.

4. CONCLUSIONS

In this paper, a new sound localization method, DNAH method is proposed. This method is converted method of conventional NAH method. The DNAH method needs doubled measurement plane in the measurement of sound field. The analyzing theory, the way of reconstruction computation of DNAH method is explained. And the performance of DNAH method as low frequency sound localization method is studied by numerical simulations.

As a result, the DNAH method shows sharper images than NAH method in numerical simulation results. Therefore it is said that the DNAH method which is newly proposed in this paper, has better resolution in low frequency sound localization than NAH method.

REFERENCES

1. Earl G. Williams, Fourier Acoustics, Academic press, 1999.
2. M. Nagamatsu, Experimental Results of Converted NAH Method, JSME international Journal Series C Vol49. No.3, 2006, pp.670-674