I am now developing the new sound localization method, the Double Near-field Acoustic Holography (DNAH) method. This method can localize the location of low frequency sound source precisely. In this method, the measurement plane of NAH method is doubled. To measure the sound information on the doubled measurement plane, two microphones which move vertically and horizontally are used. In former research, the distance between two microphones, the distance between two measurement planes is 0.2m. In this paper, the experiments are carried out with variable distance. As the result, it is verified that the DNAH method is also effective in the case that the distance between two microphones is short, several cm. Therefore, it is proved that the intensity probes can be used for measurement of DNAH method. 

Keywords: noise localization, acoustic holography

1. Introduction

I am now developing a new sound localization method, the Double Near-field Acoustic Holography (DNAH) method. The purpose of this method is to improve the resolution of sound localization in low frequency sound field. Currently, there is no sound localization method which has high resolution imaging for low frequency sound sources. Formerly, I did several experimental results about low frequency sound localization, and verified that the DNAH method has good resolution as low frequency sound localization method.

The DNAH method is converted method of conventional near-field acoustic holography (NAH) method, which has most precise resolution in conventional sound localization methods. In this method, the measurement plane in the measurement of NAH method, is doubled. Therefore the measurement of DNAH method needs a lot of information than NAH method. In my experiments, scanning type measurement system is used, and 2 microphones are used as scan microphone in measurement, compared with one microphone in NAH method.

In this research, to shorten the gap between 2 microphones is tried. If the gap between 2 microphones is shorten, the intensity probe which is widely used in the sound measurement area can be used. Therefore the measurement of DNAH method becomes easy. Furthermore, the measurement may become more precise because the intensity probe is made well calibrated in factory.

In this paper, some experimental results of low frequency sound localization are explained.
2. The theory of Double Nearfield Acoustic Holography (DNAH) method

In this chapter, the measurement setting and analysis theory of proposing DNAH method is explained. Because DNAH method is converted from conventional NAH method, the explanation of DNAH method is based on NAH method.

2.1 The measurement setting of DNAH method

The conventional NAH method needs measurement of sound field on one measurement plane. This measurement plane is set in the distance of the nearfield sound area from the sound sources, the surface of the machine. The figure 1 shows the draft of measurement of Conventional NAH method. On the measurement plane, the measurement points, which are the points that the sound pressure is actually measured, are located as the 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.

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

2.2 The Analysis of DNAH method

In the holographic method, the analysis calculation is required to acquire the visualized images. This calculation is called as the reconstruction calculation, and the visualized image is called as the reconstructed image. The figure 3 shows the computation steps of reconstruction calculation of the conventional NAH method.

Figure 3: The analysis steps in conventional NAH method.

In the conventional NAH method, the measured sound pressures are divided into the spectra 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. From these spectra, the 2 dimensional wave number domain spectra 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.

\[ G(k_x, k_y, z) = e^{i\sqrt{k^2-k_x^2-k_y^2}z} \]  \hspace{1cm} (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 spectra 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 inner part of \( \sqrt{k^2-k_x^2-k_y^2} \) in the equation 1 is a positive value, the absolute and argument of complex value \( G \) are as follows.

\[ |G| = 1 \]  \hspace{1cm} (2)
\[ \arg(G) = z\sqrt{k^2-k_x^2-k_y^2} \]  \hspace{1cm} (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.

\[ \arg(G) = z\left\{\frac{\arg(P_d) - \arg(P_f)}{d}\right\} = \frac{z}{d}\left\{\arg(P_d) - \arg(P_f)\right\} \]  \hspace{1cm} (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, \( \sqrt{k^2 - k^2_f - k^2_r} \) 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 inner part of \( \sqrt{k^2 - k^2_f - k^2_r} \) in the equation 1 is a negative value, the absolute and argument of complex value \( G \) are as follows.

\[
|G| = e^{-\sqrt{k^2 - k^2_f - k^2_r}}
\]

arg\((G) = 0\) \hspace{1cm} (5)

In the proposing method, 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: The analysis steps in proposing DNAH method.](image)

3. The experimental setting and experimental equipment

In this paper, the performance of DNAH method as sound localization method in low frequency is discussed by some experiments. The experiments are carried out at 100Hz and 40Hz. In former presentation, the outperformance of proposing DNAH method in low frequency sound localization is identified. In this document, the experiments are carried out to research how the outperformance of this method may change in case that the gap between 2 microphones is short. The measurement method is scanning method. Two microphones which move vertically and horizontally are used as scanning microphones. In reconstruction computation of conventional NAH method, only the datum measured by front scanning microphone is used. In reconstruction of proposing DNAH method, both of front and rear datum are used. In order to investigate the effect of gap length of 2 microphones, the gap length is changed from 0.2m to 0.025m. Though the sound of experiments is constant, the reference signal is input from the signal generator which makes the signal for the speaker.

The experiments are executed in the laboratory environment. The largeness of measurement plane is 1m x 1m. And the numbers of measurement points are 11 x 11 points. The measurement distance
is 0.1m. The sound source is a small speaker. The diameter of the speaker is 8cm. The figure 5 is a photo of measurement equipment of experimentations.

![Image](image.png)

**Figure 5: The measurement equipment.**

4. **The experimental results**

In this chapter, the experimental results are explained, in order to test the effectiveness of variable gap between front and rear scan microphone. In each images, the highest level in image is painted in red, and -5db is painted yellow, -10db is painted green, -15db or under is painted blue. The white dot indicate the position of the centre of speaker.

4.1 **The experimental results for 100Hz sound source**

Firstly, the experimental results for 100 Hz sound sources is shown. One sound source is located at centre of measurement planes. The parameter \( d \) is the gap length between 2 scan microphones.

![Image](image.png)

(Conventional NAH method) (DNAH method, \( d=0.20m \)) (DNAH method, \( d=0.10m \))
Figure 6: The experimental results. 100Hz single sound source located at centre.

From these experimental results, it is verified that the preciseness of DNAH method does not change due to the gap length between 2 microphones. The preciseness of DNAH method in low frequency is constantly better than conventional NAH method.

In the figure 7, the experimental results for right side sound source are shown.

Figure 7: The experimental results. 100Hz single sound source located at right side.

From these images, the proposing DNAH method show better results for low frequency sound localization. In the figure 8, the experimental results in case with the right under corner sound source.

Figure 8: The experimental results. 100Hz single sound source located at a corner.
The figure shows, same as the other cases, the effectiveness in low frequency sound localization. As a result, even if the gap length between 2 microphones becomes short, the proposing DNAH method shows the better resolution than the conventional NAH method.

4.2 The experimental results for 40Hz sound source

In this section, the experimental results for 40Hz single sound source are explained. In figure 9, the experimental results for single sound source with variable gap length are shown.

![Figure 9: The experimental results. 40Hz single sound source located at centre.](image)

By these images, the preciseness of proposing DHAN method dose not change, even if the gap length between 2 microphones changes. In the figure 10, the reconstructed images in case of right side single sound source is shown.

![Figure 10: The experimental results. 40Hz single sound source located at right side.](image)
Figure 10 shows the good results same as former results. In the figure 11, the reconstructed images for right low corner single sound source are shown.

![Figure 10](image1.png)  ![Figure 11](image2.png)

Figure 11: The experimental results. 40Hz single sound source located at a corner.

As a general, the proposing DNAH method shows the better results than conventional NAH method, in case of short gap length between 2 microphones.

5. Conclusion

The developing DNAH method shows the better resolution in its image in case that the gap between 2 scan microphones is short. Therefore, in developing DNAH method, the intensity probe which is widely used, can be used. If it is used, DNAH method is measured easy and precisely.

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