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Resolution Improvement of Low Frequency Noise Sources in Acoustic Holography

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ABSTRACT

The beamforming technique, which has been widely used in various engineering fields, is practical for identifying moving noise positions. However, this method has a disadvantage that it provides a low resolution in the low frequency range. Thus, the technique can not derive a specific noise source in low frequency ranges. Therefore, this study introduces a method of improving the resolution in the low frequency region based on the beamforming method. In order to improve the resolution, it is important to derive a point function which provides the relation between the actual sound source and a beamformer results. In addition, the optimization problem with iteration was applied to solve the ill-conditioned inverse problem. The algorithm developed in this study was investigated with a moving vehicle test.

INTRODUCTION

Generally, the noise signals generated from a moving sound source such as trains or cars is not stationary. Therefore, in order to derive the position of the sound source based on the measured signal, methods which is not sensitive to the measured signal are effective. From this point of view, the beamforming method using a microphone array is effective in visualizing the sound field of a moving sound source. However, the beamforming method has a disadvantage of low resolution in the low frequency range. This makes it difficult to obtain a detailed noise source in the low frequency range. Therefore, when various noise sources are distributed in the low frequency region, the exact positions of the noise source can not be confirmed by the beam forming method.

This paper presents a method to improve the noise source in the low frequency region based on the beamforming method. At first, an algorithm to realize the sound field visualization in the conventional beamforming method was investigated. From this analysis, the point spread function which provides the relation between actual noise source and the beamformer out was derived. Based on the point function and the beam power value, the position of the actual sound source can be more accurately predicted through the inverse problem. However, it has a disadvantage that the inverse problem can be ill-conditioned. Therefore, the inverse problem is approached by the optimization problem.

RESOLUTION IMPROVEMENT ALOGRITHM

Simulation tests about the various 96 channel arrays were performed in order to investigate source identification in the low frequency noise regions. First, three sources were located in a prediction plane as shown in Figure 1 and source location test at the frequencies of were conducted by using National Instrument's Microphone Array Startup. Figure 2 shows the resolution test result of the 96 channel rectangular array. The advantage of the rectangular array is simple development and installation. However, it has poor resolution in the high frequency by spatial aliasing. At the low frequency of 500 Hz, the three sources were not identified with the array. Moreover, lots of grating lobes were occurred in the high frequency of 2000 Hz.

In this study, the theoretical study on the resolution enhancement was performed. Figure 3 shows how the actual sound source is projected onto the prediction plane through various arrays on the measurement plane. At this point, propagation and beamforming functions were known functions. Therefore, it is possible to identify the location of the actual sound source through the inverse problem. However, generally this inverse problem can be ill-conditioned. Therefore, a mathematical approach is needed to solve the problem more stably.

The ill-conditioned problem was replaced by the non-negativity constrained least squares problem as followed. To make constraints non-negativity, the measured sound pressure is squared. Finally, optimization problem for a high-speed train was deduced. To obtain convergence of the source, iteration method was used to solve the problem. In addition, the beam output value at a specific position can be implemented as the sum of the sound source and the point spread function. Also, the actual sound source value can be represented by dividing the point function by the beam output value. Then, the solution can be derived through repetition until the estimated sound source value converges.

- *Initial states*

$$s^1(i,j) = \frac{\beta\,(n,m)}{T_{i,j}(n,m)} \tag{1}$$

- *Iterations*

$$s^k(i,j) = \frac{\beta\,(n,m)}{T_{i,j}(n,m)}$$

$$-\frac{\left[\sum_{j'=1}^{j-1} s^{k-1}(i',j')\,T_{i',j'}\,(n,m) + \sum_{j'=j+1}^{N} s^{k-1}(i',j')\,T_{i',j'}\,(n,m)\right]}{T_{i,j}(n,m)}$$

$$-\frac{\left[\sum_{i\prime=1}^{i-1}\sum_{j\prime=1}^{N} s^{k-1}(i',j')\,T_{i\prime,j\prime}(n,m) + \sum_{i\prime=i+1}^{M}\sum_{j\prime=1}^{N} s^{k-1}(i',j')\,T_{i\prime,j\prime}(n,m)\right]}{T_{i,j}(n,m)}$$

$$\tag{2}$$

- *Iteration condition*

$$s_n^{(i+1)} = \max(s_n^{(i)}, 0) \tag{3}$$

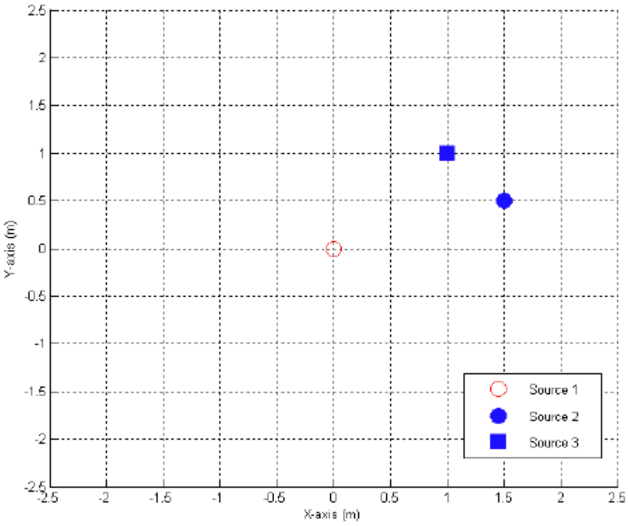
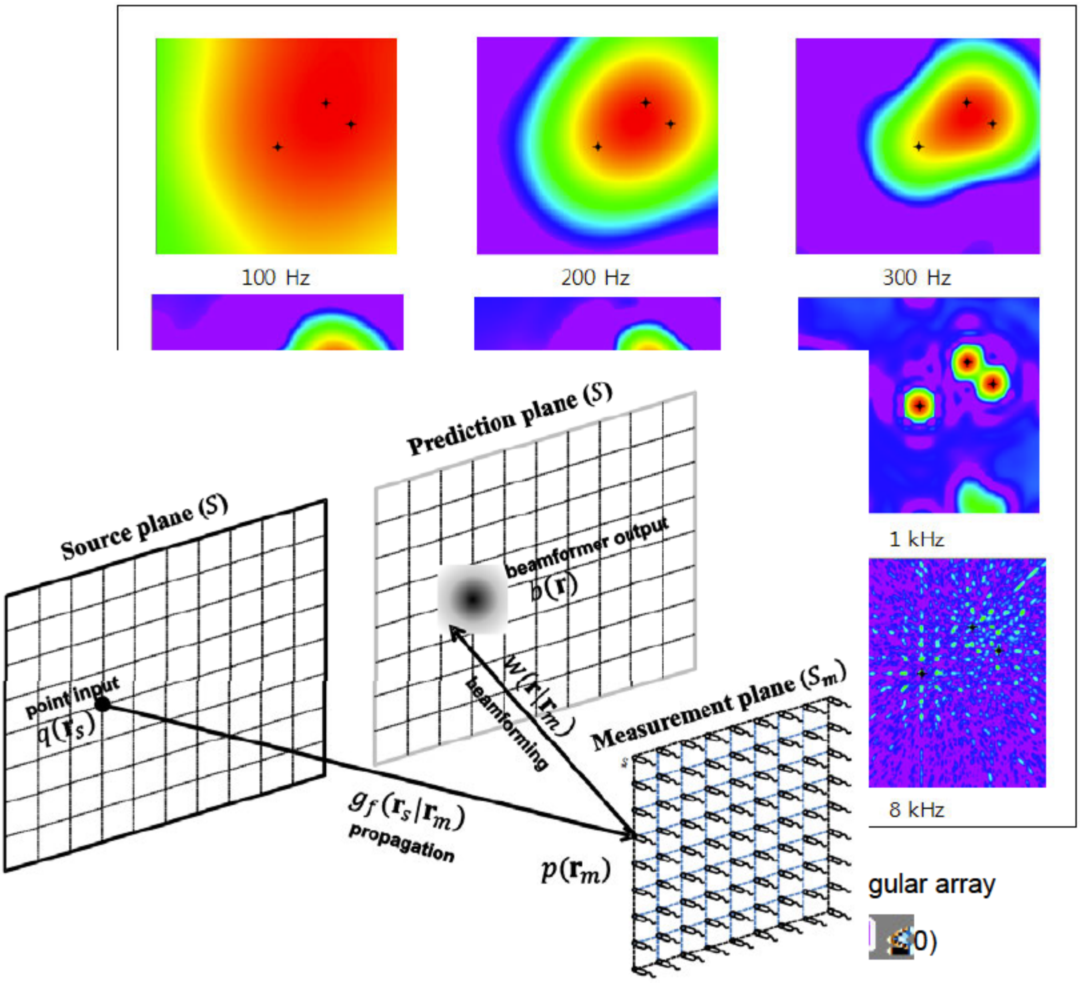


Figure 1: Source positions used for performance simulation



gular array

0)

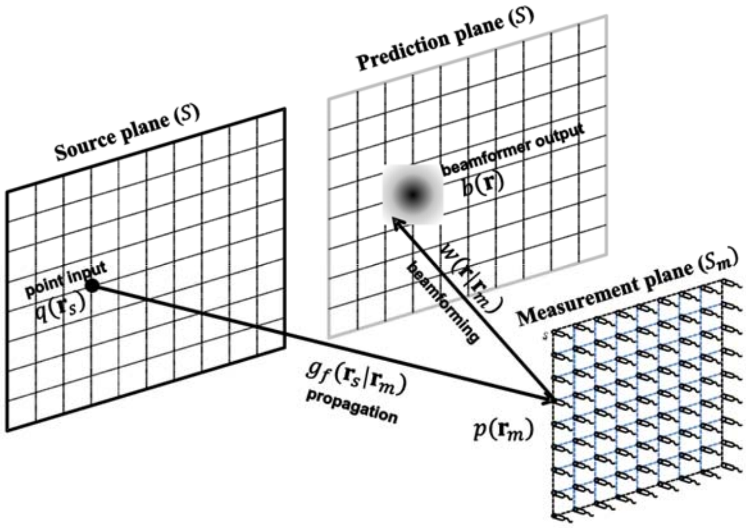


Figure 3 : Concept of point input in source plane and beamformer output in prediction plane

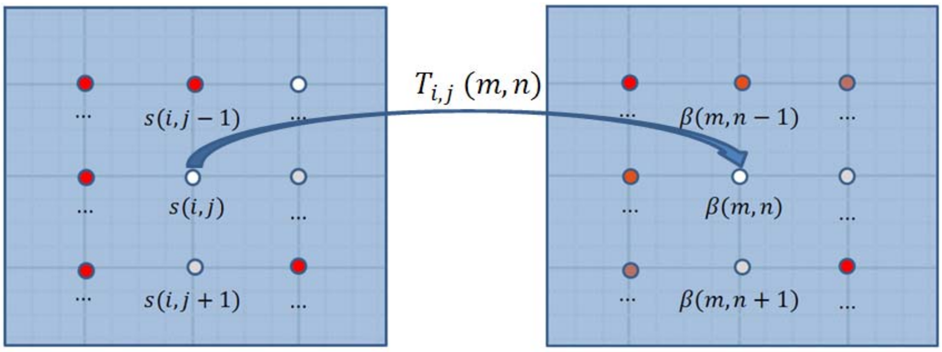


Figure 4 : Sources and prediction planes

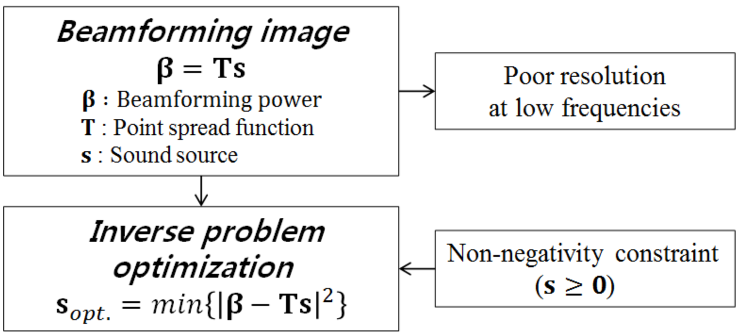


Figure 5 : Beamforming method and inverse problem optimization

APPLICATIONS AND DISCUSSIONS

In this study, a method of improving the resolution of low frequency sound source based on the sound field visualization is suggested. Point spread functions have been derived to improve the resolution of the low frequency domain. As previously suggested, the point function represents the relationship between the actual sound source and the beam output. In addition, the beam output can be derived from the array response function and the measured signal to the array sensor. Therefore, the position of the actual sound source can be estimated from the beam output value and the point function. Especially, iteration method is used to solve the inverse optimization problem.

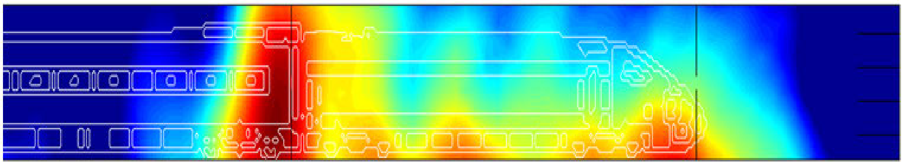
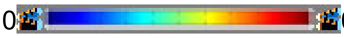


Figure 6 : Low-frequency noise sources of leading power car (300 Hz)

(Relative level (dB): -10  0)

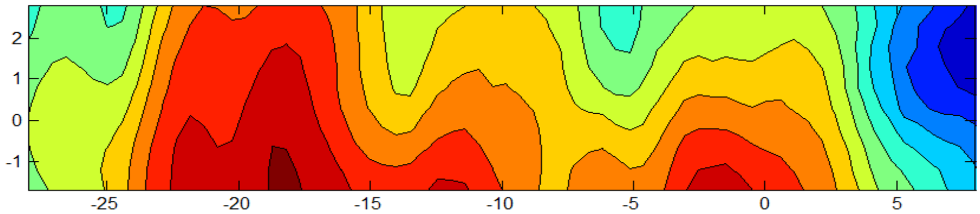


Figure 7 : Beampower image contour of power car

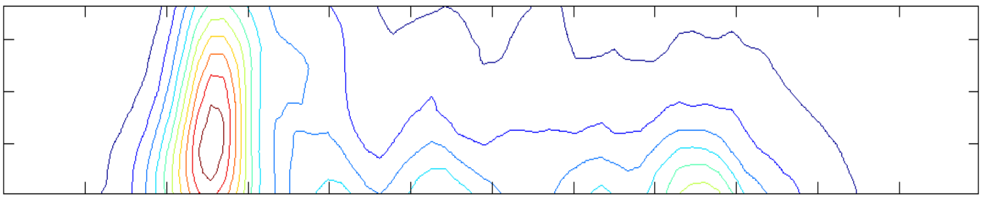


Figure 8 : Iteration method at initial state

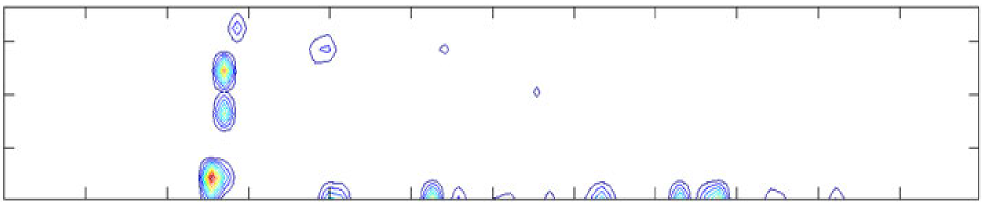


Figure 9 : Iteration method at convergence state

CONCLUSIONS

The beamforming technique, which has been widely used in various engineering fields, is practical for identifying moving noise positions. However, this method has a disadvantage that it provides a low resolution in the low frequency range. Thus, the technique can not derive a specific noise source in low frequency ranges. Therefore, this study introduces a method of improving the resolution in the low frequency region based on the beamforming method. In order to improve the resolution, it is important to derive a point function which provides the relation between the actual sound source and a beamformer results. In addition, the optimization problem with iteration was applied to solve the ill-conditioned inverse problem. The algorithm developed in this study was investigated with a moving vehicle test.

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