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DESIGN OF A SECONDARY SOURCE THAT MINIMIZES THE EFFECT ON THE REPRODUCTION AREA WHILE FORMING A QUIET AREA WHEN THE PRIMARY SOURCE IS PRESENT

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Sound generated by loudspeakers can be reproduced sound for listeners or noise for other people. To prevent spreading of noise, loudspeaker array and signal processing techniques can be used rather than a physical soundproof wall. However, this may have a negative effect on the listeners. In particular, this problem occurs when controlling the reproduction and quiet areas simultaneously. The purpose of this study is to develop a loudspeaker array system that allows the reproduced sound from the loudspeakers to be delivered to the listeners and not to others. The reproduction and suppression processes of this independent audio system are separated and controlled. A double-layer loudspeaker array is used and sequential process that removes noise and minimizes the effect on the listeners is applied.
Keywords: sound field control, loudspeaker array

1. Introduction

Loudspeaker arrays and sound field control techniques make it possible to simultaneously form sound reproduction and quiet areas [1]. The performance of the playback area and the quiet area affects each other's area. One control method [2] was introduced to control the importance of reproduction area and quiet area performance. However, it is difficult to grasp these effects if both areas are controlled at the same time. Although there is another research that forms only a quiet area by separating the control sequence, the influence of the reproduction area is not considered [3]. In this study, we propose a control method that separates reproduction and suppression processes instead of controlling reproduction area and quiet area simultaneously.

2. Problem definition

Fig. 1 shows the configuration. The primary source consists of four loudspeakers. Four sound sources are used, spaced 8 cm apart. The secondary source consists of double-layer loudspeaker array and is 2 meters away from the primary source. Twenty-four sound sources were used, and 12 sound sources are arranged at equal intervals of 8 cm in one array. The distance between the two arrays is 26 cm. The reproduction area is between the primary source and the secondary source, and the quiet area is behind the secondary source. Control microphone arrays for controlling the secondary source are located between the secondary source and the reproduction area, and the quiet area.

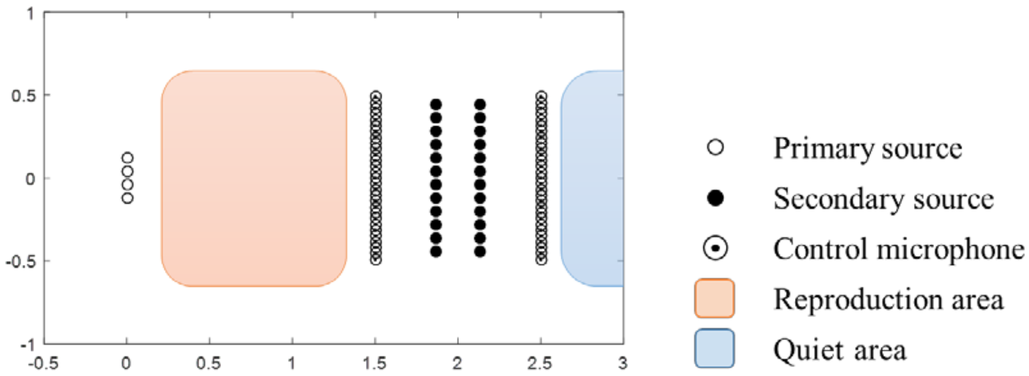

Figure 1: System configuration

The sound pressure at the suppression control microphones by the primary source can be expressed by using transfer function.

$$\mathbf{p}_{sp} = \mathbf{G}_{sp}\mathbf{q}_{p} \tag{1}$$

where, $\mathbf{q}_p$ is the primary source strength vector, $\mathbf{G}_{sp}$ is the transfer function matric between the primary source locations and the suppression control microphone locations. In the same way, the sound pressure at the suppression control microphones by the secondary source, and the sound pressure at the reproduction control microphones by the secondary source can be expressed.

$$\mathbf{p}_{ss} = \mathbf{G}_{ss}\mathbf{q}_{s} \tag{2}$$

$$\mathbf{p}_{rs} = \mathbf{G}_{rs}\mathbf{q}_{s} \tag{3}$$

The purpose of this study is design the secondary source that aims to reduce the total noise in quiet area and minimize the radiation in reproduction area when the primary source is present.

3. Designing the secondary source when the primary source is present

The primary source $\mathbf{q}_p$ is the sound source provides sound to the reproduction area. This primary source can be mono, stereo, or array, and it can also control the sound field in the reproduction area. The secondary source should be controlled so that the sound generated from the primary source does not propagate to the quiet area, and the effect on the reproduction area must be minimized as well. In order to achieve the control objective of the secondary source, the sum of the primary source and the secondary source is minimized at the suppression control microphones and the radiation of the secondary source to the reproduction control microphones is minimized. So we form the following objective function.

$$\min\ J = \kappa\left(\mathbf{p}_{sp} + \mathbf{p}_{ss}\right)^H\left(\mathbf{p}_{sp} + \mathbf{p}_{ss}\right) + (1-\kappa)\mathbf{p}_{rs}{}^H\mathbf{p}_{rs} + \beta\mathbf{q}_s^H\mathbf{q}_s \tag{4}$$

The first term minimizes the sum of the primary source and the secondary source at the suppression control microphones, the second term minimizes the influence of the secondary source at the reproduction control microphones, and the third term controls the input power of the secondary source.

κ determines the importance between the reproduction area and the quiet area performance. β is used to limit the magnitude of the input power or regularization.

Substituting Eq. (1, 2, and 3) into Eq. (4)

$$\min\ J = \kappa\left(\mathbf{G}_{sp}\mathbf{q}_p + \mathbf{G}_{ss}\mathbf{q}_s\right)^H\left(\mathbf{G}_{sp}\mathbf{q}_p + \mathbf{G}_{ss}\mathbf{q}_s\right) + (1-\kappa)\left(\mathbf{G}_{rs}\mathbf{q}_s\right)^H\left(\mathbf{G}_{rs}\mathbf{q}_s\right) + \beta\mathbf{q}_s^H\mathbf{q}_s \tag{5}$$

The primary source strength vector $\mathbf{q}_p$ already exists and the solution of Eq. (5) is as follows.

$$\mathbf{q}_s = -\frac{\kappa\mathbf{G}_{ss}^H\mathbf{G}_{sp}\mathbf{q}_p}{(1-\kappa)\mathbf{G}_{rs}^H\mathbf{G}_{rs} + \kappa\mathbf{G}_{rs}^H\mathbf{G}_{rs} + \beta\cdot\mathbf{I}} \tag{6}$$

4. Numerical simulation and results

Fig. 2 and Fig. 3 show the results of applying the control solution obtained from Eq. (6) in the configuration of Fig. 1. The primary source is reproduced without control, and 0.5 is used to the κ of Eq. (6). Both the primary source and the secondary source are monopole sources. The contour plots in Fig. 2 and 3 are the sum of the squares of all the frequency responses.

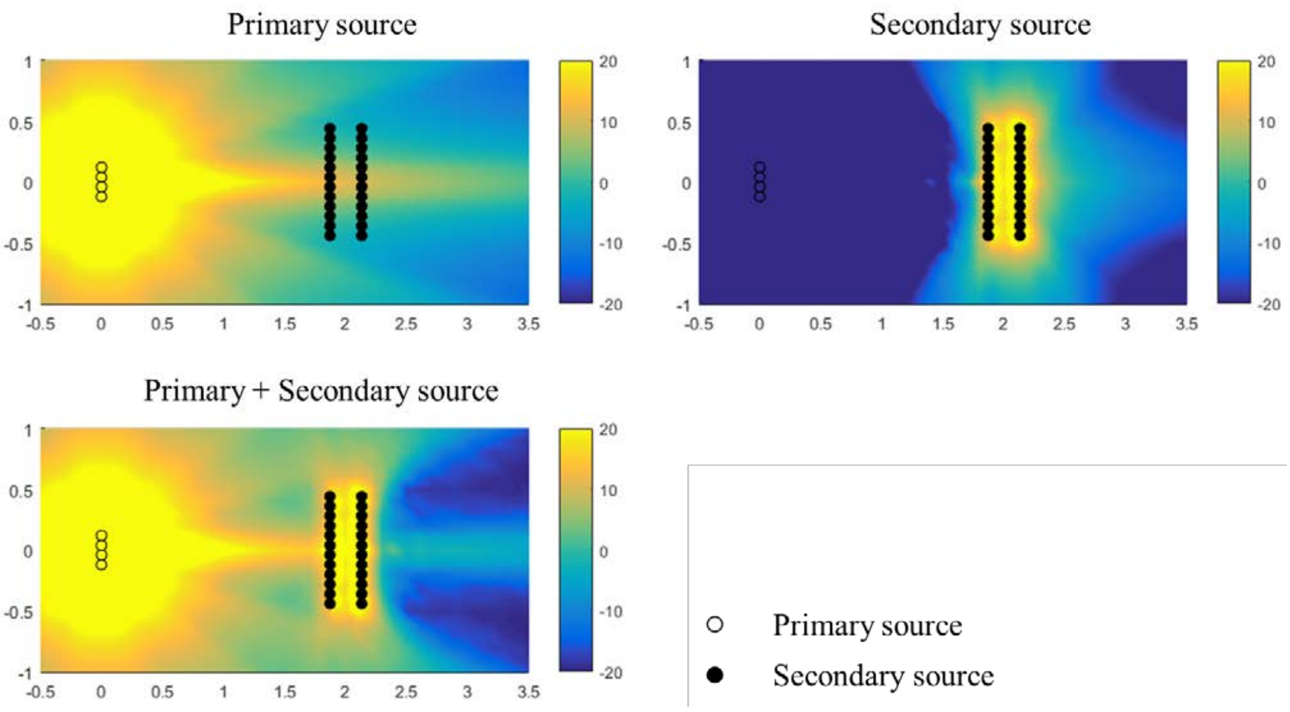

Figure 2: Control results. Only the primary source works, only the secondary source works, and the primary and secondary sources work together.

Fig. 2, it can be seen that the secondary source forms a quiet area and there is less sound propagating to the reproduction area. Fig. 3 shows the frequency responses in the reproduction and quiet areas. The effect by the secondary source is small in the reproduction area, and the sound pressure is reduced in the quiet area.

Separating the control process between the reproduction area and the quiet area has the following two advantages. First, it is possible to identify a reproduction area having the best performance that can be formed on the set configuration. Secondly, when forming a quiet area, the influence on the reproduction area can be known.

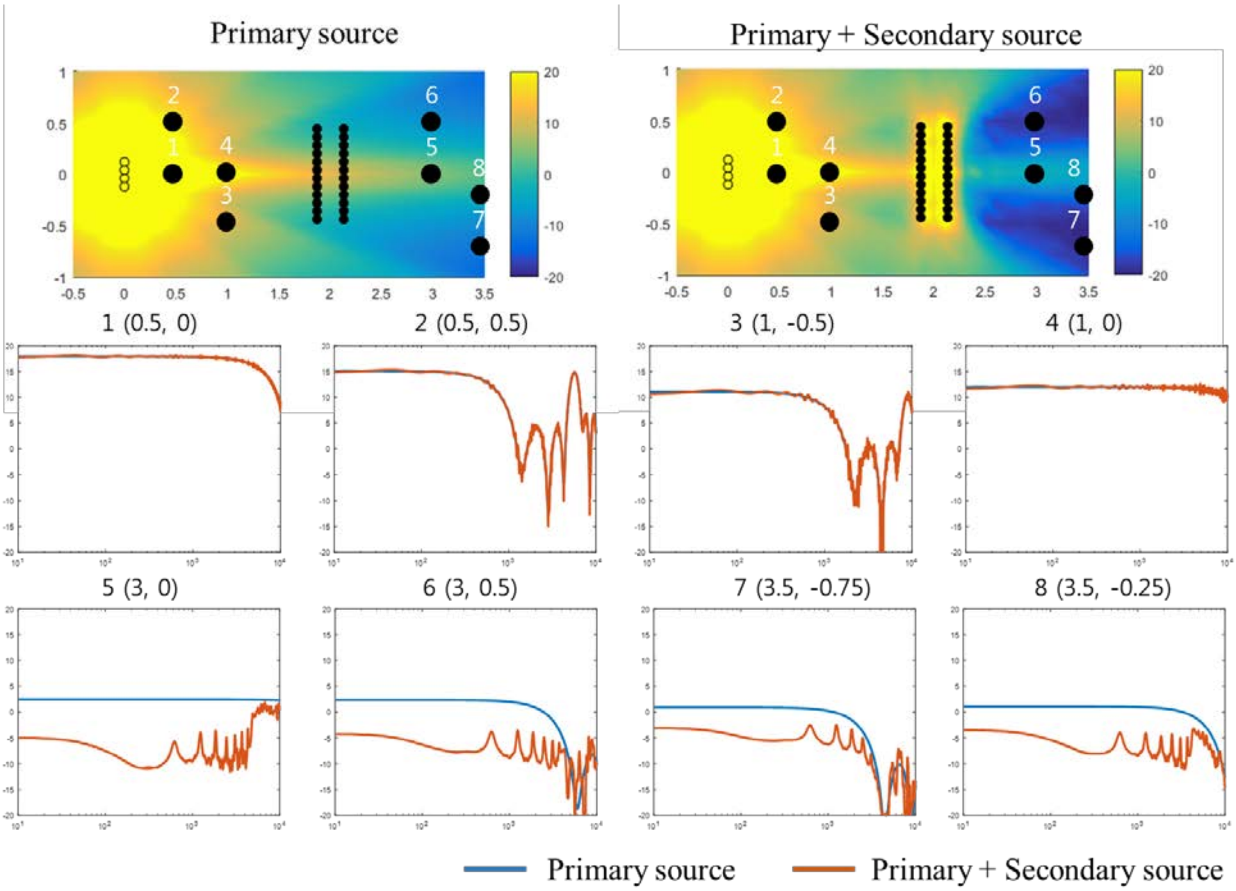

Figure 3: Control results. Only the primary source works and the primary and secondary sources work together frequency response at specific points.

5. Conclusion

Conventional sound field control technology simultaneously controlled the sound field of reproduction area and quiet area. Good performance in the reproduction area not deteriorate the sound quality of the reproduced sound, and good performance in the quiet area attenuates the noise (reproduction sound) to maintain a low sound pressure. But they are a trade-off relationship. There is a disadvantage that it is difficult to control the performances in the reproduction and quiet areas at the same time. Separating control sequences instead of controlling two areas at the same time makes it easier to understand the interference that occurs between them. We propose a control method that separates reproduction and suppression processes instead of controlling reproduction area and quiet area simultaneously.

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