Fundamental Study on Active Noise Control with Audio-Spot for Minimum Area Using Parametric Loudspeakers

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Noise pollution which often interferes with our lives is a huge social problem. Therefore, various methods have been studied to overcome noise problems. As one of a traditional method for suppressing the noise, an active noise control have been proposed. The active noise control can suppress a noise power by emitting an inverted phase signal to the original noise. However, the conventional active noise control have a problem that a control signal become a secondary noise outside control point due to a diffusion of it. Here, we have previously proposed a method for designing a minimum audio-spot with parametric loudspeakers. The previous method designs the audio-spot by individually emitting the carrier and sideband waves. It can design the audio-spot at minimum area where the emitted carrier wave spatially overlaps the emitted sideband waves. In this paper, we therefore propose a method for reducing the diffused control signal by applying the previous method to the active noise control. As a result of evaluation experiment, we confirmed the effectiveness of the proposed method.

1 INTRODUCTION

Noise pollution which arises from factories, traffic and living environments is a huge social problem. Therefore, a lot of methods have been studied to overcome this problem. As one of a
traditional technique for suppressing the noise, an active noise control\(^1\) (ANC) have been proposed. ANC can suppress a noise power by emitting an inverted phase signal to the original noise. However, the ANC with an electrodynamic loudspeaker have a problem that a control signal become a secondary noise outside a control point due to a diffusion of the control signal. For resolution of this problem, we focused on a parametric loudspeaker\(^2\) which can reproduce sound in only particular area. The parametric loudspeaker has a higher directivity by utilizing an ultrasound. It emits an amplitude modulated (AM) wave designed by modulating the amplitude of the ultrasound with an audible sound. The emitted AM wave is demodulated into the original audible sound\(^3\). Furthermore, we have previously proposed a separating emission method\(^4\) that it can design an audio-spot at only required point. The demodulated sound with the parametric loudspeaker is represented as difference tones between the carrier wave and sidebands on the frequency domain. The previous method designs the audio-spot on an overlapped area of these emitted waves with respective parametric loudspeakers. In this paper, we therefore propose an ANC method by applying the previous method for suppressing the noise power at the required point without arising the secondary noise outside there. The effectiveness of the proposed method is evaluated by measuring a sound pressure level (SPL) distribution in the evaluation experiment.

2 PARAMETRIC LOUDSPEAKER

2.1 Principal of a parametric loudspeaker

A parametric loudspeaker obtains a higher directivity by utilizing an ultrasound as a carrier wave. Figure 1 shows a flow of the audible sound reproduction with the parametric loudspeaker. It emits an intense AM wave designed by amplitude modulating the carrier wave with an audible sound. The AM wave \(V_A(t)\) is derived from Eqn. (1).

\[
V_A(t) = (1 + mV_s(t))V_c(t),
\]

\[
m = \frac{V_{sm}}{V_{cm}},
\]

\[
V_c(t) = V_{cm} \cos(2\pi Ft),
\]

\[
V_{sm}(t) = V_{sm} \cos(2\pi ft),
\]

where \(t\) represents a time index, \(V_c(t)\) and \(V_s(t)\) represent the carrier wave and the original audible sound, respectively. \(F\) and \(f\) represent their frequencies, \(V_{cm}\) and \(V_{sm}\) represent their maximum amplitudes, respectively. \(m\) represents an amplitude modulation factor. The AM wave consists of the carrier frequency and sidebands on the frequency domain as shown in Fig. 1. The emitted intense AM wave is self-demodulated into the original audible sound by nonlinear interaction in the air. The demodulated audible sound is represented as difference tones between the carrier and sidebands.

2.2 Design method for audio spot based on a separating emission

The parametric loudspeaker can easily transmit the audible sound to a specific area. However, if non-listeners are between the target listener and the parametric loudspeaker, the reproduced sound may be a noise for them. Therefore, we have previously proposed a designing...
method for minimum audio-spot based on the separating emission. Figure 2 shows an overview of the previous method. For designing the minimum audio-spot, it firstly divides the AM wave into the carrier and sideband waves by using a band-pass filter. Next, it individually emits these divided waves to the target point with parametric loudspeakers. The emitted waves are demodulated into the original audible sound on the only area where these waves overlaps.

![Fig. 1](image1.png)  
**Fig. 1** – The principle of an audible sound reproduction with a parametric loudspeaker.

![Fig. 2](image2.png)  
**Fig. 2** – Overview of the previous method.

### 3 SUGGEESSION ON ANC WITH MINIMUM AUDIO-SPOT

In this paper, we propose an ANC method for suppressing the noise power at only target area by applying the previous method. Figure 3 shows the overview of the proposed method. The proposed method suppresses the noise power by reproducing an inverted phase signal (control signal) of a noise signal to only control point. In Fig. 3, $x(t)$ and $y(t)$ indicate the noise and control signals, respectively. $g(t)$ indicates the transfer function between an error microphone and a parametric loudspeaker for an emitting sideband. $\hat{g}(t)$ indicates an estimated transfer function of $g(t)$. $h(t)$ indicates a transfer function between reference and error microphones. $e(t)$
represents an error signal derived from noise and reproduced control signals at the error microphone. Here, if a noise signal is sine wave, \( x(t) \) is represented as follows:

\[
x(t) = A_x \sin(2\pi f_x t),
\]

where \( A_x \) and \( f_x \) represent a maximum amplitude level and frequency of the noise signal, respectively. If \( g(t) \) and \( h(t) \) give an only delay to an input signal, \( y(t) \) is represented as follows:

\[
y(t) = -1 \times A_x \sin\left(2\pi f_x \left(t - \tau_h - \tau_g \right)\right),
\]

where \( \tau_h \) and \( \tau_g \) indicate delay time of \( h(t) \) and \( g(t) \), respectively. In this paper, the proposed method designs an adaptive filter based on Filtered-X algorithm\(^2\) for calculating \( y(t) \). Finally, the proposed method obtains the sideband \( y'(t) \) which is demodulated into \( y(t) \). \( y'(t) \) is obtained as follows:

\[
y'(t) = -1 \times A_x \sin\left(2\pi(F - f_x)\left(t - \tau_h - \tau_g \right)\right).
\]

When the proposed method emits \( y'(t) \) and the carrier wave \( c(t) \) to the control point, \( e(t) \) is represented as follows:

\[
e(t) = dem(t) + x'(t) = 0
\]

\[
dem(t) = -1 \times A_x \sin\left(2\pi f_x \right)\left(t - \tau_h \right),
\]

\[
= -1 \times x'(x),
\]

where \( dem(t) \) represents the demodulated signal at the control point by the proposed method. From Eqn. (8), it is confirmed that the proposed method can suppress the noise at only the control point by applying the previous method. Furthermore, the proposed method can reduce the secondary noise outside the control point.

![Fig. 3 – Overview of the proposed method.](image-url)
4 EVALUATION EXPERIMENT

We carried out an objective evaluation experiment to confirm the effectiveness of the proposed method. In this paper, the proposed method is comparing with the conventional ANC by measuring each distribution of SPL around a control point. We employed an ANC method with electrodynamic loudspeaker as the conventional ANC method.

4.1 Experimental conditions

We evaluate SPL distributions of each method. Figure 4 shows an arrangement of parametric loudspeakers, electrodynamic loudspeakers and microphones. Table 1 shows an experimental conditions. In measurement about the conventional method, an electrodynamic loudspeaker is arranged at the point of ELC in Fig. 3. In measurement about the proposed method, each parametric loudspeaker are arranged at points of PLC and PLs in Fig. 4. The control point is located at (0, 0) in Fig. 4. Sine wave (500 Hz) is emitted from ELN as the noise signal.

![Arrangement of loudspeakers and microphones in the evaluation experiment.](image)

**Fig. 4 – Arrangement of loudspeakers and microphones in the evaluation experiment.**

<table>
<thead>
<tr>
<th>Table 1 – Experimental conditions.</th>
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<tbody>
<tr>
<td>Sampling frequency</td>
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<tr>
<td>Quantization</td>
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<tr>
<td>Carrier frequency</td>
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<tr>
<td>Ambient noise level</td>
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<td>Noise source</td>
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<td>Environment</td>
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4.2 Experimental results

Figures 5 (a) ~ (c) show the experimental result. Figure 5 (a) shows the SPL distribution of the only noise around the control point. Figs. 5 (b) and (c) show SPL distributions by using conventional and proposed methods, respectively. Color of Figs. 5 (a) ~ (c) demonstrate the SPL at each measurement point. From these results, the noise level is suppressed more than 20 dB at
the control point by both methods. However, we confirmed the conventional method increases the noise level around (-0.5, 0.5). This cause is a diffusion of the control signal by using the electrodynamic loudspeaker. The proposed method can reduce the secondary noise power in contrast with the conventional method. This result demonstrates that the propose method is quite effective for suppressing the noise power without arising the secondary noise.

Fig. 5 – SPL distributions w/ and w/o each ANC method.

5 CONCLUSIONS

We proposed the new ANC method for reducing the secondary noise outside the control point based on the separating emission with the parametric loudspeakers. Results of the evaluation experiment, we confirmed the effectiveness of the proposed method. In future work, we will study an ANC method for suppressing a complex tone with parametric loudspeakers.

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7 REFERENCES


