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The Suppression for Undesired Reflection towards Audio Spot

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ABSTRACT

The loudspeaker is widely used for transmitting the sound wave. As the sound wave emitted by the loudspeaker is propagated in all directions, emitting the sound wave to only the specific area is difficult. The parametric loudspeaker which uses the ultrasound wave has been proposed to emit the sound wave to only the specific area by using non-linear distortion of the ultrasound. The sound wave emitted by the parametric loudspeaker has the sharp directivity. However, the sound wave is propagated to the undesired area by reflection. Therefore, suppression of the undesired reflection is crucial to emit the sound wave to only the specific area. The purpose of this study is to suppress the undesired reflection wave by using Active Noise Control (ANC) with the parametric loudspeaker. ANC is the method to suppress the sound pressure level of the noise by emitting a sound wave with the same amplitude but with the inverse phase by the noise-cancellation loudspeaker. In this study, the noise is defined as the first reflection wave because many reflection waves can be suppressed by suppressing the first reflection wave. However, the sound wave to suppress the noise is emitted in all directions, provided that the noise-cancellation loudspeaker is the conventional loudspeaker. Therefore, the sound wave to suppress the noise must be emitted by the parametric loudspeaker to avoid the sound diffusion by using the conventional loudspeaker. The evaluation experiment was conducted to verify the effectiveness of the proposed method. The direct sound wave was emitted at angles of 15, 30, 45, 60 and 75 degrees. The evaluation index is the noise suppression level of the reflection wave. In this evaluation, the frequency band from 500 Hz to 2000 Hz was used to calculate the noise suppression level because suppression of the high frequency noise by ANC is difficult and the parametric loudspeaker can not emit the low frequency sound. The result of the evaluation experiment demonstrated the effectiveness of the proposed method. Furthermore, this effectiveness was angle-independent.

INTRODUCTION

Recently, the loudspeaker is used to transmit the sound wave such as voice and music. However it is difficult to emit the sound wave to only the specific area because the conventional loudspeaker emits the sound wave in all directions. Therefore, the emitted sound wave is the noise for people who don't need it.

Furthermore, when there are a lot of loudspeakers in a space, it is difficult for people to only hear the desired sound wave because the sound waves overlap with other sound waves. To overcome these problems, the superdirective loudspeaker has been proposed to transmit the sound wave to only the specific area. Moreover, the method is called "audio spot" because the sound wave is transmitted such as light beam "spot light". The loudspeaker array and the parametric loudspeaker have been proposed in the studies of the superdirective loudspeaker [1]. To transmit to only the specific area, the loudspeaker array system requires many loudspeakers, but the parametric loudspeaker system requires only one loudspeaker. In this study, we focused on the parametric loudspeaker.

The parametric loudspeaker utilizes the higher directivity characteristic of the ultrasound. Therefore, the sound wave emitted by the parametric loudspeaker has a reflective radiation characteristic. However having the reflective radiation characteristic causes the problem that the sound wave is transmitted not only to the desired area but to the undesired area. To overcome this problem, the undesired reflection sound wave, which is transmitted to the undesired area, must be suppressed. In this study, we try to suppress the undesired reflection sound wave with ANC for transmitting the sound wave to only the specific area.

PALAMETRIC LOUDSPEAKER

The principle of the parametric loudspeaker

The parametric loudspeaker designs the higher directivity with the ultrasound as the carrier signal.

Figure 1 shows the flow chart about emitting the input signal with the parametric loudspeaker.

The audible input signal (Fig. 1 (a)), such as voice and music, is modulated into the amplitude modulation signal (Fig. 1 (c)) by the carrier signal (Fig. 1 (b)). It is emitted into the air by the parametric loudspeaker (Fig. 1 (d)). It generates the difference tone based on the nonlinear interaction between intense amplitude modulated ultrasound waves in the air. Since the parametric loudspeaker uses the ultrasound wave which has the higher directivity characteristic, the difference tone is transmitted to only the specific area called "audio spot". Therefore, the original input signal (Fig.1 (e)) reappears in "audio spot". Thus, the parametric loudspeaker designs the higher directivity.

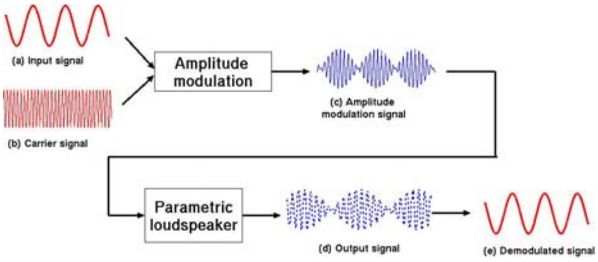

Figure 1 The flow chart about emitting the sound wave with the parametric loudspeaker.

A problem caused by the reflective radiation characteristic

The parametric loudspeaker can transmit the sound wave to only the specific area. However, the sound wave emitted by the parametric loudspeaker is transmitted not only to the desired area but also to the undesired area because of radiation characteristics and reflection conditions.

Figure 2 shows an example of a problem of the parametric loudspeaker caused by reflections. In case that the sound wave is transmitted to only Area A with the parametric loudspeaker, it is transmitted on the wall before its sound pressure level sufficiently attenuates. Furthermore, it is reflected to the Area B through the wall. Thus, the relation between the look direction of the loudspeaker and the wall causes that the sound wave is transmitted to the undesired area.

To overcome this problem, we need to suppress the undesired reflection sound wave for transmitting the sound wave to only the specific area.

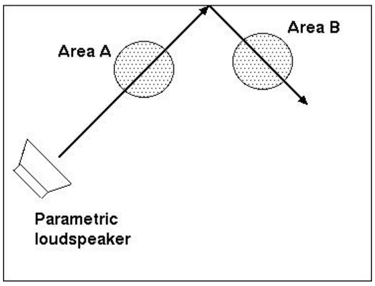

Figure 2 A problem cased by the reflective direction characteristic of the parametric loudspeaker

PROPOSED METHOD

In this study, the undesired reflection wave is defined as the noise, and it is suppressed with Active Noise Control (ANC).

Overview

The overview of proposed method is shown in Fig.3.

The purpose of this study is to suppress the undesired reflection wave and to prevent the sound wave from being transmitted to the undesired area. In this study, we utilize ANC system proposed as a conventional noise reduction system.

The ANC system requires the noise-cancellation loudspeaker. In ANC system, the conventional loudspeaker is utilized as the noise-cancellation loudspeaker. However, in this study, the parametric loudspeaker is utilized as the noise-cancellation loudspeaker. The reason is that it is possible to avoid the increasing of gain at around the control point [2][3].

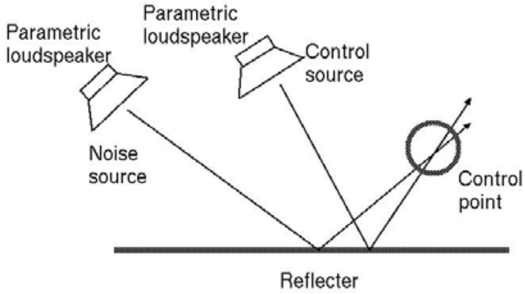

Figure 3 Overview of the proposed method

ANC (Active Noise Control)

ANC[4][5] is the method to suppress the sound pressure level of the noise by a sound wave, with the same amplitude and with the inverse phase, emitted by the noise-cancellation loudspeaker. The base of the ANC is shown in Fig. 4.

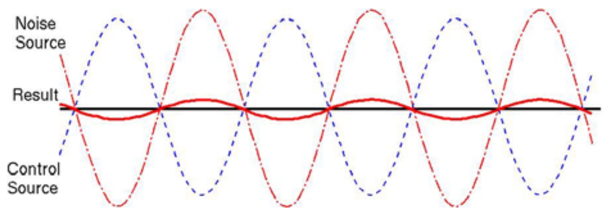

Figure 4 The base of the ANC

The Fig. 5 shows ANC system with the adaptive filter. The ANC system requires a reference microphone M_R (which is mounted near the noise source and captures noise waves) an error microphone M_E (which captures observed sound waves) and a noise-cancellation loudspeaker SP (which emits the noise-cancellation wave). Moreover, the ANC system should estimate the transfer function between the reference microphone and the error microphone. In this study, we utilized the LMS algorithm with the few computational complexities to design the adaptive filter. LMS algorithm is derived from

$$\mathbf{w}(k+1) = \mathbf{w}(k) + 2\mu e(k)\mathbf{x}(k), \quad (1)$$

where $\mathbf{w}$(k) is the coefficients of the adaptive filter, μ is a step size parameter, e(k) is error signals and $\mathbf{x}$(k) is noise signals. The LMS algorithm updates the coefficients of the adaptive filter based on filter coefficients of past one clock.

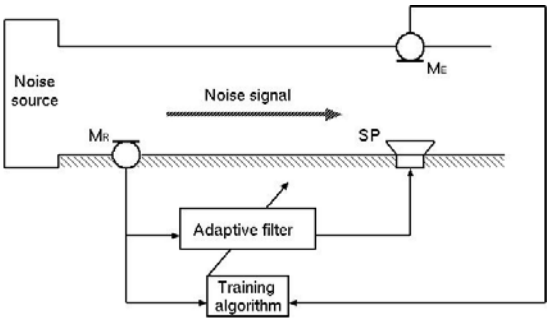

Figure 5 The ANC system with the adaptive filter

Proposed Noise Reduction Approach

Figure 7 shows the proposed ANC system. In this study, the noise and the reflecting path are given, so the noise estimation is unnecessary. Therefore, we only estimate the filter to offset the transfer function between the noise-cancellation loudspeaker and the control point. Figure 6 show Noise suppression by each noise-cancellation loudspeaker. The parametric loudspeaker is utilized as the noise-cancellation loudspeaker to prevent the gain from increasing at around the control point (Fig. 6 (a) (b)). The reflection sound wave is used to suppress the noise, provided that the undesired reflection wave, which should be suppressed, caused by using the direction sound wave as the noise-cancellation sound wave (Fig. 6 (c)).

An overview of the proposed ANC system is shown in Fig. 7, where X(z) is the noise sound, P(z) is the transfer function between the loudspeaker which emits the noise and the control point, Y(z) is the offset signal, S(z) is the transfer function between the noise-cancellation loudspeaker and the control point and H(z) is the adaptive filter. The signal captured by the error microphone is represented as

$$E(z) = X(z)P(z) - X(z)H(z)S(z) . \quad (2)$$

Therefore, to suppress the noise at the control point, H(z) is shown as

$$H(z) = \frac{P(z)}{S(z)} . \quad (3)$$

Thus, Eq. (3) shows that we only design the filter to offset S(z) because P(z) is given.

EXPERIMENTS

In this study, the purpose is to suppress the undesired reflection wave. We conducted three experiments. One is the experiment for the direct sound wave suppression with the conventional loudspeaker. Another is the experiment for the direct sound wave suppression with the parametric loudspeaker. The other is the experiment for the reflection sound wave suppression with the parametric loudspeaker.

Experiment with the Conventional Loudspeaker for Direct Sound Wave Suppression

The experiment is conducted with the conventional loudspeaker. The experimental conditions are shown in Tab. 1 and Fig. 8, and Tab. 2 shows the designed filter conditions.

Figure 9 shows the experimental result. The figure shows that ANC system of this experiment reduced noise from 500 Hz to 2000 Hz by an average of 7.74 dB. In addition, we verified that the amount of suppression from 500 to 1000 Hz is better than that from 1000 to 2000 Hz.

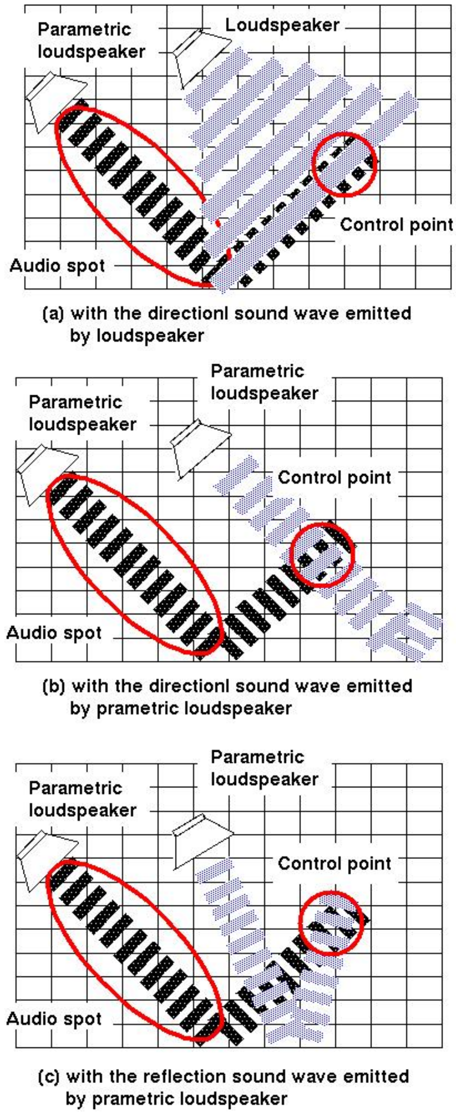

Figure 6 Noise suppression by each noise-cancellation loudspeaker

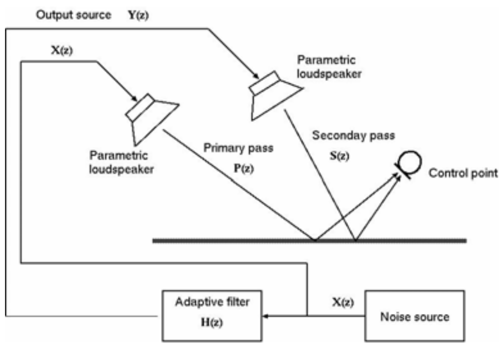

Figure 7 The proposed ANC

Table 1. Experimental conditions

Common condition	
Microphone	HOSHIDEN, KUC-1333
Loudspeaker amplifier	YAMAHA, P2500
Microphone amplifier	PAVEC, Thinknet MA-2016

Condition of using the conventional loudspeaker	
Loudspeaker	MITSUBISTH DIATONE DS-7h
Recording condition	48kHz, 16bit
Condition of using the parametric loudspeaker	
Loudspeaker	MITSUBISH, MSP-50E
Recording condition	96kHz, 16bit

Table 2. The designed filter condition

Adaptation algorithm	LMS algorithm
Filtered signal length	250
Step size parameter	1.0×10^{-12}

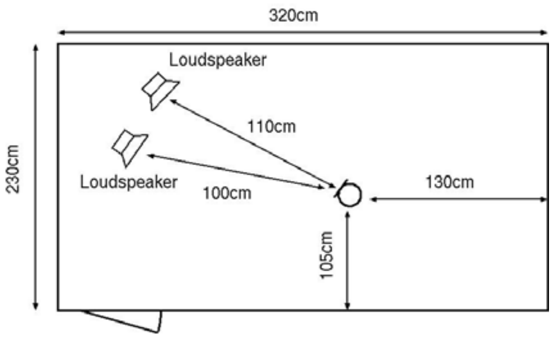

Figure 8 Experimental conditions with the conventional loudspeakers

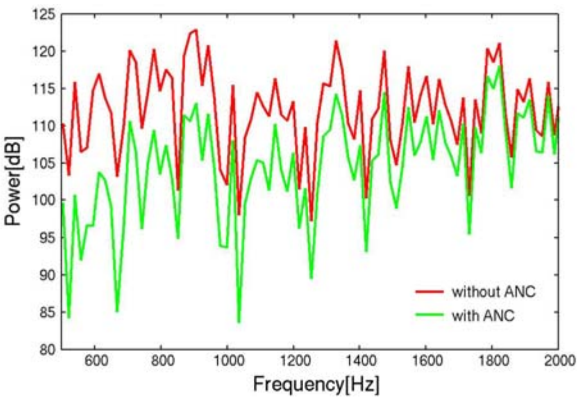

Figure 9 Experimental results with the conventional loud-speakers

Experiment with the Parametric Loudspeaker for Direct Sound Wave Suppression

This experiment was conducted to verify whether the parametric loudspeaker can suppress the direct sound wave emitted by the other parametric loudspeaker at the control point. The experimental conditions are shown in Tab. 1 and Fig. 10.

Figure 11 shows the experimental result. The figure shows that this system reduces the noise from 500 Hz to 2000 Hz by an average of 3.16 dB. Therefore, we confirmed that the sound wave emitted by one parametric loudspeaker can suppress with the other parametric loudspeaker.

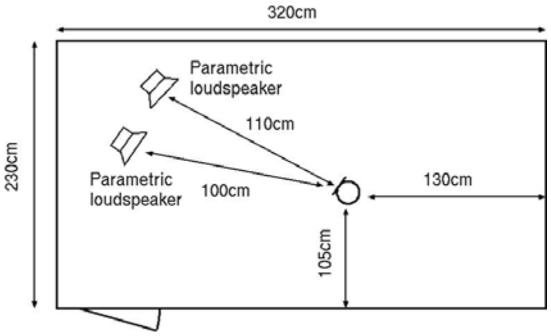

Figure 10 Experimental conditions with the parametric loudspeakers

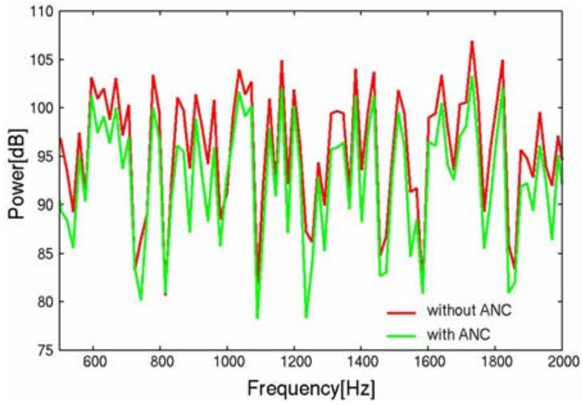

Figure 11 Experimental results with the parametric loud-speaker

Experiment for Reflective Sound Wave Suppression

We conducted the experiment to verify the effectiveness of the proposed method. The experimental conditions are shown in Tab. 1, Fig. 12 and Fig. 13. The direct sound wave was emitted at angles of 15, 30, 45, 60 and 75 degrees. For example, the sound wave is transmitted from Noise point 1 in Fig. 13 to Control point 1 in Fig. 13. The reason is that the incidence angle and reflection angle are the same from the wall. Thus, the area, where the sound wave is transmitted, is defined as the control point, and the sound wave is suppressed there. The noise-cancellation loudspeaker is mounted at Control source in Fig. 13. The look direction of the noise-cancellation loudspeaker is controlled so that the first reflection wave of the emitted sound wave will be transmitted to the control point.

Figure 14 shows the result of the experiment. The average of the suppression amount of all results is 3 dB. These results are almost the same as that of direct sound wave suppression with the parametric loudspeaker. It is verified from the result that it is possible to suppress the reflection sound wave. Since there is tiny difference in results of each angle, we also confirmed it is possible to suppress the reflection sound wave without angle-dependence. Thus, we confirmed the effectiveness of the proposed method.

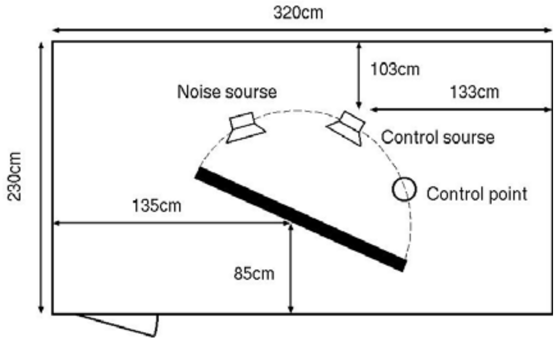

Figure 12 Experimental conditions for reflection sound wave suppression

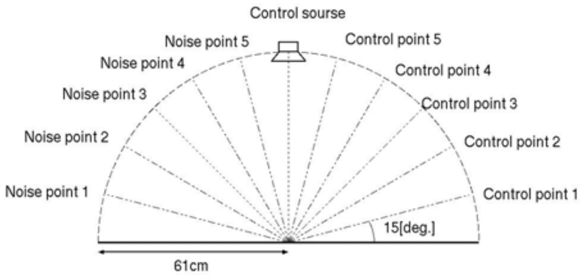

Figure 13 The relation between noise points and control points

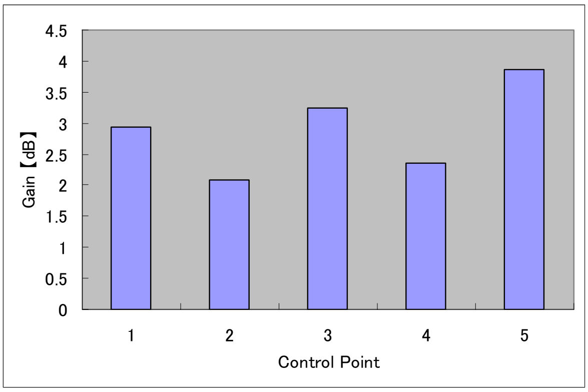

Figure 14 Experimental results for reflection sound wave suppression

Discussion

The experimental results with the parametric loudspeaker suppressed the noise with an average of 3.16 dB. Therefore, we verified that the sound wave emitted by one parametric loudspeaker can suppress the sound with the other parametric loudspeaker. However, to suppress sufficiently the noise with the parametric loudspeaker is more difficult than ANC with the conventional loudspeaker because the ANC system with the conventional loudspeaker suppressed the noise by an average of 7.74 dB. The reason that ANC with the parametric loudspeaker can suppress insufficiently the noise is that the transmitted sound wave was different from the forecasted sound wave by the parametric loudspeaker problems such as harmonic distortion incidence [6].

Next, we describe the experiment for the reflective sound wave suppression. The average of the suppression result of each angle was 3 dB.

The above result and the experimental results for direction wave suppression with the parametric loudspeaker are same tendency on suppression amount. Since there is tiny difference in results of each angles, we confirmed that it is possible to suppress the reflection wave without angle-depending. Thus, we also confirmed the effectiveness of the proposed method.

CONCLUSIONS

We focused the parametric loudspeaker which transmits the sound wave to only the specific area. However, there was the problem that the sound wave is transmitted not only to the desired area but also to the undesired area. The reason is that the sound wave emitted by the parametric loudspeaker has a reflective radiation characteristic. We proposed to suppression the undesired reflection wave. First, we conducted the experiment for direct sound wave suppression with the parametric loudspeaker. From the experimental results, we verified the sound wave which one parametric loudspeaker is suppressed with the other parametric loudspeaker. Next, we conducted the experiment for reflection sound wave suppression to verify the effectiveness of the proposed method. The average of the results of each angle is close to the result of the experiment for directive sound wave with the parametric loudspeaker. We verified that it is possible to suppress the reflection sound wave. In addition, the reflection sound wave is suppressed without angle-depending. Thus, we accomplished to suppress the undesired reflection sound wave. In future work, to achieve more suppression, we have to consider the loudspeaker arrangement and the problems of the parametric loudspeaker.

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