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Effectiveness of ANC Partition with Film Speaker

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Abstract

In this paper, we design an ANC partition with film speaker and demonstrate the effectiveness through experimental results. In a cubicle of public areas, like a reception desk inside bank, surrounding sound including conversation and environment noise avoids smooth conversation and the privacy may not be protected due to leaking to the adjacent cubicles. In such a case, the partition should have not only passive sound control function but also active sound control function. However, the ordinary loudspeaker (electrodynamic loudspeaker) may not be implemented into the partition effectively and may not control enough region in the cubicle. In this paper, we implement a film speaker into the partition and realize active noise control (ANC) system. The proposed ANC partition can achieve more than 10 dB noise reduction and wider zone of quiet compared with the ANC partition using the ordinary loudspeaker.

1 INTRODUCTION

In recent years, when many people talk at the same time in an open place, there are problems such as difficulty in conversation and information leakage such as TV and snoring disturb sleep in a hospital room, and conversations leak to people next to a bank window, a meeting room, and a shared office. We therefore examine a partition with active noise control (ANC) in order to solve the problem. Active noise control (ANC) is a means of reducing noise. ANC is a system that can reduce noise by superimposing anti noise of the same amplitude and opposite phase as the target noise (1-4).

As similar applications, ANC headrest for reducing broadband noise has been already proposed and examined in the reference (5). In the ANC headrest, since the headrest part is surrounding the user's head, this could be thought one kind of ANC partitions. As another approach, an ANC partition for reducing snore noise in bed rooms has been proposed in the reference (6). In this approach, the ANC partition is located between a snoring person and the partner, and then creates Zone of Quiet (ZoQ) for the partner. Either approach considers creating ZoQ for one person who is sitting a chair with the ANC headrest or is exposed by snore noise from the partner. However, this paper aims at controlling sound environments in a cubicle of public areas like a reception desk inside band. In this case, one partition should reduce noise in not only one cubicle but also the adjacent cubicle at the same time, and two loudspeakers must be consequently implemented at the same location on the both sides of the partition as secondary sources. In such a situation, ordinary loudspeaker (e.g. electrodynamic loudspeaker) requires a thick partition to ensure a back cavity for the loudspeaker and such bulky partition is not practical. Moreover, multiple loudspeakers with large diameter are needed to control wider area in the cubicle and costly, bulky and complicated system is accordingly required. Furthermore, active noise control barriers have been studied by many researchers as a similar application (7-12). However, these studies aim at larger sound barriers for road noise and surrounding noise around house, so that ordinary loudspeakers can be easily installed for such ANC barriers unlike ANC partitions for small cubicle.

In this paper, we utilize a thin film speaker instead of an ordinary loudspeaker as a secondary source. By using thin film speaker, the secondary sources can be implemented at the same location on both sides of a

thin partition and the cost and space can be consequently saved. Moreover, this thin film speaker can generate similar sound wave surface as the diffraction sound with the partition from the noise source and can control wider areas in the cubicle.

2 ANC PARTITION

ANC partition where secondary sources are installed on the partition can create zone of quiet (ZoQ) around the user's ears and multiple ANC partitions can create quiet sound environment in a cubicle surrounding by the partitions. In this case, a multi-channel ANC is required to realize higher noise reduction while considering the crosstalk paths. In the ANC partition, the error microphones are generally put on the partitions, so that ZoQ cannot be created around user's ears. One of solutions is to utilize fixed noise control filters which are obtained by setting the error microphones around the user's ears and estimating the optimal filter coefficients in advance. In this paper, we realize an ANC partition based on the fixed noise control filter. Moreover, we utilize two ANC partitions to control sound near the user's ears and apply CASE (1,2,2) ANC which has one reference microphone, two secondary sources and two error microphones.

3 CASE (1, 2, 2) ANC SYSTEM

A block diagram of the CASE (1,2,2) ANC system is shown in Fig. 1. In Fig. 1, $e_m(n)$ is an error signal, $y_k(n)$ is an output signal of a noise control filter, and $x(n)$ is a reference signal. Here, $m(=1,2)$ represents the channel of the error microphone, and $k(=1,2)$ represents the channel of the secondary source. The filtered reference signal is given by

$$r_{mk}(n) = \hat{s}_{mk} * x(n) \tag{1}$$

using $x(n)$ and the secondary path model $\hat{s}_{mk}$. Also, the noise control filters are updated by

$$\mathbf{w}_k(n+1) = \mathbf{w}_k(n) + \sum_{m=1}^{2} \frac{\alpha}{\beta + \|\mathbf{r}_{mk}(n)\|^2} \mathbf{r}_{mk}(n) e_m(n), \tag{2}$$

where $\mathbf{w}_k(n)$ is the filter coefficient vector, and $\mathbf{r}_{mk}(n)$ is the filtered reference signal expressed as

$$\begin{aligned} \mathbf{w}_k(n) &= [w_{k0}(n)\ w_{k1}(n)\ \cdots\ w_{kM-1}(n)]^T, \\ \mathbf{r}_{mk}(n) &= [r_{mk}(n)\ r_{mk}(n-1)\ \cdots\ r_{mk}(n-M+1)]^T, \end{aligned} \tag{3}$$

where M is the tap length of the noise control filters, α is a step size parameter, and β is a regularization parameter which prevents the divergence due to small reference signal, respectively.

4 EXPERIMENTAL RESULTS

The effectiveness of the ANC partition based on the CASE (1,2,2) ANC is examined through noise reduction experiments using an actual system. In the experiments, we compare the error spectra at the error microphone locations and the size of noise reduction areas between an ordinary loudspeaker and a film speaker which are installed on the partitions respectively. A dynamic loudspeaker (P650K from FOSTEX) is used as an ordinary loudspeaker and a film speaker is made by Nitto Denko corporation. The experimental conditions are shown in Table 1, the experimental environment is shown in Fig. 2(a), and the system arrangement is shown in Fig. 3, respectively. The experiments were conducted in a soundproof room ($2.9 \times 3.1 \times 2.1\mathbf{m^3}$). The sound pressure level of the noise was set to be 60 dB near the right ear (Ch. 1) of the HATS (Head and Torso Simulator). Figure 4 shows the sound pressure distribution when the ANC is not operating.

Figures 5 and 6 show the error spectra at each error microphone (each ear) using the ordinary loudspeakers and film speakers as the secondary sources, respectively. It can be seen from Figs. 5 and 6 that the ANC

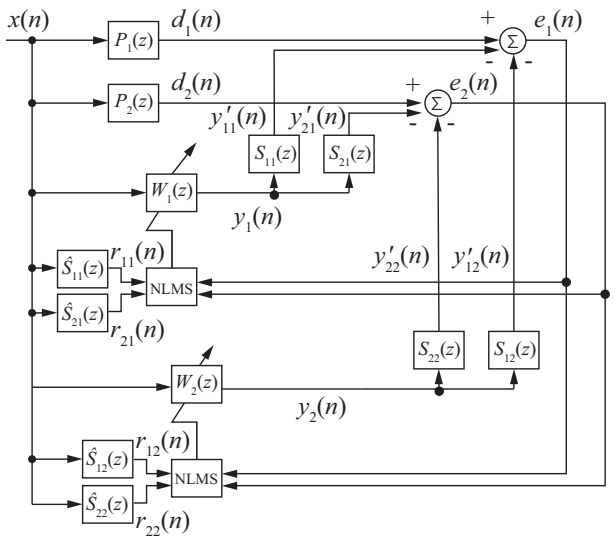


Figure 1. Block diagram of CASE(1, 2, 2) ANC system.

partition with the ordinary loudspeaker can reduce the noise more at the both error microphones (ears) than the ANC partition with the film speaker. However, the dynamic loudspeaker requires sufficient thickness for the partition, it is consequently difficult to install it on the partition. Hence, the film speaker is more suitable for the ANC partition.

Next, Fig. 7 shows sound pressure level distributions after ANC inside the cubicle bounded by the two ANC partitions. It can be seen from Fig. 7 that the ANC partition with the film speaker can create wider noise reduction area (ZoQ) than that with the ordinary loudspeaker. We measured the phase planes from noise source (diffraction wave due to the partition), the ordinary loudspeaker installed on the partition, and the film speaker installed on the partition, respectively. Fig. 8 shows the phase planes when emitting a sinusoidal wave whose frequency is 800 Hz. It can be seen from Fig. 8 (a) and (b) that the film speaker can generate plane wave rather than spherical wave unlike the dynamic loudspeaker. Moreover, it can be found from Fig. 8 (c) that the diffraction sound from the noise source has the same characteristics as the film speaker. Hence, the film speaker can realize the similar sound wave surface as the diffraction sound from the noise source in wider areas, so that the wider ZoQ can be created inside the space bounded by the partitions. From the above results, the film speaker is more suitable for the ANC partition.

Table 1. Measurement conditions in noise reduction experiments

Unwanted noise	White noise (500 - 800 Hz)
Tap length of noise control filter W_k	200
Tap length of secondary path model $\hat{S}_{mk}$	70
Step size parameter α	0.01
Regularization parameter β	1.0×10^{-6}
Sampling frequency	4000 Hz
Cut-off frequency of analog low-pass filter	1000 Hz

(a)Ordinary loudspeaker (b)Film speaker

Figure 2. Experiment environment

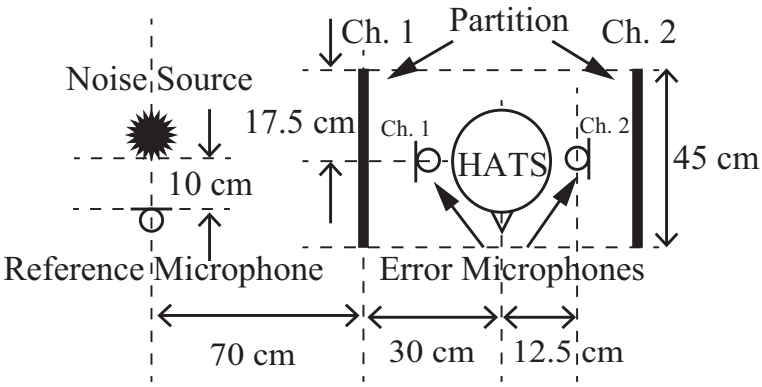


Figure 3. System arrangement in CASE(1, 2, 2) ANC system.

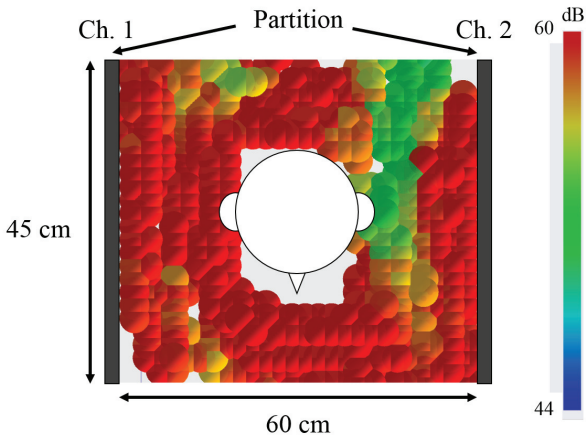
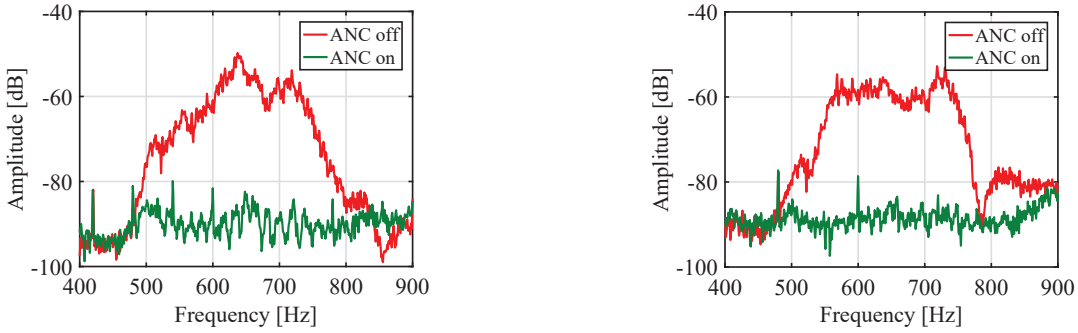
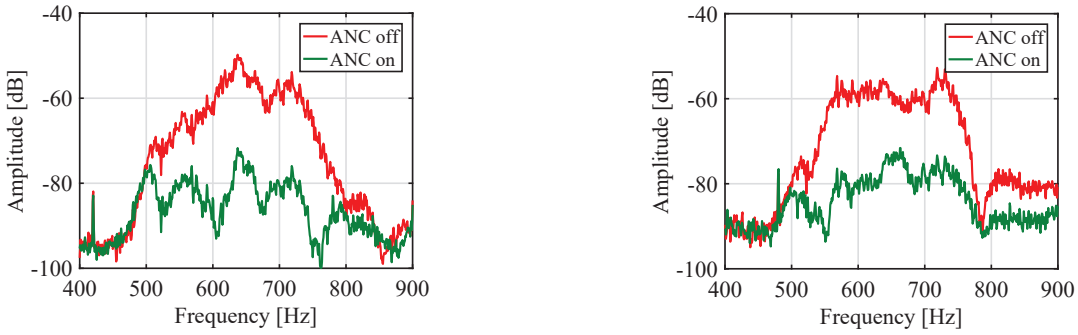


Figure 4. Sound pressure distribution at ANC off.



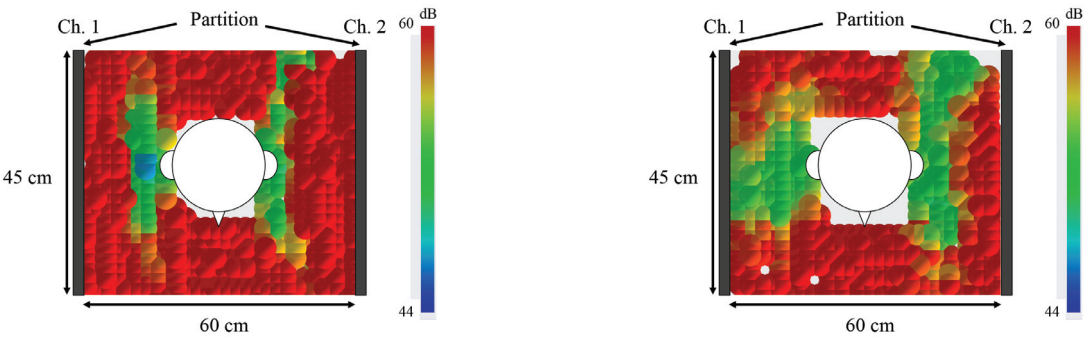
(a)Right ear (Ch. 1) (b)Left ear (Ch. 2)

Figure 5. Comparison of error spectra at the error microphone locations in CASE(1, 2, 2) ANC system with ordinary loudspeaker



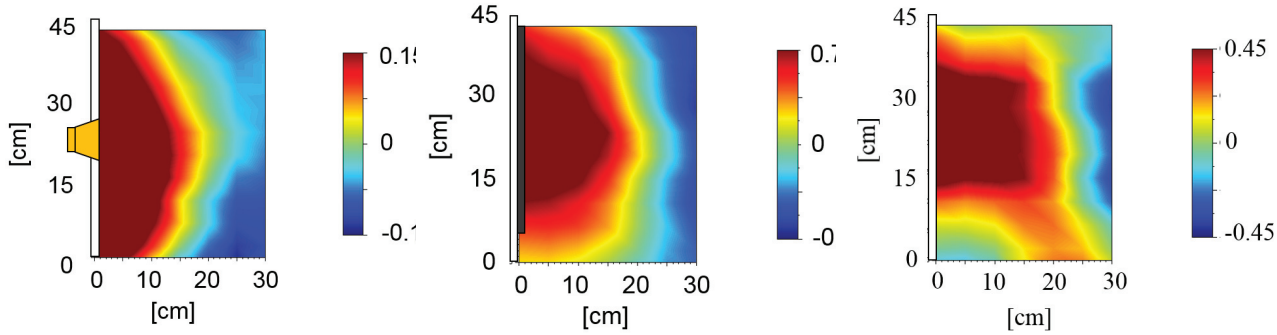
(a)Right ear (Ch. 1) (b)Left ear (Ch. 2)

Figure 6. Comparison of error spectra at the error microphone locations in CASE(1, 2, 2) ANC system with film speaker



(a)Ordinary loudspeaker (b)Film speaker

Figure 7. Sound pressure distributions in CASE(1, 2, 2) ANC system.



(a)Ordinary loudspeaker (b)Film speaker (c)Noise source

Figure 8. Comparison of phase planes from ordinary loudspeaker, film speaker, and noise source.

5 CONCLUSION

In this paper, we developed an ANC partition using a film speaker and demonstrate the effectiveness through some experiments. The ANC partition with the film speaker can realize wider ZoQ than the ordinary (dynamic) loudspeaker inside the space bounded by the partitions. This is because the film speaker can generate similar sound wave surface as the diffraction sound with the partition from the noise source. Hence, the film speaker is more suitable for the ANC partition. In the future, we will develop an ANC partition which can control sound spaces of both sides of the partition.

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