HEAD-MOUNTED ACTIVE NOISE CONTROL SYSTEM FOR MR NOISE

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ABSTRACT

Recently, magnetic resonance imaging (MRI) devices are used in many medical institutions on the grounds of safety and convenience. An open-configuration MR system is introduced at Shiga University of Medical Science in order to conduct microwave coagulation therapy by using near-real-time MR images. However, this system has a fatal defect. When MRI device works to take images, it also generates serious noises (MR noise). Hence, an operator and other medical staff (ex. nurses and anesthetists) suffer from MR noise and cannot communicate with each other during the operation. In this paper, we therefore propose a head-mounted ANC system in order to reduce the MR noise, and some experimental results demonstrate cancellation performance of the system implemented by digital signal processor (DSP).

Index Terms— Adaptive signal processing, Digital signal processors, Piezoelectric devices, Active noise control, Magnetic resonance imaging

1. INTRODUCTION

MRI devices are introduced in many hospitals and other medical institutions in late years. This is because it has no health risk and can be used freely. Shiga University of Medical Science has introduced an open-configuration MR system[1] in order to implement operations using near-real-time MR images. An image of the system is shown in Figure 1. In an operation, medical staff use three kinds of modes of the MRI device, whose names are Axial, Sagital, and Coronal. Figure 2 shows the cross-sectional directions which correspond to each mode. This system, however, have a serious defect. When the MR device takes images, it also generates harsh noise, which is called MR noise[2][3], and this noise makes an operator and other medical staff torn, or unable to communicate with each other. In order to solve this problem, we have already studied an active noise control (ANC) system [4] for MR noise.

There is, however, a severe constraint to implement ANC systems near the MRI device. MRI device generates strong magnetic field, because of its principle. In ANC systems, on the other hand, dynamic acoustic equipment is usually used,

Fig. 1. Open-configuration MR system.

but not be able to be used in the MR room. Hence, we have to overcome this difficulty at first of all. In an intense magnetic field, we can use piezoelectric loudspeakers and optical microphones. Here is, however, another problem. Piezoelectric loudspeaker cannot generate enough sound pressure level at low frequency band. To solve this problem, we consider a head-mounted composition, which has short secondary path interval and does not require high output sound pressure level of secondary source.

In this paper, we propose a head-mounted ANC system using piezoelectric loudspeakers and optical microphones and demonstrate the effectiveness to MR noise through some experimental results.

2. MR NOISE

MR noise signals which are measured by using optical microphones in the MR room of Shiga university of medical science are shown in Figure 3, and their spectra are shown in Figure 4. MRI device has three modes for taking images, whose names are Axial, Sagital, and Coronal. From Figure 3, it can be seen that MR noise is nonstationary regardless of the mode of MR device. In addition, it also can be seen that MR noise has periodic components from Figure 4. Moreover, MR noise is spread by oscillation of the MR device itself, and its

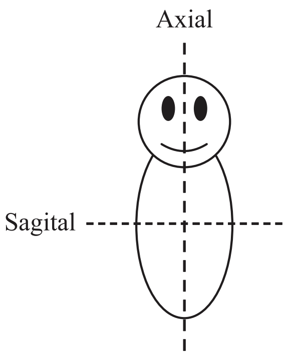


Fig. 2. Modes of the MRI device.

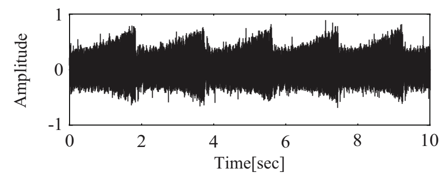
size is so large that we cannot detect it correctly by using one or two microphones. If we want to detect it, then we have to use a lot of reference microphones. It is not desirable for feedfoword ANC systems, because ANC requires real-time-implementation and using many microphones means growth of computing difficulty. Feedback ANC systems, on the other hand, do not need any reference microphones. It therefore does not depend on where noise source is, or how large it is and we may expect the good cancellation performance. Hence, we use a feedback ANC system for MR noise.

3. FEEDBACK ANC SYSTEM

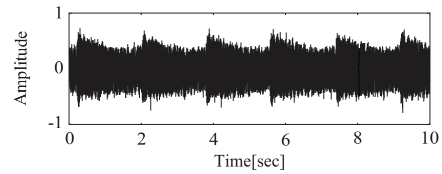
For the updating algorithm of noise control filter in the feedback ANC system, Filtered-x LMS (FXLMS)[5] is the most popular. Block diagram of feedback ANC system using the FXLMS algorithm is illustrated in Figure 5. In this algorithm, an unknown system between secondary source and error microphone, which is called secondary path and shown as **C** in the figure, is modeled by the secondary path model $\hat{\mathbf{C}}$, before the ANC system starts operating. The updating algorithm of noise control filter in the feedback FXLMS is expressed as follows.

$$\begin{aligned}
\mathbf{w}_{k+1} &= \mathbf{w}_k + \mu \mathbf{r}_k e_k \qquad (1)\\
r_k &= \hat{\mathbf{c}}^T \mathbf{x}_k\\
x_k &= y_k^{'} + e_k\\
y_k &= \mathbf{w}_k^T \mathbf{x}_k\\
y_k^{'} &= \hat{\mathbf{c}}^T \mathbf{y}_{k-1}\\
\mathbf{w}_k &= [w_k \; w_{k-1} \cdots w_{k-i+1} \cdots w_{k-N+1}]^T\\
\mathbf{r}_k &= [r_k \; r_{k-1} \cdots r_{k-i+1} \cdots r_{k-N+1}]^T\\
\mathbf{x}_k &= [x_k \; x_{k-1} \cdots x_{k-i+1} \cdots x_{k-N+1}]^T\\
\mathbf{y}_k &= [y_k \; y_{k-1} \cdots y_{k-i+1} \cdots y_{k-N+1}]^T
\end{aligned}$$

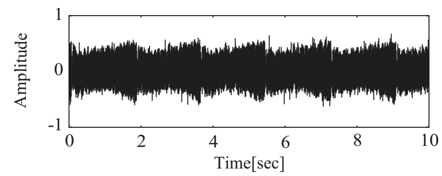
where $\mathbf{w}_k$ is tap-weight vector of the noise control filter and x_k is prediction of primary noise at iteration k. In this algorithm, the linear prediction of the primary noise is used instead of using reference microphones. Hence, the system using this algorithm cannot control non-periodical noises. This



(a) Axial

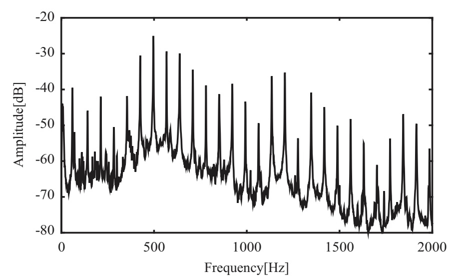


(b) Sagital

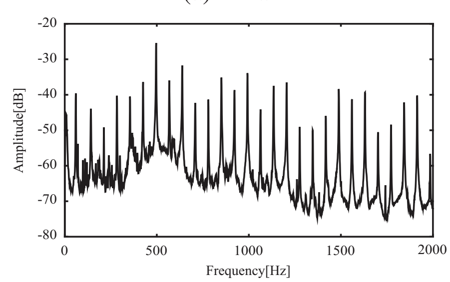


(c) Coronal

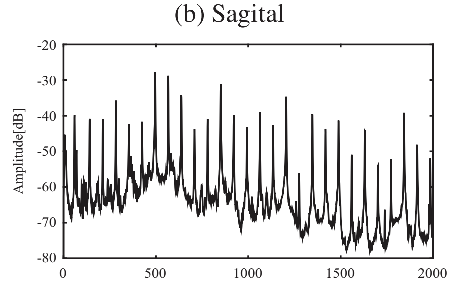
Fig. 3. MR noise signals.



(a) Axial



(b) Sagital



(c) Coronal

Fig. 4. MR noise spectra.

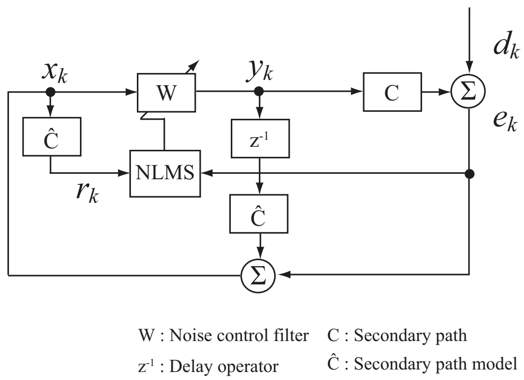


Fig. 5. Block diaglam of feedback ANC system using the FXLMS algorithm.

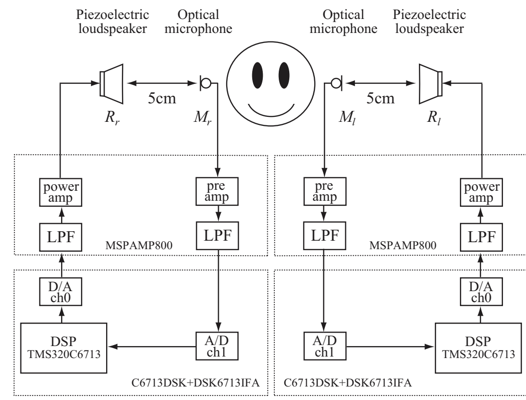


Fig. 6. Composition of the head-mounted ANC system.

shortage is fatal for an ANC system, because the reducing capability is widely restricted. In this case, however, MR noises have some periodicities, and then this problem has little or no effects. Moreover, an advantage of feedback ANC system that does not need any reference microphones, makes the system itself small.

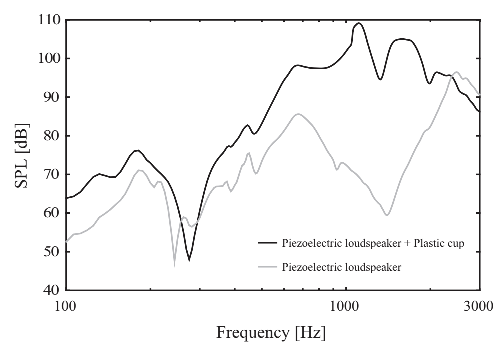
4. COMPOSITION OF THE FEEDBACK SYSTEM

MR devices generate intense magnetic fields that defy use of dynamic audio equipment. To overcome this problem, we use optical microphones and piezoelectric loudspeakers, because they can work in an intense magnetic field. There is, however, another problem on implementation of ANC system. Piezoelectric loudspeakers can surely work, even if they are near the MRI devices, but cannot generate sound pressure level at low frequency band effectively. Hence, we have to consider some compositions, which cover the defects of these loudspeakers.

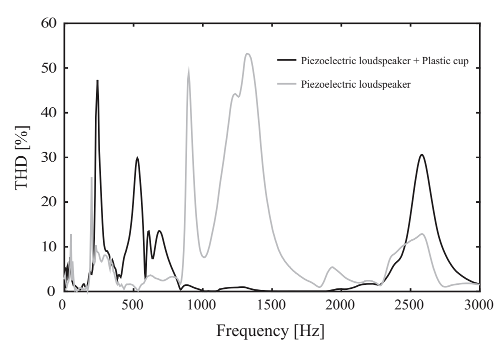
An available composition is a head-mounted one. In this composition, we set two loudspeakers near the user's ears, respectively and put two microphones on each ears in order to make the secondary path short enough, and cover the weakness of sound level of loudspeakers. In addition, it has another advantage. We do not have to regard effects of cross talks. In general, we have to use some specific algorithms which can treat the effects of cross talks[6] when we want to control multiple points. On the other hand, in this system, the user's head is located between each pair of the microphone and loudspeaker, and then we can ignore the cross talk problem. Hence, we may control the right and left channels of the user with a single channel feedback ANC system, respectively.

In addition, we attached a plactic cup on each piezoelectric loudspeaker to improve the sound pressure level. Figure 8 shows the sound pressure level and the total harmonic distortion rate of the piezoelectric loudspeakers.

Fig. 7. Head-mounted ANC system used in this experiment.



(a) Sound Pressure Level



(b) Total Harmonic Distotion Rate

Fig. 8. Characteristics of piezoelectric loudspeaker.

5. EXPERIMENT RESULTS

We demonstrate that a head-mounted ANC system using piezoelectric loudspeakers and optical microphones can control MR noise through an experiment carried out in the MR room. Figures 6 and 7 show a composition and image of the head-mounted ANC system used in this experiment. Piezoelectric loudspeakers and optical microphones used in this system are M-PZT-02(Eishin Denki Co.,Ltd. product) and Optimic-1160 (Optoacoustics Co.,Ltd. product). DSP used in this experiment is TMS320C6713 (Texas Instruments Co. product). Table 1 shows basic measurement conditions. Figures 9 and 10 show error signals and error spectra of the ANC system at each error microphone. From these results, the head-mounted ANC system can operate stably and reduce the MR noise effectively. In addition, we were able to feel the reduction of the noise by this 2-point control on our ears.

6. CONCLUSION

In this paper, we have proposed the head-mounted ANC system using piezoelectric loudspeakers and optical microphones for MR noise. As a result, this system can reduce MR noise effectively. This system, however, cannot control low frequency band of the noise. Hence, we will go on the study in order to improve the capability of the system at the low frequency band.

7. REFERENCES

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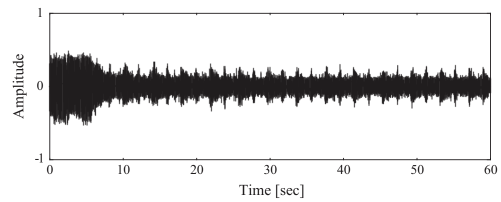
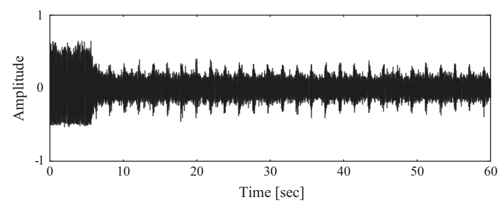
Table 1. Measurement conditions.

Step sizde parameter of NLMS	0.005
Tap length of noise control filter	800
Tap length of secondary path model	100
Cut-off frequency of low-pass filter	2.5[kHz]
Sampling frequency	12[kHz]

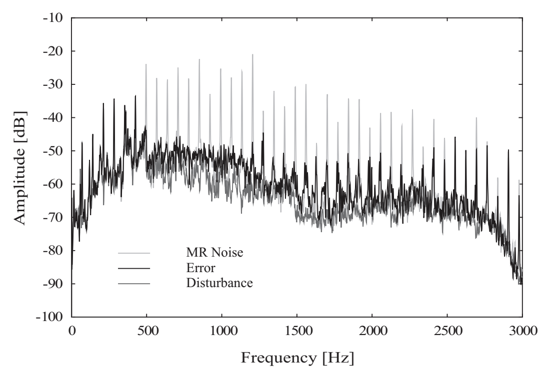


(a) R-ch

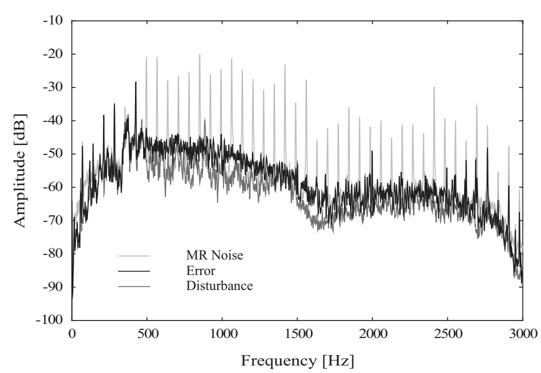


(b) L-ch

Fig. 9. Error signals at each error microphone.



(a) R-ch



(b) L-ch

Fig. 10. Error spectra at each error microphone.