Effective position of reference microphone of active noise control for acoustic noise of magnetic resonance imaging

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ABSTRACT

Acoustic noise produced by magnetic resonance imaging (MRI) is over 100 dB. Ear protectors, such as earmuffs or earplugs, are insufficient for reducing the subjects' discomfort. The reference microphone position is the outside of the ear pad in case of general active noise control (ANC) headphones. We propose an effective position for the reference microphone for ANC for the subjects undergoing lower limb examination via MRI device. The MRI noise source is shown to be near the center in the hole of the MRI device. Here, we discuss the effect of the reference microphone position in ANC of the feedforward-type filtered-x normalized LMS algorithm. The normalization of the input signal is needed because this signal comprises unsteady pulsed MRI noise. The noise was simulated in a laboratory with the reverberation to evaluate the effects of the proposed method. The simulated result showed that controlling the sound-source position is more effective than the controlling the conventional ANC headphone position. The experiment showed that the proposed setup reduced the noise level by 3 dB more than that of the conventional one, just as predicted by computer simulation.

Keywords: MRI acoustical noise, Reference microphone, hearing protection
I-INCE Classification of Subjects Number(s): 36.4

1. INTRODUCTION

Magnetic resonance imaging (MRI) equipment generates loud sounds when operated. This noise is generated when a pulsed current is applied to the gradient magnetic field coils in a static magnetic field. The sound pressure level depends on the imaging sequence method, but it is generally 100 dB or more [1–3]. This makes patients uncomfortable and may result in temporary hearing loss if ear protectors are not used. Conventional ear protectors decrease the sound pressure level by approximately 20 dB; however this noise level is still unsatisfactory in terms of patient comfort, to the point where MRI diagnosis and treatment may be refused in some cases. We have studied an ear protector with an active noise control (ANC) system; conventional protection decreases the sound pressure level for a range of high frequencies, but the ANC system effectively extends this protection to low frequencies.

Using feedback control during MRI preoperative procedures for supporting conversations between doctors and patients has been proposed [4–6]; and Resonance Technology manufactures noise reduction headphones for exclusive use in MRI inspections. Our study aims to develop an active noise control system to improve the acoustical environment for the MRI patients. MRI acoustical noise is not only periodic but also has variations in peak level. Thus, an ANC system of the feedback type that is effective at reducing periodic noise cannot adapt to all MRI acoustical noise. Therefore we have developed a feedforward control system [7–10], but they evaluated the noise reduction without considering the position of the reference microphone [4, 5]. It is important for a feedforward ANC system that the reference microphone be situated near the sound source. We estimate the location of the sound source and find it to be near the center of the MRI gantry. The simulation result shows effective noise reduction in case of the proposed ANC system [11].

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In this paper, the noise reduction level is estimated by simulation examination in the laboratory room for various locations of the reference microphone. Good performance is shown when the reference microphone is located in the vicinity of the noise source. The results in the time and frequency domains in the cases of the proposed and conventional positions are shown in this paper.

2. REFERENCE POSITION FOR MRI ACOUSTICAL NOISE REDUCTION

We produce a signal using a proposed position of the reference microphone for a feedforward-type of active noise canceller to reduce the MRI acoustical noise. Figure 1 shows the conventional position of the reference microphone of the active noise canceller. This is an effective technique when the sound source location is uncertain or when it moves. In this experiment, we vary the reference microphone position for confirmation of improvement in accuracy and causality because all of our previous studies on the location of the MRI acoustical noise source and effect of noise reduction have been conducted via computer simulation. All parameters except the microphone positon are kept constant. Figure 2 shows our proposed position, which is a schematic of the system used for reducing the MRI acoustic noise [12, 13]. Noise reduction systems using the conventional and proposed methods are simulated in a general room.

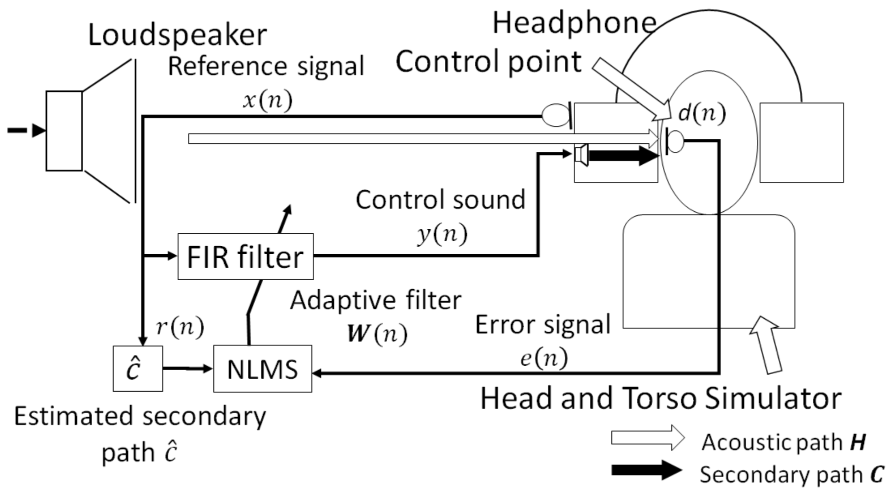

Figure 1 – Schematic of the system of a conventional active noise canceller.

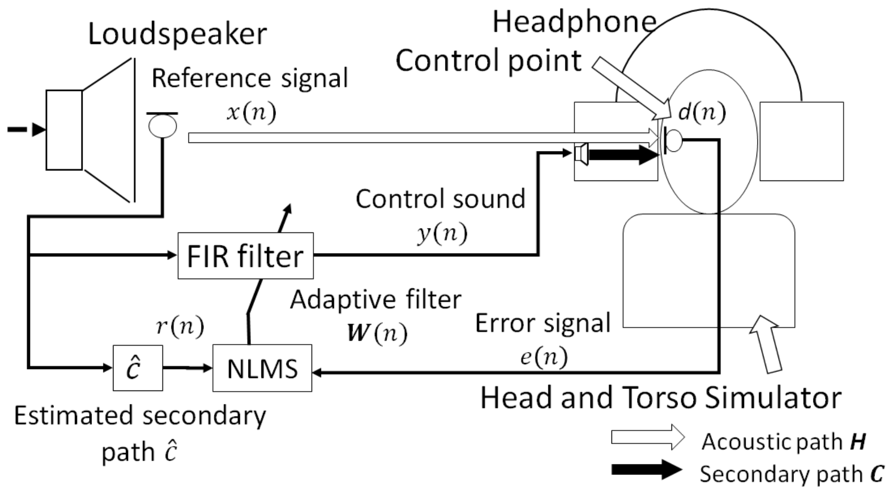

Figure 2 – Schematic of the system with the reference microphone for active MRI noise cancellation in the proposed position.

2.1 Theory of the filtered-x normalized LMS algorithm

The proposed ANC system uses a filtered-x normalized least mean squares (NLMS) algorithm, which is a type of general ANC algorithm. At time n, the filter coefficient vector, $w(n) = [w_0(n), w_1(n), \cdots, w_{L-1}(n)]^T$, is updated as follows:

$$\boldsymbol{w}(n+1) = \boldsymbol{w}(n) + \alpha \frac{e(n)\boldsymbol{r}(n)}{\| \boldsymbol{r}(n) \|^2}. \tag{1}$$

Here, L is the length of the filter vector $\boldsymbol{w}(n)$; $\boldsymbol{r}(n) = [\, r(n), r(n-1), \ldots, r(n-M+1)\,]$ is the filtered reference signal; α is the step gain; and $e(n)$ is the error signal. The filtered reference signal $r(n)$ is given by

$$r(n) = \sum_{j=0}^{M-1} \hat{c}(j)x(n-j). \tag{2}$$

Here, M is the length of filter vector $\boldsymbol{r}(n)$; $\hat{\boldsymbol{c}}(n) = [\hat{c}(n), \hat{c}(n-1), \cdots, \hat{c}(n-M+1)]$, the estimated secondary path; and $\hat{\boldsymbol{c}}(n)$ is the coefficient of the FIR filter used for the secondary path, $\boldsymbol{c}$, between the control output and error sensor input to the controller.

2.2 Experimental setup

In the experiment, MRI acoustic noise is radiated with loudspeaker. The reference microphone is set on the headphone for the conventional active noise canceller, as shown in Figure 1; on the contrary, the position of the reference microphone is set in front of the loudspeaker for the proposed method, as shown in Figure 2. The encapsulated-type headphone with a dynamic loudspeaker as the ANC protector is attached to the head and torso simulator (HATS), and the noise signal at the headphone is evaluated for noise reduction. Each signal is calculated by the computer in advance.

The following apparatus is used in the simulation of the reduction in MRI acoustical noise: headphone amplifier (TA-F333ESA, Sony Corporation), HATS (4100D, Brüel & Kjær), microphone in the HATS (2693-A-OS2, Brüel & Kjær), loudspeaker (802 Series, Bose Corporation), sound recorder (R-05, Roland Corporation), earmuff (EM-68N, Trusco Nakayama Corporation), piezoelectric vibration plate (7BB-41-2LO, Murata Manufacturing Co., Ltd), and MRI device (Achieva 3.0T X-series, Philips).

The pulse sequence for T1W is used to generate the MRI acoustic noise. The following parameters are set in the simulation: recorder sampling frequency, 48 kHz; FIR filter length $\boldsymbol{w}(n)$, $L = 500$; and impulse response length $\hat{\boldsymbol{c}}(n)$, $M = 200$.

3. EXPERIMENTAL RESULTS

The resulting sound pressure waveforms and frequency characteristics are as follows.

First, the results of the conventional setup are shown in the simulation environment for T1W acoustic noise. In the case of a conventional ANC protector, the reference microphone is placed on the headphone attached to the dummy subject. The cancellation algorithm is played starting at time = 0. When the time is negative, the waveform shows the MRI noise received by the subject wearing only an earmuff. When the time is positive, the waveform shows the convergence by the conventional ANC protector. Figure 3 shows the sound pressure waveform before and after noise cancellation in the case of a conventional ANC protector. For T1W noise, the sound pressure level reduces from 88.1 to 83.8 dB, a reduction of 4.3 dB. Figure 4 shows the spectra before and after noise cancellation in the case of the conventional ANC protector. The level of the narrow band of the peak frequency around 300 Hz is reduced.

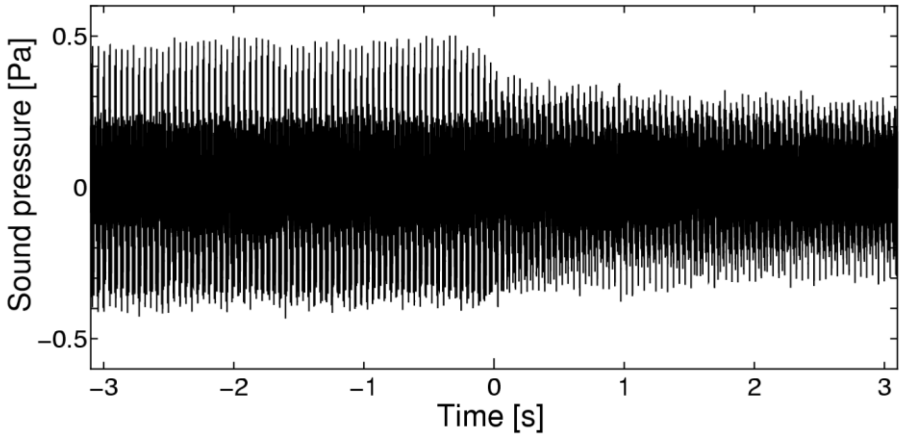

Figure 3 – Waveform of sound pressure received by the subject using the conventional active noise canceller in the case of T1W imaging noise.

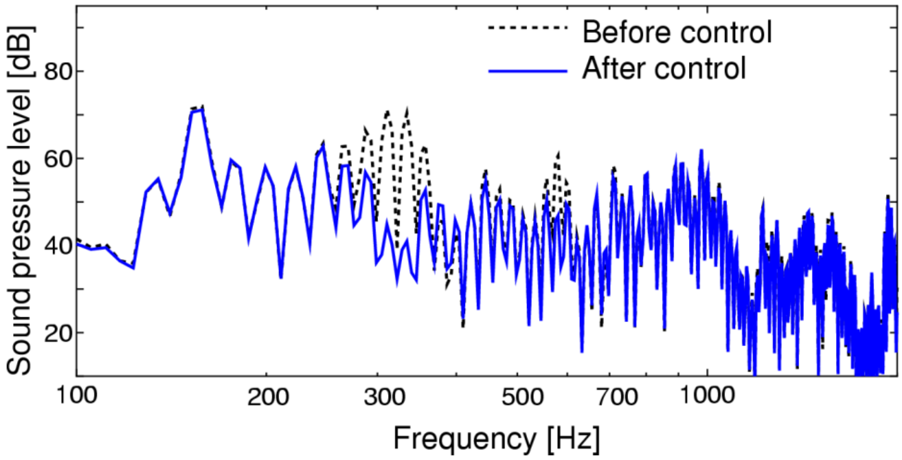

Figure 4 – Spectra of the noise received by the subject using the conventional active noise canceller in the case of T1W imaging noise.

Next, the results of the proposed setup are shown. In the case of the proposed ANC protector, the reference microphone is put in front of the loudspeaker as an MRI noise source. The cancellation algorithm is played starting at time = 0. When the time is negative, the waveform shows the MRI noise received by a subject wearing only an earmuff. When the time is positive, the waveform shows convergence by the proposed ANC protector. Figure 5 shows the sound pressure waveform before and after noise cancellation in the case of the proposed ANC protector; the peak sound pressure reduces from 0.53 to 0.13 Pa, and the sound pressure level reduces from 87.9 to 72.0 dB, a reduction of 15.9 dB. This demonstrates that the peak sound pressure is adaptively controllable by feedforward ANC. Figure 6 shows the spectra before and after noise cancellation in the case of the proposed ANC protector. The level of the wide band between 250 Hz and 1,000 Hz is reduced.

In the case of the reverberating environment and already-known source location, when the reference microphone is put on the sound source, it becomes clear that the noise-reduction effect is improved. These results are the same as those via computer simulation.

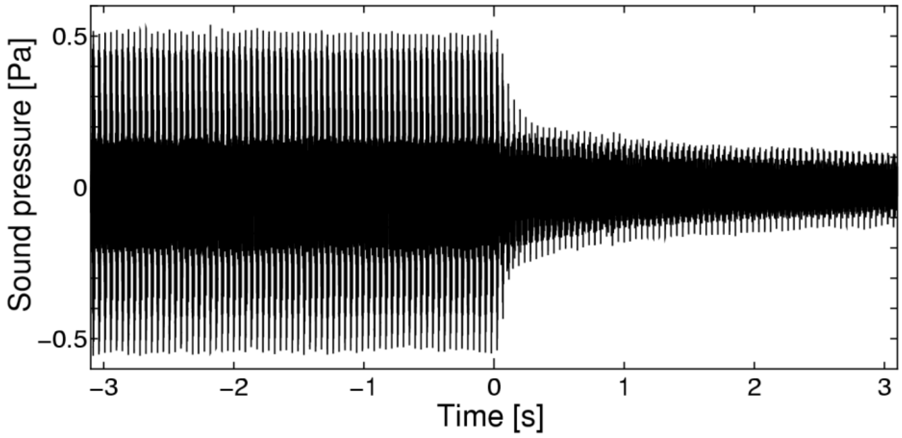

Figure 5 – Waveform of sound pressure recieved by the subject using the proposed acitive noise canceller in the case of T1W imaging noise.

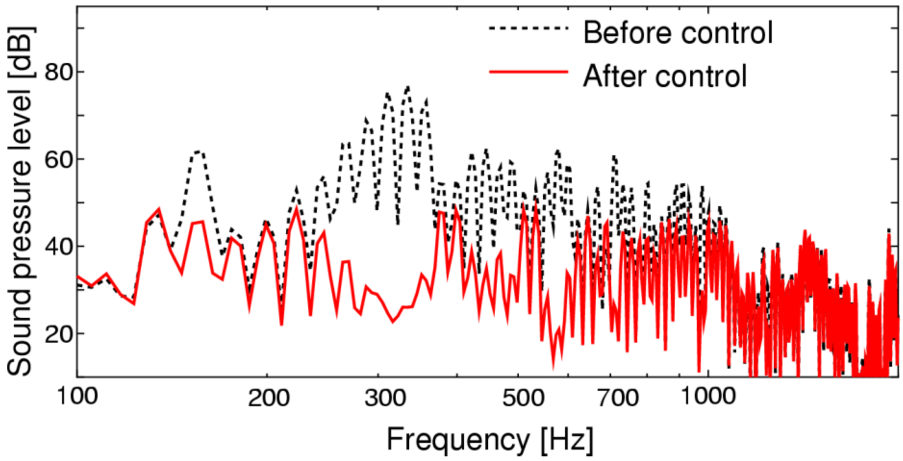

Figure 6 – Spectra of the noise recieved by the subject using the proposed acitive noise canceller in the case of T1W imaging noise.

4. CONCLUSIONS

This study aimed to reduce MRI acoustic noise to 60 dB to realize a quieter environment for MRI subjects undergoing lower limb examination. This paper describes the experimental results of noise reduction under a proposed setup wherein the reference microphone of the active noise canceller is installed near the source of the noise. The result showed that active noise cancellation by the proposal position is more effective than the cancellation at the conventional position. The noise reduction level of the proposed method is approximately 3 dB higher than that under the conventional system, and the effective level was as same as the result of the computer simulation. A future study will evaluate an active noise canceller using a piezoelectric headphone.

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