Experimental Study of Active Acoustic Noise Control with MRI Compatible Headphones and Microphones in a 4T MRI Scanner

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Introduction

The acoustic noise generated from the MRI system has become a serious safety concern as well as a technical challenge for MR and acoustic noise control scientists. Although various passive methods have been proposed to deal with this problem, active noise control (ANC) has attracted much attention in recent years [1]. In this work, we demonstrate some promising experimental results with MRI compatible headphones and microphone.

Methods and Results

A 4T Varian UnityINOVA whole-body MRI scanner operated using EPI pulse sequences was utilized in this study. The sound pressure data at the patient ear locations was acquired with a multi-channel data recorder and processed using a laptop computer. The recorded sound pressure signals were played back by an audio system to reproduce the MRI noise in a sound quality research chamber. The experimental setup is shown in Figure 1. The controller was implemented using a desktop computer equipped with the dSPACE system. The multi-channel device is used as anti-aliasing and reconstruction filters. The headset shown in Figure 1 is a high fidelity set utilizing speakers with magnetic components. The microphone (not visible) is installed in the binaural head. This system generates the acoustic noise signal needed to control the MRI noise at a targeted dominant frequency. In addition to the high fidelity headphone/microphone, data were also acquired with an MRI compatible headphone utilizing piezoelectric speakers and an optical microphone installed in the earpiece.

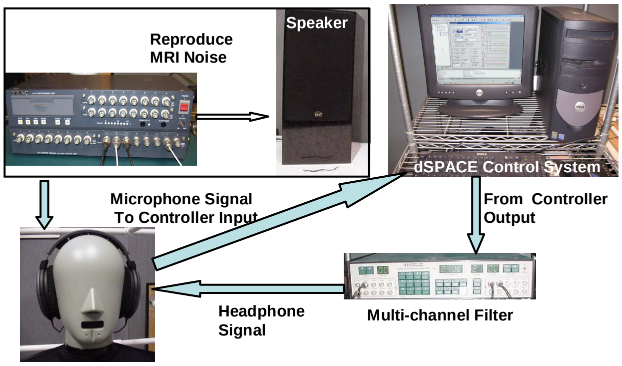

Figure 1 – Active MRI Noise Lab Setup

The control system shown in Figure 2 has a secondary path model, $S(z)$, representing the speaker-microphone system. The transfer function, $\hat{S}(z)$, in the feed-forward controller is an estimation copy and was used in the Filtered-x least mean square (FxLMS) algorithm. $W(z)$ is the transfer function of the feed-forward finite impulse response (FIR) control filter. The reference signal, $r(n)$, is generated by estimating the principal harmonic frequency from the measured gradient excitation currents, 850 Hz in this experiment. The error signal, $e(n)$, that is picked up by the error microphone, is the sum of the original MRI acoustic noise and the control sound signal at the error microphone position. This signal is the response sensed by patients and is to be minimized by the control algorithm. Signal $d(n)$ is the untreated MRI noise response. The feed-forward control was implemented using the FxLMS algorithm. The controller is designed as a digital model with a 4 kHz sampling rate.

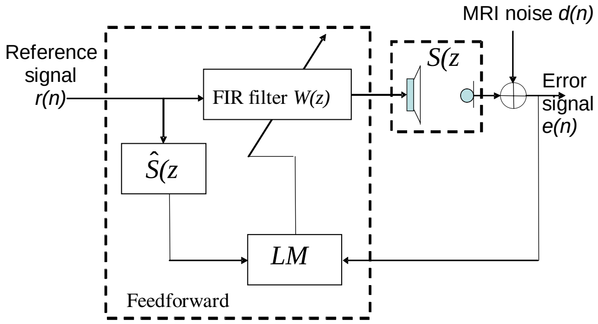

Figure 2 – Active Control System

Figure 3 shows the experimental results for the MRI compatible headphone/microphone combinations. For safety reasons, the reproduced sound was intentionally set to a lower level in the sound quality chamber. The overall sound pressure levels (SPL) of the originally recorded and reproduced MRI noise are about 120 dB and 98 dB, respectively. The plot shows the uncontrolled SPL measurement is reduced to approximately 90 dB due to the passive reduction of the headphones. With the control algorithm running, the measured SPL is reduced by another 19 dB, to 71 dB. Testing showed the high fidelity system is capable of greater ANC reduction, but has virtually no passive reduction (data not shown). The uncontrolled SPL measured with the high fidelity system is virtually the same as the environment at 98 dB, while the controlled SPL is reduced by 25 dB to 73 dB. Despite the increased ANC reduction of the high fidelity system, the end result is that the measured SPL at the patient's ear is slightly lower with the MRI compatible system when compared to the high fidelity system. Similar to an earlier work [2], the waterbed effect [3] again resulted in out-of-band amplification. Regardless, the increases occur at lower magnitude response levels and have little influence on the target frequency range.

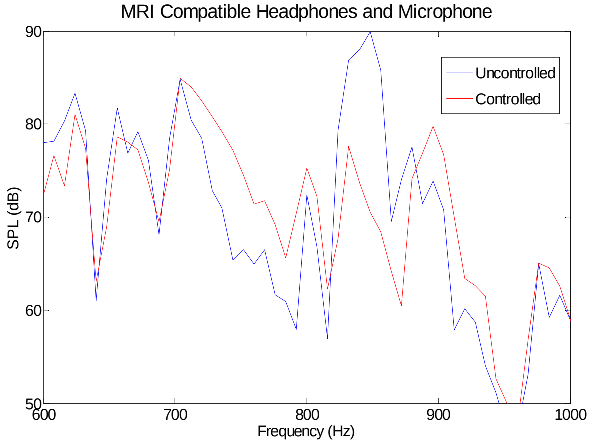

Figure 3 – SPL of MRI Compatible Setup

Conclusion

From the experimental study of the two different systems, a high fidelity headphone/microphone and an MRI compatible set, we conclude that the MRI compatible system provides performance that is comparable to that of the high fidelity system. Additional work is in progress to further refine the ANC controller and to measure SPLs at the MRI scanner room.

References [1] Li M, et al. Proceedings ISMRM 14, 2049 (2006). [2] Curtis A.R.D. A methodology for the design of feedback control systems for the active control of sound and vibration. Active 97, 851-860 (1997). [Supported by NIH R21 EB005042]