Experimental Study of Active Acoustic Noise Control in a 4T MRI Scanner In-Situ

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Introduction

The acoustic noise generated from the MRI system is a serious safety concern as well as a technical challenge for MR and acoustic noise control scientists. The emitted high noise levels can be both annoying and harmful to patients and healthcare workers, especially after long term exposure. Although various passive methods have been proposed to deal with this problem, active noise control (ANC) has attracted much attention in recent years. In our prior study [1, 2], we demonstrated noise reduction in a simulated MRI environment with MRI compatible headphones and microphones. Here, we report noise reduction achieved using our ANC system during scanning at the MRI in-situ.

Methods and Results

A 4T Varian UnityINOVA whole-body MRI scanner, operated using EPI pulse sequences, was utilized in this study. A dummy was outfitted with a pair of MRI compatible headphones containing piezoceramic speakers with optical microphones installed in the earpiece, shown in Figure 1. A controller was implemented using a laptop computer equipped with a dSPACE system. The multi-channel device also has anti-aliasing and reconstruction filters. First, the sound pressure level (SPL) at the patient ear locations was measured during EPI scanning without the ANC system activated. Then the scanning was repeated with the ANC system operational and the measured SPL compared to the original data.

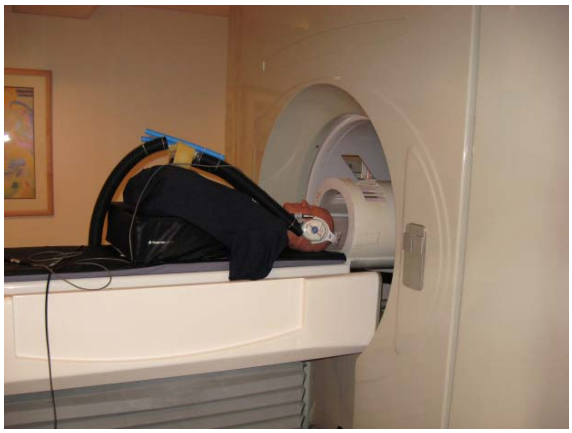

Figure 1 Dummy With Headphones At MRI Scanner

The control system [3], 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 the Y gradient excitation current in this experiment. The error signal, $e(n)$, measured by the optical microphone located inside the earpiece near the "patient's" ear, is the sum of the original MRI acoustic noise and the control sound signal. This signal 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, which is designed as a digital model with a 6kHz sampling rate.

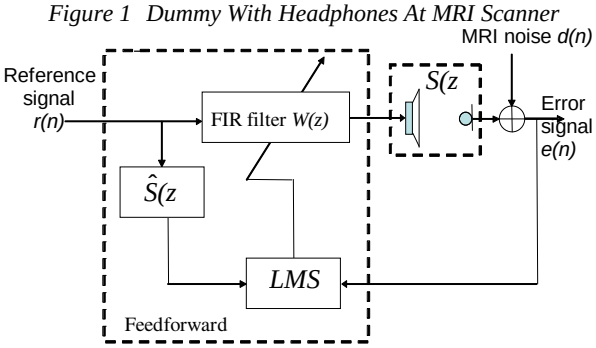

Figure 2 – Active Control System

Figure 3 shows the experimental results comparing the SPL measured at the patient ear location with and without the ANC system operating. The first dominant frequency in the reference signal is at approximately 830Hz. This corresponded to the original SPL peak of 89dB. The ANC system reduced the SPL measured inside the earpiece at 830Hz to 59dB, a reduction of over 30dB. The plot shows substantial reduction achieved over 750-950Hz without any noticeable increase in SPL at nearby frequencies.

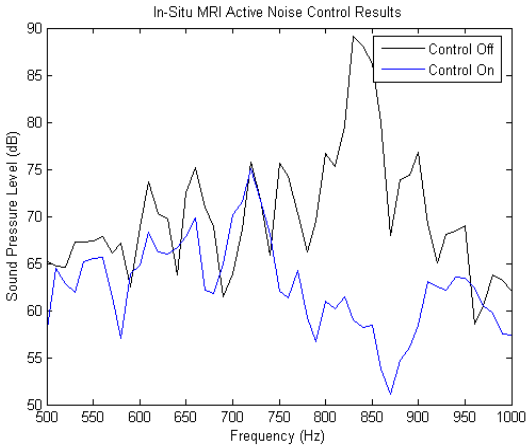

Figure 3 – SPL of ANC Results for MRI In-Situ

Conclusion

A feed-forward ANC system has been refined specifically to address MRI scanner noise by using the MRI gradient current signals for reference. While earlier simulation and experimental studies have demonstrated the feasibility of the approach, they have not been conducted in an actual MRI scanner environment. The experimental results presented here were measured during an EPI scan with the ANC system operating in real time and all necessary instrumentation (microphones, headphones, etc.) installed with a dummy representing the patient. For the first time ever (to the best of our knowledge), these in-situ measurements demonstrate the plausibility of the ANC system in the MRI environment. Further research is planned and will pursue decreasing the SPL across broader frequencies, expanding to additional scanning sequences, and enhancing the functionality of the underlying algorithms controlling the noise reduction.

References [1] J-H Lee, et. al. Proceeding of ISMRM 16, 5229 (2008). [2] M Li, et. al. Magn Reson Imaging. 26, 393-400 (2008). [3] Sen M. Kuo and D. R. Morgen. Proceedings of The IEEE 87(6), 943-973 (1999).