Simulation Study of Active Noise Control in a 4T MRI Scanner

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Introduction

The acoustic noise generated from the MRI system, which has always been an annoyance since the invention of MRI, has become a serious safety concern as well as a technical challenge for MR and acoustic scientists. The emitted high noise levels from MRI scanners often agitate the patients and healthcare workers. Long term exposure may also lead to serious health problems. A variety of methods have been proposed to reduce acoustic noise emission during MRI scans [1], but few investigators are pursuing active acoustic noise control (ANC) due to its complexity. In this study, we are investigating a hybrid ANC system that incorporates feed-forward and feed-back controls for the feasibility of reducing MRI noise. In this preliminary report, the simulation results show that the hybrid system performs better than the feed-forward or feed-back controller alone.

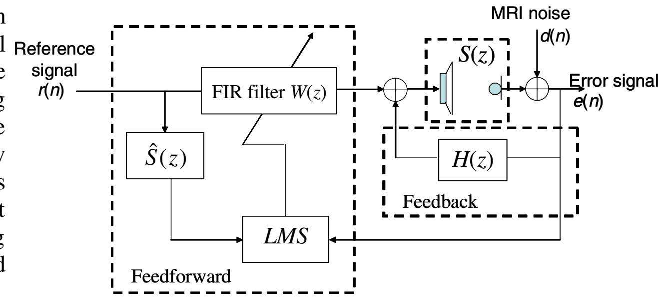

Fig. 1 – Proposed Hybrid Active Noise Control System for MRI scanner.

Methods and Results

A 4T Varian UnityINOVA whole-body MRI scanner operated using EPI pulse sequence was considered in this study. The sound pressure data at the patient ear and mouth locations are acquired with a multi-channel recorder and processed using a laptop computer. The recorded sound pressure signals are employed to represent the unwanted disturbances in the simulation. The proposed system is shown in Fig 1. In this simulation model, the secondary path model, $S(z)$, i.e. the speaker-microphone system, is identified as a state space model using the Matlab system identification toolbox. The transfer function, $\hat{S}(z)$, is a copy model of the secondary path and is used in the Filtered-x least mean square (FxLMS) algorithm. Also, $H(z)$ denotes the transfer function of the feedback controller, while $W(z)$ is the transfer function of feed-forward finite impulse response (FIR) type control filter. Reference signal, r(n), is generated by estimating the principal harmonic frequency from measured gradient excitation currents. Error signal, e(n), measured by the microphone is the sum of the original MRI acoustic noise and the canceling sound signal at the error microphone. This signal is the sound pressure sensed by patients and is to be minimized by the control system. Signal d(n) is the untreated MRI noise. The feed-forward control is implemented with the FxLMS algorithm.

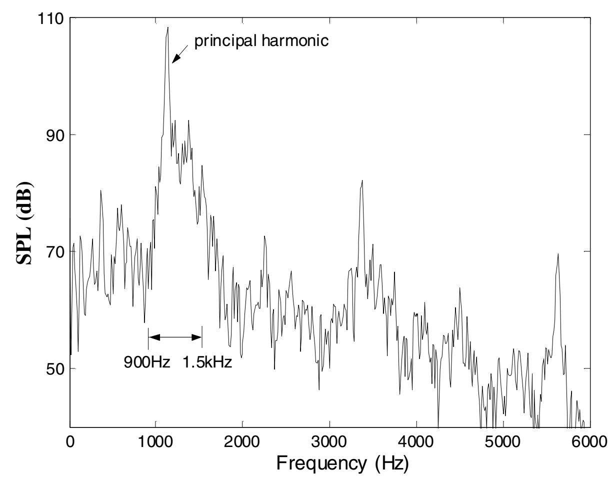

Fig. 2 - MRI noise spectrum at the left ear position.

Figure 2 shows the measured MRI acoustic noise signal at the left ear for a typical EPI pulse sequence. It reveals that the acoustic noise energy is mainly at the principal harmonic of about 1 kHz. In addition, the sideband response is also quite significant. The bandwidth of sideband is typically from 900Hz to 1.5 kHz. For a typical ANC application, the effective frequency is generally in the hundreds of Hz to ensure that the system operates well within a given volume space. Utilizing a headset, the effective frequency upper limit may extend up to 1.5 kHz because of the fact that the smaller operating area is within 1/8 of the wavelength of the upper frequency limit. Furthermore, higher order harmonics can be reduced through headset by passive means. Hence, for this application, the feed-forward part in Fig. 1 is used to deal with the principal harmonic, while the feed-back part can be used to tackle the sideband noise.

Figure 3 shows the simulation results for three different control systems, i.e. a feed-back only, a feed-forward only, and a hybrid control system that combines feed-back and feed-forward types. The simulation results demonstrate that hybrid structure provides more noise reduction than the feedback and feed-forward controls alone. Also, we noticed there is the waterbed effect [2] that is depicted by out-of-band response amplification. Fortunately, the out-of-band increase appears at low frequencies and not critical to our problem. However, we will continue to monitor the waterbed effect to avoid any deterioration in the system performance.

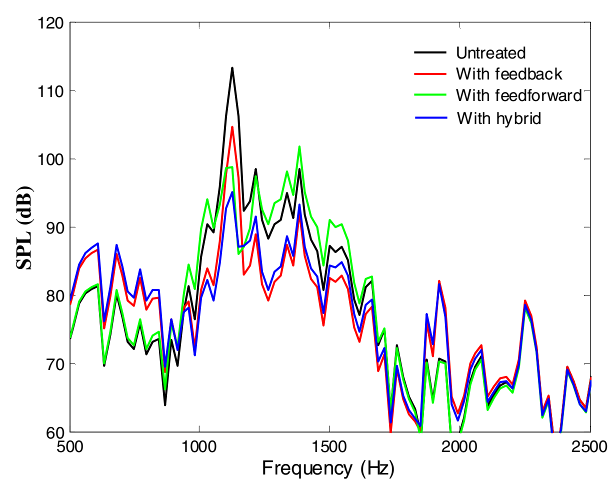

Fig. 3 - Active noise control simulation result for various active control structures.

Conclusion

By studying the three different control systems, namely feed-back, feed-forward and hybrid control, computationally, our results revealed that hybrid control system performs better than each system alone. Further studies are in-progress to utilize more sophisticated technique to further enhance the hybrid control system for MRI acoustic noise reduction application.

References

[1] Kanal et al. Radiology 1990; 176: 593-606. [2] Doyle et al. Feedback control theory. Macmillan Publishing Company 1992. pp. 97-99.