Feedback Controllers for Suppression of Acoustic Noise Response of a 4T MRI Scanner

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Introduction

The high level of acoustic noise emitted during MRI scanner operation has become a very annoying problem and a safety concern to patients and care givers. To address this problem, a hybrid control system that combined feedback control and feedforward control was proposed, which has been analyzed previously [1] and also been investigated in a simulated environment [2]. The objective of this study is to design the most suitable feedback controller for MRI noise suppression applications; hence other types of controllers are excluded. Here, numerous feedback controllers are designed and compared experimentally.

Methods and Results

An active noise control system containing a feedback controller, K(s), for MRI noise reduction is shown in Fig 1. The transfer function, G(s), denotes the speaker-microphone system. The speaker was used to generate the synthesized acoustic noise signal that was applied to suppress the response from the MRI. Error signal, E(s), is the sum of the original MRI acoustic noise and the control sound signal at the error microphone position. This signal represents the response sensed by patients and is the target of the feedback controller. Signal D(s) represents the untreated MRI noise response. The controller is designed as a digital filter with 6 kHz sampling rate. The experiment was performed in a sound quality research chamber. The speaker-microphone system includes a headset with a microphone inside to pick up the error signal. The measured MRI noise was played back using an audio system controlled by a digital sound quality system. The measured signal used for this playback was previously recorded from a 4T Varian UnityINOVA whole-body MRI scanner operated using an EPI pulse sequence. The controller is implemented on a desktop equipped with the dSPACE system.

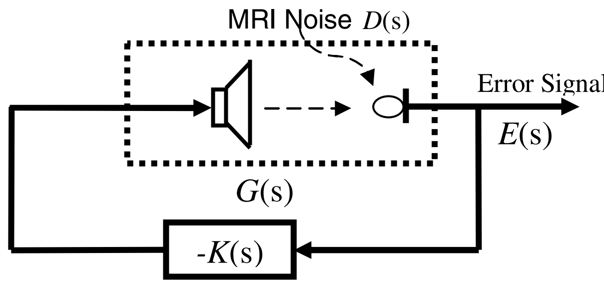

Fig. 1 – Feedback Control of MRI Noise

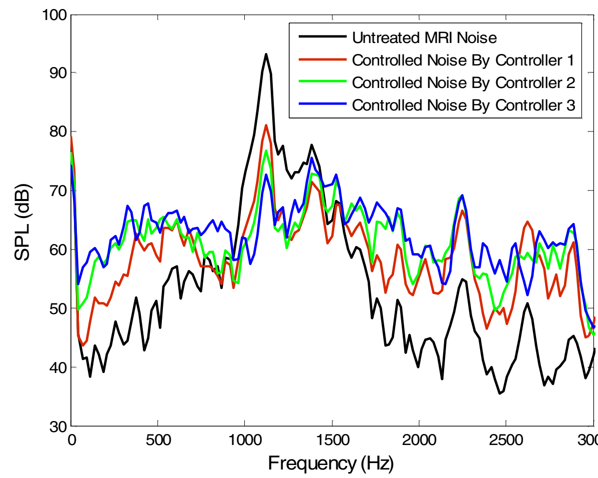

Fig. 2 - Active noise control experiment results for three forms of feedback controllers.

Figure 2 shows the experimental results for 3 forms of feedback controllers that were designed using the Matlab command, loopsyn. This Matlab command was used to design *K(s)* by giving a desired loop shape function. Here, these three controllers, namely controller 1, controller 2 and controller 3, were designed by generating three different loop shape functions, which were Butterworth bandpass filters with three different bandwidths corresponding to 950~1350 Hz, 950~1250 Hz and 1~1.2 kHz, respectively. Another consideration during the design of the feedback controller was to reduce the principal component as much as possible by changing the within-band magnitude of the filter until the designed controller became unstable. By using our digital sound quality system, the overall sound pressure levels (SPLs) of the reproduced MRI noise reached to about 102.3dB. The SPL of the controlled signals after being treated by the three feedback controllers are 92.2dB, 91.5dB and 92.3dB, respectively. Furthermore, from the results shown in Figure 2, one can see that the narrower the bandwidth, the more reduction that can be obtained at the principal component. But, more out-of-band overshot is also noticed. Hence, although controller 3 provides more reduction at the principal component, it does not produce a better performance in the overall SPL measure. Table 1 lists the overall SPLs of controlled and uncontrolled MRI noise for different within-band magnitudes of the filter in a frequency range of 1~1.2 kHz. The results show that there is no direct correlation between the overall reduction performance and the filter magnitude, which is primarily related to the principal component reduction and the out-of-band overshot. To find a proper magnitude value for the filter, the characteristics of MRI noise should be analyzed first. The maximum principal reduction and the out-of-band overshot should be considered as tradeoffs. Hence, simply seeking more reduction in the principal component may not be a good controller design guideline. A feedback controller with an optimal bandwidth and within-band magnitude should be designed according to the overall sound pressure response.

Table 1.- Results of numerous within-band magnitudes of filters

Within-band Mag. of Filter	10	20	30	40	50	60	70
Uncontrolled MRI Noise (dB)	104.6	104.5	104.4	104.5	104.6	104.6	104.2
Controlled MRI Noise (dB)	97.1	96.3	95.2	95.4	95.4	94.7	96.0

Conclusion

From the experimental study of the 3 different forms of feedback controllers and the effect of within-band magnitude of the filter, we conclude that the feedback controller should be designed by selecting a loop shape filter with an optimal bandwidth and within-band magnitude to achieve a satisfactory performance in the overall sound pressure response.

References

[1] More SR, et al. JMRI 2006; 23(3): 388-397. [2] Li M, Lim TC, Lee J-H, ISMRM 14, 2049 (2006).

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