Implementation of Feedforward Active Noise Control Techniques for Headphones

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***Abstract*— This paper develops active noise control (ANC) system with headphones to reduce recording environmental noise, such as from bus, train and airplane. By applying an additional MEMS microphone to get reference signal at each side of headphones, the proposed ANC headphones apply TMS320C6713 as the computing core to generate the anti-noise signal to destructively interfere the undesired noise. The anti-noise signal, which can be integrated with the audio signal, drives the speaker of the commercial headphones to reduce the environmental noise. Experimental results show the presented ANC headphones achieves larger bandwidth of noise reduction than the commercially available headphones.**

I. Introduction

Active noise control (ANC) has become an effective technology to reduce low-frequency noise, it works by the principle of acoustics to destructively interference the undesired noise [1]. There are some papers published on the applications of ANC headsets [2-4]. Also, ANC is widely used in the commercial market for headphones and hearing aids. However, there are still many problems of ANC that need improvements, including performance of noise reduction, computational load [5], noise direction of arrival [6-7] and psychoacoustic effects. The proposed research focuses on using the feedforward ANC method for headphones to reduce environmental broadband noise. Therefore, the causality problem of the control filter is crucial. That is to say, the electrical delay for the ANC system must be shorter than the acoustic delay of the noise [1]. To effectively attenuate the noise, DSP with high processing speed and high sampling rate are required. Therefore, the computational load should be saved to meet the sampling requirement. Comparisons with the leading brands of ANC headphones are provided to verify the performance of the proposed headphones. The presented audio integration and the proposed ANC systems both work well and do not affect each other's effect.

II. Propose System

This section analyzes and compares the environmental noise and then proposes the ANC algorithm for headphones. In order to verify the effectiveness of the proposed algorithm. We setup the experiments in a quiet room to conduct a series of subsequent verifications.

A. Environmental Noise Analysis

A digital recorder (Tascam DR-680MKII, sampling rate 48 kHz at 16 bit) was applied with microphone (Shure MX183) to record environmental noise. We placed the microphone near passenger's right ear (sit at a suitable seat) to record the noise. Based on the recording method, we also recorded the noise from a bus (idle speed, 65 dB (A)), Taiwan high speed train (speed: 300 km/h, 64 dB (A)); airplane cabin (steady flight, 76 dB (A)). The spectrum of those noise are shown in Fig. 1. These results show that those noise are broadband noise and their magnitude spectra are similar with significant low frequency noise power.

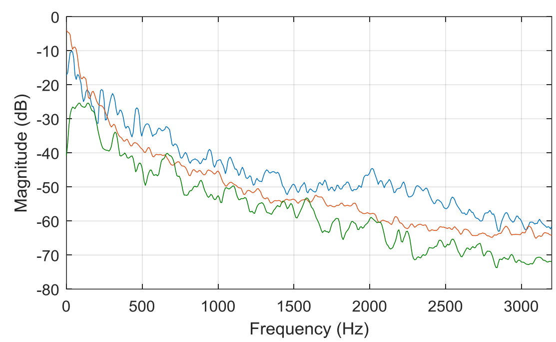


Fig. 1 Magnitude spectra of the environmental noise: bus noise (blue); Taiwan high speed rail noise (red); airplane noise (green).

B. Feedforward ANC

This research uses the FxLMS algorithm for feedforward ANC system to train the optimum coefficients for the control filter $W(z)$ as shown in Fig. 2 [1].

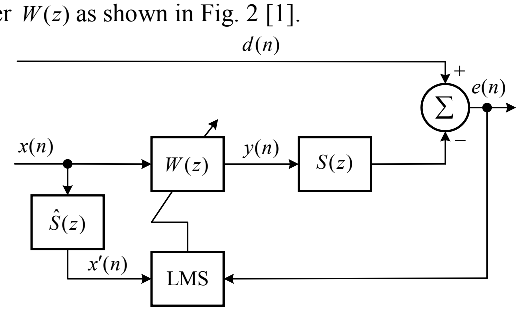


Fig. 2 Block diagram of feedforward ANC system using FxLMS algorithm.

The secondary path transfer function $S(z)$ is from $y(n)$ to $e(n)$. By modeling the secondary path, we used random noise as the excitation signal to estimate $S(z)$ and then get $\hat{S}(z)$ as the estimate transfer function [1]. The feedforward ANC system uses a reference microphone to measure the reference signal $x(n)$, this signal is then processed by the control filter $W(z)$ to generate the output signal $y(n)$ to drive the secondary loudspeaker to cancel the primary noise $d(n)$. The output signal is generated as:

$$y(n) = \sum_{l=0}^{L-1} w_l(n) x(n-l), \tag{1}$$

where $w_l(n)$ is the l^{th} coefficient of control filter $W(z)$ at time n, and L is the filter length. The filtered signal $x'(n)$ is generated as:

$$x'(n) = \sum_{m=0}^{M-1} \hat{s}_m x(n-m), \tag{2}$$

where $\hat{s}_m$ is the m^{th} coefficient of secondary path estimation $\hat{S}(z)$. The adaptive filter coefficients are updated by the FxLMS algorithm expressed as:

$$w_l(n+1) = w_l(n) + \mu x'(n-l)e(n), \quad l = 0,1,...,L-1. \tag{3}$$

The objective of ANC is to minimize the measured error signal $e(n)$. By choosing a small enough step size μ, the adaptive control filter $W(z)$ converges to the optimal transfer function is expressed as:

$$W^{\circ}(z) = \frac{P(z)}{S(z)}. \tag{4}$$

The audio integration method for the feedforward ANC system is shown in Fig. 3. The mixed signal consists of anti-noise $y(n)$ and audio signal $a(n)$ to drive the speaker simultaneously. In addition, this system does not need to feedback residual noise $e(n)$ to update adaptive control filter $W(z)$. Therefore, the audio and ANC system do not affect each other's effects.

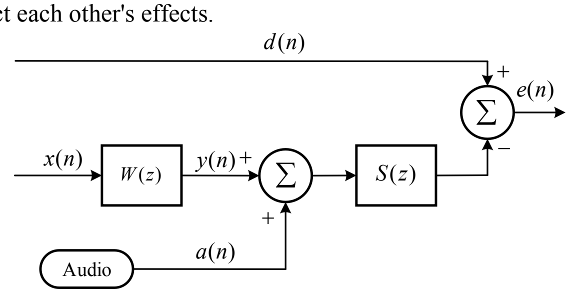
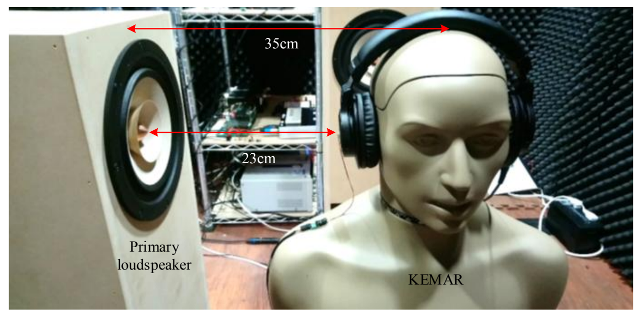


Fig. 3 Block diagram of audio-integrated feedforward ANC system.

C. *Experimental Setup*

The experimental setup of the proposed ANC headphones system is shown in Fig. 4, a loudspeaker (Tang Band, W8-1808) was placed 35 cm away from the KEMAR to generate the primary noise. Besides, we took a commercial available headphones (Rockville, PRO-M50) with a MEMS microphone (Transsound, TSMA-2418F221) on the shell as the reference microphone to cover the KEMAR's ear to test the performance of noise reduction. This research uses TMS320C6713 DSK with sampling rate 200 kHz to calculate the feedforward ANC algorithm to implement the real-time experiments. All the types of undesired primary noise were played at the same level in a quiet room and several commercial available ANC headsets were applied for fair comparisons.



(a)

(b)

Fig. 4 Experimental setup for testing the proposed ANC headphones: (a) front view; (b) right view.

III. Real-Time Experiments Results And Analysis

This section presents real-time experiments of the developed ANC headphones. We employ control filter $W(z)$ by pre-designed handle different types of environments noise and then evaluate the effectiveness of audio-integrated ANC. In addition, we also compare the performance of commercial ANC headphones.

A. *Transfer functions*

The desired transfer function of both control filter $W^{\circ}(z)$ and the secondary path $S(z)$ as shown in Fig. 5 (black lines). Obviously, the estimated curve (red lines) fulfills the desired curve (black lines) so the ANC system can have good noise reduction performance.

B. Noise Reductions

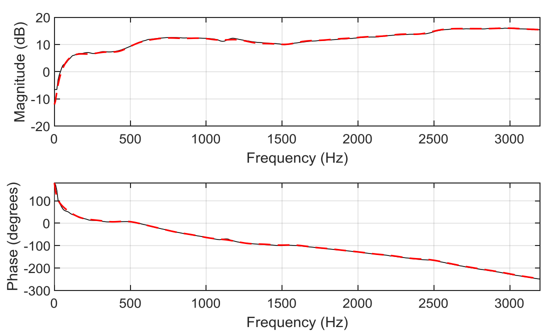
Fig. 6 shows the performance of the feedforward ANC to cancel the 0~3.2 kHz random noise and environmental noise. Also, the spectra show passive attenuation with (blue lines) and without (black lines) headphones. The passive attenuation shows noise reduction effect above 1 kHz. After turning on the ANC system (red lines), the spectra shows it can effectively reduce the noise from 100 Hz~3.2 kHz.

C. Comparison with the commercial ANC headphones

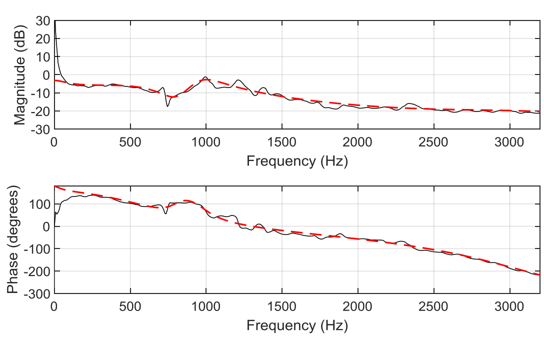
The experiments also compared the noise reduction performance of commercial ANC headphones with this developed ANC headphones. Fig. 7 shows that Bose QC35 and Bose 700 can effectively reduce noise over the wide frequency range from 40 Hz to 1 kHz. Also, this SONY WH-1000XM2 can effectively reduce noise over the wide frequency range from 40 Hz to 750 Hz too.

D. Audio Integration

This experiment uses spectrogram to evaluate the performance of audio-integrated feedforward ANC system. Fig. 8 show the music signal and ANC both perform well and do not affect each other.

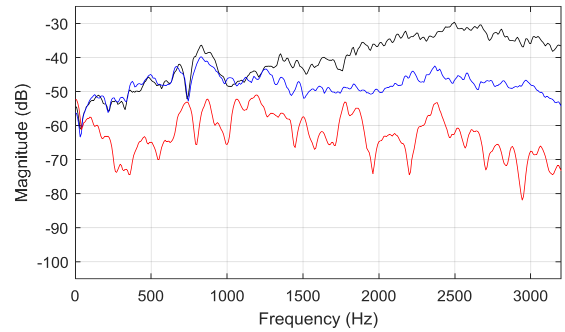


(a) Transfer function of secondary path: $S(z)$ (black); $\hat{S}(z)$ (red)

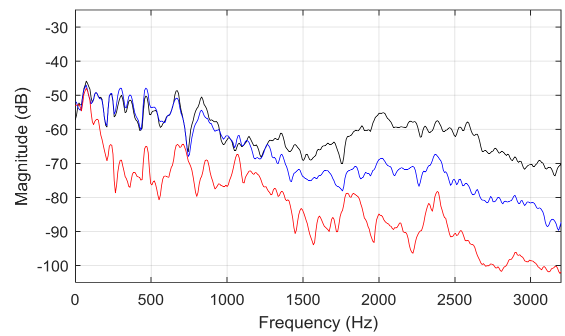


(b) Transfer function of control filter: $W^{o}(z)$ (black); $W(z)$ (red)

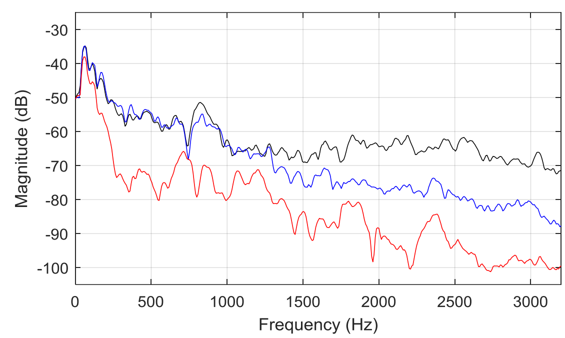
Fig. 5 Frequency response from transfer function: desired curve (black); estimated curve (red).



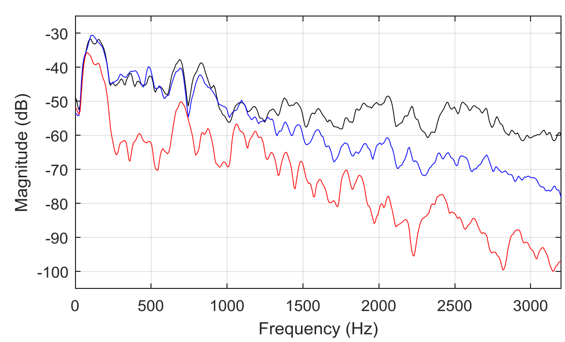
(c) Random noise



(d) Bus noise

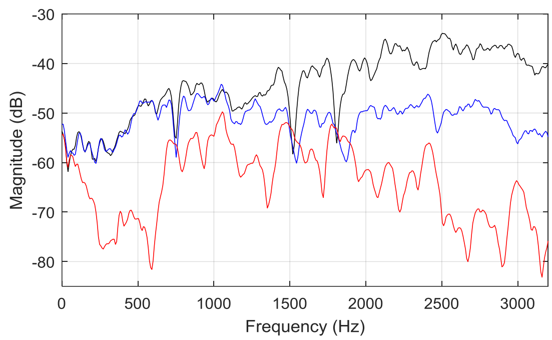


(e) Taiwan high speed rail noise

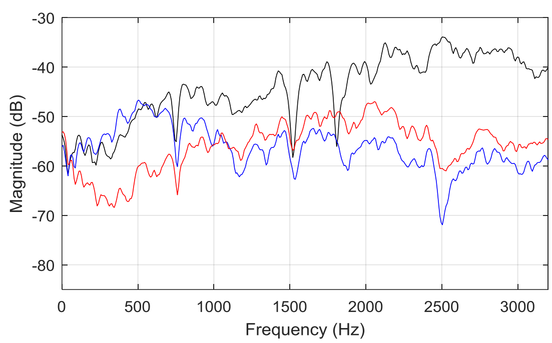


(f) Airplane noise

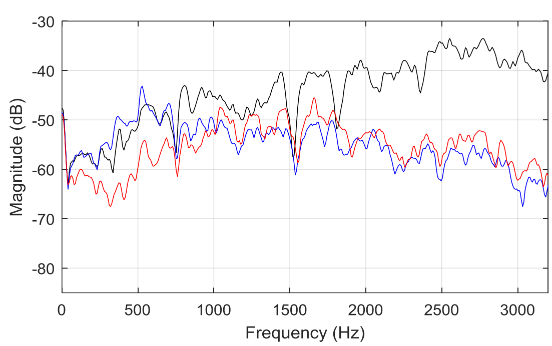
Fig. 6 Magnitude spectra of noise measured at the KEMAR's right ear for ANC Headphones: without headphones on it (black); with headphones and turn off ANC (blue); with headphones and turn on ANC (red).



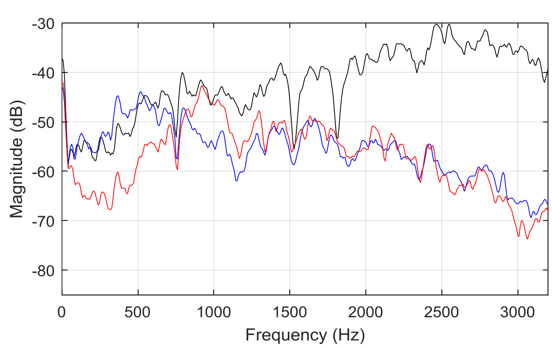
(a) ANC headphones by this research



(b) Bose QC35 headphones



(c) Bose 700 headphones



(d) SONY WH-1000XM2 headphones

Fig. 7 Magnitude spectra of noise measured at the KEMAR's right ear for commercial ANC headphones: without headphones on it (black); with headphones and turn off ANC (blue); with headphones and turn on ANC (red).

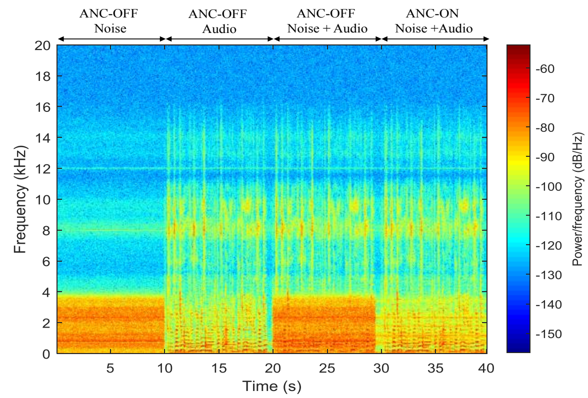


Fig. 8 Spectrograms of signals measured at KEMAR's right ear used the audio-integrated feedforward ANC system.

IV. Conclusions

This research implemented feedforward ANC system for headphones to reduce environmental broadband noise. The proposed using the trained coefficients of the control filter to alleviate the computational burden of DSP systems. Experiments show that the music signal and ANC system both perform well too.

References

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