Active Noise Control with Virtual Sensing Technology for Headrest

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***Abstract*— This paper presents using a $1x2x2$ active noise control (ANC) system with virtual sensing technology on headrests. Based on the feedforward structure and the filtered-x least mean square (FXLMS) algorithm, the proposed system cancels broadband noise without put an error sensor at desired location. Real time processing experiments show that the $1x2x2$ feedforward ANC system with integration of virtual sensing technique achieves satisfactory performance for noise reduction. The zone of quiet (ZoQ) is measured to assure system performance.**

Keyword: Active noise control (ANC), Real time processing, Headrest, Virtual sensing

I. Introduction

For those people who live close to an airport, it is quite noisy when an airplane taking off or landing. This paper tries to implement ANC on headrests to reduce the airplane taking off noise and other broadband noise. Basically, ANC system is an effective approach to reduce the noise at control point by generating anti-noise with the same amplitude and 180 degree phase shift to the undesired noise. This idea was proposed by Lueg [1] with the principle of superposition, as shown in the Fig. 1.

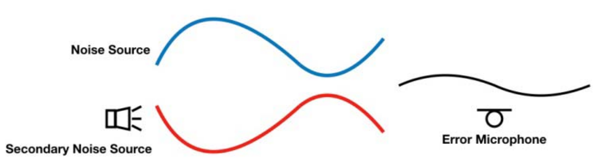


Fig. 1 - Superposition idea of ANC

In general, ANC systems can be divided into two parts-feedforward and feedback structures. The feedback structure is effective to cancel predictable noise, while the feedforward ANC system (see Fig. 2) [2-4] uses a reference microphone to pick up the reference noise signal and uses a secondary loudspeaker to generate the anti-noise to reduce the undesired noise. The error microphone is used to monitor the performance of the ANC system. The feedforward method is the effective scheme to cancel broadband noise. Usually, the center of zone of quiet (ZoQ) of the feedforward scheme is at the location of the error microphone and the size of ZoQ is strongly depends on the wavelength of noise to be canceled [5, 6]. When the frequency of the noise is higher, the wavelength is smaller and the ZoQ which achieved by a feedforward ANC system will be small accordingly.

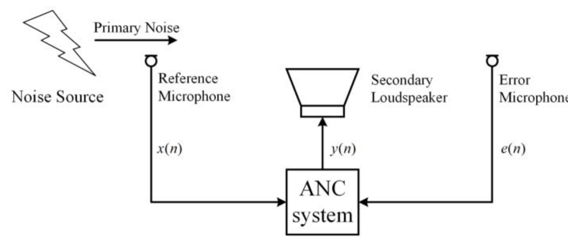


Fig. 2 - Basic Feedforward ANC system

The best performance of the feedforward ANC is at the location of the error microphone. However, the desired location of noise reduction is usually around user's ears for a headrest case. But it is not convenient to place the error microphone and take signal from people's ear canal. Hence, in this paper, we focus on the development of a $1x2x2$ feedforward structure [7-11] with virtual sensing technique [12] in order to reduce broadband noise around users' ears. Experimental results demonstrate the performance of the proposed scheme on a headrest ANC system.

II. Propose System

A general multi-channel feedforward filtered-x LMS (FXLMS) algorithm uses multiple reference sensors, secondary loudspeakers, and error sensors. The goal of the proposed work is to generate a quiet zone with adequate size surrounding the headrest. Therefore, we choose the $1x2x2$ feedforward ANC with FXLMS algorithm which uses one reference sensor, two secondary sources, and two error sensors.

A. $1x2x2$ Feedforward ANC

As shown in Fig. 3, the $x(n)$ is the reference signal, $y_1(n)$ and $y_2(n)$ are the canceling signals generated by the corresponding adaptive filters $W_1(z)$ and $W_2(z)$, respectively; $e_1(n)$ and $e_2(n)$ are the error signals measured by the error sensors; $S_{11}(z)$ and $S_{21}(z)$ are the secondary paths from $y_1(n)$ to two error sensors; $S_{12}(z)$ and $S_{22}(z)$ are the secondary paths from $y_2(n)$ to two error sensors. The FIR filtering for generating anti-noise are expressed a

$$y_1(n) = w_1^T(n) * x(n) \quad , \quad y_2(n) = w_2^T(n) * x(n) \tag{1}$$

where T denotes the transpose operation, $x(n)$ is the reference signal vector, $w_1(n)$ and $w_2(n)$ are the weight vectors of $W_1(z)$ and $W_2(z)$, respectively. The weight vectors are updated by the $1x2x2$ FXLMS expressed as

$$w_1(n+1) = w_1(n) + \mu\{[\hat{s}_{11}(n) * x(n)]e_1(n) + \hat{s}_{21}(n) * x(n)]e_2(n)\} \tag{2}$$

and

$$w_2(n+1) = w_2(n) + \mu\{[\hat{s}_{12}(n) * x(n)]e_2(n) + \hat{s}_{22}(n) * x(n)]e_2(n)\} \tag{3}$$

where * denotes linear convolution, $\hat{s}_{11}(n)$, $\hat{s}_{21}(n)$, $\hat{s}_{12}(n)$, and $\hat{s}_{22}(n)$ are the identified impulse response of the secondary-paths, $\hat{S}_{11}(z)$, $\hat{S}_{21}(z)$, $\hat{S}_{12}(z)$, and $\hat{S}_{22}(z)$ respectively. The error signal

$$e_1(n) = d_1(n) - y_1(n) \quad ; \quad e_2(n) = d_2(n) - y_2(n) \tag{4}$$

can be derived accordingly.

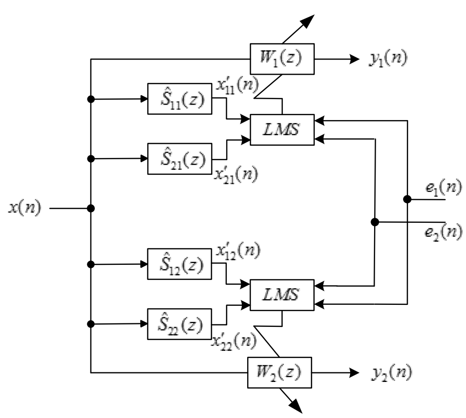


Fig. 3 - Conventional $1x2x2$ FFANC block diagram

We integrate the virtual sensing technology [13] with the conventional $1x2x2$ ANC system to transfer the quiet zone to close to the users' ears. The detail deduction of the virtual sensing technology was described in [13] which is neglected in this paper.

B. Experimental Setup

The experimental setup of the proposed headrest ANC system is shown in Fig. 4. One microphone is put closed to the primary loudspeaker (L0) to pick up the reference signal. Two secondary loudspeakers (L1 and L2) are mounted inside a headrest to generate anti-noise signals for left and right ears. Two microphones (M1 and M2) are set beside the secondary loudspeakers to pick up the error signals. A manikin is put to sit on the chair with its head slightly in front of the headrest. Since the error microphones are not very close to the manikin's ears, we set the locations of the two virtual microphones (M3 and M4) to be just at the manikin's both ears. Besides, the distance between the primary loudspeakers to the headrest is about 150 cm. The distances between of manikin to the headrest and between the microphones to the loudspeakers are shown accordingly. The size of the headrest is 40 cm x 15 cm.

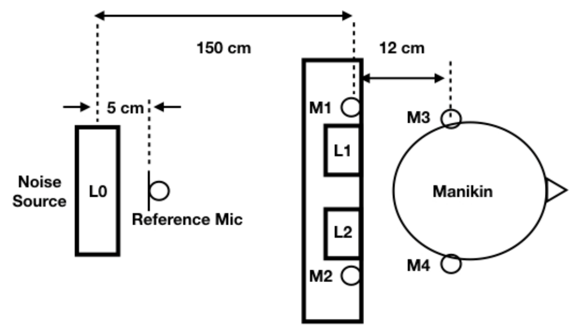


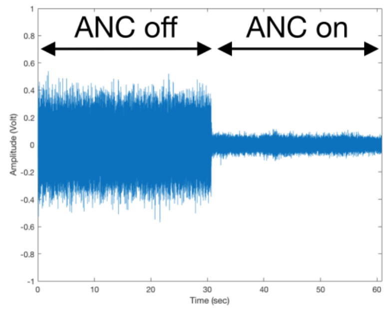
Fig. 4 - Top view of the experiment setup

III. Experimental Result and Analysis

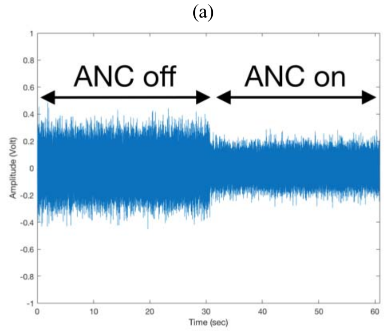
Two kinds of broadband noise are used to verify the effectiveness of the proposed $1x2x2$ FFANC system with the virtual sensing technique. The ZoQ is examined too. All the performance shown below is taken by the left ear of KEMAR. The sampling rate is 2kHz, the filter lengths for both the secondary path and virtual filter are 120. The tap length is 250 for $W_1(z)$, $W_2(z)$ and the auxiliary filter for virtual sensing. The step size is 0.2 for the secondary path at tuning stage and 0.001 for $W_1(z)$ and $W_2(z)$.

A. Reduction for White noise

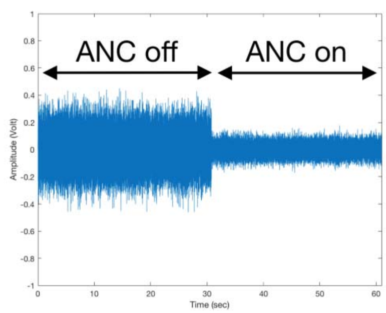
Figure 5 shows the performance of the proposed method to cancel the white noise. The locations of the microphones and loudspeakers are the same as shown in Fig. 4. The characteristic of a general ANC system is to achieve the best noise cancelation at the location of the error microphone. In Fig. 5 (a), we show the signal at the error microphone while the ANC system is turned on. However, in the meantime, the performance at the ear of the manikin (virtual microphone location) is not satisfactory when the ANC is activated, as shown in Fig. 5(b). By integrating the virtual sensing technique, we can find the performance at the virtual microphone is enhanced, shown in Fig. 5(c).



(a)



(b)

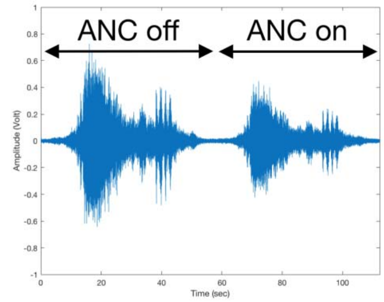


(c)

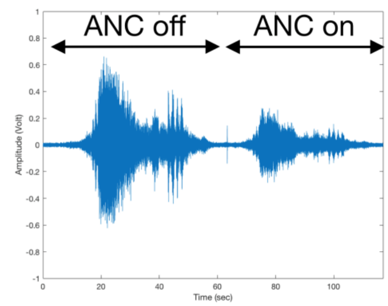
Fig. 5 - White noise reduction, (a) 1x2x2 Feedforward ANC at error microphone, (b) manikin's ear location, (c) Feedforward ANC with virtual sensing at ear location.

B. Reduction for practical noise

Figure 6 shows the performance of the proposed method to cancel airplane take off noise. The locations of the microphones and loudspeakers are the same as shown in Fig. 4. The characteristic of a general ANC system is to achieve the best noise cancelation at the location of the error microphone. In Fig. 6 (a), we show the signal at the ear of the manikin (virtual microphone location) while the ANC system is turned on. However, the performance is not satisfactory. By integrating the virtual sensing technique, we can find the performance at the virtual microphone is enhanced, shown in Fig. 6 (b).



(a)



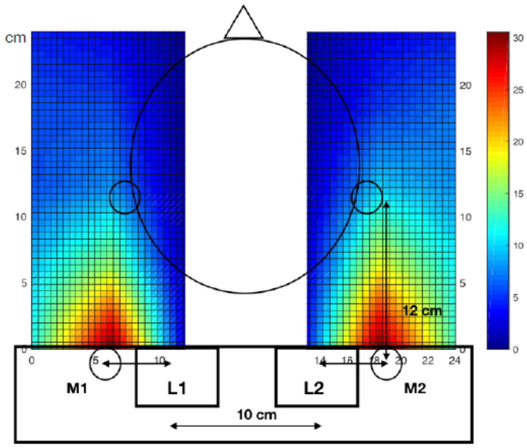
(b)

Fig. 6 - Airplane taking-off noise reduction, (a) Conventional Feedforward ANC and (b) Feedforward ANC with virtual sensing at ear location in time-domain

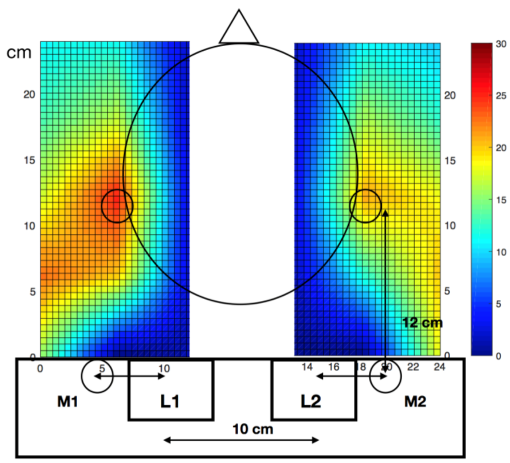
C. Quiet Zone Performance

The performance of ZoQ which is measured using a measurement grid. The measurement grid is performed at every 6 cm in the plane with the same height of the manikin's left and right ears, shown in Fig. 7. First, we show the ZoQ of the testing noise (80 to 850 Hz band-limited white noise). The noise reduction is calculated by measuring the different of noise level when the ANC system is activated or not. This paper only present the plane which is through the manikin’s ears and the height of the manikin is simulates a 175 cm tall human sitting on the headrest chair. The filter length of $1x2x2$ ANC system are both 250.

The result in Fig. 7(a) shows the conventional $1x2x2$ feedforward ANC performance of the ZoQ by white noise at ear location. It shows the performance is good at the error microphone location but is not satisfactory around manikin's ear location. By integrating the virtual sensing technique, the result in Fig. 7(b) achieves a better performance when compared with the conventional feedforward ANC at ear location.



(a)



(b)

Fig. 7 - ZoQ by (a) Conventional Feedforward ANC system, (b) Feedforward ANC system with virtual sensing

IV. Conclusions

In this paper, we follow the technique of virtual sensing and successfully integrate with the $1x2x2$ feedforward ANC system on a headrest system. Experimental results to cancel band-limited white noise and an airplane taking off noise are examined. Experimental results verify that the virtual sensing technique can transfer the center of ZoQ to a desired location. When compared with the conventional feedforward ANC system, the virtual sensing technology provides a better solution especially for those cases where the desired noise cancellation point is not suitable to put an error sensor.

V. References

[1] P. Lueg Process of silencing sound oscillations. U.S. patent, 1936, No. 2,043,416.
[2] P. A. Nelson, A. R. D. Curtis, S. J. Elliott, and A. J. Bullmore, "The minimum power output of free field point sources and the active control of sound," J. of Sound and Vibration, Vol. 116, 1987, pp. 397-414.
[3] S. J. Elliott and P. A. Nelson, "Active noise control", IEEE Signal Process. Mag., 1993, pp. 12-35.
[4] S. M. Kuo and D. R. Morgan, Active noise control systems: Algorithms and DSP implementations. NY: Wiley, 1996.
[5] S. J. Elliott et al., "Near Field zones of quiet," J. of Sound and Vibration, vol. 172, 1994, pp. 605–627.
[6] S. J. Elliott et al., "Active cancellation at a point in a pure tone diffuse sound Field," J. of Sound and Vibration, vol. 120, 1997, pp. 183–189.
[7] S. J. Elliott, Signal processing for active control. CA: academic Press, 2001.
[8] S. J. Elliott and M. Jones, "An active headrest for personal audio," J. Acoust. Soc. Am., vol. 119, no. 5, 2006, pp. 2702–2709.
[9] M. Brothanek and O. Jiricek, "Formatting of zones of quiet around a head simulator," in Proc. Active-The 2002 Int. Symp. On Active Control of Sound and Vibration, Southampton, United Kingdom, 2002, pp. 117-122.
[10] M. de Diego, et al., "On the performance of a local active noise control system," Proc. 1999 IEEE ICASSP Conf., Arizona, 1999, pp. 885-888.
[11] A. Siswanto, C.Y. Chang, S. M. Kuo, "Active noise control for headrests," Proceedings of APSIPA 2015, Hong Kong, 2015, pp. 688-692.
[12] S. Edamoto, C. Shi, and Y. Kajikawa, "Directional feedforward ANC system with virtual sensing technique," in Proc. Int. Workshop Smart Info-Media Syst. Asia, Ayutthaya, Thailand, Sep. 2016.
[13] N. Miyazaki, Y. Kajikawa, "Head-mounted active noise control system with virtual sensing technique," J. of Sound and Vibration, vol. 339, 2015, pp. 65-83.