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Stability Improvement of Feedback Active Noise Control System Using Linear Prediction

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Abstract—In this paper, we propose a feedback active noise control (ANC) system which can surpress disturbance. The conventional feedback ANC system has a possibility of divergence because the disturbance of broadband noise corrupts the input signal for the system. To surpress the disturbance, we incorporate a linear prediction filter into the feedback ANC system. Simulation results show that the proposed feedback ANC system is superior to the conventional feedback ANC system on the stability.

I. INTRODUCTION

Recently, acoustic noise problems caused by the increased numbers of industrial equipment become more and more serious. Active noise control (ANC) [1], [2] has been applied to such acoustic noise problems. ANC is a technique based on the principle of superposition, i.e., an antinoise with equal amplitude and opposite phase is generated and combined with an unwanted noise, thus resulting in the cancellation of both noises. A feedback ANC system [3], [4] is one of the control structure in ANC. The feedback ANC system is effective for narrowband noise and widely used for headset apprications [5], [6] in advatage that the system scale is small in comparison with common feedfoward ANC system. However, the feedback ANC system tends to be affected by disturbance of broadband noise and be unstable because of the scheme. In order to improve the stability, therefore, we propose the feedback ANC system which can surpress the disturbance. The proposed feedback ANC system surpresses the disturbance by a linear prediction filter [7], [8].

The organization of this paper is as follows. First, the principle and problem of the conventional feedback ANC system are introduced. Second, we show the proposed feedback ANC system using the linear prediction filter. Third, the effectiveness of the proposed feedback ANC system is demonstarated through the computer simulation. Finally, conclusions and future works are presented.

II. FEEDBACK ANC SYSTEM

Figure 1 shows the scheme of the feedback ANC system. The feedback ANC system consists of a secondary source which radiates an antinoise and an error microphone which measures a residual error. The controller attempts to minimize the residual error. The feedback ANC system is advantageous in that the scale of the system is small in comparison with the
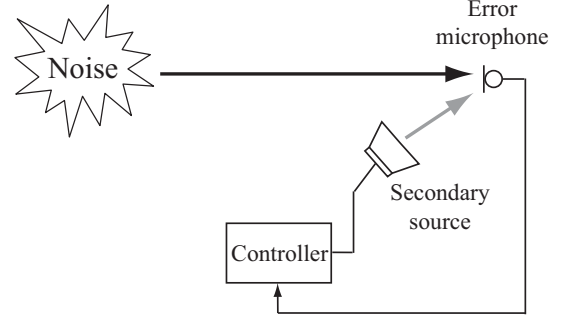

Fig. 1. Scheme of feedback ANC system.

feedforward ANC system which needs a reference microphone to get a reference input. Moreover, the feedback ANC system can cancell the narrowband noise but not the broadband noise. Hence, the broadband noise is uncontrollable disturbance in the feedback ANC system.

A. principle

Figure 2 shows the block diagram of the feedback ANC system using filtered-x LMS (FXLMS) algorithm [9], [10], where W is the noise control filter, C is the secondry path from the output of W to the error microphone, $\hat{C}$ is the estimated model of C called a secondary path model, and n denotes sample time. Also, d_n is the narrowband noise which is the control target, v_n is the disturbance of broadband noise, e_n is the error signal mearsured at error microphone, x_n is the input signal for the system, r_n is the filtered reference signal, and y_n is the output signal of the noise control filter. The basic idea of the feedback ANC system is to estimate the narrowband noise d_n and use it as an input signal x_n. In other words, it is desirable for d_n and x_n to become equal. The narrowband noise d_n is not available during the operation of ANC because of being cancelled by the antinoise. The error signal e_n and the output signal y_n filtered by $\hat{C}$ are combined with each other in order to reconstruct d_n as follows:

$$x_n \equiv \hat{d}_n = e_n + \hat{\mathbf{c}}^T \mathbf{y}_{n-1} \qquad (1)$$
$$\hat{\mathbf{c}} = [\hat{c}(1)\ \hat{c}(2)\cdots\hat{c}(i)\cdots\hat{c}(M)]^T$$
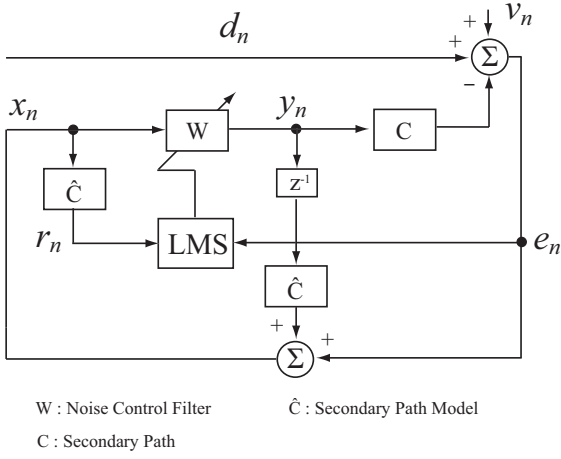$$\mathbf{y}_n = [y_n\ y_{n-1}\cdots y_{n-i+1}\cdots y_{n-M+1}]^T$$

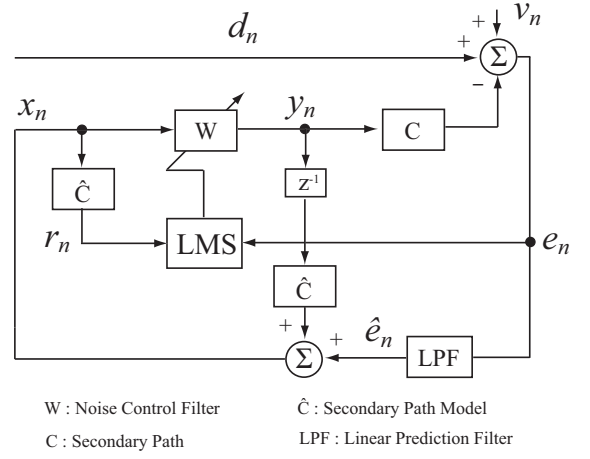Fig. 2. Block diagram of the conventional feedback ANC system using FXLMS algorithm.

Fig. 3. Block diagram of the proposed feedback ANC system using FXLMS algorithm.

where $\hat{\mathbf{c}}$ is the coefficient vector of the secondary path model and M is the tap length. Also, T denotes transpose. The output signal y_n is generated as

$$y_n = \mathbf{w}_n^T \mathbf{x}_n \qquad (2)$$
$$\mathbf{w}_n = [w_n(1)\ w_n(2) \cdots w_n(i) \cdots w_n(N)]^T$$
$$\mathbf{x}_n = [x_n\ x_{n-1} \cdots x_{n-i+1} \cdots x_{n-N+1}]^T$$

where $\mathbf{w}_n$ is the coefficient vector of the noise control filter and N is the tap length. The coefficients of the noise control filter are updated by FXLMS algorithm as follows:

$$\mathbf{w}_{n+1} = \mathbf{w}_n + \mu \mathbf{r}_n e_n \qquad (3)$$

where μ is the step size parameter and the filtered reference signal r_n is expressed as follows:

$$r_n = \hat{\mathbf{c}}^T \mathbf{x}_n \qquad (4)$$

The algorithm for the feedback ANC system is summarized in (1) to (4). By the way, in real application, the power normalized version of FXLMS algorithm called as FXNLMS algorithm [3] is commonly used because of giving a better convergence property. FXNLMS algorithm is expressed as follows:

$$\mathbf{w}_{n+1} = \mathbf{w}_n + \frac{\mu}{\|x_n\|^2 + \beta} \mathbf{r}_n e_n \qquad (5)$$

where

$$\|x_n\|^2 = \mathbf{x}_n^T \mathbf{x}_n \qquad (6)$$

is Euclidian norm of the input signal vector $\mathbf{x}_n$ and β is the regularization parameter.

B. problem

As stated above, the error signal and the output signal are combined with each other in order to generate the input signal. However, the uncontrollable broadband noise such as background noise is always included in the error signal. As
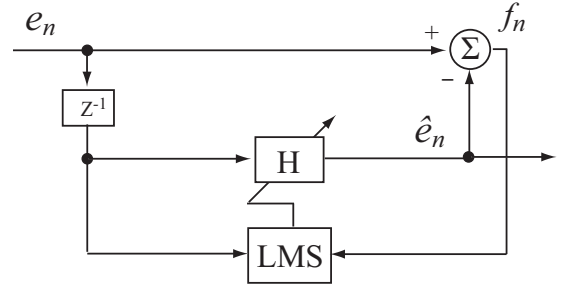

Fig. 4. Block diagram of the linear prediction filter using LMS algorithm.

a result, the broadband noise corrupts the input signal as the disturbance at all times. If the disturbance corrupting the input signal increases, the system may be unstable and diverge. Hence, it is desireble to surpress the disturbance.

III. PROPOSED FEEDBACK ANC SYSTEM

We propose the feedback ANC system which can surpress the disturbance to improve the stability. Figure 3 shows the block diagram of the proposed feedback ANC system. In the proposed feedback ANC system, the linear prediction filter whose input is the error signal e_n is incorporated. Figure 4 shows the block diagram of the linear prediction filter using LMS algorithm [11]. The linear prediction filter outputs nothing for unpredictable broadband signal and passes only predictable narrowband signal. The update algorithm of the linear prediction filter at sample time n is expressed as follows:

$$\mathbf{h}_{n+1} = \mathbf{h}_n + \mu \mathbf{e}_{n-1} f_n \qquad (7)$$
$$\hat{e}_n = \mathbf{h}_n^T \mathbf{e}_{n-1}$$
$$f_n = e_n - \hat{e}_n$$
$$\mathbf{h}_n = [h_n(1)\ h_n(2) \cdots h_n(i) \cdots h_n(K)]^T$$
$$\mathbf{e}_n = [e_n\ e_{n-1} \cdots e_{n-i+1} \cdots e_{n-K+1}]^T$$

where μ is the step size parameter, $\mathbf{h}_n$ is the coefficient vector of the linear prediction filter, f_n is prediction error, and K

TABLE I
SIMULATION CONDITIONS

Sampling frequency	6000Hz
Tap length of noise control filter	300
Tap length of secondary pass	250
Tap length of secondary pass model	250
Tap length of linear prediction filter	300
Update algorithm of ANC system	FXNLMS
Update algorithm of LPF	NLMS
Step size parameter of FXNLMS	0.01
Step size parameter of NLMS	0.05

(a) Conventional feedback ANC system

(b) Proposed feedback ANC system

Fig. 5. Comparison of convergence properties in the case where iteration numbers are 60000.

is the tap length of the linear prediction filter. At early stage of the converegence of the proposed feedback ANC system, the linear prediction filter passes only the narrowband noise d_n while surpressing the disturbance v_n. In this case, the disturbance v_n is removed from the original error signal e_n in the new error signal $\hat{e}_n$ filtered by the linear prediction filter. Moreover, after the feedback ANC system converges enough, $\hat{e}_n$ equals zero because the narrowband noise d_n is cancelled and the original error signal e_n contains only the disturbance v_n. Therefore, the stability improvement of the feedback ANC system can be expected because the disturbance v_n corrupting the input signal x_n is surpressed. The update algorithm of the proposed feedback ANC system is the almost same as the conventional one except for Eq (1) to generate the input signal x_n, that is, Eq (1) is rewritten as follows;

$$x_n \equiv \hat{d}_n = \hat{e}_n + \hat{\mathbf{c}}^T \mathbf{y}_{n-1} \qquad (8)$$

IV. COMPUTER SIMULATION

In this section, the effectiveness of the proposed feedback ANC system is demonstrated through the computer simulation. We compare the convergence properties of the proposed feedback ANC system with that of conventional one in the case where the magnitude of the disturbance is changed. The simulation conditions are shown in Table I. We use the multi-sinusoidal wave which has the fundamental frequency $f_0 = 200$Hz as the narrowband noise d_n:

$$d_n = a_n \left\{ \sum_{k=1}^{5} \sin(2\pi k f_0 n) \right\} \qquad (9)$$

where a_n is the amplitude of the multi-sinusoidal wave changing with time according to Eq (10).
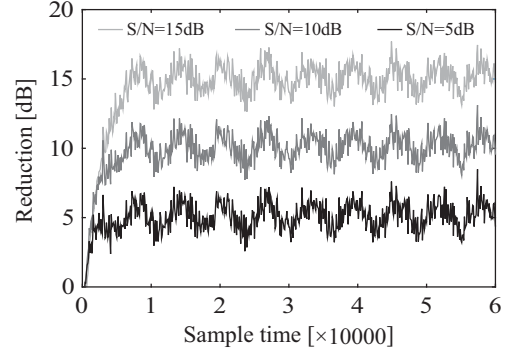
$$a_n = 6000 + 600\sin(0.001n) \qquad (10)$$

Also, white noise is used as the disturbance. The impulse response of the secondary path model is identical with that of the secondary path. The vertical axis in the convergence properties indicates the reduction on the noise (Reduction) which is defined as follows:

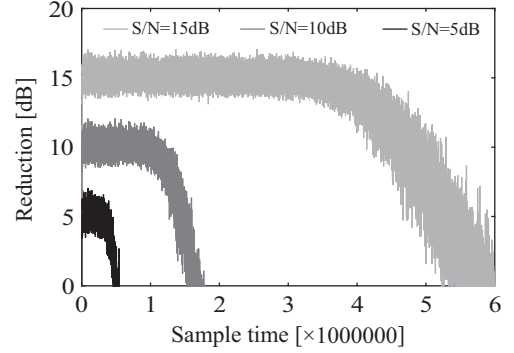$$\text{Reduction} = 10\log_{10} \frac{\sum d_n^2}{\sum e_n^2} \qquad (11)$$
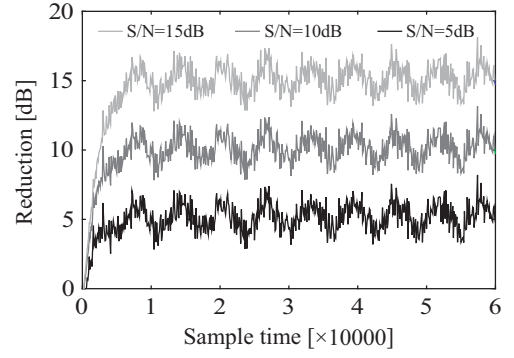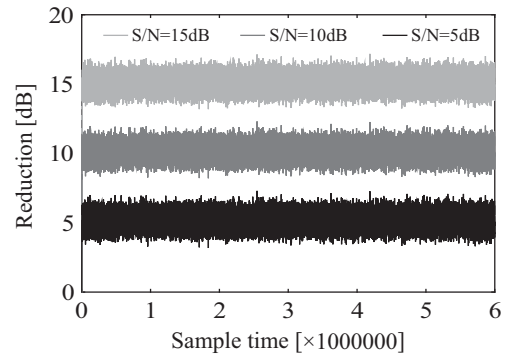

(a) Conventional feedback ANC system

(b) Proposed feedback ANC system

Fig. 6. Comparison of convergence properties in the case where iteration numbers are 6000000.

Figures 5 and 6 show the convergence properties in the case where S/N (narrowband noise-to-disturbance power ratio) is changed to 15, 10 and 5dB. It can be seen from Fig. 5, which is the graphs in the case where iteration numbers are set at 60000, that the proposed and the conventional feedback ANC system have similar properties at early stages of convergence. On the other hand, it can be seen from Fig. 6, which is the graphs in the case where iteration numbers are set at 6000000, that the proposed and the conventional feedback ANC system have different properties. Fig. 6(a) shows that the conventional feedback ANC system tends to diverge after convergence. Moreover, we recognize that the disturbance causes the instability of the system because the system diverges fastly as much as S/N becomes low. In contrast, it can be seen from Fig. 6(b) that the proposed feedback ANC system can converge stably for a long time regardress of the magnitude of the disturbance. Figure 7 shows the spectra of the input signal x_n in the proposed and the conventional ANC systems. It can be seen from Fig. 7 that the disturbance of the broadband noise included in the input signal x_n is reduced about 15dB at the frequency range from 0 to 3000Hz. Hence, the effectiveness of the proposed system has been demonstarated.

V. CONCLUSIONS

In this paper, we have proposed the feedback ANC system which can suppress the disturbance. Then, the effectiveness of the proposed system has been demonstrated through the computer simulation. The simulation results have verified that the proposed feedback ANC system can reduce noise stably regardress of magnitude of the disturbance.

In the future, we will implement the proposed feedback ANC system on DSP and examine the performance through some experiments.

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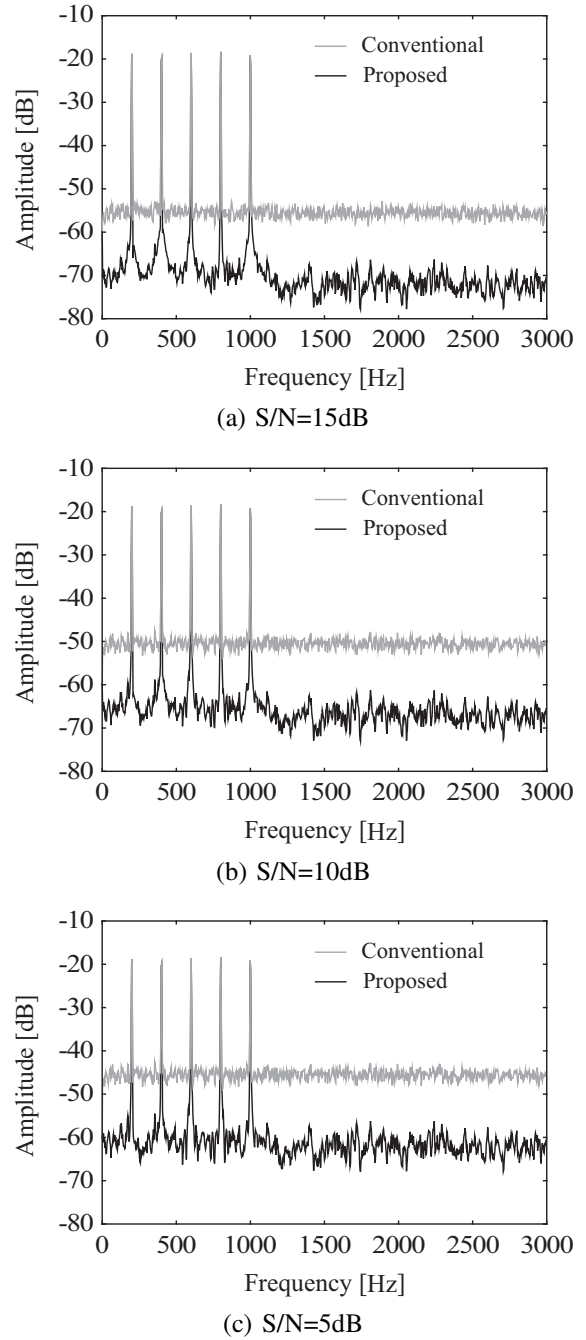(a) S/N=15dB

(b) S/N=10dB

(c) S/N=5dB

Fig. 7. Comparison of input spectra between the proposed and the conventional feedback ANC systems.