Active noise control in a duct to cancel broadband noise

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Abstract. The paper presents cancelling duct noises by using the active noise control (ANC) techniques. We use the single channel feed forward algorithm with feedback neutralization to realize ANC. Several kinds of ducts noises including tonal noises, sweep tonal signals, and white noise had investigated. Experimental results show that the proposed ANC system can cancel these noises in a PVC duct very well. The noise reduction of white noise can be up to 20 dB.

1. Introduction

Exhaust duct is commonly use for ventilation or cooling system. However, when the fresh air has transmitted by the duct, the noise happens accordingly. This paper studies the noise problem in a 1-dimensional duct. Traditionally, based on acoustic theory, noise propagation in a 1-dimensional can keep its same acoustic property at its cross section [1]. In general, the conventional method to cancel duct noise only is effective in higher frequency. However, for the ventilation or cooling system, the noise has its main power at low frequency, so it is suitable to use active noise control (ANC) technique as an alternative.

There are some papers discuss the performance of ANC system in a duct. But most of them only cancel narrowband noise or use simulation to verify performance and lack implementation [2],[3]. Actually, there are random noise component in mechanical system such as ventilation or cooling system. In order to cancel random noise, online modeling for the error path and secondary path is necessary. Also, the filter length of the adaptive filter has to be increased to fit the acoustic plant. In [3], an ANC system with filtered-X least mean square (FXLMS) algorithm is developed. The adaptive filter has updated using the FXLMS algorithm [5]. In order to realize the ANC system, we have to use a microphone to get the noise source signal as the reference signal. This techniques used a signal at upstream and control the noise at downstream. It is called the feed forward ANC algorithm, which is proven to effective to cancel broadband noise [6]. In [7], the noise for the heating, ventilation and air conditioning (HVAC) system is studied. Several ANC systems had also developed for applications [8]-[10].

This paper studies the feed forward ANC system with FXLMS algorithm. A feedback neutralization algorithm has also proposed to overcome the acoustic feedback problem. Besides, we also studied the distance between the reference microphone to the secondary speaker to make the PVC duct short, more practical for applications. Several experiments are presented to show the effectiveness of the ANC system to reduce noises in ducts.

2. Feedforward ANC system with FXLMS algorithm

Active noise control uses an artificial noise to destructive interfere the undesired noise. In order to cancel the noise effectively, several ANC approaches has been developing. The most popular way is feedback and feed forward structures. The feedback ANC uses only one error microphone to synthesize the original noise, hence, only periodic noise signal can be cancel.

However, the feed forward ANC structure applies a microphone upstream to measure the undesired noise as a reference signal of ANC system, and uses an error microphone downstream to measure the residual noise. This method is effective to cancel broadband noise under the constraint of causality issue.

2.1. Single channel feed forward ANC system

Figure1 shows the single channel feed forward ANC system, where $x(n)$ denotes the reference signal, $e(n)$ represents the error signal. The $P(z)$ is the primary path between reference microphone and error microphone and the $W(z)$ is the adaptive filter that will estimate the primary path. After deriving the anti-noise $y(n)$, we send it to destructively interfere the undesired noise $d(n)$. The $S(z)$ is the secondary path that is the electrical and acoustical information of the transfer functions from the output of the adaptive filter to the error sensor, including the digital to analogue converter, low pass filter, power amplifier, loudspeaker, error microphone, pre-amplifier, anti-aliasing filter and analogue to digital converter. The $\hat{S}(z)$ is the estimated model of $S(z)$.In the single channel feed forward ANC system, we design finite impulse response (FIR) filter for $W(z)$ and $\hat{S}(z)$, an adaptive filtered-X least mean square (FXLMS) algorithm is applied to update the weights, so we have

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

$$x'(\mathrm{n}) = \sum_{m=0}^{M-1} \hat{S}_m x(n-m) \quad (2)$$

$$w_l(n+1) = w_l(n) + \mu e(n)x'(n-1), L = l-1, \quad (3)$$

The most widely used FIR, or transversal, the digital filter computes its output in a linear fashion. That is, given a set of L filter coefficients, $w(n)$, l=0,1,…,L-1, and a data sequence,{ $x(n)$ $x(n-1 \ldots x(n-L+1)$ }, the output signal is computed as (1).

The $x'(\mathrm{n})$ is a filtered version of the reference input signal. Where $\hat{S}_m$ is an Mth-order estimate of the secondary-path impulse response. A further simplification can be achieved by replacing $\hat{S}_m(z)$ with a simple delay, as in Ziegler's method.(2)

Where a one-sample delay was used to produce $x(n-1)$. Both weights are update by the FXLMS algorithm as (3).

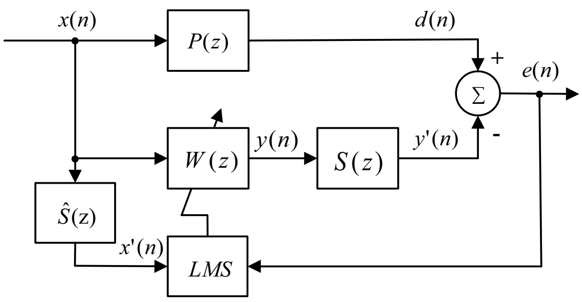

Figure 1. Single channel feedforwardANC system

2.2. Feedback neutralization

In general, the ANC system uses a microphone at upstream to measure the noise source as a reference signal and uses a loudspeaker to play the antinoise. However, when the loudspeaker is playing the antinoise, the reference microphone also takes some antinoise signal besides the noise source. This situation has illustrated in Fig. 2. In order to solve this problem, a feedback neutralization algorithm has proposed. In Fig. 2, the $u(n)$ is the reference signal picked up by a reference microphone. It also takes some component from the antinoise$y(n)$. Assuming that the transfer function from the secondary speaker to the reference microphone is $F(z)$, and the$\hat{F}(z)$ is its estimated filter. Therefore, we applies a negative feedback signal to the $u(n)$ and get the true reference signal.

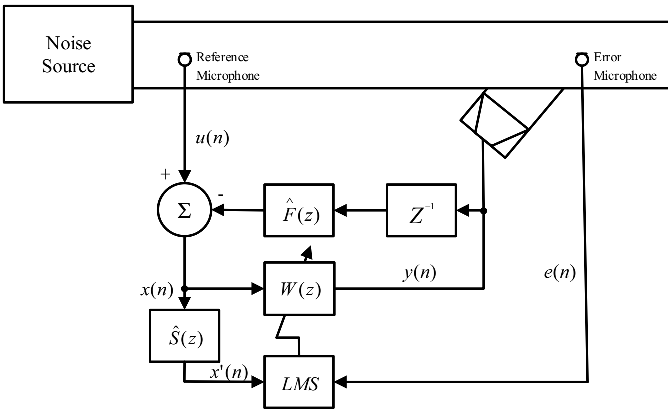

Figure 2. Feed forward ANC with feedback neutralization.

The models $\hat{S}(z)$ and $\hat{F}(z)$ can be estimated simultaneously by using the off-line modeling technique illustrated in Fig.3. The filters $S(z)$ and $\hat{F}(z)$ must have enough taps to successfully model S(z) and F(z). The impulse response length is determined by the propagation delay associated with the secondary source and signal-conditioning low pass filters, $\hat{W}(z)$ is able to model the primary path and generate the proper signal to attenuate the primary noise .

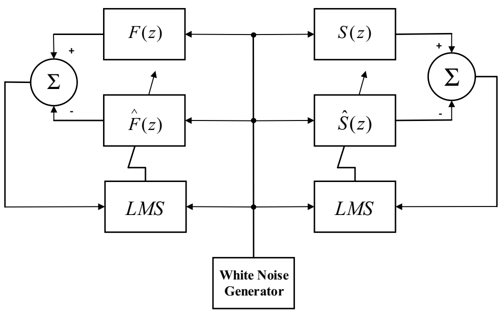

Figure 3. Simultaneous modeling of both feedback and secondary paths.

3. Experimental Results

3.1. Experimental setup

A duct made by polyvinyl chloride (PVC) is applied to implement all the duct noises cancellation experiments. One speaker (primary speaker) has mounted at one end of the duct to play the noise as the noise source. Another speaker (secondary speaker) has mounted at the side to play the anti-noise signal. One micro electromechanical systems (MEMS) microphone

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is inserted near the primary speaker to measure the noise source as the reference noise for the ANC system and another MEMS microphone is put at the end to measure the residual noise signal and acted as feedback signal to the ANC system. The apparatus of the duct system is shown in Fig. 4. The distance from the reference microphone to the secondary speaker is 135cm, and the diameter of the duct is 6 inches. The core for the ANC system is Texas Instrument (TI) TMS320C6713DSK and an Alexis Microtube Duo microphone preamp is used for both the reference and error microphones. Two SMSL SA-98E power amplifiers are used to drive the speakers. We also use several analog circuits such as ADC/DAC and low pass filters for necessary data processing and conversion.

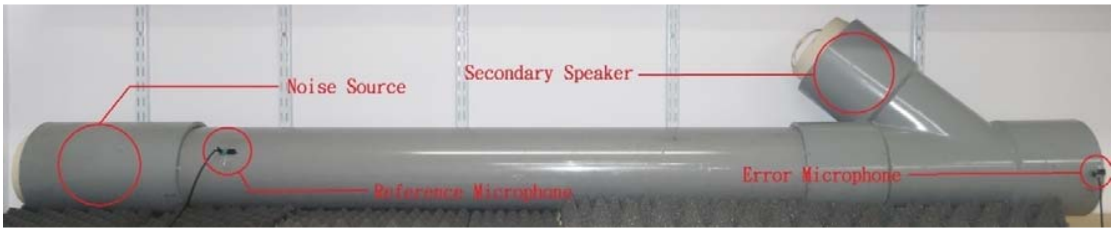

Figure 4. The duct system.

3.2. Results

The first experiment shows the single tonal noise reduction. The primary speaker plays a pure tone with frequency 350 Hz and use the ANC system to cancel it. Experimental result has taken from the error microphone and has shown in Fig. 5(a). The horizontal axis denotes the time, and the vertical axis presents the frequency of the signal. In the figure, the dark color represents the higher density of noise power. We turn on the ANC system after playing the noise several seconds. Obviously, the noise power decreases dramatically when the ANC system has turned on.

The second experiment uses multi-tonal noises with 350 Hz, 450 Hz, 550 Hz and 650 Hz as the undesired noise. The experimental result is shown in Fig 5(b) and depicts similar result as in Fig. 5(a). The noise reduction performance is very well.

Figure 5(c) illustrates the results of sweep sine signals cancellation. We generate 15 tonal noises within 200-500 Hz, and then increase the frequency to 200-700 Hz and decrease the frequency to its original frequency. After ANC has turned on, we can compare the performance as shown in Fig. 5(c). This experiment shows that the proposed system is capable to cancel the noise with changing frequency, and reliable to system change.

Figure 5(d) depicts the white noise reduction. We use the white noise with frequency 200-750 Hz as the noise source. Since the speaker is not able to play the noise below 200 Hz, meanwhile, most industrial noise has its main power at frequency below 700 Hz. Therefore, we cut the frequency lower than 200Hz and higher than 750 Hz for simplicity. This is also reasonable because human ear is not sensitive to the sound with lower frequency.

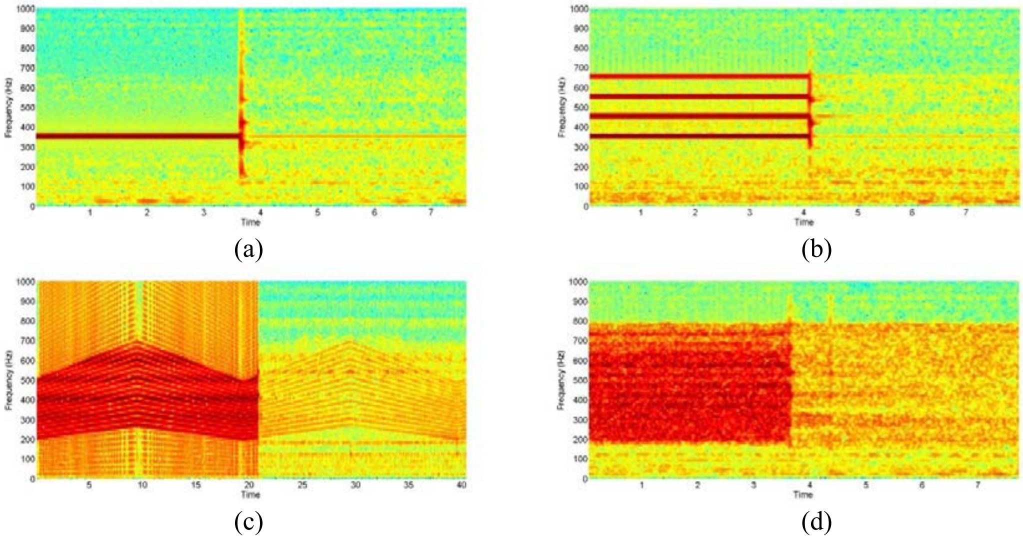

Figure 5. Noise reduction performance, (a) single tonal noise, (b) multi-tonal noise, (c) sweep sine signal and (d) white noise.

We use a sound pressure meter with A-weighting to test the noise reduction before and after ANC is turning on. The result is shown in Table 1. Obviously, the ANC system performs very well. The noise reduction can be up to 20 dB.

Table 1. Noise reduction used sound pressure meter with A-weighting.

Noise type	ANC OFF	ANC ON	Noise Reduction
Single tonal noise	86	60	26
Multi-tonal noise	80	60	20
Sweep sine signal	86	64	22
White noise	88	66	22

4. Conclusions

A single channel feed forward ANC system with feedback neutralization is proposed to cancel the duct noises. We successfully cancel the noise in a PVC duct and the length between reference microphone and secondary speaker is 135 cm. Several noises including the white noise was tested to be cancelled. Experimental results show that the causality problem can be overcomes and the noise reduction is up to 20 dB.

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