Active noise reduction for traffic noise based on Filtered-X least mean square algorithm

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Abstract: In this study, active noise reduction device is designed based on Filtered-X least mean square (FX-LMS) algorithm, which can reduce the traffic noise in low-frequency stage. There are three main modules in this device: active noise control system, intelligent control system and noise test and evaluation system. The result shows that FX-LMS algorithm has a good denoising effect on low-frequency traffic noise in a certain frequency band.

1. Introduction

With the continuous development of traffic industry, various means of transportation is of great convenience for people's life, whereas it also brings many problems such as air pollution, traffic noise and so on. According to the statistics of "12369 environmental protection report network management platform" in 2018, it is reported that the proportion of noise related complaint in this report was 35.3%, ranking the second. In the national report of noise problems, there are 43.0% of the residents who are disturbed by traffic and construction noise. This indicates that people are paying more attention to noise pollution, especially traffic noise. As a matter of fact, the existence of traffic noise will not only dramatically interfere with people's normal rest, but it also has a negative impact on people's health. For example, living in the vibration and noise environment can make people irritable, nauseous, headache and insomnia, thus affecting people's sleep quantity. In addition, noise can cause and even aggravate vascular diseases in the elderly, and if children have been exposed to noise for a long time, their intellectual development will also be lowered.

In order to solve the above problems, Filtered-X least mean square algorithm (FX-LMS) is adopted in the intelligent device to light the effect of traffic noise. The device uses a radio channel to facilitate the collection of sound. The noise collector, secondary noise output device and information processor can play the matched secondary noise according to the external noise, so as to reduce the noise.

2. Experiment

2.1 Active Noise Control

Generally speaking, there are three main noise reduction measures which usually used to reduce noise, that is noise reduction at the sound source, in the process of transmission and at the human ear. All of them are passive noise reduction, so their results are limited. In order to eliminate noise more efficiently, the technology of ANC (active noise control) is invented [1], which is often used in earphone and automobile noise reduction. The principle is that through the noise reduction system, the opposite sound wave equal to the external noise is generated to neutralize the noise, so as to achieve the effect of noise reduction. In fact, all sound is composed of a certain spectrum, thus if a sound can be found, whose frequency and amplitude are exactly the same but opposite phase (difference of 180 degree) as the original noise to be eliminated, then the noise can be completely canceled.

2.2 Filtered-X least mean square (FX-LMS)

As shown in **Figure 1**, the Filtered-X least mean square (FX-LMS) algorithm is applied in ANC system [2], Where *x(n)*, *y(n)* and *d(n)* are reference signal, output signal and desired signal of error pick-up, respectively. Bucking signal (*b(n)*) is the response of the filter output *y(n)* passing through the secondary path, which is calculated by following equation:

$$b(n) = y(n) * h(n) \tag{1}$$

where *h(n)* is the transfer function of the secondary path between the loudspeaker and the microphone. Control filter length and secondary path length are defined as L and M, respectively, and the filter weight coefficient and reference input at the moment *n* can be calculated as following:

$$w(n) = [w_1(n), w_2(n), w_3(n) \cdots w_L(n)]^T \tag{2}$$

$$x(n) = [x(n), x(n-1), x(n-2) \cdots x(n-L+1)]^T \tag{3}$$

Thus, the output function (*y(n)*) of the filter is defined:

$$y(n) = x^T(n) * w(n) \tag{4}$$

In order to simplify the calculation, the filter weight coefficient is assumed as basically unchanged within L sampling points, thus:

$$S(n) = V^T(n) * w(n) \tag{5}$$

where *V (n)* is the filter-x signal:

$$V(n) = x(n) * h(n) \tag{6}$$

The signal *e(n)*, that is received by the error microphone, can be defined as follows:

$$e(n) = d(n) + s(n) \tag{7}$$

According to the least mean square error criterion, the objective function (*J(n)*) of the active control system is $J(n) = E[e^2(n)]$. According to the principle of the steepest descent:

$$w(n+1) = w(n) - 2 * \mu * e(n) * v(n) \tag{8}$$

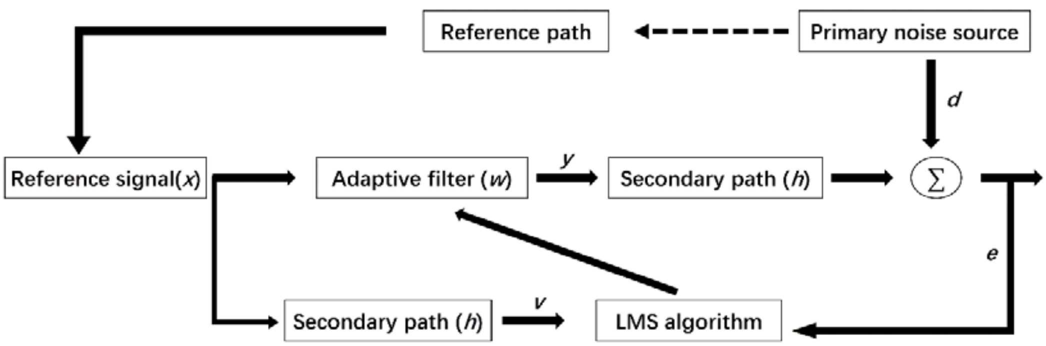

Figure 1. Filtered-X least mean square algorithm

3. Module designed

Active noise control system [3]: FX-LMS algorithm is applied in this system, and the noise reduction system is feedforward ANC, which is used to reduce low-frequency noise made by transportation. There are mainly three modules: noise acquisition module, algorithm processing module and secondary noise output module. First, the ADC module samples the noise input, then the result is read and calculated by the digital signal processor. Through D/A conversion, the loudspeaker outputs the secondary noise and noise superposition to achieve the purpose of reducing the original noise.

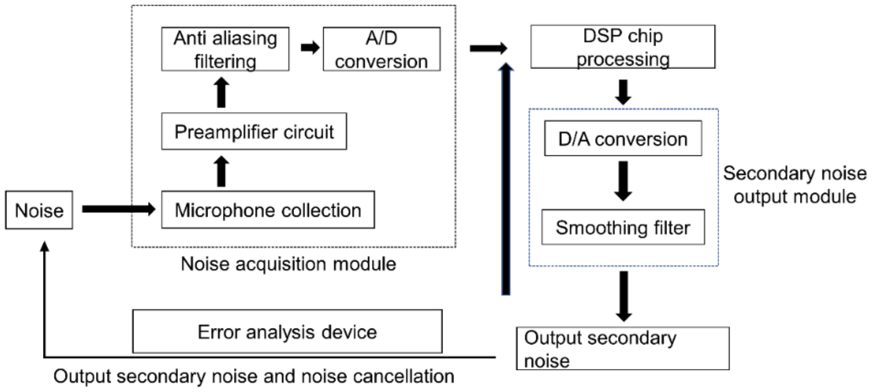

Figure 2. Module designed in the Active noise reduction intelligent device

4. Simulation

In this study, different traffic noise was collected in different spots and the noise frequency domain was analysis to determine the sampling frequency [4].

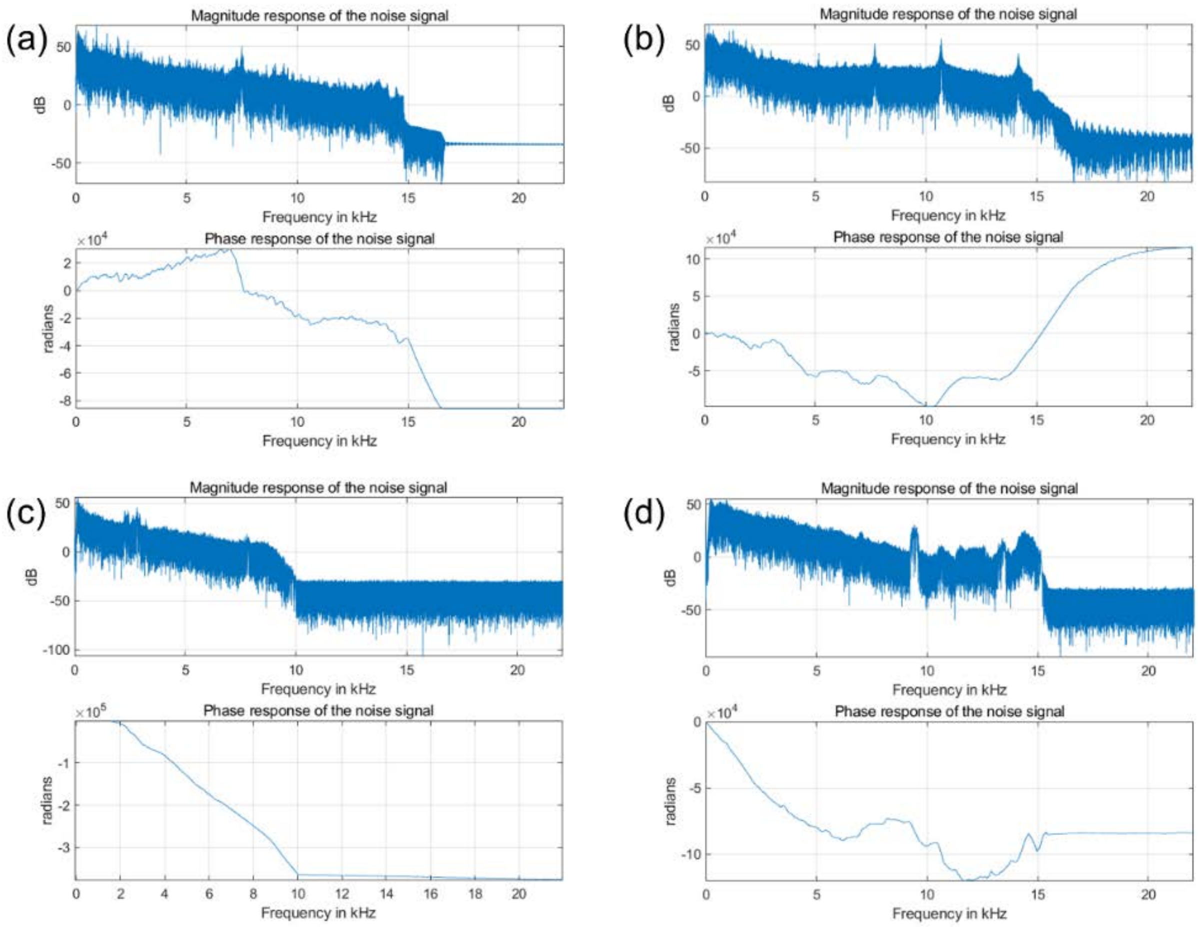

Figure 3. Traffic noise analysis for different spots

The noise bandwidth limitation of active noise reduction is determined, and the point with the highest amplitude of four noise segments is defined as follows:

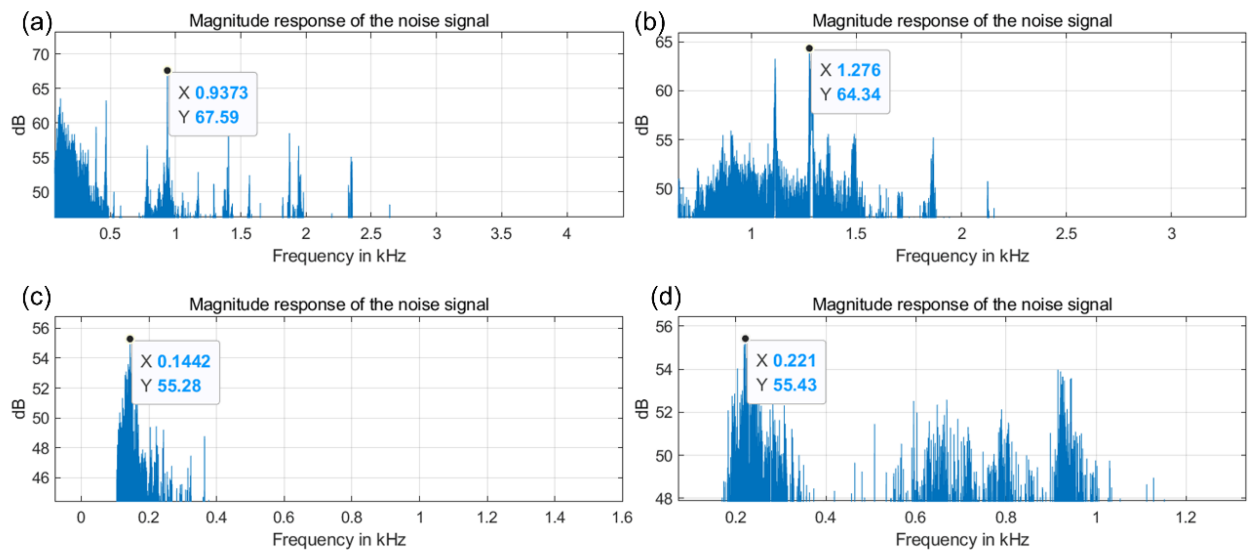

Figure 4. Spectrum analysis of selected noise using Fourier transform

The frequencies corresponding to the four highest noise amplitudes are 937.3, 1276, 144.2 and 221 Hz, respectively. So the bandwidth is limited between 100Hz and 1500Hz. Through the analysis of three frequency-domain analysis of the real area noise acquisition shown as Figure 5(a)-(c).

When applying FX-LMS algorithm, estimation of H(z) of secondary channel should have been determined firstly, which can be obtained by system identification [5]. The aim of identification process is to estimate the system parameters continuously and finally get a stable value. This process could be realized by adaptive algorithm of least mean square, in which the step size is fixed and related to the input signal. The influence of different step size factors on the algorithm is analyzed as follows:

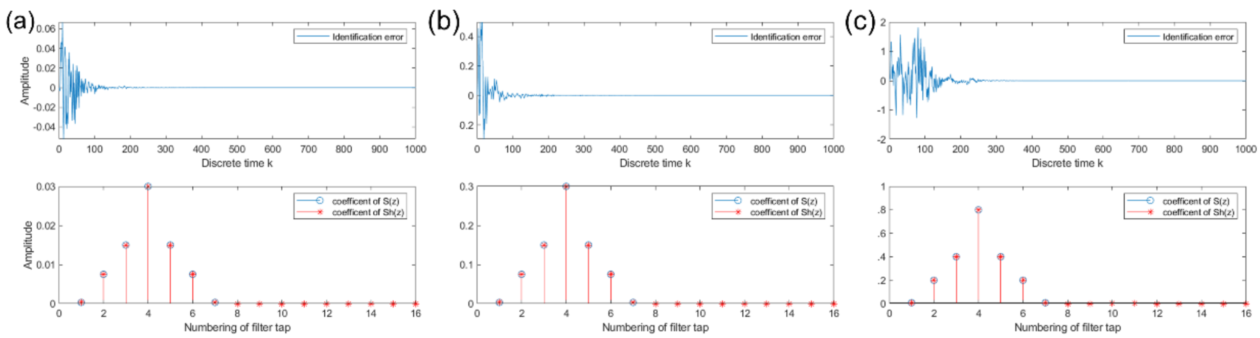

Figure 5. Different step size factors in FX-LMS algorithm(a): 0.03, (b): 0.3, (c):0.8.

When the step size factor is relatively small, the weight s of the position channel can be obtained by the identification of h(n). As the step size factor increases, the identification of the secondary channel by the adaptive filter fails， and the convergence speed is also accelerated. However, if the step size factor is too large, the algorithm cannot converge and the system is out of balance.

The FX-LMS system is designed and simulated. The secondary channel is taken from the output speaker to the detection error microphone in the quiet area. The bandwidth is limited to 100-1500hz, and the filter length is 0.1s as shown in Figure 6 (a), The random signal is used to simulate the noise, which is played through the loudspeaker. Then, the signal measured by the error microphone is collected, and the filter of secondary channel is designed and normalized LMS algorithm is adopted. The algorithm converges after about 10000 iterations as presented in Figure 6 (b). Through a linear filter to set the main channel noise, the bandwidth is limited in the range from 100 to 800Hz with the filter length of 0.1s. Finally, the whole active noise control system is simulated. In order to observe the difference clearly, active noise reduction control is not carried out on the system at the first 100 iterations, and the sound collection on the error microphone is also cancel. The Figure 6 (d) shows that the noise converges adaptively after enabling the adaptive filter about 5s. Comparing the spectrum of residual signal and original signal, the obvious attenuation is observed. From the above simulation results, it can be seen that FX-LMS algorithm has a good denoising effect on low-frequency traffic noise in a certain frequency band.

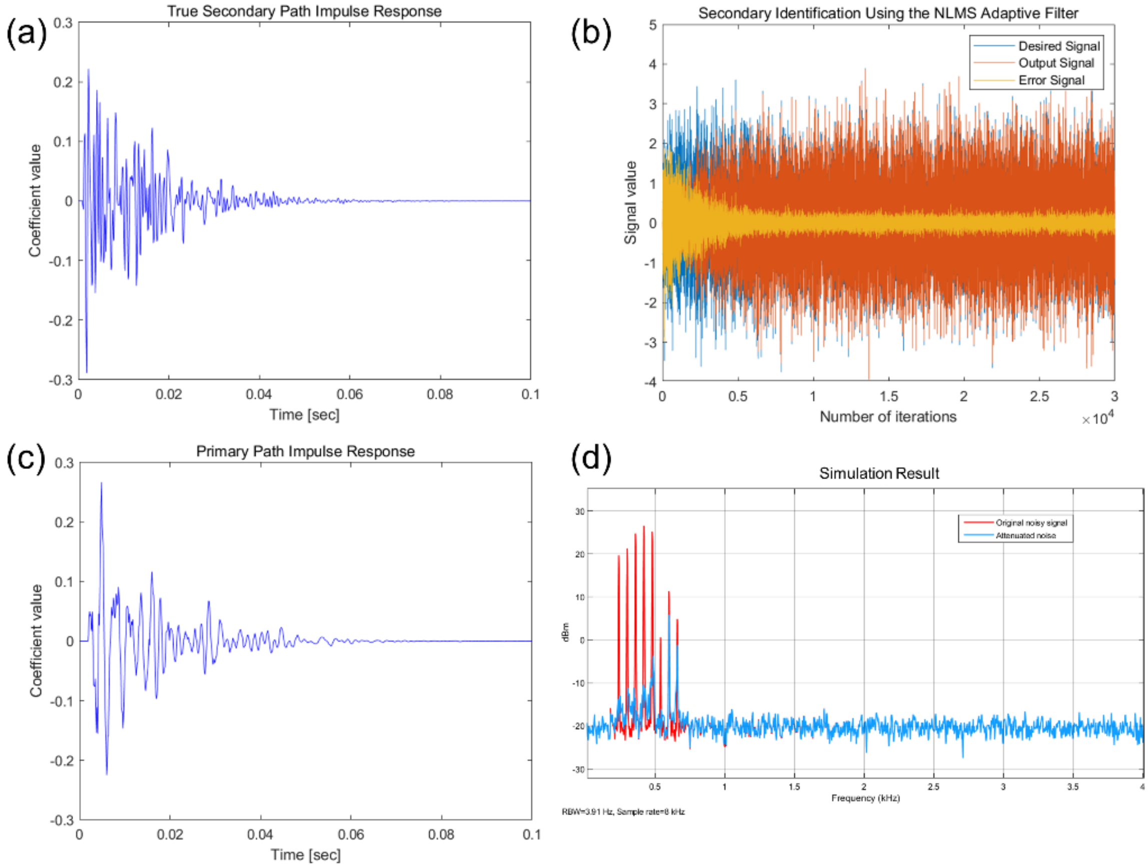

Figure 6. (a)True secondary path impulse response; (b)Secondary identification using the normalized LMS adaptive filter; (c)Primary path implused response; (d)Simulation results

5. Conclusions

Active noise reduction device is designed based on FX-LMS algorithm, which can reduce the traffic noise in low-frequency stage. The experiment result shows that FX-LMS algorithm has a good denoising effect on low-frequency traffic noise in a certain frequency band. This study provides a solution for daily traffic noise problem, which can relief the pressure for those who suffers from traffic noise.

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