A NOVEL SELECTIVE ACTIVE NOISE CONTROL ALGORITHM TO OVERCOME PRACTICAL IMPLEMENTATION ISSUE

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ABSTRACT

Selective active noise control (SANC) is a method to select a pre-trained control filter for different primary noises, instead of using conventional real-time computation of the control filter coefficients. This paper:

1. Proves the frequency-band-match method.
2. Propose a SANC based on a partitioned frequency domain filter.
3. Both simulation and real-time experiment is carried out to validate the algorithm.

FREQUENCY-BAND MATCH I

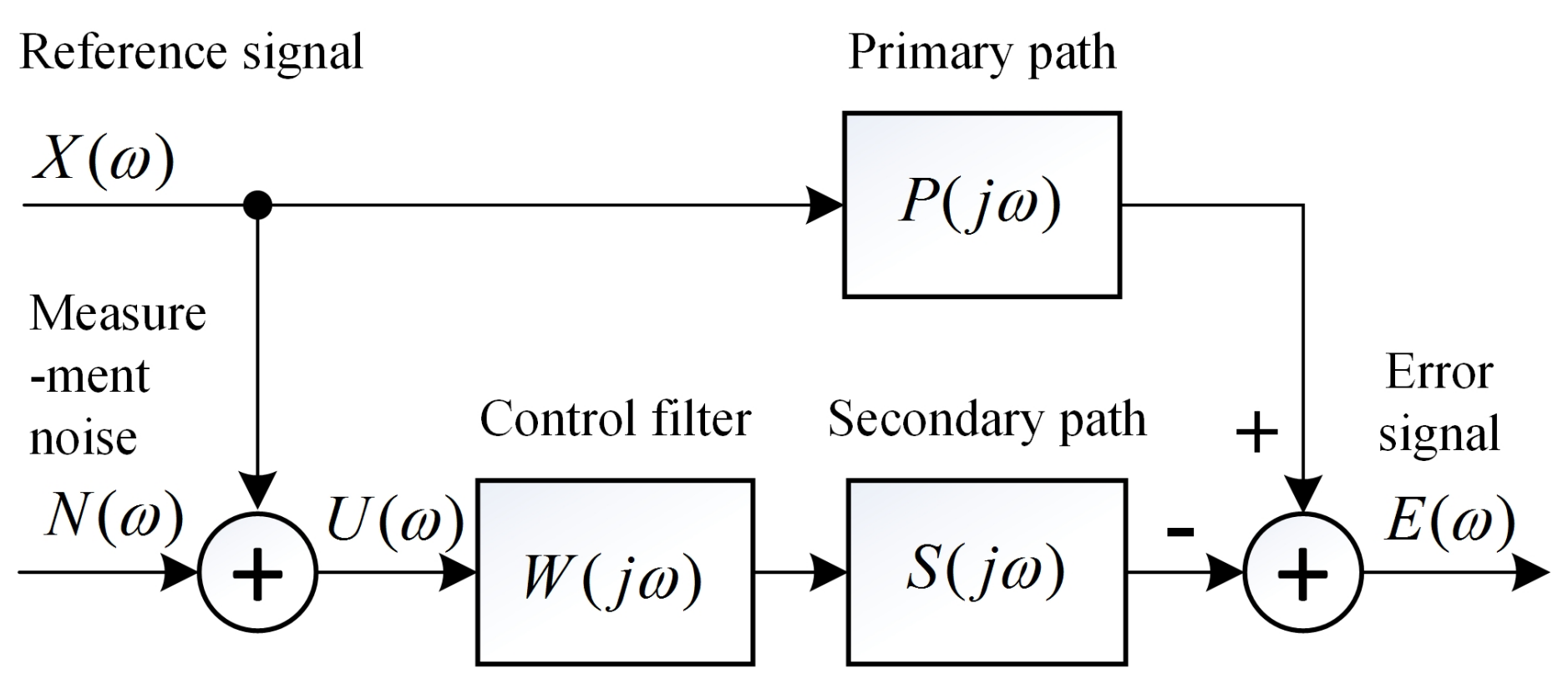

Figure 1: Single channel feedforward ANC.

In the training phase, a broadband training signal $X_0(\omega)$ is input as a reference signal

$$X_0(\omega) = T_0(\omega) rect(\frac{\omega-\omega_0}{2B_0}). \tag{1}$$

The power spectral density of filtered signal $r_0(n) = s(n) * x_0(n)$ can be stated as

$$S_{r_0r_0}(\omega) = S_{x_0x_0}|S(j\omega)|^2 rect\left(\frac{\omega-\omega_0}{2B_0}\right). \tag{2}$$

The optimal control filter is obtained from (1) and (2)

$$W^0_{opt}(j\omega) = \frac{P(j\omega)}{S(j\omega)} rect\left(\frac{\omega-\omega_0}{2B_0}\right). \tag{3}$$

Next, we assume that the primary noise is a broadband noise with the central frequency of ω_1 and bandwidth B_1 $(B_1 \leq B_0)$,

$$X_1(\omega) = T_1(\omega) rect\left(\frac{\omega-\omega_1}{2B_1}\right). \tag{4}$$

The optimal control filter of the primary noise $X_1(\omega)$ can be derived as

$$W^1_{opt}(j\omega) = \frac{P(j\omega)}{S(j\omega)} rect\left(\frac{\omega-\omega_1}{2B_1}\right). \tag{5}$$

FREQUENCY-BAND MATCH II

If we apply $W^0_{opt}(\omega)$ as the control filter in Fig. 1 to cancel the primary noise, the error signal is written as

$$\begin{aligned} E(\omega) &= X_1(\omega)P(j\omega) \\ &\quad - (X_1(\omega) + N(\omega))\, W^0_{opt}(j\omega)S(j\omega). \end{aligned} \tag{6}$$

Hence, when $\omega_0 = \omega_1$, its power spectral density can be derived as

$$\begin{aligned} S_{e_1e_1}(\omega) = S_{e_1e_1}(\omega)_{min} rect\left(\frac{\omega-\omega_0}{2B_1}\right) + \frac{N_0}{2} \\ \left|\frac{P(j\omega)}{S(j\omega)}\right|^2 \left[rect\left(\frac{\omega-\omega_0}{2B_0}\right) - rect\left(\frac{\omega-\omega_0}{2B_1}\right)\right]. \end{aligned} \tag{7}$$

where

$$\begin{aligned} S_{e_1e_1}(\omega)_{min} &= S_{d_1d_1}(\omega) \\ &\quad - \frac{|S_{r_1d_1(\omega)}|^2}{S_{r_1r_1(\omega)}} + \frac{N_0}{2}\left|\frac{P(j\omega)}{S(j\omega)}\right|^2. \end{aligned} \tag{8}$$

and $S_{d_1d_1}(\omega) = E\{D^*(\omega)D(\omega)\}$.

$$\begin{aligned} E\{e(n)^2\} &= \frac{1}{2\pi}\int_{-\infty}^{\infty} S_{e_1e_1}(\omega)d\omega \\ &= J_{min} + \frac{N_0}{2\pi}\left(B_0 - B_1\right), \end{aligned} \tag{9}$$

J_{min} is MMSE of Wiener-Hopf solution. When the bandwidth B_0 equals to B_1, the MSE of SANC is same as of FxLMS.

PROPOSED SANC ALGORITHM I

1. Comb-partitioning FFT: an M-point FFT is applied to complete an N-point frequency domain transform $(M < N)$. The reference signal $x(n)$ is first input into an $(N-K)$ taps delay line $(M = N/K)$. Hence, the partitioned input vector is defined as

$$\mathbf{x}(n) = \left[x(n), x(n-K), \ldots, x\left(n-(M-1)K\right)\right]^{\mathrm{T}},$$

and its Fourier transform is stated as

$$\mathbf{X}(k) = \left[X_0(k), X_1(k), \ldots, X_{M-1}(k)\right]^{\mathrm{T}}.$$

PROPOSED SANC ALGORITHM II

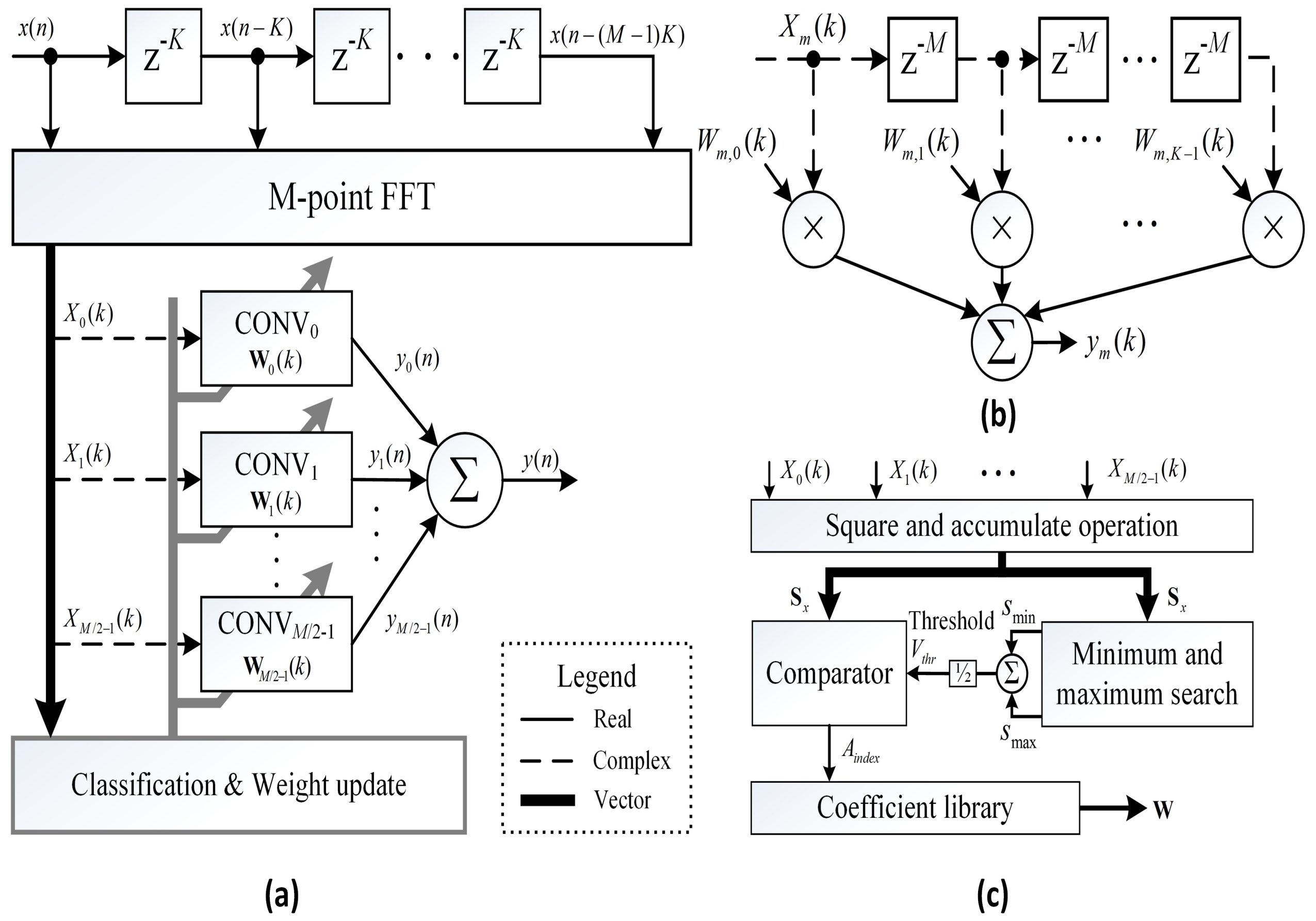

Figure 2: (a) Overall block diagram of SANC; (b) The m-th convolution block; (c) Classification and weight update part.

2. Convolution: the output $y_m(n)$ of the m-th convolution unit is

$$y_m(n) = real\left\{\sum_{q=0}^{K-1} W_{m,q}(k)X_m(k-qM)\right\}$$

The output $y(n)$ of the control filter is given by

$$y(n) = \sum_{m=0}^{M/2-1} y_m(n) \tag{10}$$

3. Classification and weight update: SANC algorithm adopts the frequency-band-match for classification, and continuously updates the coefficients of the control filter, at every L iterations. The classification estimates the power spectrum $\mathbf{S}_x$ of the primary noise $X(k)$. A threshold is derived by the average of the minimum scalar s_{min} and the maximum scalar s_{max} of the vector $\mathbf{S}_x$. It is compared with the vector $\mathbf{S}_x$, which results a $\frac{M}{2}$ bit binary A_{index}. The coefficient library selects a set of coefficients $\mathbf{W}$ according to the index A_{index}.

SIMULATION AND EXPERIMENT

The simulation shows the relationship between noise reduction and the frequency band similarity of primary path and the selected filter. The SANC is realized on the **NI PXIe 8135** platform and compared to FxLMS in a duct. Sampling frequency is 16 kHz, the filter length N of the SANC and FxLMS is 1024, K and L are chosen as 16 and 256, and the length of the secondary path model is 512. The frequency range of primary noise is from 400 to 600 Hz. The noise reduction of the SANC and FxLMS are 21.9 dB and 23 dB.

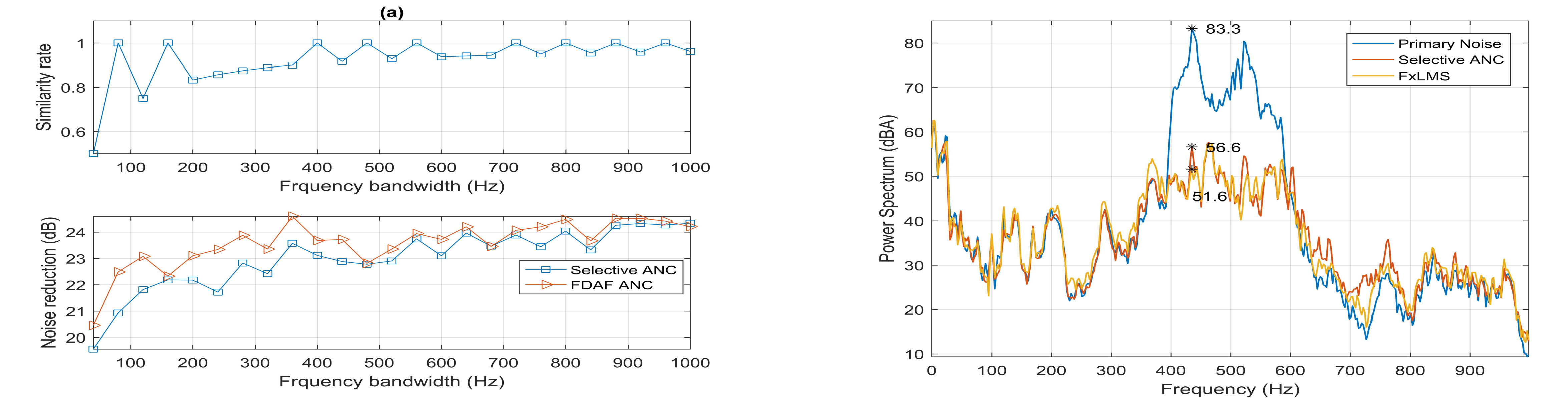

Figure 3: (Left) Similarity ratio of selected filter and primary noise; Noise reduction of SANC and frequency domain (FDAF) ANC for different frequency-band noise; (Right) Power spectrum of the primary noise and error signal.

CONCLUSION

This paper proves the frequency-band-match method for the implementation of selective ANC, in which the algorithm will choose a suitable pre-trained control filter based on the frequency band of the primary noise rather than adaptively updating the coefficients of the control filter. A SANC technique is proposed based on frequency domain adaptive filter (FDAF) algorithm, which significantly reduces the computational burden of FFT.

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