PERFORMANCE OF SINGLE AND MULTI-REFERENCE NLMS NOISE CANCELLER BASED ON CORRELATION BETWEEN SIGNAL AND NOISE

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Abstract Single-reference and multi-reference noise canceller performance depends on the correlation between signal and noise. However, exact relations between them are not known yet. In this paper, the above relations are investigated based on mathematical analysis and computer simulation. From the simulation results, it is proven that the single reference noise canceller (SRNC) and Multi-reference noise canceller (MRNC) performances are inversely proportional to the signal-noise correlation. By using larger number of adaptive filter taps, the signal distortion is increased.

Key Words
System identification, Noise canceller, Adaptive filter, Correlation, Filtering

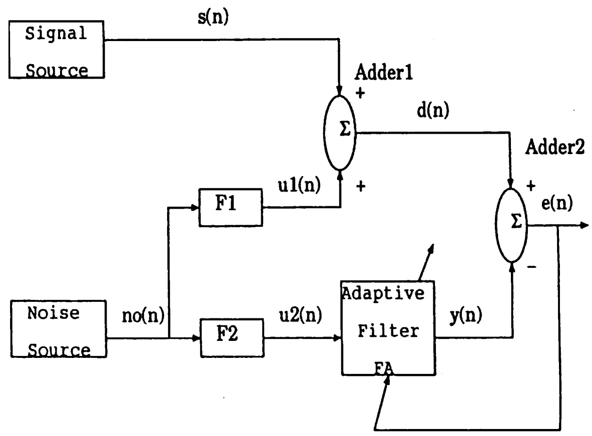

Fig. 1 Single-reference noise canceller

1. Introduction

Usually, noise canceller problem is investigated based on a single reference noise source. Unfortunately, in some practical applications, several noises may be propagated from defferent noise sources [1]. In SRNC and MRNC, one essential assumption is that, the primary and auxiliary input signals must be noncorrelated [2]. However, exact relations between noise canceller performance and signal-noise cross-correlation are not well known.

The objective of this paper is to investigate these relations . The noise canceller circuits are described in both configurations.

2. Single-Reference Noise Canceller

2.1 Block Diagram

Figure 1 shows a block diagram of SRNC. The blocks F1 and F2 represent the transfer function of the noise paths. A transversal FIR adaptive filter is employed. The adaptive filter is adjusted by using NLMS algorithm.

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3. Computer Simulation

3.1 Noise Path Characteristics

A second order transfer functions are employed for the noise paths F1 and F2. It is given by

$$H(z) = \mathrm{h_o}\frac{1 - 2\rho\cos\theta z^{-1} + \rho^2 z^{-2}}{1 - 2r\cos\phi z^{-1} + r^2 z^{-2}} \qquad (1)$$

F1: $r = 0.8$, $\phi = \pi/4[Rd]$, $\rho = 1$, $\theta = \pi[Rd]$
F2: $r = 0.8$, $\phi = \pi/2[Rd]$, $\rho = 1$, $\theta = \pi[Rd]$
Figure 2 shows the amplitude responses of the filters F1 and F2.

3.2 Simulation Results

Computer simulation was carried out using the combinations, (1) Voice1/Multitone, (2) White noise/White noise, (3) Voice1/Workstation noise, (4) Voice1/Voice2, (5) Multitone/White noise + one common frequency. Defferent SNR (signal-to-noise ratio) are investigated. The signal and noise correlation is computed based on the unbiased estimate [3], [4]. Table1 establishes the relation between noise canceller

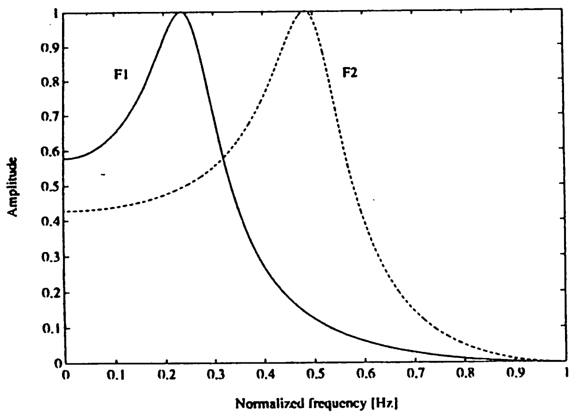
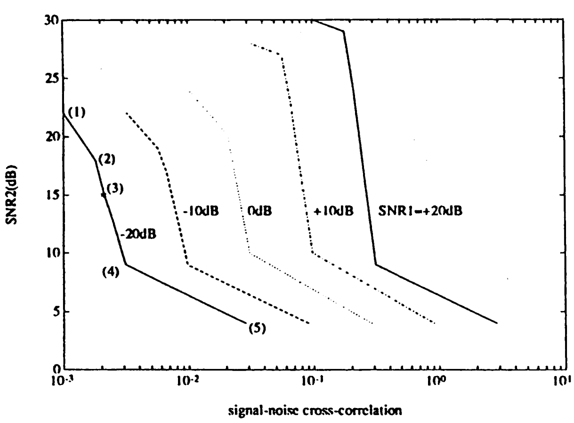


Fig. 2 Amplitude response of F1 and F2.

performance and the signal-noise correlation. The cross-correlation mean (CCM) is calculated by averaging the absolute value of the cross-correlation function. Figure 3 illustrates Table 1. As shown in Fig. 3, the noise canceller performance is inversely proportional to the signal-noise correlation.

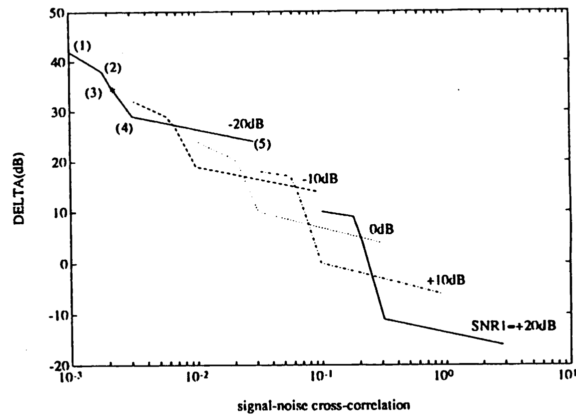


(a)

4. Multi-Reference Noise Canceller

4.1 Block Diagram

The signal is generated from a single source. The noises are genereated from two separated sources. Figure 4 [1] shows a block diagram of the multi-reference noise canceller. F_{ij}, i=1, 2, j=1, 2, 3 represent noises paths from the noise sources 1 and 2 to the adders 1, 2 and 3. Two FIR transversal adaptive filters, AF1 and AF2 with M tap-weights, are em-



(b)

Fig. 3 Signal-noise Cross-correlation and NLMS Performance. (a) Cross-correlation and SNR2 Relation. (b) Cross-correlation and Delta Relation.

ployed. The adaptive filters tap-weights are adjusted using the NLMS algorithm.

4.2 Optimum Adaptive Filters for Noise Cancellation

We derive a simple relationship giving the optimum transfer functions of the adaptive filters, from Fig. 4 . The z-transform of the desired response is

$$D(z) = S(z) + N1(z)F11(z) + N2(z)F21(z) \quad (2)$$

Where, S(z), N1(z) and N2(z) denote the z-transforms of the signal, noise1 and noise2, respectively. The adaptive filter1 z-transform is given by

$$U1(z) = N1(z)F12(z) + N2(z)F22(z) \quad (3)$$

Similarly, the adaptive filter2 z-transform is

$$U2(z) = N1(z)F13(z) + N2(z)F23(z) \quad (4)$$

The z-transform of the adaptive filters 1 and 2 outputs resultant is

$$Y(z) = AF1(z)U1(z) + AF2(z)U2(z) \quad (5)$$

The z-transform of the canceller output is

$$\begin{aligned} E(z) &= D(z) - Y(z) \quad (6) \\ &= S(z) + N1(z)F11(z) + N2(z)F21(z) - \\ &\quad AF1(z)[N1(z)F12(z) + N2(z)F22(z)] - \\ &\quad AF2(z)[N1(z)F13(z) + \\ &\quad N2(z)F23(z)] \quad (7) \end{aligned}$$

Table1: Relations between noise cancellation and signal-noise cross-correlation using different SNRs

Combination / SNR1	Voice1/ Multitone	White noise/ White noise	Voice1/Work station noise	Voice1/ Voice2	Multitone/White noise+ one common frequency
-20 dB	CCM=0.0010 SNR2=22 Delta=42	CCM=0.0018 SNR2=18 Delta=38	CCM=0.0021 SNR2=15 Delta=37	CCM=0.0031 SNR2=9 Delta=29	CCM=0.0287 SNR2=4 Delta=24
-10 dB	CCM=0.0032 SNR2=22 Delta=32	CCM=0.0057 SNR2=19 Delta=29	CCM=0.0067 SNR2=17 Delta=27	CCM=0.0098 SNR2=9 Delta=19	CCM=0.0906 SNR2=4 Delta=14
0 dB	CCM=0.0100 SNR2=24 Delta=24	CCM=0.0179 SNR2=21 Delta=21	CCM=0.0210 SNR2=20 Delta=20	CCM=0.0310 SNR2=10 Delta=10	CCM=0.2865 SNR2=4 DELTA=4
+10 dB	CCM=0.0317 SNR2=28 Delta=18	CCM=0.0565 SNR2=27 Delta=17	CCM=0.0663 SNR2=23 Delta=13	CCM=0.0981 SNR2=10 Delta=0	CCM=0.9061 SNR2=4 Delta=-6
+20 dB	CCM=0.1001 SNR2=30 Delta=10	CCM=0.1786 SNR2=29 Delta=9	CCM=0.2096 SNR2=24 Delta=4	CCM=0.3102 SNR2=9 Delta=-11	CCM=2.8653 SNR2=4 Delta=-16

SNR1: Signal-To-Noise ratio before cancellation; SNR2: Signal-To-Noise ratio after cancellation

CCM: Croos-correlation mean; Delta=SNR2-SNR1

When the two adaptive filters converge to the optimum solution, the canceller output equals the signal. That is, E(z)=S(z). Then,

$$0 = N1(z)[F11(z) - AF1_{opt}(z)F12(z) - AF2_{opt}(z)F13(z)] + N2(z)[F21(z) - AF1_{opt}(z)F22(z) - AF2_{opt}(z)F23(z)] \quad (8)$$

Where, $AF1_{opt}$ and $AF2_{opt}$ denote for the adaptive filters 1 and 2, the optimum transfer functions respectively. Under the assumption that noise1 and noise2 are independent, Eq.(7) is true, if and only if

$$\begin{cases} AF1_{opt}(z) = \frac{F11(z)F23(z)-F21(z)F13(z)}{F12(z)F23(z)(z)-F13(z)F22(z)} & (9) \\ AF2_{opt}(z) = \frac{F12(z)F21(z)-F11(z)F22(z)}{F12(z)F23(z)-F13(z)F22(z)} & (10) \end{cases}$$

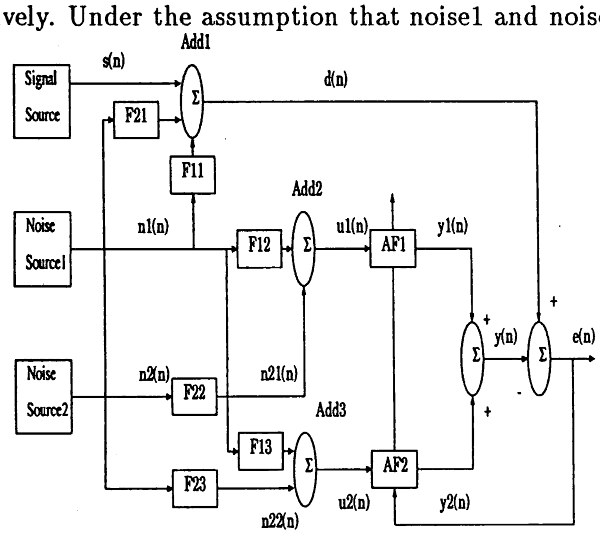


Fig. 4 Multi-reference noise canceller block diagram

5. Computer Simulation

5.1 Noise Path Characteristics

F11: Unity, F12: Unity, F13: Unity, F21:Unity

F22: $r = 0.8$, $\phi = \pi/4[Rd]$, $\rho = 1$, $\theta = \pi[Rd]$

F23: $r = 0.8$, $\phi = 3\pi/2[Rd]$, $\rho = 1$, $\theta = \pi/2[Rd]$

Figures 5 show the amplitude responses of F22 and F23.

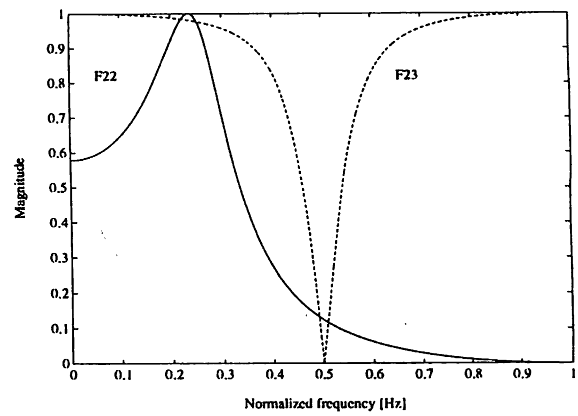


Fig. 5 Amplitude responses of F22 and F23

5.2 Simulation Results

The signal source generates a speech signal. Noise sources 1 and 2 generate white noise and workstation noise, respectively. Table2 shows the simulation results . The optimum solutions do not include effects of the signal-noise correlation. The adaptation is affected by the correlation. The cancellation is increased as the number of adaptive filter taps is increased. To confirm this analysis, the following combination is considered. White noise & Single tone 1 and White noise & Single tone 2. SNR1 equals 0 dB and each adaptive filter has 20 taps. Table3 shows the results.

Table2: SNR2 after noise cancellation using optimum solutions with a finite number of M taps.

M	20	50	100	200	400	800	2000	2500
SNR2 (dB)	27	42	51	72	117	197	281	296

From Table3 the lower the tone frequency, the worse the cancellation. Of course, speech spectrum is mainly at low frequencies ; then, when the tone approaches the low band, its correlation with the speech increases.

Table3: Tones 1 and 2 frequencies and SNR2 relation.

f2 [KHz] \ f1 [KHz]	0.1	0.2	0.3	1	3.8
0.1	SNR2= 10 dB	13	14	14	14
0.2	11	13	16	18	19
0.3	12	14	16	20	22
1	13	17	20	21	23
3.8	12	15	18	22	26

f1: Tone 1 frequency; f2: Tone 2 frequency.

Table4 shows effects of the number of taps on the cancellation. The combination Speech signal,White noise and Workstation noise is considered. SNR1 equals 0 dB. For 20 taps, the improvement is 15 dB. This is lower than 20 dB obtained in SRNC for the combination of Speech and Workstation noise shown in Table1. As a matter of fact, MRNC is more sensitive to cross-correlation, than SRNC. Moreover, when the number of adaptive filter taps is increased, SNR2 is reduced.

Table4: SNR2 after noise cancellation by adjusting the adaptive filters of M taps.

M	20	50	100	200	400	800	2000	2500
SNR2 (dB)	15	15	14	12	9	7	5	5

6. Conclusion

Single-Reference and Multi-Reference noise canceller performance have been investigated based on signal-noise correlation. The simulation has shown that the performance is inversly proportional to the signal-noise correlation. Moreover, a larger number of adaptive filter taps provides significant signal waveform distortion. The performance of MRNC is more sensitive to the cross-correlation than that of SRNC.

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References

[1] Widrow, B. and Stearns, D., "Adaptive Signal Processing," Prentice-Hall, 1985.

[2] Haykin, S., "Adaptive Filter Theory," Second Ed, Printice Hall, 1991.

[3] Bendat, S. and Piersol, G., "Random Data Analysis and Measurement Procedures," Wiley-Interscience, 1971.

[4] Papoulis, A., "Probability, Random Variables, and Stochastic Processes," Second Ed, Mc-Graw-Hill, 1984.