Experimental Results with Increased Bandwidth Analysis Filters in Oversampled, Subband Acoustic Echo Cancellers

Phillip L. De León II, Student Member, IEEE and Delores M. Etter, Fellow, IEEE

Abstract — The motivation for adaptive filtering in subbands stems from two well-known problems in least-mean square fullband adaptive filtering. First, the convergence and tracking can be very slow if the input correlation matrix is ill-conditioned as in the case with speech input. Second, very high order adaptive filters are computationally expensive. One application with adaptive filtering in subbands is the slow, asymptotic convergence associated with oversampled systems. Increasing the bandwidth of analysis filters relative to the synthesis filters is proposed to reduce the slow asymptotic convergence. This letter will motivate this approach and present experimental results illustrating the benefits of this modification.

I. INTRODUCTION

The motivation for adaptive filtering in subbands stems from two well-known problems in fullband adaptive filtering. First, the convergence and tracking of a least-mean square (LMS) adaptive filter can be very slow if the input correlation matrix is ill-conditioned as in the case with speech input [1]. Second, very high order adaptive filters are computationally expensive. One application that has both speech input and typically needs a very high order adaptive filter is acoustic echo cancellation (AEC) [2].

The subband adaptive filter system, illustrated in Fig. 1, offers the possibility of performing the equivalent task of a fullband adaptive filter but with several key benefits that overcome some of the previously mentioned problems with the fullband system [2].

One method to remove the band edge components might use bandpass filters but this has the undesirable effect of introducing spectral gaps in the reconstructed fullband signal. The alternate method proposed here is to increase the bandwidth of the analysis filters \((f_0, f_1, \ldots, f_{M-1})\) relative to the synthesis filters \((g_0, g_1, \ldots, g_{M-1})\). This has the effect of shifting the slowly converging spectral components of the subband error signals further out in the spectrum. Subsequent synthesis filtering removes these components from each subband and thus out of the fullband signal thereby increasing the convergence of the MSE.

The experiments with this proposed modification use a 4/3-oversampled, 4-subband AEC as in Fig. 1 \((M = 4, D = 3)\). A simulated acoustic echo path \((h)\) was used with white noise input \((x)\) and the results were averaged over 100 runs. Uniform-DFT filter banks were used for analysis and synthesis. The analysis and synthesis prototype filters were designed using the Parks-McClellan algorithm. The \(-3dB\) down frequency of the analysis prototype filter was set to \(\frac{\pi}{M} + \frac{\pi}{D}\).
where $\delta$ is the amount of bandwidth increase, assuming a normalized sampling frequency, $f_s = 1$. The -3dB down frequency of the synthesis prototype filter was set to $\frac{2}{f_s}$.

Finally, the normalized LMS (NLMS) algorithm was used to update the adaptive filters.

An upper bound on $\delta$ is computed as follows. Assume that the prototype analysis filter has significant (at least -70dB) stopband attenuation at all frequencies beyond $f_c + \frac{\delta}{2}$ and a downsampling factor of $D$ is used in the system. Therefore the analysis filter prototype should be designed so that the band edge of the subband signal is located no further than the Nyquist frequency of the downsampled signal. This requires:

$$\delta \leq 2\left(\frac{1}{2D} - f_c\right).$$  \hfill (1)

Choosing $\delta$ within this bound should not significantly increase the aliasing in the AEC since only the signal beyond $f_c + \frac{\delta}{2}$ (which is small by design) is aliased. The previously described analysis filter prototype used in the experiments had:

$$f_c = 0.143$$  \hfill (2)

which can be seen with the solid line in Fig. 2. Substitution of (2) into (1) with $D = 3$ yields an upper bound for $\delta$ of:

$$\delta \leq 0.0473.$$  \hfill (3)

Four values of $\delta$ were used in the experiments: 0%, 33%, 67%, and 100% of the bound so that $f_c + \frac{\delta}{2}$ was evenly spaced from the original stopband frequency of the analysis prototype filter to the maximum given by $f_c + \frac{\text{max}}{2}$. Fig. 2 contains a plot of the magnitude responses of the analysis filters for the various values of $\delta$.

**III. EXPERIMENTAL RESULTS**

As the bandwidth of the analysis filter is increased, the band edge spectral components of the subband error signals are shifted beyond the cutoff of the synthesis filters as illustrated with subband 0 in Fig. 3 at sample index $k = 5000$. Note that for $\delta$ equal to the upper bound in (3), the band edge spectral components are excited to a higher degree than the others. This is because of a spectral peak in the echo path located along this band edge. In general this is unpredictable, since the echo path is unknown.

![Figure 3: Average power spectrum of subband 0 error signal at $k = 5000$.](image1)

As illustrated in Fig. 4, there is minor difference between the subband 0 MSEs for the various values of $\delta$ (with the exception of $\delta$ equal to the upper bound in (3)). This exception is a result of the effect noted above.

![Figure 4: Subband 0 MSE.](image2)
The final result of shifting the large spectral components of the subband error signal, which are removed by the synthesis filters, is the increase in the convergence of the fullband error signal as indicated in Fig. 5.

![Figure 5: MSE of AEC.](image)

The subband AEC with maximally increased analysis filter bandwidth now attains -40dB of echo cancellation in about 4500 samples compared to about 9500 samples for the conventional subband AEC (no analysis filter bandwidth increase)—a factor of 2.1 better. An alternate evaluation is to note that after 5000 samples, the MSE for the conventional subband AEC is down -35dB as compared to the AEC with maximally increased analysis filter bandwidth which is down -45dB.

IV. CONCLUSION

Experimental results with the oversampled, subband AEC system with increased bandwidth analysis filters have demonstrated better convergence than conventional designs. The increased bandwidth analysis filters are used in conjunction with the synthesis filters to remove the slowly converging, band edge spectral components. For fixed $D$, this modification adds no additional computational overhead to the system and is thus an inexpensive improvement.

ACKNOWLEDGMENT

We wish to thank Dennis R. Morgan for his contributions to this work.

REFERENCES


