SUBBAND ACOUSTIC ECHO CONTROL USING NON-CRITICAL FREQUENCY SAMPLING

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ABSTRACT

Aliasing is often generated in critically decimated subband schemes which can reduce the performance of subband adaptive algorithms. This paper investigates non-critical decimation schemes in which the generation of aliasing in the subbands is avoided by down-sampling the subband signals by a smaller factor than would normally be expected, thereby allowing for analysis filters with finite transition bands. The implementations of two such non-critical schemes are presented, one using FIR and one using IIR filter banks. Simulation results for acoustic echo control using both USASI noise and male speech signals show the non-critical schemes' performance in comparison to critically decimated filter bank approaches.

1. INTRODUCTION

The interest in subband approaches to acoustic echo control (AEC) arises from their potential for faster convergence and lower computational complexity compared to full-band approaches [1][3]. In practice, it is not usually possible to achieve the full potential of subband adaptive filters because of aliasing errors introduced by critical (maximal) decimation of the subband signals at the output of analysis filter banks with non-ideal characteristics. Gilloire and Vetterli [3] show a sufficient condition to avoid inter-band aliasing is as given in equation (8) which requires ideal filters. The aliasing perturbs adaptive filtering operations performed in the subbands [2] whether or not the synthesis filter bank is designed for aliasing cancellation.

Several approaches have been proposed which aim to minimise the loss of performance due to aliasing. Whilst several such methods have successfully addressed the issues, some problems still remain. Gilloire and Vetterli [3] investigated an approach in which cross-adaptive filters are embedded in the subband structure with the specific aim of cancelling the aliasing components. It was reported that the convergence behaviour of the cross-filters was slower than desired and that the additional computation required was significant. In a previous paper by the authors [4] an alternative approach using a "near-ideal" filter bank based on allpass polyphase IIR filters was investigated. This technique reduced the aliasing to a very narrow band but consequently gave rise to some coherent, and therefore audible, distortions.

In this current paper we report an investigation of an alternative approach in which the finite transition band of non-ideal subband analysis filters is accommodated by decimating the subband signals, not critically, but instead by less than the critical amount so as to avoid the generation of aliasing components. We have aimed to consider two types of aliasing. In the first case, FIR analysis and synthesis filters are employed which have been designed to have a relatively narrow transition band as would often be desirable in typical filter banks. These filters achieve a narrow transition band at the expense of poor stopband attenuation so that condition (8) is violated to some degree across the whole frequency band. In the second case, IIR filters based on [4] are applied which satisfy (8) to a close approximation except near the band edges. Simulations show the relative effectiveness of the non-critical approach in overcoming aliasing in each case.

2. NON-CRITICAL DECIMATION

Figure 1 shows a half-band example in which the signal $X(e^{j\omega})$ has been band-limited to a frequency $\sigma = \pi/2$ by a non-ideal filter such that the resultant signal is actually band-limited to $\sigma + \Delta$. Decimation of such a signal by 2 would lead to aliasing. In this work we have investigated the application of decimation by rational fractions $M/L < 2$ such that the Nyquist sampling criteria is more fully satisfied even when non-ideal band-limiting filters are employed. This leads to a non-critical sampling of the frequency spectrum such that the "guard band" of width $\approx \Delta$ allows for a finite transition bandwidth of the filters.

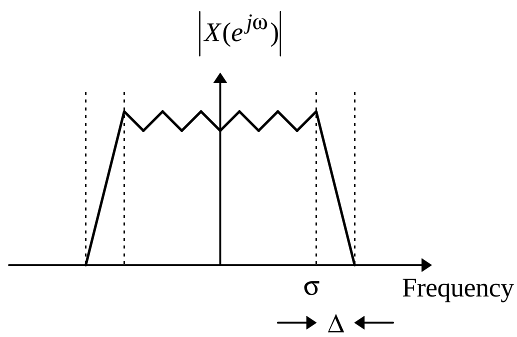

Figure 1. Stylised view of output of a non-ideal subband analysis filter

3. NON-CRITICAL DECIMATION USING EFFICIENT RESAMPLING BY RATIONAL FACTORS

Figure 2 shows an example 2-band echo canceller in which *d(n)* is the microphone signal, *e(n)* is the residual error and $u_0(n)$ and $u_1(n)$ are loudspeaker signals for the lowpass and highpass bands respectively derived using the same decimation scheme as applied to the microphone.

We have taken an example case of decimation by a factor of 3/2 and have shown a direct implementation, for clarity in figure 2, even though in practice a more efficient (polyphase) implementation would be obtained by application of the Noble Identities [5]. We consider initially a 2-band structure and later build 4-band and higher structures from a tree of 2-band structures.

$\breve{W}_M$ specifies a frequency rotation

$$e^{-j2\pi/M} \qquad (1)$$

The subband signals $D_0(z)$ and $D_1(z)$ can be written

$$D_0(z) = \tfrac{1}{3}\left(H(z^{1/3})D(z^{2/3}) + H(z^{1/3}W_3)D(z^{2/3}W_3^2) + H(z^{1/3}W_3^2)D(z^{2/3}W_3^4)\right)$$
$$D_1(z) = \tfrac{1}{3}\left(H(z^{1/3})D(-z^{2/3}) + H(z^{1/3}W_3)D(-z^{2/3}W_3^2) + H(z^{1/3}W_3^2)D(-z^{2/3}W_3^4)\right) \qquad (2)$$

Ignoring temporarily the effect of the signals $u_0(n)$ and $u_1(n)$, the subband "error" signals $E_0(z)$ and $E_1(z)$ can be written

$$E_0(z) = \tfrac{1}{6}\left(H^2(z^{1/2})D(z) + H^2(z^{1/2}W_2)D(zW_2^2)\right)$$
$$E_1(z) = \tfrac{1}{6}\left(H^2(-z^{1/2})D(z) + H^2(-z^{1/2}W_2)D(zW_2^2)\right) \qquad (3)$$

under the assumptions that

$$H(z)H(zW_3) = 0$$
$$H(z)H(zW_3^2) = 0 \qquad (4)$$

Summing the subband error signals gives

$$E(z) = \tfrac{1}{3}\left(H^2(z^{1/2}) + H^2(-z^{1/2})\right)D(z) \qquad (5)$$

Thus, for this filter bank to give perfect reconstruction, we require

$$H^2(z^{1/2}) + H^2(-z^{1/2}) = k, \text{ constant.} \qquad (6)$$

This analysis leads to the design specification

$$\left|H(e^{jw})\right| = \begin{cases} 1 & \text{for } |w| \le \pi/4 \\ 0 & \text{for } |w| \ge \pi/3 \end{cases} \qquad (7)$$

The conditions (4) and (6) can be compared to the equivalent perfect reconstruction conditions for the maximally decimated 2-band case in which the requirement

$$H(z)H(-z) = 0 \qquad (8)$$

can be seen to be significantly harder to satisfy.

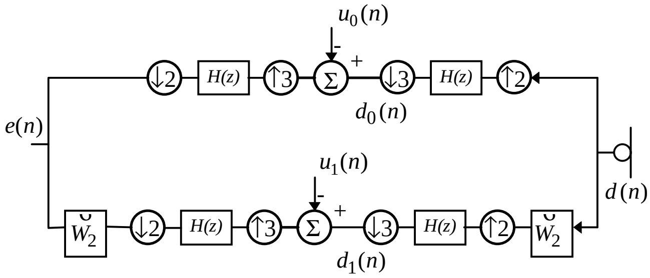

Figure 2 - 2-band non-critically decimated echo canceller

4. NLMS CONVERGENCE

The convergence properties of the LMS algorithm are dependent upon the eigenvalues of the autocorrelation matrix of the tap input vector. When non-critical decimation is employed, regions of the spectrum near the band edges have low energy - the so-called "guard bands". Consequently, the spread of eigenvalues for a non-critically decimated signal would be expected to be greater than for a critically decimated signal. In this work we have employed the NLMS [6] algorithm because it has several advantages for in acoustic echo control applications but, in particular, because it is found to be robust to the ill-conditioning of the autocorrelation matrix caused by the guard-bands.

To verify this, we have performed tests on the subband signals to compare eigenvalue spread. We found that, compared to critical decimation, the non-critical decimation increases the eigenvalue spread for the subband USASI signals from between 2 and 5 orders of magnitude. A further test was performed to test a full-band NLMS echo canceller with (i) USASI noise input and (ii) USASI noise filtered to approximate the spectrum and eigenvalue spread after non-critical decimation.

The results of this test are shown in figure 3 from which we conclude that the increase in eigenvalue spread due to the introduction of non-critical (instead of critical) decimation does not significantly perturb the convergence properties of the NLMS algorithm applied on the non-critically decimated subband signals.

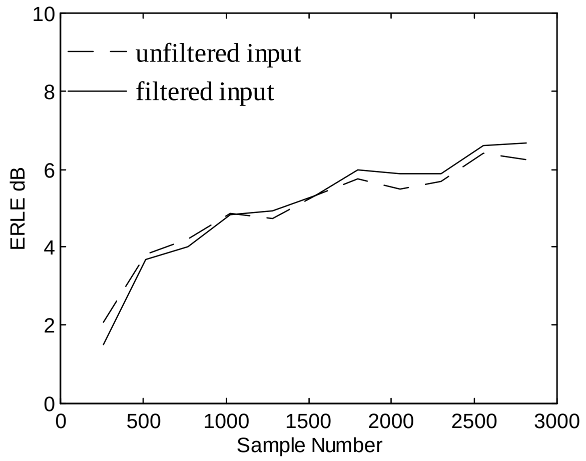

Figure 3 - ERLE performance of full-band NLMS echo canceller for unfiltered and filtered USASI noise input

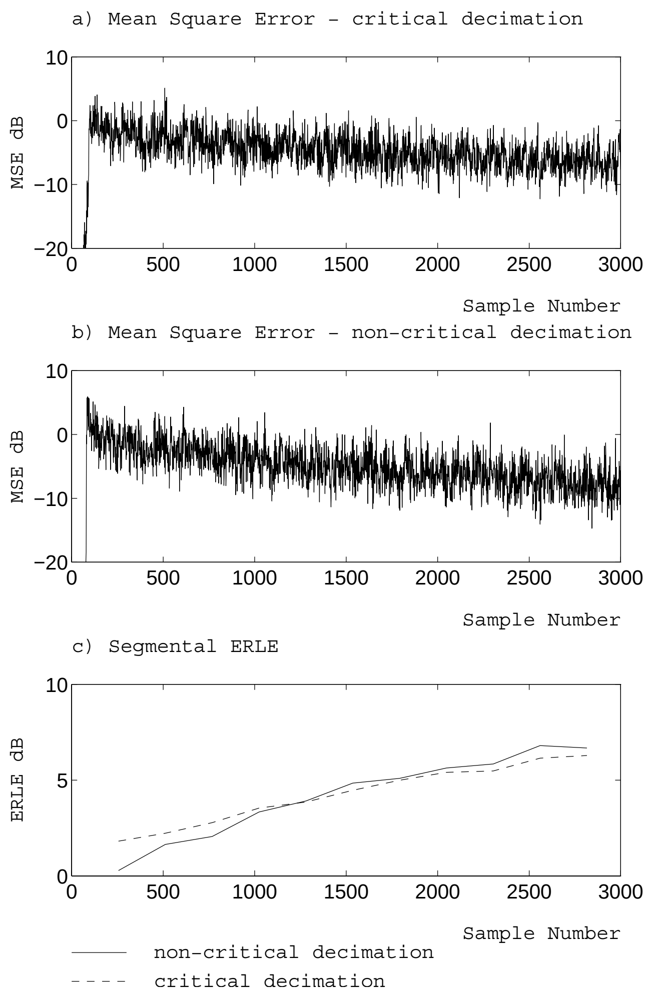

Figure 4 - Subband AEC performance using FIR filter banks on USASI noise signals

5. SIMULATION EXAMPLES

Experiments have been performed using 4-band NLMS-based echo cancellers for the four combinations of FIR/IIR and critical/non-critical decimation. The FIR filter bank tested was a standard design using 32 tap linear phase filters with $\omega_c = \pi / 2$ for the critical case and 64 taps for the non-critical case with $\omega_c = \pi / 4$. The IIR filter bank was as given in [4] for the critical case. For the non-critical IIR case $H(z)$ was obtained from the frequency transformation [8] of the filters given in [4]. The 4 bands were obtained using 2-band systems in a binary tree. The test data was USASI noise and male speech recorded in a realistic office environment using a hands-free telephone system [7]. 512 taps were used in the adaptive filter divided equally among the bands. The NLMS stepsize parameter fixed at 0.1 for each band for all experiments for the purposes of algorithm comparison. In the USASI experiments, the results shown are averaged across 20 trials. Results are shown in figures 4, 5, 6 and 7 for mean square error and for segmental Echo Return Loss Enhancement (ERLE) computed over 32 ms frames.

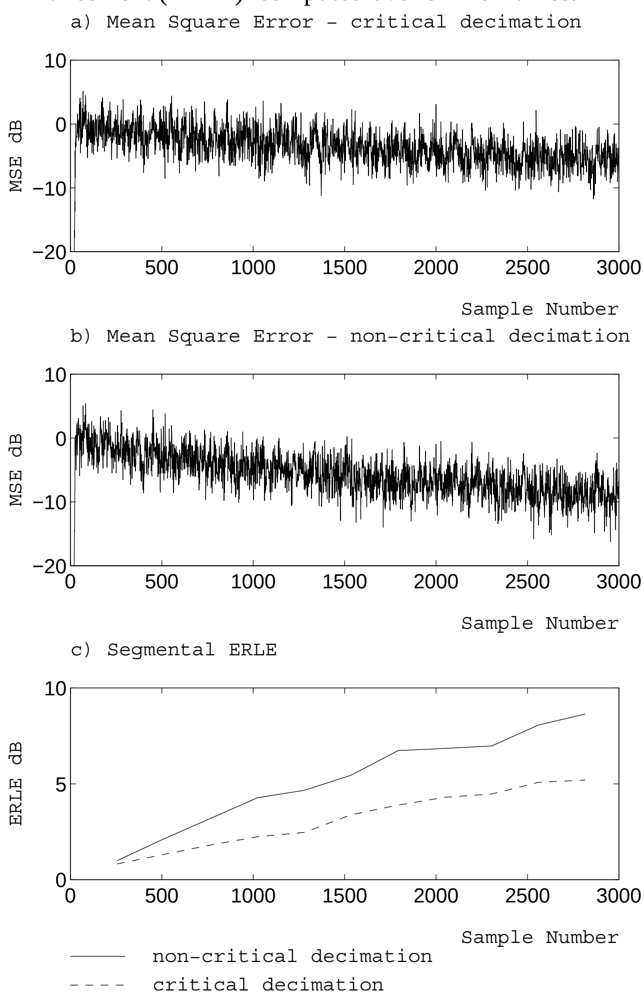

Figure 5 - Subband AEC performance using IIR filter banks on USASI noise signals

6. SUMMARY AND CONCLUSIONS

An approach to the aliasing problem in subband acoustic echo control has been reported here in which a non-critically decimated filter bank has been used. Two cases have been studied, one using FIR filters in the filter bank which give relatively poor stop band attenuation and one using IIR filters which give relatively good attenuation. When the aliasing errors are spread across the band, as in the FIR case, there is no justification for using non-critical decimation schemes. When the aliasing errors are concentrated around the band edges, as in the IIR case, the non-critical scheme brings and improvement of around 5dB in segmental ERLE compared to a critically decimated scheme. The increase in eigenvalue spread caused by the non-critical decimation does not significantly perturb the NLMS algorithm applied in the subbands. The computational complexity of the non-critically decimated filter banks is about double that of the critical case but, for the IIR design, no additional delay is required because of the nature of the filters in [4]. The complexity of the filter banks is still small compared to the NLMS algorithm.

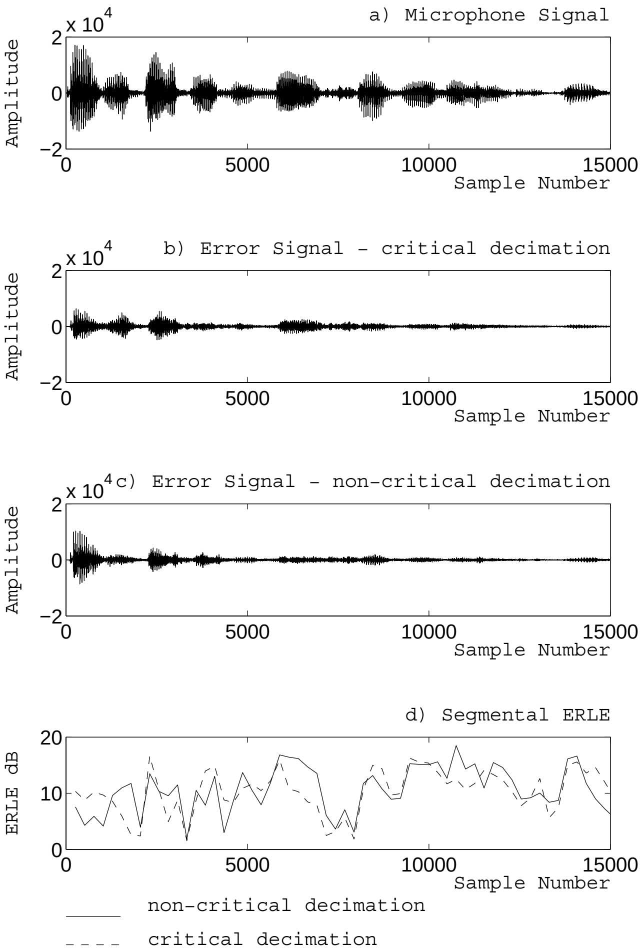

Figure 6- Subband AEC performance using FIR filter banks on male speech

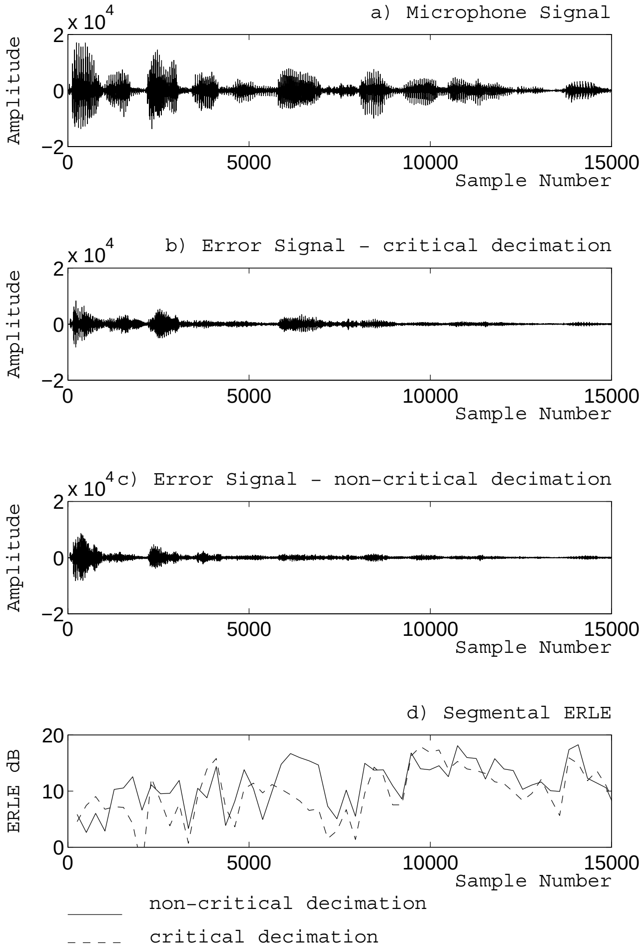

Figure 7- Subband AEC performance using IIR filter banks on male speech

7. REFERENCES

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