15B.3 RANGE OVERSAMPLING TECHNIQUES ON THE NATIONAL WEATHER RADAR TESTBED

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1. INTRODUCTION

Faster observation of severe weather is a primary need of radar users. However, modifying scanning strategies to provide faster updates usually leads to trade-offs such as losses in data quality and/or spatial resolution. Range oversampling techniques can lead to faster updates and/or lower estimation errors without increasing the transmit bandwidth and with minimal degradation of the spatial resolution. The National Weather Radar Testbed (NWRT) is a natural platform for range oversampling research because, by default, the system oversamples in range by a factor of 4, 8, or 16. A simple pseudowhitening strategy has already been implemented and tested on the NWRT using a fixed transformation matrix. To better deal with varying conditions, an adaptive strategy is introduced that utilizes different pseudowhitening matrices based on the measured signal-to-noise ratio (SNR) and spectrum width at each range gate. Replicating the behavior of matched filtering at low SNR values is also considered. Adaptive pseudowhitening is a step towards establishing range oversampling techniques as operationally viable on weather surveillance radars.

In this paper, a short background describing range oversampling techniques and the associated noise enhancement is provided. Several methods for mitigating the effects of noise enhancement are then presented and compared. Finally, some results applying adaptive pseudowhitening to NWRT data are shown.

2. BACKGROUND

In general, range oversampling describes the process of sampling in range at a rate greater than the inherent range resolution determined by the length of the transmit pulse. When oversampling by a factor of L, the L samples in range will be correlated because the inherent range resolution is not changed. All of the range oversampling techniques proposed in this paper are based on applying a linear transformation to the correlated time series samples in order to reduce the range-time correlation. The autocorrelations computed from the transformed samples are then averaged and processed to produce moments at the original non-oversampled resolution.

The linear transformation, **W**, is applied to **V** which is an L x M matrix of time series data. L is the oversampling factor and M is the number of pulses in the radial. The result is the transformed matrix of time series data, **X**.

$$\mathbf{X} = \mathbf{W}\mathbf{V} \tag{1}$$

Since **V** is made up of both a signal and a noise component, $\mathbf{V} = \mathbf{V}_S + \mathbf{V}_N$ and $\mathbf{X} = \mathbf{W}\mathbf{V}_S + \mathbf{W}\mathbf{V}_N$. This linear transformation of the noise component can increase the noise resulting in noise enhancement. More details can be found in Torres and Zrnić (2003).

3. NOISE ENHANCEMENT

The easiest way to visualize the effects of noise enhancement is to use a time series simulation (Zrnić 1975) showing the change in the standard deviation of a spectral moment versus the signal-to-noise ratio (SNR). In this paper, the simulated time series are utilized to estimate reflectivity performance using the parameters for a surveillance cut on the NWRT. The parameters were chosen to match the weather data plotted in Section 5: number of pulses, M = 15, pulse repetition time or PRT, T_S = 3.1 ms, and spectrum width, σ_v= 2 m s^{-1}. The operating frequency of the NWRT is 3.2 GHz.

The two curves shown in Figure 1 illustrate two different methods for processing the data. The first curve (red) is a digital matched filter which is similar to conventional processing. The second curve (blue) is pure whitening. The performance at high SNR is better using the whitening transformation because of decorrelation. At low

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SNR, the noise enhancement effects cause the errors for whitening to increase significantly. There is a crossover point around 4 dB where both techniques have similar performance.

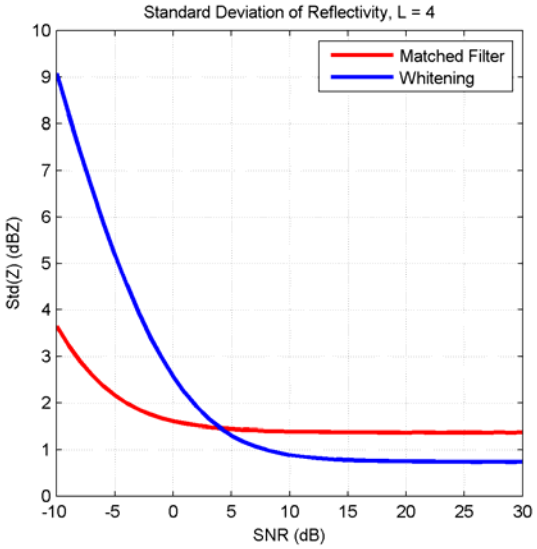

Figure 1. Comparison of digital matched filter and whitening using a time series simulation.

4. NOISE ENHANCEMENT MITIGATION

In this section, three different range oversampling techniques to mitigate the effects of noise enhancement will be described and compared. The standard deviation of reflectivity and estimator bias will be used to compare the techniques.

4.1 Crossover Whitening

The first technique, crossover whitening, was suggested in Torres (2001). The basic idea is to estimate the SNR and pick the whitening transformation when the SNR is greater than the crossover SNR and use the matched filter when the SNR is less than the crossover. The crossover SNR depends only on the normalized spectrum width (Torres 2001) so both need to be estimated when implementing the technique operationally.

Figure 2 shows the matched filter and whitening curves from Figure 1 with an added curve for crossover whitening. The crossover whitening performs as expected at the extremes with performance like matched filter at low SNR and like whitening at high SNR. In the transition region, it seems to perform better than both whitening and matched filter.

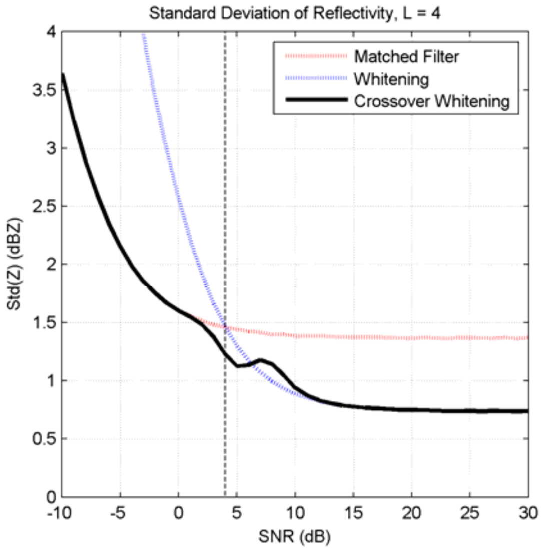

Figure 2. Comparison of digital matched filter, whitening, and crossover whitening using a time series simulation.

The performance in the transition region led to an examination of the bias of the combined estimator. The biases for matched filter, whitening, and crossover whitening are shown in Figure 3. Although matched filter and whitening are unbiased, crossover whitening is biased by as much as -0.5 dB in the transition region. This explains the seemingly better performance of crossover whitening. Apparently, the distribution that results from drawing from both the matched filter and whitening distributions has a different mean from the two original distributions.

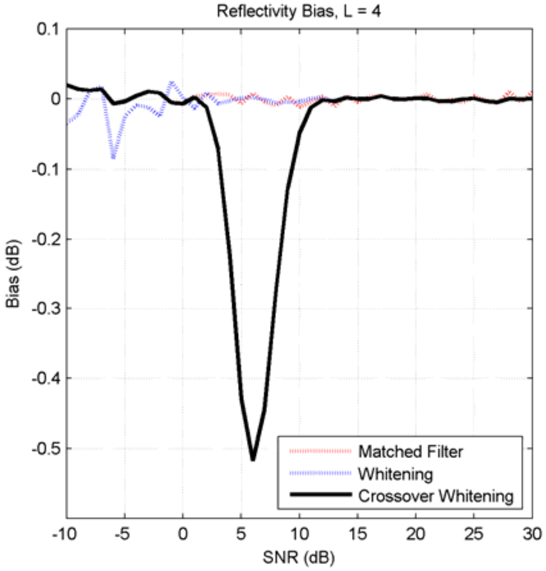

Figure 3. Comparison of reflectivity bias for digital matched filter, whitening, and crossover whitening using a time series simulation.

4.2 Pseudowhitening

The next attempt to deal with this problem was to use a fixed transformation that trades some performance at high SNR to perform better at low SNR than pure whitening. The advantage is that a fixed transformation is not biased, but the disadvantage is less than optimal performance at both high and low SNR. Figure 4 illustrates the performance of pseudowhitening using a sharpening filter with *α* = 0.9 (Torres et al. 2004).

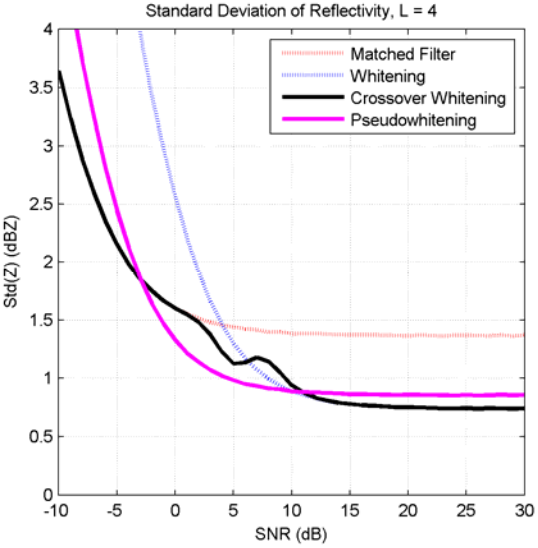

Figure 4. Comparison of digital matched filter, whitening, crossover whitening, and pseudowhitening using a time series simulation.

The pseudowhitening transformation performs better in the transition region than crossover whitening but does not perform as well at the extreme SNRs. Another requirement for sharpening is the determination of the proper *α* parameter to use for each spectral moment and waveform. More research is needed to find the best pseudowhitening transformation for any given situation.

4.3 Adaptive Pseudowhitening

Adaptive pseudowhitening is based on what was called optimal pseudowhitening in Torres et al. (2004). This approach uses equations that minimize the variance for each spectral moment based on the SNR and normalized spectrum width. For optimal pseudowhitening, it was assumed that the actual SNR and spectrum width were known. For adaptive pseudowhitening, the SNR and spectrum width are estimated using matched filter data. Based on the estimated parameters, a different transformation is used at each rage gate. The performance of adaptive pseudowhitening is illustrated in Figure 5.

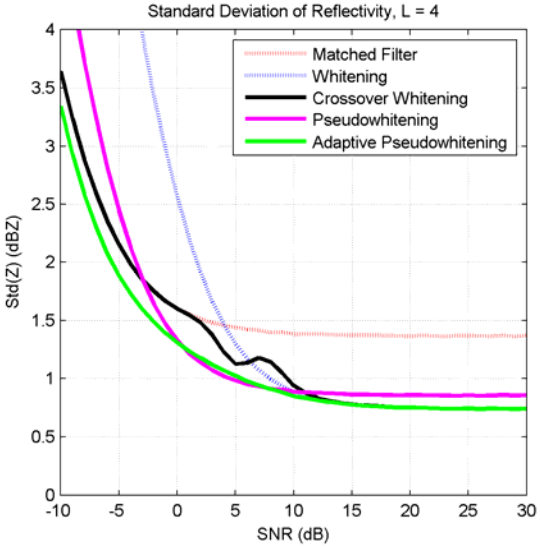

Figure 5. Comparison of digital matched filter, whitening, crossover whitening, pseudowhitening and adaptive pseudowhitening using a time series simulation.

Adaptive pseudowhitening does perform better at the extremes than a fixed pseudowhitening transformation but slightly worse in the transition region. Another concern is that since adaptive pseudowhitening does not use a fixed transformation that there may be a bias. Figure 6 shows the biases for all the techniques.

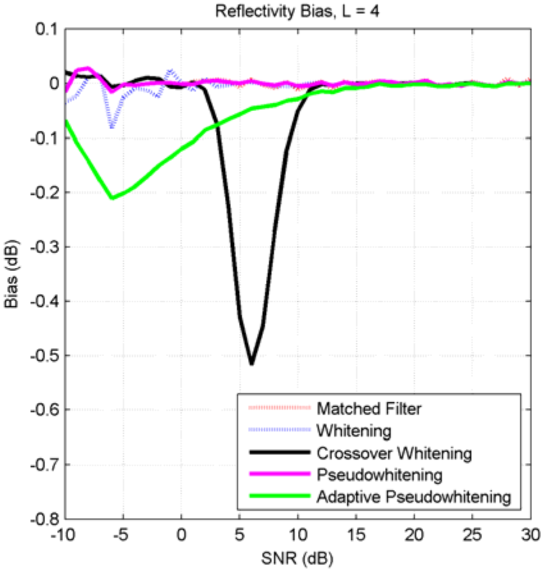

Figure 6. Comparison of reflectivity bias for digital matched filter, whitening, crossover whitening, pseudowhitening, and adaptive pseudowhitening using a time series simulation.

Adaptive pseudowhitening does have a bias, but it is significantly less than the one for crossover whitening. The bias is at most -0.2 dB and is only about -0.1 dB for signals of interest (greater than 2 dB SNR). Adaptive pseudowhitening improves performance at extreme SNR values compared to fixed pseudowhitening at the cost of a bias which is smaller than that for crossover whitening.

5. NWRT WEATHER DATA

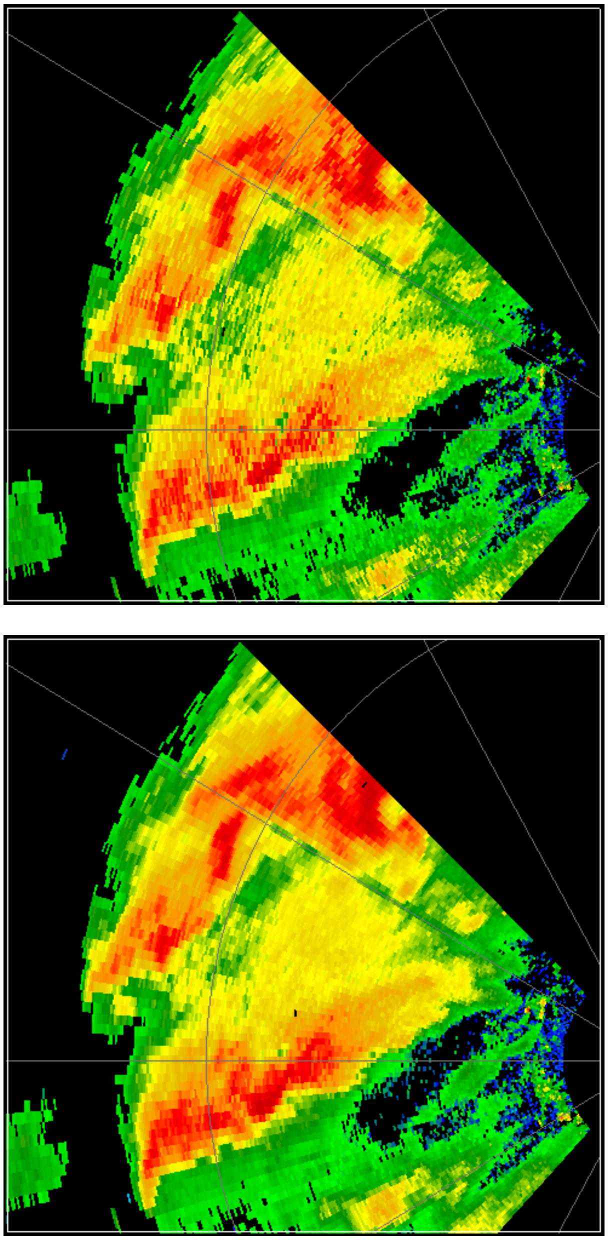

Figure 7. Comparison of digital matched filter (top) and adaptive pseudowhitening (bottom) using NWRT data from 20:20 UTC, February 10, 2009.

Figure 7 shows part of a 90° sector collected using the NWRT and processed using both a digital matched filter (top) and adaptive pseudowhitening (bottom). The adaptive pseudowhitening image seems to be smoother than the matched filter image which is the result of lower errors. In this case the same number of pulses was used for both which leads to better data quality for the oversampled data, but fewer pulses could also be used to save time if similar data quality was needed.

6. CONCLUSIONS

Adaptive pseudowhitening has been successfully implemented using NWRT data and will be operational for the 2010 spring season. This range oversampling technique is nearly optimal at all SNR values but does have a slight bias because the transformation varies from range gate to rage gate.

Future work will entail further study of the bias and additional comparisons with fixed pseudowhitening transformations. Research on efficient implementations of these techniques will be continued.

7. REFERENCES

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