P4D PRACTICAL ASPECTS OF WIDEBAND RECEPTION AND PROCESSING IN DUAL-POLARIZED WEATHER RADARS

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1. INTRODUCTION

In conventional radar systems the receiver bandwidth is designed to be similar to be bandwidth of the transmit pulse. For a given range sample estimates are averaged over time to improve the estimation accuracy. A number of methods have been proposed in the past for improving the quality of estimates without sacrificing range resolution (Mudukutore et al, 1998). Schemes using shorter pulsewidth or pulse compression techniques require opening up the system bandwidth. Recently Torres and Zrnic (2001) have suggested oversampling the radar signals in range and whitening the range samples as a potential way to decrease the measured standard deviation of various radar signal parameters. This process requires increasing only the receiver bandwidth. For the whitening of the received waveform to be accurate, numerous details have to be addressed such as full knowledge of amplitude and phase of the transmitted pulse. This paper presents a theoretical and experimental investigation of the procedure of oversampling in range (at a resolution smaller than normal pulse width). It is shown that use of oversampling and whitening improves the quality of reflectivity and velocity estimates nearly in agreement with the theory, however improvement is not so obvious for the polarimetric variables.

2. THEORETICAL BACKGROUND

As shown in Bringi and Chandrasekar 2001, the correlation among the range samples $v(t)$ at the input of the receiver is given as,

$$R_v(t, t + \Delta t) = \bar{P}_r R_u(\Delta t) \tag{1}$$

Where $u(t)$ is the transmitted pulse waveform, and $\bar{P}_r$ is the mean power of the range samples. In the case of oversampling where multiple samples are taken within the pulse duration, the range samples will be correlated. Applying an orthogonalizing transformation on the oversampled signals that would yield a set of uncorrelated samples in range, the reflectivity estimates obtained from these transformed samples could be averaged to reduce their standard deviation. Consider the samples of the received signal from a pulse of transmitted width T_0/L. Where T_0 and L are normal pulsewidth and oversampling factor respectively. Then the received signal sample at time t corresponds to a resolution volume whose range extent is $CT_0/2L$ and located at $Ct/2$ from the radar. Each sample from this sub volume is a complex gaussian random variable with zero mean (Bringi and Chandrasekar, 2001).

For a longer pulse of length T_0, each subpulse/chip of length T_0/L defines a range interval $CT_0/2L$. A combination of echoes from these intervals weighted by the pulse shape produces the samples at the receiver. With the assumption that the mean properties of the signal returns corresponding to each of the L sub volumes are the same, the orthogonalizing transformation transforms these to the original independent samples and obtain variance reduction through averaging over L ranges.

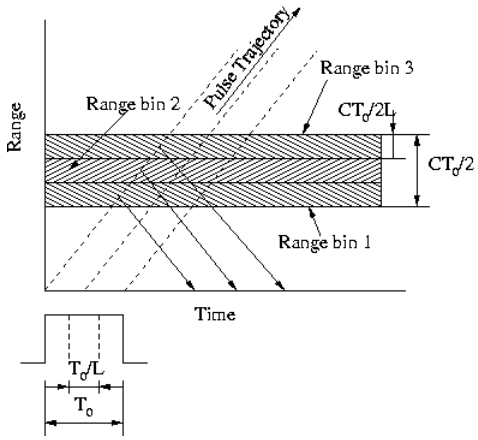

Figure 1. Illustration of oversampling process for L = 3

3. ORTHOGONAL TRANSFORMATION

The orthogonal transformation matrix is obtained through diagonalizing the covariance matrix of the range samples. Let C_v is the covariance matrix of the range samples. For a rectangular pulse, the elements of the covariance matrix are known. But in reality, as shown in Fig.2, the transmitted pulse is not a perfect rectangle. However, C_v can be estimated from the pulse samples.

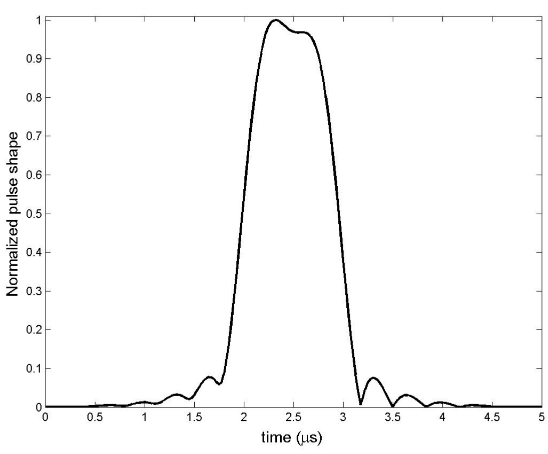

Figure 2. Shape of the CHILL transmitted pulse

An Eigen value decomposition (EVD) operation is performed on C_v to obtain the transformation matrix,

$$C_v = V\Lambda V^{*T} \tag{2}$$

Where V is a matrix whose columns are the eigenvectors of C_v and Λ is a diagonal matrix whose diagonal elements $\{\lambda_i\}$ are the eigenvalues of the covariance matrix. The corresponding transformation matrix W is obtained as

$$W = DV^{*T} \tag{3}$$

Where D is a diagonal matrix with elements $\left\{\lambda_i^{-1/2}\right\}$

4. IMPACT OF NOISE

The received signal consists of signal as well as noise. The noise was uncorrelated before transformation. In the process of diagonalizing the signal covariance matrix, the noise becomes correlated (or colored). Now the noise power after transformation can be expressed as,

$$N_w = N\frac{tr\left\{C_v^{-1}\right\}}{L} \tag{4}$$

For uniform precipitation in range the noise is enhanced by a factor $L^2/(L+1)$ (Torres and Zrnic, 2001), which limits the applicability of this technique under low signal-to-noise ratio situations. Therefore, after whitening the signal-to-noise ratio is updated for evaluating the quality of various parameters such as signal power (P), differential reflectivity (Z_{dr}) and copolar coefficient (ρ_{co}). Let $V_h[n], V_v[n], n = 1, \ldots, M$ are the samples of received signal in horizontal and vertical receiver respectively. For operation in hybrid mode, the following equations are used to estimate the above-mentioned parameters,

$$\hat{P_h} = \frac{\frac{1}{LM}\sum_{j=0}^{M-1}\sum_{k=0}^{L-1}|V_h(j,k)|^2}{(1+1/SNR)} \tag{5}$$

$$\hat{Z_{dr}} = 10log_{10}\frac{\hat{P_h}}{\hat{P_v}} \tag{6}$$

$$\hat{\rho_{co}} = \frac{\frac{1}{LM}\sum_{j=0}^{M-1}\sum_{k=0}^{L-1}V_v(j,k)V_h(j,k)^*}{\sqrt{\hat{P_h}\hat{P_v}}} \tag{7}$$

5. DATA ANALYSIS

Time-series data was collected from CSU-CHILL radar in hybrid mode. Both $1\mu s$ and $0.333\mu s$ long pulses were transmitted and the range returns were sampled at $0.333\mu s$ interval to collect received signals. Moreover, data collected using pulses with 0.333μs length were used to evaluate the performance of the whitening scheme.

5.1. Analysis of Oversampled Data

It has been established through theory and simulation (Torres and Zrnic 2001) that whitening transformation improves the estimation accuracy of all the parameters by a factor $\frac{L^2+1}{2L}$, where L is the oversampling factor. As mentioned earlier, it is implicitly assumed in formulating the transformation that the source signals have identical variance, or rather the samples associated with each sub-volume are realization of the a random process with identical statistics. In reality this property may not be true. It's common to find gradients in the range profile of various spectral moments (see Fig.3). This has two implications; the aforesaid assumption yields a transformation matrix that doesn't produce a set of uncorrelated samples. The effect of gradient on whitening is illustrated in Fig.4. Secondly, the estimation algorithms compute various parameters by averaging over L range-bins, but the deviation from ideal condition results in a higher-than-expected estimation error.

While estimating the polarimetric variables, the standard deviation of the whitened estimates do not show any improvement over their oversampled counterparts. The standard deviation of the polarimetric variable estimates are strongly dependent on the magnitude of ρ_{co}, the copolar correlation coefficient (Bringi and Chandrasekar 2001). It is shown in Fig.3 that whitening transformation causes a drop in the co-polar correlation, which nullifies the improvement obtained through whitening.

5.2. Analysis of Shortpulsed Data

As mentioned earlier the whitening algorithm increases the noise power. Equation (8) was used to correct the ρ_{co} estimates in presence of noise,

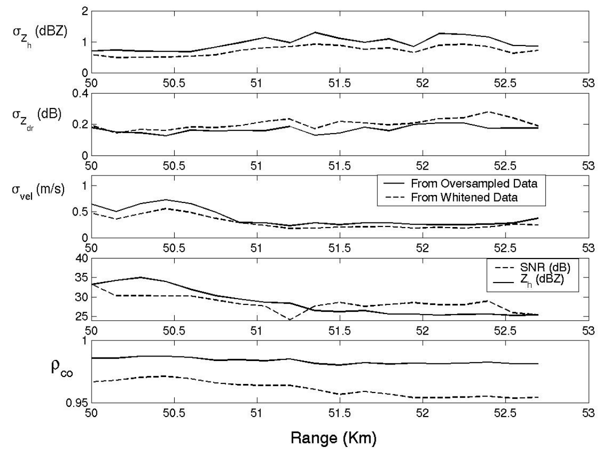

Figure 3. Range profile of estimates of spectral moments and polarimetric variables from oversampled and whitened data

but noise boost doesn't seem to account fully for the drop in ρ_{co}.

$$\rho_{co_{true}} = \frac{\rho_{co_{noisy}}}{\left[\frac{1}{1+1/SNR}\right]^{1/2}\left[\frac{1}{1+Z_{dr}/SNR}\right]^{1/2}} \qquad (8)$$

Whitening of oversampled signals is expected to produce identical estimates as obtained by using a pulse whose length is reduced by the oversampling factor. For an experimental verification, the performance of oversampled data (1μs pulse length, $0.333\mu s$ sampling) was compared to the estimates obtained from data collected using a shorter pulse ($0.333\mu s$ pulse length, $0.333\mu s$ sampling). Next, range samples obtained from using the shorter pulse were combined to simulate oversampled data. The estimates of ρ_{co} obtained from collected time-series (using short pulsewidth), after combining and whitening are shown in Fig.5 . As can be seen that after the samples are averaged in range to simulate oversampling, the correlated samples in range exhibit a higher copolar correlation.

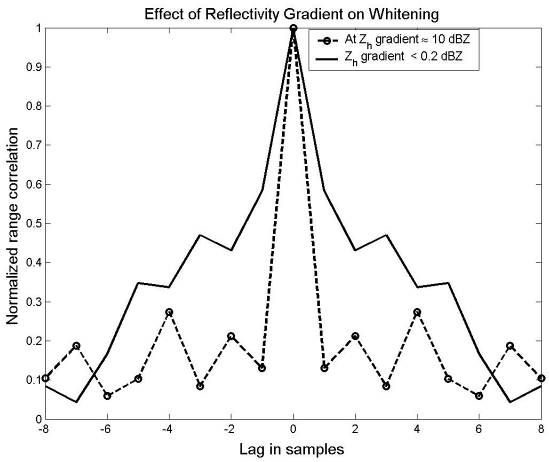

Figure 4. Effect of reflectivity gradient on whitening

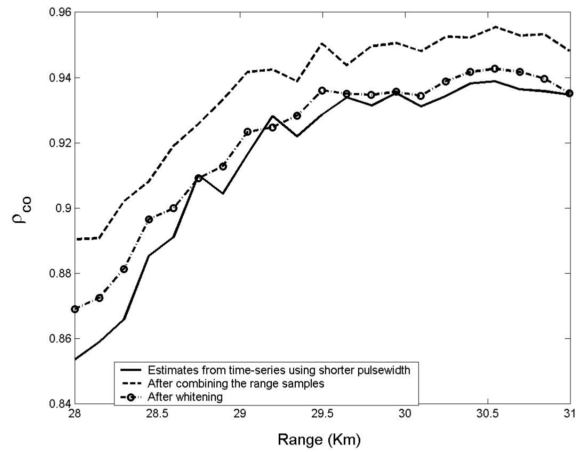

Figure 5. Estimates of ρ_{co} from analysis of time-series collected using $0.333\mu s$ pulses

6. SUMMARY

An extensive study on the applicability of whitening transform on dual-polarized data has been carried out. The results indicate the application of whitening technique could be really effective for estimating the reflectivity and velocity. However, for polarimetric variables there does not seem to be an improvement because of the drop in correlation. The reason for drop in ρ_{co} is being investigated. Large number of data sets are being analyzed to explore this further.

7. ACKNOWLEDGEMENT

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