5.5 RADAR OPERATIONS CENTER (ROC) EVALUATION OF THE WSR-88D OPEN RADAR DATA ACQUISITION (ORDA) SYSTEM SIGNAL PROCESSING

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INTRODUCTION

The WSR-88D Radar Operations Center (ROC) is evaluating the new signal processor, digital receiver, and software algorithms under development by the National Weather Service (NWS) Office of Science and Technology (OST), Open Radar Data Acquisition (ORDA) project (Cate, 2003). The ROC is responsible for ensuring that ORDA systems comply with WSR-88D system specifications, and is focusing on the performance of system signal processing algorithms, including base moment estimators and clutter filters. Radar Operations Center engineering team members are also evaluating the capability of the ORDA system to incorporate planned enhancements. These improvements include production of higher resolution base products, range-velocity ambiguity and anomalously propagated clutter mitigation, range over sampling, and full power spectrum analysis.

The initial focus is on performance of the basic moment estimators. The spectrum width estimation process is of particular interest because the SIGMET RVP8 system offers use of the poly-pulse, or R1/R2 estimator in addition to the traditional method currently employed in the WSR-88D. The ORDA system will likely make use of an optimal combination of both estimators, therefore it is important to fully characterize the performance of both. Recently, the Open RDA team asked ROC engineers to evaluate a new clutter filtering technique provided by SIGMET as a potential alternative to the legacy 5-pole elliptic time domain filter. This paper reports preliminary results of the velocity and spectrum width estimators and clutter filter evaluations.

EVALUATION METHODS

The engineering team uses several methods for analyzing system performance, focusing on both quantitative and qualitative techniques. Most of the evaluations depend on controlled experiments. These controlled experiments, making use of digital signal simulation, comprise the largest portion of the system evaluation, and result in quantitative verification of algorithm performance. The digital signal simulator is an integrated utility provided with SIGMET's IRIS software package. This simulator is based on techniques used by early investigators researching velocity and spectrum width estimators (Sirmans and Bumgarner, 1975). The simulator allows users to specify weather, noise, and clutter signal parameters, generates Gaussian spectra to match, and then performs an inverse Discrete Fourier Transform to produce time series signal data. The simulated time series data is then input to the normal RVP8 signal processing routines, in precisely the same manner as real time data via an Applications Programming Interface (API).

Output from the signal processor can then be viewed and subsequently recorded to disk by means of other software utility features. This process allows for end to end simulation, processing, and evaluation of any data sets the evaluation team requires. The built in record function saves user specified data sets to disk files that are then post processed by off-line MATLAB routines for analysis. The engineering team uses MATLAB for converting data from the native RVP8 format, for running appropriate computations, and for providing graphical comparisons.

SIMULATOR VERIFICATION

The team collected data to verify the Gaussian statistical performance of the digital signal simulator. Input parameters for the verification run included a signal mean velocity of zero m/sec, spectrum width of 3 m/sec, and with no clutter signals. The output of the simulation provides input to MATLAB routines that average the spectral coefficients and display the resulting average powers as a function of velocity. If the simulator is producing true Gaussian statistics, the resultant data points will be normally distributed with standard deviation of 3 m/sec. Plots of the simulator output spectrums overlaid with an ideal Gaussian distribution show that the averaged spectrum plots all lie within the expected Gaussian distribution.

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SPECTRUM WIDTH AND VELOCITY ANALYSIS

The team collected data with a range of input parameters designed to encompass WSR-88D performance requirements. All data sets include simulated signals covering the entire Nyquist velocity interval, signal to noise ratios (SNR) of 10 to 60 dB, clutter to signal ratios (CSR) of up to 50 dB and spectrum widths of 0.5 to 8 m/sec. Most data sets feature a Pulse Repetition Frequency (PRF) of 1000 and a radar wavelength of 10.7 cm, resulting in a Nyquist velocity of 26.8 m/sec.

Figure 1 is an example of a MATLAB generated output data histogram showing velocity and spectrum width estimates using time series data produced by the simulator. The displayed data represents the RVP8 polypulse estimator outputs for a total of 4000 estimates, with simulated input parameters of 4.0125 m/sec spectrum width, 8.025 m/sec velocity and 30 dB SNR.

The spectrum width estimates are produced by the RVP8 signal processor with the R1/R2 algorithm using a sample size of N=64. By calculating the mean and standard deviation of this data set, performance of the estimator can be analyzed against system specifications.

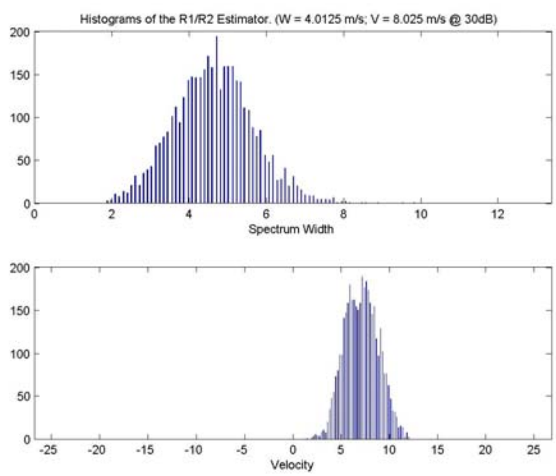

Figure 1 - Sample of Velocity and Spectrum Width Estimator Outputs (N=64, SNR 30 dB, CSR = 50dB)

For this set of input parameters, the estimated mean velocity is 7.06 m/sec, the standard deviation of the velocity estimate is 1.75 m/sec, the mean estimated spectrum width is 4.63 m/sec and the standard deviation of the spectrum width is 1.03 m/sec. The biases of spectrum width and velocity are under 1 m/sec and the standard deviations are within 2 m/sec, compliant with system specifications.

Figures 2 and 3 summarize the two spectrum width estimator performances in terms of estimator bias. Figure 2 documents performance of the R0/R1 estimator that is similar to the legacy algorithm except that the WSR-88D algorithm has a more complex noise compensation scheme. The noise term causes the bias to be more pronounced for low SNR as seen in the 10 dB curve of Figure 2.

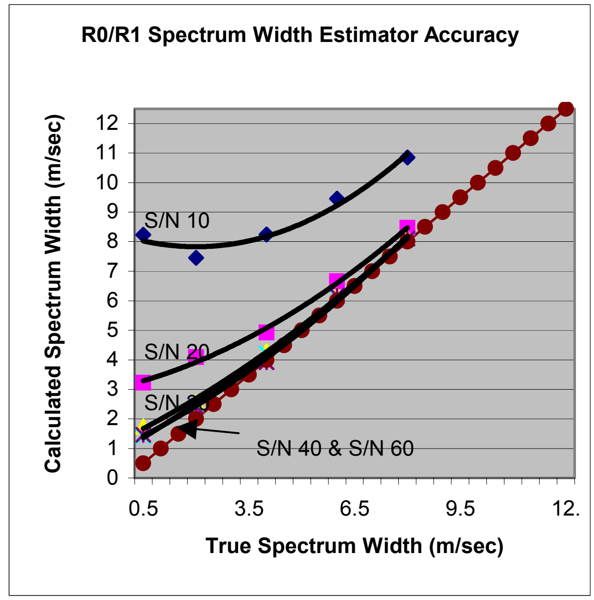

Figure 2 - Bias of WSR-88D Legacy Style Estimator without Noise Compensation.

For sufficiently high SNR (30 dB) and N=64, the R0/R1 estimator performs within specifications over most of the true spectrum width range as simulated.

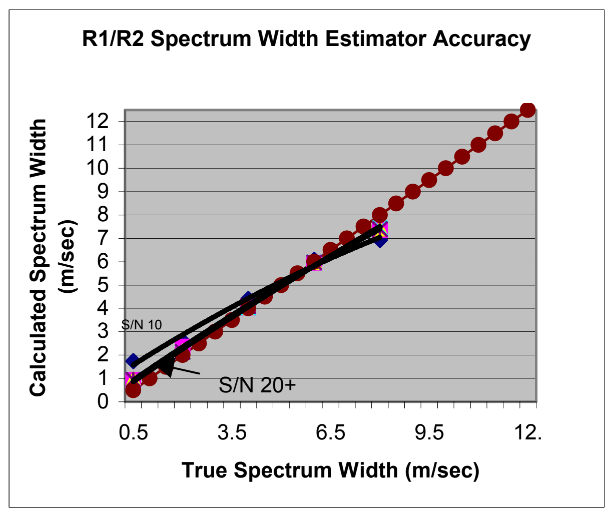

Figure 3 - Bias Performance of R1/R2 Estimator

The R1/R2 estimator has a more linear transfer curve than the R0/R1 algorithm, but exhibits a number of samples bias. This bias is slightly high at low spectrum widths and slightly low at higher spectrum widths (reference figure 3). At higher spectrum widths, a significant portion of the estimator outputs can be “folded over” in the Nyquist interval and thus bias the cumulative mean values. The bias increases for decreasing N and decreases for larger values of N.

These biases are consistent with expected results (Srivastava, 1979).

Figure 4 and 5 are summaries of the standard deviation values related to the two spectrum width estimators. Data is plotted for SNR values of 10 to 60 dB over the same spectrum width ranges of the previous two graphs. The number of samples is N=64.

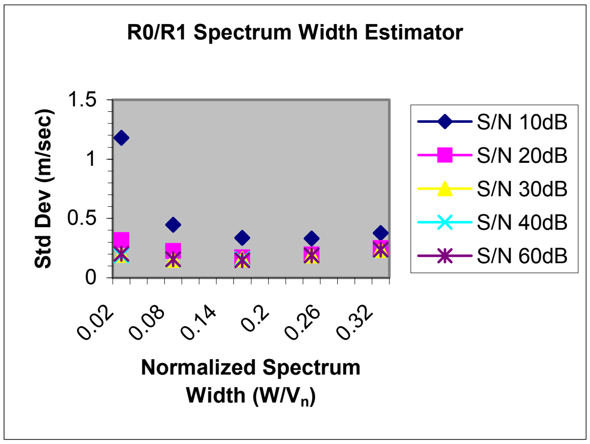

Figure 4 - Standard Deviation of the R0/R1 Estimator

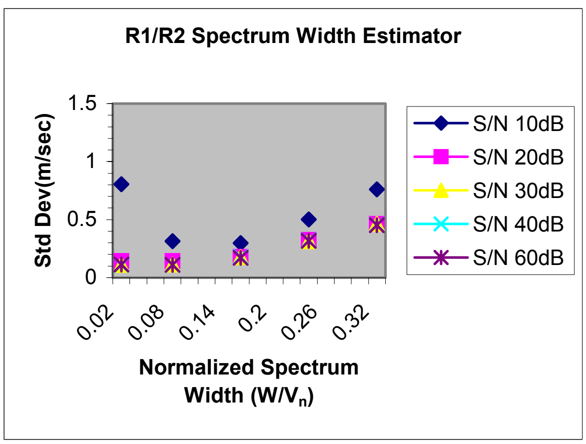

Figure 5 - Standard Deviation of the R1/R2 Estimator

The standard deviations follow the expected trends for these two estimators as reported in the literature (Doviak, 1993). With the exception of extremely low widths in the R0/R1 estimator, performance is compliant with WSR-88D requirements. The variance of the R1/R2 estimator is compliant over all tested widths.

CLUTTER FILTER EVALUATION

The original RVP8 software provided two methods for clutter filtering, featuring both time and frequency domain techniques. Both of the original schemes fall slightly short of meeting WSR-88D system specifications. The RVP8 4-pole elliptic time domain IIR filter does not exhibit the sharp notch width roll off characteristics of the WSR-88D 5-pole filter and the frequency domain technique does not meet requirements for the small number of samples required in the WSR-88D surveillance mode operation. SIGMET has subsequently developed a new clutter filtering approach that is the focus of the second part of this evaluation.

This new software employs more sophisticated spectral processing techniques than previous versions, and promises improved clutter filter performance. Returning to the data of Figure 1, the histogram represents estimator output results from filtering with the new algorithm on an input data set which includes a clutter signal 80 dB above the noise with a 50 dB CSR and with clutter spectrum width of 0.28 m/sec. Note the absence of a clutter signal in the velocity histogram at 0 m/sec velocity indicating the clutter filter has removed the clutter signal, while maintaining estimate bias and standard deviations within system performance requirements. The process performs well with sufficient samples, in this case N=64.

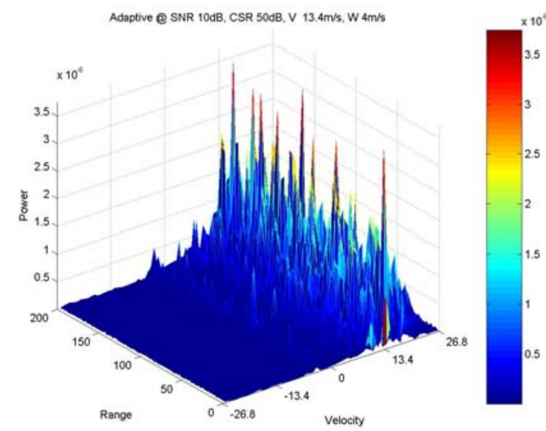

Figure 6 - Power Spectrum Plot with CSR = 50 dB

For the clutter filter performance evaluation, the engineering team has an extensive simulation database. Only a small sampling can be presented here. Figure 6 is a representative of spectrum samples available to the evaluation team. Figure 6 depicts the power spectra from 200 range bins produced by the RVP8 processor based on simulated input data sets with mean velocity of 13.4 m/sec, spectrum width of 4 m/sec, 10 dB SNR and 50 dB CSR.

The plot is a qualitative indicator of system behavior with a low signal in the presence of clutter. From the plot, only a relatively low level of clutter residue remains along the 0 velocity line while each spectrum is dominated by remaining signal powers.

Preliminary analysis of the proposed algorithm performance can be summarized for a subset of cases. For sufficiently large sample sets (N=32 and 64), the clutter filter scheme performs adequately for WSR-88D requirements. In general, the process yields estimates with substantially lower biases than the legacy filter. The process yields somewhat higher variances than seen in the legacy system, but it is still compliant with system specifications over most operating conditions. The proposed process has several advantages over the legacy system which overcome the higher variances. Two of these advantages include an ability to restore spectral components and expected compatibility with planned phase coding enhancements.

Analysis so far is based on sample sizes of N=32 and N=64. For the WSR-88D surveillance mode operations, the system must meet reflectivity estimate specifications for range bins containing as few as 16 samples. Evaluation of the algorithm's performance for N=16 is not complete and is the subject of continuing investigations.

REAL DATA EXAMPLE

Figure's 7 and 8 are examples of reflectivity products processed through the RVP8 using real archived time series data from the S-pol radar operated by the National Center for Atmospheric Research (NCAR). This is time series data recorded with the new Level 1 Record and Playback (L1RP) system developed for the ORDA by ROC Engineering. ROC team members have also established the capability to play back archived data into the RVP8 via the time series API and these products are one example of the playback process.

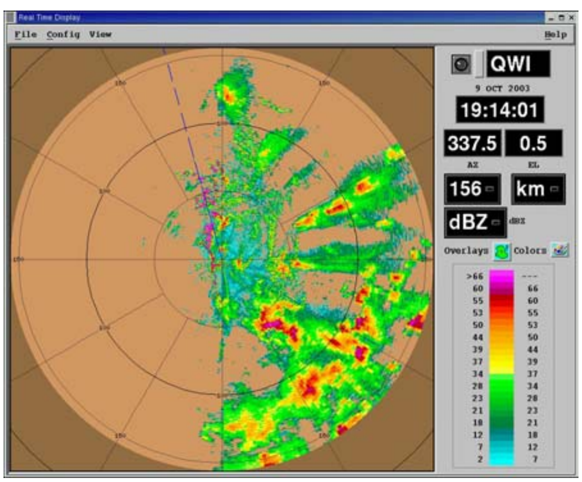

Figure 7 - Reflectivity Output Containing Ground Clutter

The reflectivity field in Figure 7 contains ground clutter resulting from nearby mountains clearly visible in the northwest quadrant near the radar (returns > 66dBZ). Figure 8 is the same data set processed with clutter filtering over the entire range. Clutter returns of over 66 dBZ are reduced to around 20 dBZ while the weather signals are not significantly affected.

EVALUATION SUMMARY

The SIGMET RVP8 signal processing approach is viable for the Doppler modes of the WSR-88D application. Spectrum width and velocity estimators meet WSR-88D system specifications and perform in accordance with well known theory. The new clutter management approach meets system requirements as long as sufficient samples are available to the process.

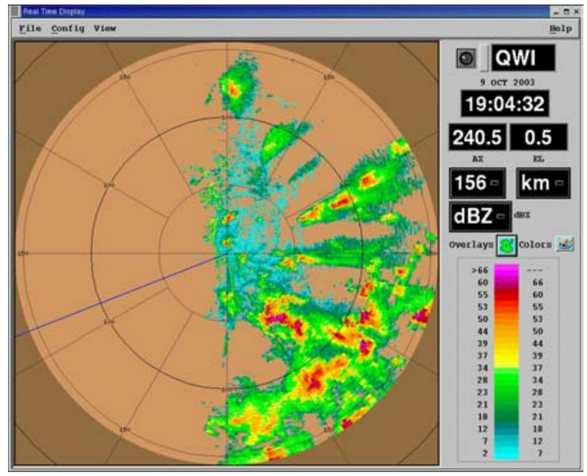

Figure 8 - Reflectivity Output with Ground Clutter Removed by the Proposed Algorithm

Preliminary analysis of limited real radar data sets in addition to simulations indicates that the new clutter signal processing algorithm is robust and is a viable solution for WSR-88D clutter filtering when a sufficient number of samples are available (N>=32). Evaluation of algorithm performance with lower numbers of samples (N=16) is on-going as of this writing. This operational scenario is very important for the WSR-88D surveillance mode where only a few samples are available. Engineers continue to evaluate and characterize the algorithm to adapt it to WSR-88D operational conditions.

The ROC engineering team has developed the necessary tools to simulate and analyze any desired performance criteria related to WSR-88D operations and can support future development, including planned enhancements. The team is currently refining tools for using archived data for playback into the RVP8.

FUTURE WORK

Much work remains. The ROC team must complete simulations and analysis of the clutter processing algorithm performance under conditions with the low number of samples related to the WSR-88D surveillance mode. They also need to build a large database of results to fully characterize performance of the RVP8 algorithms under all WSR-88D performance characteristics. This base of performance data is important for supporting system deployment and for future development of planned enhancements.

The team also plans to process the simulated time series data through other off-line tools as a further quality check on RVP8 algorithm performance. One prospect is to use the Improved MATLAB Analysis Tool (IMAT) developed for the ROC by NCAR (Meymaris, 2003). IMAT is a collection of MATLAB routines which can process radar time series data and produce estimator outputs for all moments as well as full power spectrums. NCAR implemented the WSR-88D legacy estimator algorithms in IMAT, thus making IMAT useful for verifying RVP8 software performance.

Engineers expect to continue the evaluation process by using additional archived radar data. This data, either from the new L1RP system based on the RVP8, or legacy data recorded from past weather cases, is vital for a complete end-to-end system performance check. Engineers also hope to make use of time series data from the National Severe Storms Laboratory (NSSL) Research RDA (RRDA). The NSSL has developed a flexible research signal processor integrated with an operational WSR-88D. The system has the capability to record any amount of level 1 and level 2 data. The NSSL teams have archived a significant number of data cases, and the ROC team plans to investigate selected NSSL data sets for continued evaluation efforts. Developing the proper data conversion routines and refining archived data interfaces to the RVP8 signal processor is a crucial future task for the ROC team.

Engineers also plan to evaluate the ability of the RVP8 to support system performance enhancements identified by the WSR-88D user community. ROC Engineering will continue to analyze RVP8 processor loading, input/output limitations, software infrastructure, and interface designs to ensure all planned enhancements are supported by the ORDA architecture.

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