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EVOLUTION OF WEATHER SURVEILLANCE RADARS NSSL"s PERSPECTIVE

D.S. Zrnic* and A. Zahrai
NOAA/National Severe Storms Laboratory, Norman, OK

1. INTRODUCTION

Latest technology and advanced signal processing allow significant improvements to be made on classical weather radars. The National Weather Service has been upgrading the WSR-88D to take advantage of such improvements and thus enhance its mission. The primary use of the network is for warnings of severe weather, precipitation measurements, and short term forecast by extrapolation of hazardous weather signatures. We submit that it may also be possible to assimilate weather radar data into operational models and thus achieve a better forecast. For all these mission needs valid data are essential and much of the evolutionary changes are directed to achieve this goal.

It is likely that the major components (pedestal, antenna, microwave circuits) of WSR-88D will experience little alteration for another twenty years. The exception is addition of polarimetric capability starting in about 2007. There might be changes in the transmitter but none are planed in the next five years. Signal processing and computing hardware is undergoing a quantum improvement to be completed in about 2005 and more might ensue during the network's lifetime.

NSSL has modified its research and development radar to explore, suggest, and test beneficial changes in an orderly and gradual manner so that by the end of this decade an optimum hardware/software configuration, ready for operational application, emerges.

2. RADAR CONFIGURATION

The R&D WSR-88D is being modified to meet scientific needs of NOAA and also support significant upgrades on the network. Dual polarization capability has been added; tests and evaluations have been going on for over a year. Currently the radar has two control channels. One is the same as is on operational WSR-88Ds, the other has been designed for flexibility and easy programming and we refer to it as Research Radar Data Acquisition (RRDA) system. Corresponding to these channels are two signal processing channels. In addition an RVP-7 processor (manufactured by Sigmet) is passively connected to the radar. Its primary role is to process dual polarization signals.

The final configuration of the radar will have two channels (Fig. 1). One will remain the RRDA. The other will have the same processor and control as all the rest of WSR-88Ds; these are RVP-8 processors. Initially NSSL's RVP-8 will have additional hardware to process dual polarization signals which should be installed on the network in 2008.

The RRDA has a digital intermediate frequency (IF) receiver with a sampling rate of about 95 MHz. Oversampling by a factor of 5 is automatically provided with this receiver. Further the signal processor is a Mercury system with 6 Power PC processors between two boards so that a total computational throughput is about 10 Gflops. All control and signal processing that is now done on the operational WSR-88D is achieved with two Power PCs working at about 70% capacity. Thus much computational power is available to support the enhancements envisioned in this paper. Moreover the RRDA has a capability to record vast amounts (hours) of time series data. The RVP-8 has computational capability of about 3.2 Gflops. By the time the new system is ready to accommodate the suggested improvements computational capability on the RVP-8 will likely increase by a factor of two. Therefore we submit that the RRDA and the operational system being developed are in synch. That is, suggested developments and signal handling schemes will be tested on the RRDA in time so that the beneficial ones can be transferred to the operational system as soon as it is deployed.

The RRDA will be used to test 1) procedures for mitigating range/velocity ambiguities, 2) processing of dual polarization signals, 3) processing of oversampled signals, and 4) Captured data from various phenomena and conditions to develop algorithms for detecting severe weather features as well as to devise better signal processing procedures. All of the techniques that can possibly be implemented on the RVP-8 will be tested as well and thus this technology will be transferred directly to NWS.

In development and testing any of the techniques we follow four steps. One is theoretical evaluation including simulations; two is making a computer replica of the exact signal processing algorithm as the one that will be implemented in real time; three is implementation on a signal processor; and four is subsequent evaluation by human observers.

A few words about the second step are in order. As processing on the WSR-88D entails several sequential operations, incorporation of novel algorithms requires harmonious interaction with existing data manipulations. To avoid unpleasant surprises a processing chain preceding the algorithm to be tested is replicated in a high level programming language. Time series data are then applied to this "software" version of essential signal processing steps and the results are evaluated.

3. EVOLUTIONARY CHANGES

Next we discuss specific ongoing and planed modifications.

3.1 *Dual polarization*

By far the most significant upgrade is addition of dual polarization. This capability exists on the RRDA. Our choice and recommendation is to transmit and receive Simultaneously two linear polarization states, Horizontal and Vertical (SHV). Therefore the transmitted polarization is elliptic, formed at the ortho mode coupler where the received signal is also decomposed into two orthogonal components. This choice of polarization avoids an expensive switch. As important, if not, more is that the horizontal channel is completely compatible with the current transmission/reception scheme. Therefore, all signal processing procedures and algorithms to extract meteorological features developed for the WSR-88D are completely applicable to data from the dual polarization mode.

In the SHV mode it is not possible to obtain linear depolarization ratio and two copolar to cross-polar correlation coefficients. The RRDA has a mechanical switch which enables transmission of horizontal polarization and reception of both copolar and cross-polar signals. Whereas this mode is important for investigating microphysical properties of bulk hydrometeors, there are several reasons to omit it from the operational network. For example: 1) Cross polar signals are weak and therefore degrade at a much closer range than the co-polar signals. 2) These signals and information carried therein is not independent of the other polarimetric signals hence retaining these might have only a marginal payoff. 3) Two modes would require operator interaction to choose one or the other; otherwise an automated procedure on how to blend the two modes would need to be designed. 4) The overall radar system is simpler without a mechanical switch.

3.2 *Mitigation of range/velocity ambiguities*

These ambiguities plague a radar system if Doppler velocity and spectrum width are needed simultaneously with other polarimetric variables. Note that if only polarimetric variables are required and SHV mode is the choice, the ambiguity problem disappears because all cross products for estimation are between signals from a single pulse. This has ramification on the mitigation scheme because one can devise volume coverage patterns and transmitted sequences to decouple polarimetric variables from velocity variables. That is in the SHV scheme polarimetric variables have the same ambiguity challenge as reflectivity which is much less severe than the problem facing velocity variables.

Currently the WSR-88D uses two scans at the lowest elevation angles. Estimates of reflectivity are made with a long PRT to a large unambiguous range of at least 460 km. In a subsequent scan a short PRT is transmitted to provide estimates of Doppler velocities. Recursive ground clutter filter cancels up to 50 dB of the clutter. The most severe problem in operations has been the occurrence of range overlaid echoes in the velocity fields at lower elevation scans.

In collaboration with NWS and NCAR significant strides have been made in development of techniques to mitigate range and velocity ambiguities. Two complementary techniques, staggered PRT and phase coding have been suggested and are undergoing tests.

Analysis and simulations indicate that phase coding cannot eliminate the long PRT scan for reflectivity estimation if the estimates must be unambiguous to 460 km. Phase coding is effective on uniform PRT sequences which are conducive to spectral analysis and good ground clutter filtering. Increase in clear range is at least twice the unambiguous range of the inherent uniform PRT, but not all overlaid echoes can be separated. Further, multiple overlaid signals might also cause total loss of information.

Staggered PRT can provide clear range and relatively large unambiguous velocity. But for large unambiguous range the errors in spectral moments might be prohibitive. Tests are in progress to determine if a compromise between errors and dwell time exists such that a staggered PRT could be applied at the lowest elevations. The main disadvantage of staggered PRT is that ground clutter filtering is less effective and that spectral analysis, although possible, is severely impaired by the non uniform spacing of samples.

The two methods are complementary and a volume coverage pattern has been suggested to take advantage of the benefits offered by each method; phase coding at two lowest elevations and staggered PRT at higher elevations. Patterns that use exclusively one or the other method will also be tested. Casual observations of velocity fields obtained in real time from staggered PRT hint that the scheme in practice resolves the ambiguities. To determine operational potential of the staggered PRT we must answer the question “how much clutter filter is compromised?” and more importantly “is spectral analysis required for early tornado warning?”.

3.3 *Full spectral analysis*

Extraction of weather information from Doppler spectra has the following advantages over processing of auto and cross covariances as currently done on weather surveillance radars. Identification and removal of artifacts caused by point scatterers, biological scatterers, extraneous interference and noise is possible. Significant portion of noise can be filtered so that spectral moments are more accurate at low SNR. Spectral and cross spectral processing can improve the quality of polarimetric variables. Phase coding schemes require spectral processing. The most sophisticated version to process staggered PRT data calls for spectral analysis on unequally spaced sequences; such processing is effective in reducing ground clutter and in reconstructing velocities if one overlay occurs. Potentially the most significant impact may be the possibility for early tornado detection; there is no proof yet that tornado spectral signatures would be seen before significant shear is noticeable between adjacent radials. Nonetheless, we expect that at distant range the azimuthal shear will disappear before the wide spectrum (characteristic of tornadoes) is overwhelmed by contributions of air motions from the very large resolution volume.

So far mainly wind profiling radars use spectral analysis, and for good reason. Signals from clear air are weak hence the effects of noise and artifacts are pronounced; very often these effects can be identified and eliminated from the spectra. Because surveillance radars have large SNRs and redundant data it stands that spectral analysis will be used sparingly (at low elevations where clutter is strong and where tornadoes matter). For higher elevations (comprising most of the observation volume) staggered PRT is preferred. To achieve full benefit of spectral analysis (fine spectral resolution) longer dwell times are required and this would automatically decrease the update rate of volume coverage.

3.4 *Increase speed of volume coverage*

There are compelling scientific and practical reasons to rapidly acquire volumetric radar data. For example, observations at minute intervals are required to understand the details of vortex formation and demise near the ground. Even faster rates of volumetric data are needed to determine the presence of transverse winds. Fast update rates would also yield more timely warnings of impending severe weather phenomena such as tornadoes and strong winds. Even rainfall measurement would be better if radar data were available at shorter intervals than the current 6 minutes.

Surveillance weather radars have a mechanical control of beam position and dwell a relatively long time (~ 50 ms) to obtain sufficient number of independent echo samples for accurate estimates of Doppler spectral moments. Thus, the volume update times are dictated by two limitations: 1) the inertia of the mechanically steered antenna, and 2) the correlation time of weather signals. For a continuously rotating antenna the inertia plays a minor role, mainly at restart of a volume pattern, or during a step in elevation. Therefore a viable candidate to decrease the variance of estimates is more efficient processing of weather signals. Three approaches come to mind. 1) The Maximum Likelihood (ML) estimation is complicated; closed form solutions are applicable only to special cases and filtering is not easily applied. For now we will investigate this techniques using time series data. 2) Pulse compression requires wide transmitter bandwidth. Small compression ratios (3 to 5) might be sufficient. How to handle these on the current transmitter is under investigation as well as the question of allocated bandwidth by the FCC. 3) Whitening of oversampled signals in range is a possibility compatible with the RRDA and the upgraded WSR-88D; it will be tested.

Either one, pulse compression or whitening technique is compatible with the proposed range velocity mitigation techniques. Further, both can be applied for improving the estimates of polarimetric variables as well as Doppler spectra.

Oversampled signals might offer the following possibilities heretofore not tried. Measurement of radial velocity within a pulse or, on two consecutive pulses with sufficient accuracy so that velocity aliasing interval can be identified. Clearly the ambiguity constraint on range and velocity will be considerably relaxed if not eliminated? Consider motion of the complex signal pattern during times shorter than the correlation time. It may be that such signals could be tracked in azimuth and range to determine advection of features over very short time (order of PRT) periods.

4. CONCLUSIONS

We have outlined some signal designs and processing techniques that will be tested on the RRDA in the forthcoming few years. The goal is to simultaneously reduce the errors in estimates of polarimetric variables, increase the speed of volume coverage, and mitigate the effects of range velocity ambiguities. Emerging evidence proves that this goal is achievable. For each component of the upgrade we plan short (few weeks) demonstration tests whereby radar data will be forwarded in real time to operational forecasters. These data will also be processed by standard algorithms on Radar Product Generation (RPG) system.

5. REFERENCES

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