P1.7 RADAR OPERATIONS CENTER (ROC) PRODUCTION SOFTWARE STATUS FOR RV AMBIGUITY MITIGATION

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INTRODUCTION

The WSR-88D Radar Operations Center (ROC) is responsible for implementing new signal processing algorithms planned for deployment in the Open Radar Data Acquisition (ORDA) System. SZ (8/64) Phase Coding (SZ-2) is the first new science algorithm developed for the ORDA infrastructure. SZ-2 is one of the proposed solutions to mitigate WSR-88D range and velocity ambiguities, also known as the "Doppler Dilemma." The maximum unambiguous range is the farthest distance a transmitted pulse can travel from and return to the radar before the next pulse is transmitted. Maximum unambiguous range is mathematically represented as

$$R_{max} = c / (2\ PRF)$$

where R_{max} is the unambiguous range, c is the speed of light, PRF is the pulse repetition frequency of the transmitted pulses. The maximum unambiguous velocity is the highest mean radial velocity or the largest pulse pair phase shift that the radar can measure without ambiguity. It is described as

$$V_{max} = (\lambda\ \ PRF) / 4$$

where V_{max} is the unambiguous velocity, λ is the wavelength of the pulse (WSR-88D ~= 10 cm). These two equations show that PRF affects R_{max} and V_{max} inversely. If the PRF is lowered to increase the unambiguous range, the maximum unambiguous velocity is reduced (WDTB, 2004).

In the current WSR-88D scan strategy, range and velocity ambiguities are managed by using two scans at the same elevation with different PRFs; a Surveillance scan at a low PRF to minimize range folding by maximizing the unambiguous range, and a Doppler scan at a high PRF to minimize velocity ambiguity by maximizing the unambiguous velocity. Information from the Surveillance scan is used to help place the range folded velocities from the Doppler scan.

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Range folding occurs when weather echoes from beyond the maximum unambiguous range return to the radar after the next pulse is transmitted. These are known as second trip echoes. The current processing algorithm has no way to tell that the returned echo is from the previous pulse. The resulting range of the echo is "folded" back closer to the radar than its actual range. A first trip echo is a returned signal from the pulse just transmitted. The SZ-2 algorithm provides a method to tell the first trip and second trip echoes apart.

SZ-2 OVERVIEW

In SZ-2 as defined by Sachidananda and Zrnić (Sachidananda, et. al., 1998), the transmitted pulses are phase shifted by a systematic sequence of phases called the switching code

$$\psi = \sum_{p=0}^{k} (n\, \pi\, p^2/M) \qquad k=0,1,2,...$$

where, as given by the SZ (8/64) phase coding definition, n equals 8 and is the periodicity of the modulation code, M equals 64 and is the number of samples in the spectrum (Sachidananda et. al, 1997). The returned signal is multiplied by the conjugate of the phase shifts to remove the applied phase shifts to give the resulting first trip signal. If there is overlaid second trip signal, it is modulated by the modulation code

$$\varphi = \psi(k) - \psi(k-1)$$

The resulting modulation applied to the second trip distributes the second trip echoes throughout the spectrum making it noise-like. It does this by replicating the second trip signal eight times over the power spectrum. The even distribution of the second trip signal avoids adding bias to the velocity estimate for the first trip.

The SZ-2 algorithm follows the current WSR-88D scan strategy by using two sweeps at the same elevation (thus the "2" in SZ-2); (1) a Surveillance scan to use as 'truth' data to aid in the proper placement in range of the higher velocities from (2) a high PRF, phase coded Doppler scan.

When attempting to recover overlaid signals, it is necessary to process then remove the stronger of the two overlaid signals before attempting to process the weaker signal. A strong return, or strong trip, is not always in the first trip. Similarly, a weaker return, or weak trip, is not always in the second trip. Often the stronger of the two overlaid signals is beyond the unambiguous range.

The SZ-2 algorithm is summarized by the following steps:

Cohere to strong trip by subtracting switching code.

Recover strong trip moments, reflectivity, velocity, and spectrum width.

Change to frequency domain by applying a Fourier Transform.

Notch out strong trip centered on the velocity of the strong trip. This removes the strong trip competing power leaving the weak trip signal.

Return to time domain by applying an Inverse Fourier Transform.

Cohere to weak trip by subtracting the modulation code that coheres from strong trip to weak trip.

Recover weak trip moments, reflectivity and velocity.

Properly place moments using the Surveillance scan data to place recovered strong and weak trip reflectivity and velocity into proper first and second trip. Use spectrum width from strong trip, for weak trip use spectrum width from the Surveillance scan.

FROM THEORY TO ALGORITHM

For the past several years, the scientists from the National Severe Storms Laboratory (NSSL) and from the National Center of Atmospheric Research (NCAR) have been evaluating and refining two SZ (8/64) Phase Coding Schemes; a single elevation cut of phase encoded pulses that unfolds without using a Surveillance scan for comparison (SZ-1) and SZ-2. Since SZ-2 is computationally less intensive and the Surveillance and Doppler scans already exist in WSR-88D Volume Control Patterns (VCP), the ROC decided to implement SZ-2 on the lower elevation cuts. SZ-2 will greatly improve the recovery of overlaid echoes in the WSR-88D (Torres, 2005). In August 2003, NSSL and NCAR submitted to the ROC SZ-1 and SZ-2 as pseudo-code and in the C programming language (Zrnić, et. al., 2003). In June 2004, the two laboratories delivered a modified version of the SZ-2 algorithm to handle processing variations due to clutter in trips other than the first trip (Zrnić, et. al., 2004). Production SZ-2 software implements the second version of the algorithm. It addresses the commonly occurring cases of placement of clutter vs. weather signal.

ORDA PLATFORM

The ORDA will provide the additional processing power needed by new science algorithms such as SZ-2. The ORDA system is built upon SIGMET's Radar Video Processor (RVP8) and Radar Control Processor (RCP8) (Patel et al, 2003). The RCP8 hosts the RSIS Volume Control Pattern Control (VCPC) and Digital Signal Processing Control (DSPC) software that communicate with the SIGMET's RVP8 RDA Software. The majority of the software is written in standard C. SIGMET implements processing techniques in modules called major modes. SIGMET provides a flexible and powerful way to insert custom processing software through user defined major modes, as well as a time series application programming interface (TS API). The TS API provides a means by which the major mode has access to the time series data for processing. Major modes are then built into the RDA software. Therefore, any application that controls the signal processor, such as SIGMET's IRIS or ORDA's VCPC/DSPC, can select either a SIGMET provided processing scheme, such as Pulse pair processing or Fast Fourier Transform processing, or a custom processing scheme , such as SZ-2.

STATUS OF SZ-2 PROTOTYPE SOFTWARE

The RS Information Systems (RSIS) SZ-2 software team tackled learning programming for the RVP8 in steps. First, we gained experience using SIGMET's TS API, developing a time series recording utility, Level I Record and Playback (L1RP) (Rhoton et. al., 2005). Second, we created simple user major modes by duplicating some of SIGMET's major modes.

Next, we created a user defined major mode that contained its own signal processing code. We inserted SZ-1 code (provided by NCAR in the August 2003 report) code into a user defined major mode. This exercise was valuable in understanding the complexities of SIGMETs major mode structure. Now, we needed a test method. Previously, we did not have any way to test with time series data. To provide a method to test with time series data, we inserted the time series data back into the SIGMET time series data stream creating an unconventional method for playing back the data. This became a useful testing tool. The repeatable tests using actual weather data with known results allowed us to rigorously test our user major mode as we developed it.

In the final step, we created a user major mode for SZ-2. We began implementation of the initial version of the SZ-2 algorithm in December 2003. This process was helpful with clarifying design decisions, learning and understanding the SZ-2 algorithm, and continuing to learn the complexities of the SIGMET RVP8 and RDA software. We completed the SZ-2 prototype in March 2004. It was a significant accomplishment to see SZ-2 running in real time.

SIGMET periodically updates their software. The SIGMET RDA software update release shortly after we completed the SZ-2 prototype disabled our method of inserting time series data into the SIGMET time series data stream and motivated us to find another, cleaner time series playback option (Rhoton et. al., 2005). We recently completed this solution.

On April 21, 2004, a line of separated supercells moved through Norman, OK. The SZ-2 team recorded phase coded time series radar data using SIGMET's Time Series Archive. With this data as input, we reprocessed it using SZ-2 and displayed the resulting moments in SIGMET's real time display. Figure 1 shows the reflectivity from the Surveillance scan using Fast Fourier Transform processing. Figure 2 shows the velocity for the first and the second trips using SZ-2 processing. The added ring indicates the maximum unambiguous range. The velocities beyond this ring are recovered overlaid echoes.

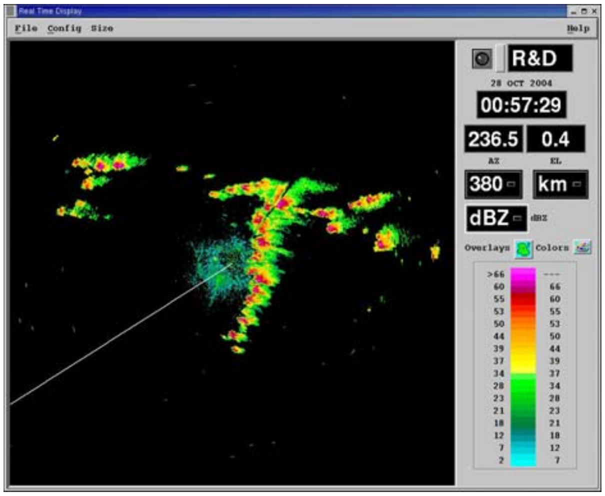

Figure 1 Surveillance Scan Reflectivity

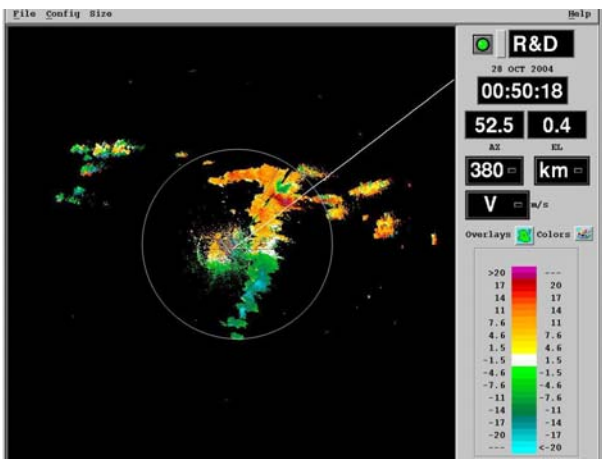

Figure 2 Recovered SZ-2 Doppler Scan Velocity. The added ring indicates the unambiguous range.

STATUS OF SZ-2 PRODUCTION SOFTWARE

The prototype provided the means to study the SIGMET environment and algorithm details for implementation of SZ-2. We began the production phase of SZ-2, implementing the June 2004 SZ-2 algorithm, in the second quarter of fiscal year 2004. Currently, SZ-2 is scheduled for deployment with RPG Build 9.

ACKNOWLEGEMENTS

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