5.13 EVALUATION OF TECHNIQUES TO MITIGATE RANGE AND VELOCITY AMBIGUITIES ON THE WSR-88D

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1. INTRODUCTION

Over the past three years scientists at the National Severe Storms Laboratory (NSSL) and the National Center for Atmospheric Research (NCAR) have been investigating various methods to mitigate velocity and range ambiguities. The goal of this investigation is to develop a scheme which would significantly reduce the occurrence of range and velocity ambiguities in the WSR-88D. Initially the following four methods had been proposed for scrutiny: 1) Determination of velocity using a single pulse, 2) Spectrum sorting, 3) Random phase coding and 4) Staggered pulse repetition time (PRT). Method 1) was abandoned because it could not produce accurate estimates with a reasonable range resolution and a dwell time required for weather surveillance radars. In method 2) long PRT establishes presence of two overlaid echoes, and separation of overlaid spectra is made in the data from the short PRT for velocity and spectrum width estimation. In this manner the strong signal's moments can be always recovered whereas the moments of the weaker signal down to 20 dB below the strong ones can also be obtained. In the process of studying the random phase coding, a systematic phase code was developed. Application of this code results in a considerably better recovery of weak signals than is possible with the random phase code. Subsequently a method of processing staggered PRT data was developed that enables significantly improved retrieval of the spectral moments. In the remainder of this paper we discuss the systematic phase coding and the staggered PRT techniques. Furthermore we point out how a combination of these two could be applied to a volume scan.

2. SYSTEMATIC PHASE CODING

The choice of phase coding implies acceptance of overlaid echoes and commits one to sort these out. This is possible because the phase coding schemes alter the spectra of the overlaid signals enabling one to estimate, with appropriate processing techniques, the spectral moments over a wide range of values. Transmitted pulses are phase coded such that when these phases are eliminated from the first trip signals the phases of the second trip signal are modulated and vise versa. For the code that we developed (termed SZ code) the phase modulations of the second trip signal cause its spectrum to be repeated at equal intervals. Then elimination of the first trip signal spectrum leaves at least two spectral replicas of the second trip signal from which estimation of the second trip spectral moments can be made. The SZ(8/64) is used on 64 pulses; it repeats the weaker (second trip) spectrum eight times and its mean velocity can be estimated with accuracy of between 1 and 2 m s^{-1} if the spectrum width of the first trip signal is less than 4 m s^{-1} and its power is at most 40 dB above the power of the weaker signal. 50 dB of ground clutter suppression is also possible.

The technique is computationally intensive requiring, in the most demanding cases (i.e., comparable spectral powers of the two signals), at least two Fourier transforms.

3. STAGGERED PRT

The staggered PRT involves transmission of a sequence of pulses in which the period alternates between T_1 and T_2. If the shorter time period T_1 in the staggered PRT sequence is chosen so that storm echoes from the most distant range are not further than $r_{a1} = cT_{1/}2$, there would be no range overlaid signals. The unambiguous velocity v_a for the staggered sequence is larger than the unambiguous velocity v_{a1} (corresponding to T_1) by a factor of $(T_2/T_1\text{-}1)^{-1}$. Processing of the staggered sequence with a pulse pair type algorithm (Doviak and Zrnic 1993) causes larger errors than processing of uniform PRT sequences. Furthermore, until very recently there were no satisfactory methods to filter ground clutter from staggered PRT sequences. A spectral method to process staggered sequences and filter the ground clutter was proposed by Sachidananda (1999). It produces statistical errors of estimates considerably smaller than errors associated with the pulse pair processing and allows filtering of ground clutter which is up to 40 dB stronger than the weather signal.

For a fixed dwell time, statistical errors in velocity estimates are inversely proportional to v_a. Therefore it might be advantageous to accept range ambiguities in the listening period of the long PRT, T_2 by reducing both T_1 and T_2. Further study is needed to determine if this option is practical.

4. COMPARISON

Incorporation of either staggered or phase coded techniques into the WSR-88D should improve the performance of the system without significantly compromising the existing capabilities. Advantages of phase coding are a) estimate errors are smaller and b) ground clutter filtering is better. Advantages of staggered PRT are a) processing is less intense, b) the signal to noise ratio is not reduced, c) tapering of the time series

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data is needed only for clutter filtering, and d) extension of unambiguous velocity is inherent. The two methods, although not compatible, are complementary. A comparison in Table 1 illustrates the main points. We choose realistic parameters to cover the range up to about 200 km. These are, dwell time of 50 ms, spectrums widths of 4 m s^{-1} (as in the specs), stagger ratio 2/3, and large SNR. For effective canceling of ground clutter, both schemes require application of the von Hann window to the time series data. In addition the window should be applied, in the case of phase coding, prior to filtering the strong signal. Otherwise it is best to retain the rectangular window because it does not increase the standard error of spectral moments. The WSR-88D specs are also in the table.

Table 1

	SZ(8/64)	Stagger (2/3)	WSR-88D specs
SD(Z_s)$^{(1)}$ [dB]	0.88	0.88	1
SD(Z_w)$^{(1)}$ [dB]	1.18	NA	1
SD(v_s) [m s^{-1}]	0.81	1.16 (1.64)$^{(10)}$	1$^{(2)}$
SD(v_w) [m s^{-1}]	1.64	NA	NA$^{(6)}$
SD(w_s) [m s^{-1}]	0.61	0.48 (0.63)$^{(10)}$	1$^{(3)}$
SD(w_w) [m s^{-1}]	1.25	NA	NA$^{(6)}$
$r_a^{(4)}$ [km]	117	197	≥115$^{(7)}$
$v_a^{(5)}$ [m s^{-1}]	32	38	≥ 25$^{(8)}$
GCF$^{(9)}$ rejection [dB]	50	40	50

1) Four estimates are averaged in range (over 1 km interval), and the WSR-88D specs are for range from 2 to 230 km, SNR ≥10 dB. The powers corresponding to Z_s and Z_w can be recovered if the corresponding powers are within 45 dB. The subscript s indicates the stronger and w the weaker signal
2) This is for SNR ≥ 8 dB
3) This is for SNR ≥ 10 dB
4) For the staggered PRT this range corresponds to the shorter period T_1
5) For the staggered PRT this is the extended unambiguous velocity
6) There are no specs for overlaid echoes, and recovery of velocities and spectrum widths is currently made only for the overlaid signal with a 5 dB advantage in power
7) This is the least unambiguous range to which v, and w, estimates are to be provided with accuracy listed in the third column of the table
8) This is the lowest unambiguous velocity specified in the Nexrad Technical Requirements (1984), but in practice smaller values are sometimes used
9) The simulated clutter spectrum width in the SZ(8/64) and staggered PRT is 0.35 m s^{-1} whereas in the test for the WSR-88D it is 0.28 m s^{-1}
10) These values are valid if the von Hann window is applied to the time series data as part of the algorithm to cancel ground clutter.

5. MITIGATION STRATEGY

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.

Simulation analysis indicates that neither phase coding nor staggered PRT can eliminate the need to have a long PRT for reflectivity estimation if the estimates must be unambiguous to 460 km and no increase in spectral moment errors is allowed.

The table 2 contains elevation angles of the current volume coverage pattern 11 (VCP-11) and the proposed wave forms (method) suitable for each elevation. These were obtained by considering statistical error of estimates and assuming that the azimuthal resolution and the antenna rotation rates are the same as in the current VCP-11. Moreover, for the staggered PRT, we are imposing the condition that there are no overlaid echoes beyond $r_{a1} = cT_1/2$ and a stagger ratio of $T_1/T_2 = 2/3$ is used; similarly for the SZ(8/64) phase coding the PRT is chosen so that there could be at most two overlaid signals within r_{a1}. In developing the strategy listed in the table 2 the overriding concern was to reduce as much as possible the occurrence of overlaid echoes while at least preserving the same unambiguous velocities as in the current VCP-11.

Spectral moment estimates associated with the SZ(8/64) phase coding satisfy the WSR-88D error requirements; clutter filtering also meets the specification of 50 dB at the two lowest elevations which is 10 dB more than possible in the staggered PRT sequence. Therefore at the lowest two elevations the scans for velocity and spectrum width measurements (Table 2) employ the SZ(8/64) phase coding.

For the intermediate elevations up to 5.2 deg the phase coding matches current WSR-88D specifications (see table 1 column 3) whereas the staggered PRT does not. (At some of these elevations it might be possible to match the specs using the staggered PRT if the two PRTs T_1 and T_2 are reduced and if satisfactory disposition of overlaid echo can be achieved.) Let's compare the two techniques at the elevation of 5.2 deg.

The PRT for the SZ(8/64) is 0.59 ms with a corresponding unambiguous range of 88.5 km (the two trips cover 177 km). The unambiguous velocity is 42.4 m s^{-1} (Table 2, el =5.2 deg) which is the same as for the staggered PRT. The spectral moments of the stronger trip signal are completely recovered and the spectral moments of the weaker signal can be recovered for overlaid power ratios less than 40 dB and for spectrum widths less than about 6 m s^{-1}. The staggered PRT scheme meets the specifications only for spectrum widths < 4 m s^{-1} but it is simpler to implement and does not incur overlaid echoes.

Table 2

El °	Me-thod	v_a m s^{-1}	r_a km	SDZ dB	SD v m s^{-1}	SD w m s^{-1}
0.5	CS(1)		466	1.1		
0.5	SZ(2) 8/64	32.0	234	1.53 1.87	1.02 1.29	0.68 1.37
1.4	CS		466	1.2		
1.4	SZ 8/64	32.0	234	1.53 1.87	1.02 1.29	0.68 1.37
2.4	SZ 8/64	32.0	234	1.53 1.87	1.02 1.29	0.68 1.37
3.3	SZ 8/64	33.3	225	1.31 1.52	0.85 1.27	0.66 1.18
4.3	SZ 8/64	40.3	186	1.32 1.52	0.9 1.15	0.59 1.41
5.2	ST(3) 2/3	42.4	177	1.25	0.95	0.58
6.2	ST 2/3	49.0	153	1.32	0.90	0.54
7.5	ST 2/3	56.8	132	1.46	1.02	0.63
8.7	ST 2/3	65.7	114	1.57	0.99	0.60
10	ST 2/3	75.7	99	1.41	1.01	0.57
12	ST 2/3	89.3	84	1.53	1.02	0.61
14	ST 2/3	89.3	84	1.53	1.02	0.61
16	ST 2/3	89.3	84	1.53	1.02	0.61
19	ST 2/3	89.3	84	1.53	1.02	0.61

1) CS signifies contiguous surveillance (same as for the WSR-88D).

2) For the SZ(8/64) scheme the standard errors are obtained for w_s = 4 m s^{-1} and w_w = 4 m s^{-1}. The pair of standard errors are for the stronger and weaker signals which differ in power by 20 dB.

3) For the ST(2/3) scheme w = 4 m s^{-1} is used.

Processing is done on overlapped (30%) pulse sequences in both schemes. This allows efficient Fourier transform computation on 64 samples while the separation between radials of data can be kept at 1 deg in az. At elevations larger than 1.45 deg the unambiguous ranges correspond to heights of the beam center at 18 km.

6. SUMMARY AND FUTURE WORK

The SZ phase coding is proposed for lowest elevations and the staggered PRT for high elevations to mitigate range and velocity ambiguities. Both techniques are ready to be tested and plans are to do so in incremental steps and thus validate crucial features of each technique. The capability to record hours of time series data exists on the R&D WSR-88D and a relatively modest effort (modifications of software on the Open Radar Data Acquisition system) is needed to transmit either signal sequence. Hence, some time series will be collected and analyzed. Processing of signals to generate spectral moments requires larger resources. Therefore, initial real time tests will be conducted on a commercial processor that has the capability to process phase coded data. The processor is passively connected to the R&D WSR-88D will be programed to replicate part of the full algorithm. Processing of the staggered PRT sequence, initially without clutter and overlaid signal removal, will be done on the ORDA. After initial evaluations, additional capabilities will be included into the algorithms and these will be tested on the ORDA.

7. REFERENCES

Doviak, R.J., and D.S. Zrnic, 1993: Doppler radar and weather observartions, Academic Press, San Diego, p. 562

NEXRAD Technical Requirements(NTR), 1984: Report prepared by the National Weather Service, Federal Aviation Administration, and Air Weather Service.

Sachidananda M, 1998: Signal design and processing techniques for WSR-88D ambiguity resolution, Part 2, NSSL report, p. 105

Sachidananda M, 1999: Signal design and processing techniques for WSR-88D ambiguity resolution, Part 3, NSSL report, p. 88