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STAGGERED PRT BEAM MULTIPLEXING ON THE NWRT: COMPARISONS TO EXISTING SCANNING STRATEGIES

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1. INTRODUCTION

Beam multiplexing (BMX) is a way to take advantage of the electronic scanning capability of a phased array antenna to collect nearly independent samples. This can lead to reductions in errors and/or scanning time. A new BMX scanning strategy is introduced to address some of the limitations of earlier BMX strategies. The staggered PRT BMX strategy (SBMX) consists of the transmission of sets of three pulses (using two PRTs) which are separated in time. Staggered PRT processing is used for velocity dealiasing. SBMX is compared to both conventional staggered PRT and a contiguous-pulse range unfolding strategy. Both simulations and real weather data collected using the National Weather Radar Testbed (NWRT) are employed for the comparisons.

2. LIMITATIONS OF CURRENT STRATEGIES

The BMX pairs collection strategy was used to show the feasibility of beam multiplexing (Yu et al. 2007), but it has several limitations.

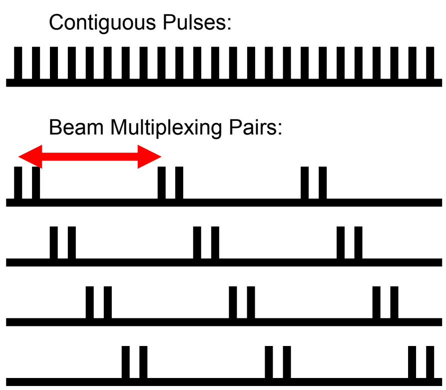

Figure 1. A comparison between contiguous pulse data collection and BMX pairs.

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Figure 1 shows how BMX pairs works in comparison to a contiguous pulse strategy. The BMX pairs strategy sends two pulses at four different beam positions in the example. Because of the time between pairs at each beam position, the samples are less correlated which can reduce the errors of estimates under certain circumstances. By jumping from one beam position to the next, the radar can be used at all times. Pairs of pulses are transmitted to enable the computation of velocity and spectrum width.

The limitations of BMX pairs fall into two main categories: general BMX limitations and limitations specific to BMX pairs. Two of the drawbacks to BMX in general include difficulty in clutter filtering and difficulty in spectral processing. Some of the difficulties are caused by the fact that BMX samples are not uniformly spaced. Most clutter filters rely on uniformly spaced samples, and spectral processing approaches using standard Fourier transforms also assume uniformly spaced samples.

A limitation that is specific to BMX pairs is that it is difficult to recover velocity and spectrum width from the second trip. Since only one pair of pulses is transmitted at each beam position, there are no second trip echoes in the data collected after the first pulse is sent. Figure 2 illustrates the problem.

Figure 2. A simplified example showing first and second trip echoes. The solid rectangles depict two transmitted pulses, and the triangles are first trip echoes from each pulse. The red rectangle is a second trip echo from the first (red) pulse.

A new 3-pulse strategy, staggered PRT BMX (SBMX), is introduced that uses staggered PRTs and velocity dealiasing. This is an attempt to take advantage of the benefits of beam multiplexing while addressing the second trip limitation of BMX pairs. Figure 3 describes the 3-pulse SBMX strategy.

Figure 3. A scanning strategy that uses both staggered PRTs and BMX.

This strategy still has the same general limitations of BMX strategies, but it does address a significant limitation of BMX pairs.

3. EXAMINING SBMX PERFORMANCE

To examine the performance of SBMX, it is compared to already-existing collection strategies. A comparison between range-unfolded contiguous pulses, conventional staggered PRT, and SBMX provides a reasonable test of the SBMX strategy.

One way to examine radar performance is from a requirements-based perspective. For example, the WSR-88D was designed to meet certain requirements to ensure an acceptable level of data quality. The NEXRAD requirements were established for a particular set of conditions. For example, the requirement for reflectivity is a standard deviation of less than 1 dBZ at an SNR of 10 dB and a true spectrum width of 4 m s^{-1} for 1 km range bins. For velocity and spectrum width, the requirements are standard deviations less than 1 m s^{-1} for 250 m range bins with a true spectrum width of 4 m s^{-1} at 8 dB and 10 dB SNR, respectively. The following scanning strategy comparisons will use these requirements as a starting point to examine performance

4. TIME SERIES SIMULATIONS

A standard time-series simulation with a uniform PRT is used for simulating all three scanning strategies. The staggered PRT strategies utilize a PRT ratio of 2/3 which allows the use of a simulation PRT with 1/3 the length of the longer staggered PRT. To get a comparable unambiguous range with the range-unfolded contiguous pulse case, the longer (or surveillance PRT) is the same as the longer of the staggered PRTs. The shorter PRT (or Doppler PRT) is set to 1/3 of the surveillance PRT which gives velocity estimates with the same maximum unambiguous velocity as the dealiased unambiguous velocity for the staggered techniques. Figure 4 shows a single set of simulated samples can be used to test the performance of all three scanning strategies.

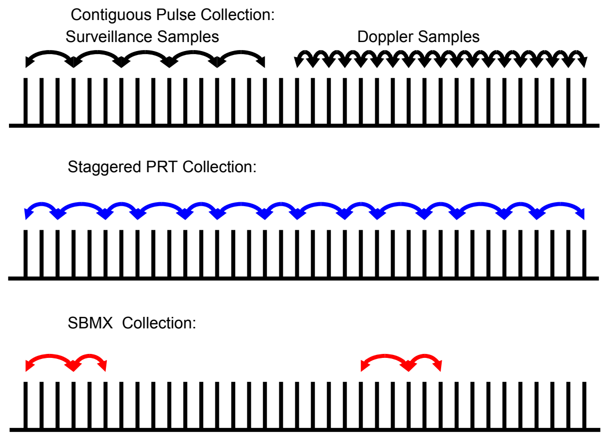

Figure 4. Simulating contiguous pulse, staggered PRT, and SBMX time series data using uniform PRT samples.

5. SIMULATION RESULTS

For this study, a simulation PRT of 1024 μs was chosen. This results in an unambiguous velocity of $v_a = c/4T_sf$ = 22.87 m s^{-1} where c is the speed of light, T_s is the PRT, and f is the transmit frequency. For the contiguous pulse strategy, the surveillance PRT is 3072 μs and the Doppler PRT is the same as the simulation PRT, 1024 μs. The staggered PRT and SBMX strategies both use a shorter PRT, T_1, of 2048 μs and a longer PRT, T_2, of 3072 μs. When the velocity is dealiased using the algorithm from Torres et al. (2004), the maximum unambiguous velocity for the staggered strategies matches the unambiguous velocity of the contiguous pulse strategy, 22.87 m s^{-1}.

The time series data were simulated without noise added so that both the 8 dB and 10 dB SNR realizations could be produced by adding noise independently. The 10 dB SNR case was used to test the performance of reflectivity and spectrum width, and the 8 dB SNR case was used for velocity. Conventional pulse pair processing was utilized to compute the velocities and spectrum widths. The two velocities from the staggered strategies were both dealiased and averaged which is a small departure from the algorithm described in Torres et al. (2004). In all three cases, the spectrum width was computed using the ratio of signal power to lag-1 autocorrelation calculated from the shorter PRT.

The conventional contiguous pulse (range unfolding) strategy outperforms both of the staggered strategies when using the original NEXRAD requirements with a true spectrum width of 4 m s^{-1}. These results can be found in Curtis (2009). In this paper, a true spectrum width of 2 m s^{-1} was used. One argument for using a narrower

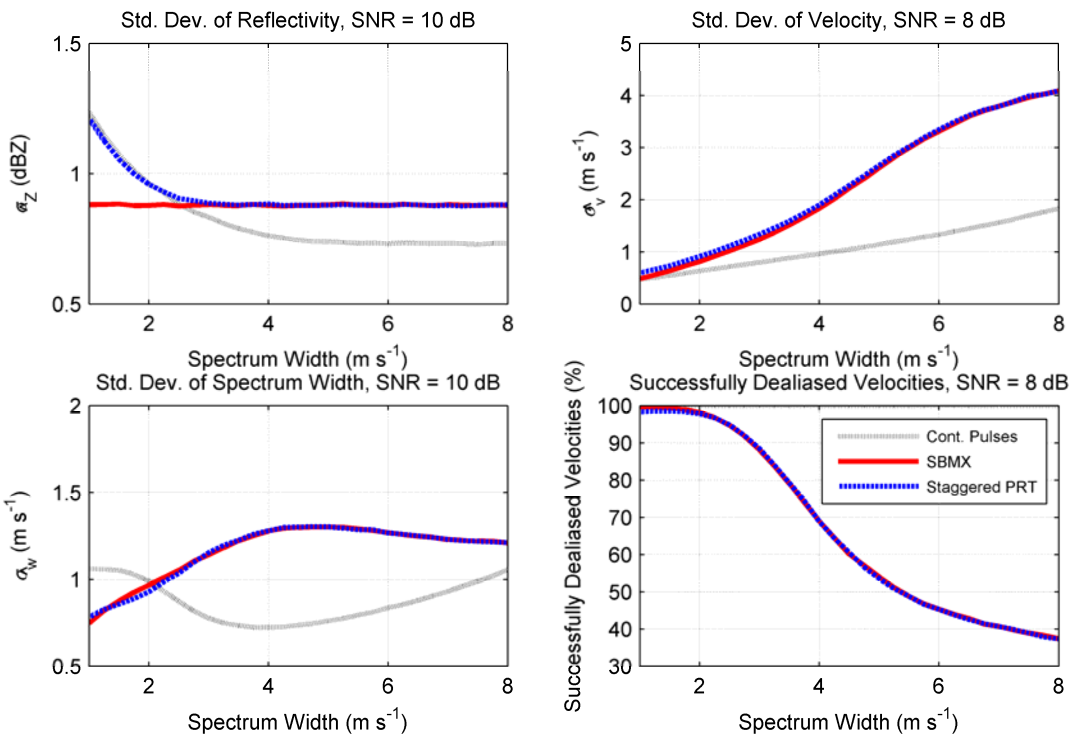

Figure 5. Representative clutter shapes for all 14 cases showing both the AC and DC parts of the spectral shapes.

true spectrum width for the requirements comes from research done after the NTR requirements were defined. In Fang et al. (2004), it was shown that the median spectrum width of most weather echoes is closer to 2 m s^{-1} than 4 m s^{-1}.

Times for all three strategies and errors of estimates are shown in Table 1 based on the modified requirements.

Collection Strategy	Acq. Time	Std(Z)	Std(v)	Std(w)
SBMX	43.01 ms	0.88 dBZ	0.82 m s^{-1}	0.97 m s^{-1}
Staggered PRT	30.72 ms	0.96 dBZ	0.91 m s^{-1}	0.93 m s^{-1}
Contiguous Pulse	65.54 ms	0.96 dBZ	0.63 m s^{-1}	0.99 m s^{-1}

Table 1. Simulation results for SBMX, staggered PRT, and contiguous pulse scanning strategies using a true spectrum width of 2 m s^{-1}.

The conventional staggered PRT strategy meets the requirements with the shortest acquisition time (30.72 ms) which is less than half the time of the contiguous pulse strategy. The SBMX strategy takes nearly two-thirds the time of the contiguous pulse strategy (43.01 ms).

The performance over a wider range of spectrum width values is shown in Figure 5. The performance of both of the staggered strategies is very similar even though the conventional staggered strategy takes less time. The only significant difference occurs for reflectivity at very narrow spectrum widths. This is expected since beam multiplexing is most effective at high signal-to-noise ratios and for narrow spectrum widths. The staggered strategies also have a significant number of catastrophic dealiasing errors at large spectrum widths. The contiguous pulse strategy outperforms the staggered strategies at all of the spectrum widths for the velocity estimates.

Although the staggered strategies are competitive with the contiguous pulse strategy at narrower spectrum widths, SBMX only outperforms staggered PRT when estimating reflectivity over a small range of spectrum width values. SBMX also takes 40% longer than staggered PRT to achieve this similar performance. Based on these results, SBMX does not look like a viable candidate for a general weather collection strategy. If good performance at large true spectrum widths is required, the contiguous pulse strategy produces significantly lower errors than the staggered strategies. If performance at narrower spectrum widths is required, staggered PRT performs comparably to the contiguous pulse strategy with an acquisition time less than 50% of the contiguous pulse acquisition time.

6. RESULTS FROM WEATHER DATA

In addition to studying the performance of these strategies using simulated data, weather data were also collected in July, 2007 using the NWRT to verify that the results from simulations can be applied to weather data. To avoid the difficulties of comparing scanning strategies collected at different times, a method similar to the simulation method was used for processing the weather data. The beam was pointed in a particular direction, and a few minutes of data were collected using a fixed PRT of 1024 μs.

Figure 6 shows the mean values for the scanning strategies in the left column and the standard deviations in the right column. Only every fifth standard deviation derived from the simulations is plotted so that the underlying estimates from the real data can be seen. The mean signal power from the three strategies agrees very well, and the calculated reflectivity standard deviations match the standard deviations predicted from the simulations. The SBMX strategy has the best performance which is expected because the spectrum width varies from a little less than 1 m s^{-1} to a little less than 2 m s^{-1}. The measured noise level is very close to 0 dB, so the mean signal power is also a good estimate for the SNR. The high SNR also leads to a strong performance for the SBMX strategy. The performances of the staggered PRT strategy and the contiguous pulse strategy are similar.

The mean velocity values from the three strategies also match up well, but some of the largest discrepancies between the standard deviations estimated from the simulation and the calculated standard deviations occur for velocity. The relative performance is well-predicted from the simulations, but the standard deviations calculated from the real data are larger for both the staggered PRT and contiguous pulse strategies. This is most likely due to deviations from the Gaussian spectrum assumption (Yu et al. 2009).

7. CONCLUSIONS

Although SMBX has several limitations that keep it from being optimal for general weather collection, the limitations should not preclude the search for other possible BMX strategies. BMX performs especially well when measuring reflectivity at small spectrum widths. This could be very useful in a scanning strategy for detecting weather signatures which utilizes only a few pulses to compute reflectivity.

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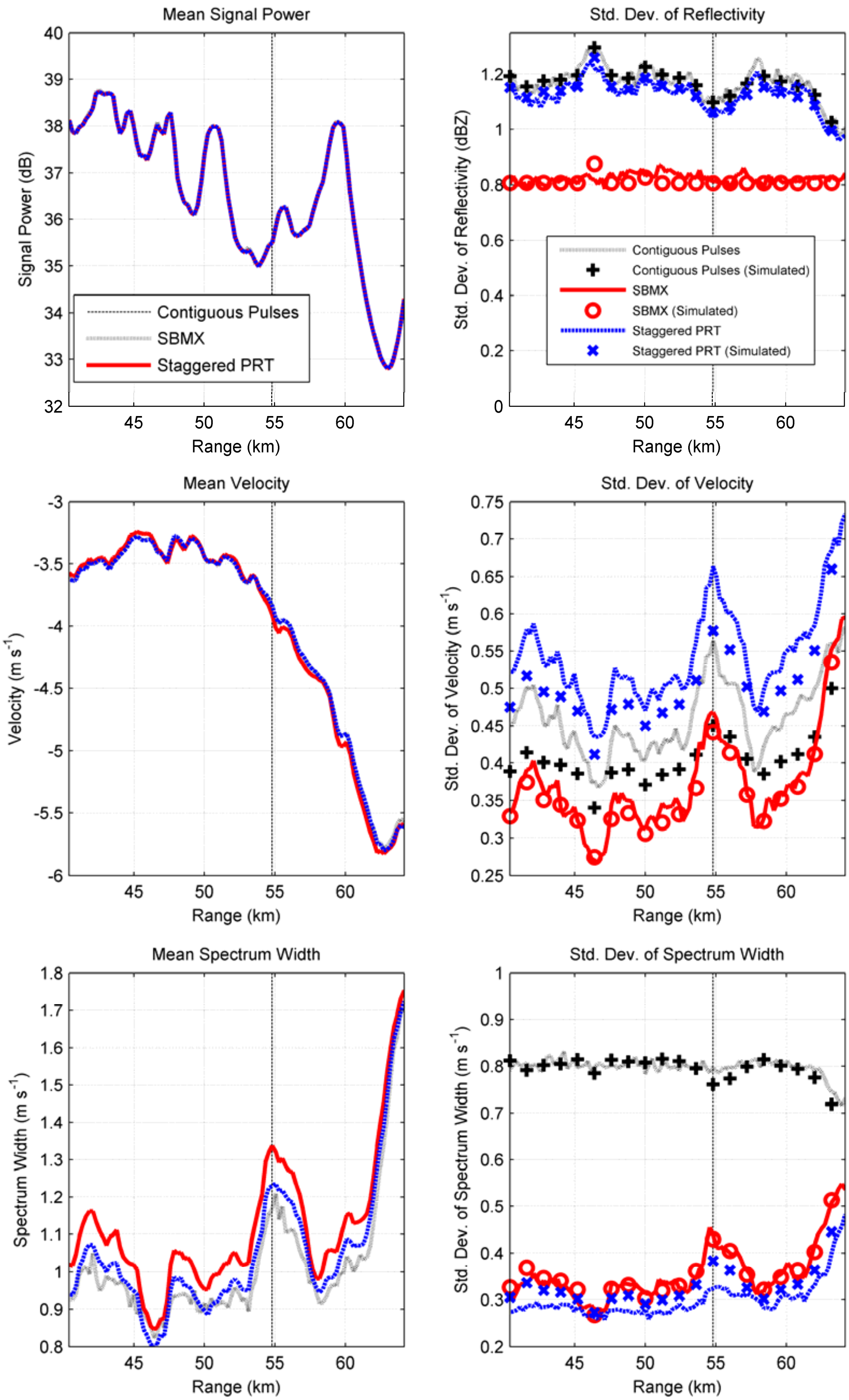

Figure 6. Means and standard deviations from weather data collected on July 13, 2007 at 14:23 UTC. The scanning strategies are the contiguous pulse (65.54 ms), staggered PRT (30.72 ms), and SBMX (43.01 ms) collection strategies.