16B.3B MITIGATING GROUND CLUTTER USING THE MULTI-CHANNEL RECEIVER ON THE NATIONAL WEATHER RADAR TESTBED

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1. INTRODUCTION

The National Weather Radar Testbed (NWRT) provides a unique opportunity to test the effectiveness of using sidelobe cancelling channels to mitigate ground clutter. Sidelobe cancelling channels are receive-only auxiliary channels that are separate from the main array. These types of channels have already been used on wind profiling radars to mitigate ground clutter, and some of the same techniques can be applied to weather surveillance radars. With the recent deployment of an eight-channel multi-channel receiver on the NWRT, the sum channel and sidelobe channel data can be recorded and processed to research different techniques for addressing ground clutter contamination. This paper will examine some of the existing algorithms for employing sidelobe cancellers especially in the context of weather surveillance radars and the NWRT in particular. The multi-channel receiver project is a collaboration between the OU Atmospheric Radar Research Center and the National Severe Storms Laboratory.

2. MOTIVATION

Ground clutter filtering is the accepted way to mitigate ground clutter for weather radars, but some types of data collection implemented with phased arrays do not lend themselves to clutter filtering. For example, beam multiplexing and surveillance collections with small numbers of pulses are both difficult cases to address with conventional clutter filtering.

The sidelobe cancellers on the NWRT phased array give us an opportunity to utilize spatial filtering to mitigate ground clutter in situations where conventional clutter filtering is not feasible.

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3. MULTI-CHANNEL RECEIVER

The NWRT multi-channel receiver is designed to simultaneously collect eight channels of time series data and archive them to a RAID in real-time. Currently, only six channels are fully functional because of hardware issues. This allows data collection from the sum channel and five of the sidelobe cancellers or collection of the sum, two difference channels, and three sidelobe cancellers. The multi-channel receiver enables data collection for the study of techniques such as ground clutter mitigation using sidelobe cancellers and crossbeam wind measurement using difference channels. Fig. 1 shows a picture of the multi-channel receiver installed at the NWRT.

Figure 1. A picture of the new multi-channel receiver instrument rack installed at the National Weather Radar Testbed.

4. THEORETICAL TWO-WAY PATTERNS

Theoretical two-way antenna patterns were computed based on the positions of the 4,352 main array elements and the six sidelobe cancellers. Future measurements of the actual antenna patterns will help in better quantifying the performance of the ground clutter mitigation algorithms.

Fig. 2 shows the locations of the 4,352 elements that make up the main array (each is a red x) and of the 6 sidelobe canceller receive antennas (blue circles). This is the view if looking at the front of the antenna.

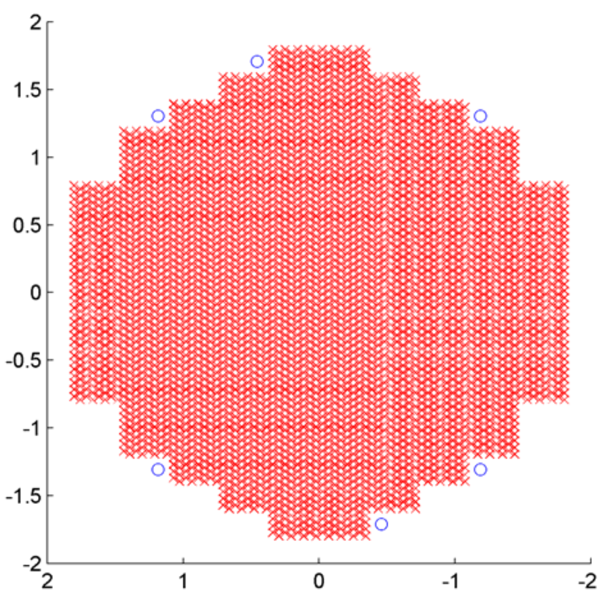

Figure 2. Locations of the main array antenna elements and sidelobe canceller receive antennas.

These elements were used as part of a theoretical antenna model to compute the shape of both the sum beam and sidelobe canceller two-way antenna patterns. Measurements of the sum receiver pattern and of the sum and sidelobe canceller gains were used to better match the model to the actual antenna patterns.

Fig. 3 shows the shape of both of the computed patterns. The sum pattern is in blue, and the sidelobe canceller pattern is in red. Spatial filtering is more successful when the sidelobes of the sidelobe canceller pattern are larger than the sidelobes from the sum pattern. Based on the theoretical patterns, the cancellation algorithms will be more effective further away from the mainlobe because of the higher sidelobes from the sidelobe cancellers.

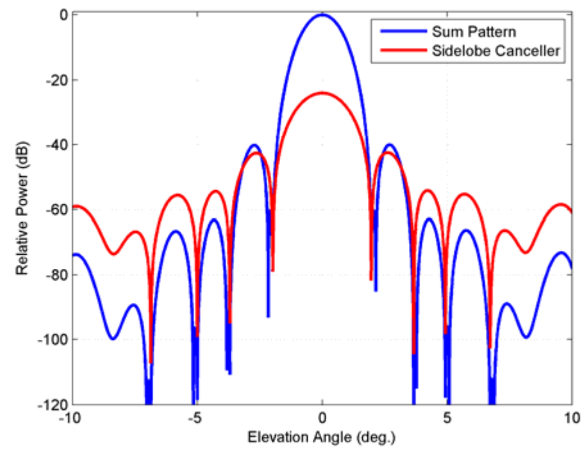

Figure 3. Theoretical two-way antenna patterns calculated based on the location of the antenna elements and sidelobe canceller receive antennas.

5. SIDELOBE CANCELLATION ALGORITHMS

In general, sidelobe cancellation algorithms provide a set of weights, **w**, that when multiplied by a matrix of time-series data produce a single spatially-filtered array of time-series values. The weight vector, **w**, is an N x 1 vector, and the time-series matrix, **V**, is an N x M matrix where N is the number of channels and M is the number of pulses. The resulting 1 x M time series array is normally written as $\mathbf{w}^H \mathbf{V}$.

After surveying several algorithms, the DCMP-CN (Directionally Constrained Minimum Power - Constrained Norm) algorithm introduced by Kamio and Sato (2004) seemed to fit the requirements of the NWRT phased array antenna relatively closely. This algorithm was developed for a wind profiler antenna and uses six additional sidelobe cancellers to mitigate ground clutter from mountains. The algorithm attempts to minimize effects on the main antenna sum pattern while still rejecting power from ground clutter sources.

This algorithm falls into a larger class described as quadratically-constrained LCMP (linear constrained minimum power) algorithms by Van Trees in *Optimum Array Processing* (2002). As the description makes clear, the algorithms have linear constraints with an additional quadratic constraint that controls the noise power and helps minimize effects on the antenna main beam.

One way of defining the quadratically-constrained LCMP algorithm is in terms of a covariance matrix, **R**, a constraint matrix, **C**, constraint vector, **g**, and quadratic constraint T_0.

$$\min_{\mathbf{w}} \left(\mathbf{w}^{H} \mathbf{R} \, \mathbf{w} \right)$$

$$\text{subject to } \mathbf{w}^{H}\mathbf{C} = \mathbf{g}^{H} \text{ and } \mathbf{w}^{H}\mathbf{w} \le T_0$$

The linear constraint often contains a directional constraint to control the effects of the weights in the mainlobe steering direction. In the simulations, an additional constraint was added to force the weight for the main beam to be 1. This follows the work of Le in his dissertation (2009).

Without the quadratic constraint, there is a closed-form solution for **w**. When the quadratic constraint is introduced, there is no closed form solution, and there are several ways to approach the problem. The DCMP-CN algorithm uses the penalty function method to satisfy the quadratic constraint. Another method is to use diagonal loading. This can be shown to be the optimal solution to the quadratic constraint problem, but there is no closed-form solution to find the amount of diagonal loading needed. A simple search was used in the simulations to find the optimal amount of diagonal loading to satisfy the quadratic constraint.

6. PRELIMINARY SIMULATION RESULTS

A simple simulation was developed to test the quadratically-constrained LCMP algorithm. Both the weather and clutter data were modeled as point sources with the appropriate corresponding spectra. The weather source was placed at the center of the mainlobe, and the clutter source was place at 0°. Time series data with M = 256 were simulated, and the data were combined based on the theoretical two-way antenna patterns. The sample covariance matrix was computed from the time series data, and the algorithm was applied. The resulting spectrum and modified antenna pattern are shown below.

Fig. 4 illustrates the theoretical performance of the LCMP algorithm on a single spectrum. The ground clutter is suppressed significantly, and there only appears to be a small effect on the weather signature. There does appear to be an increase in the noise. The amount of noise depends directly on the size of the quadratic constraint. In this case, the noise was allowed to double in power. A smaller quadratic constraint could be used to limit the increase in the noise, but this would degrade the sidelobe cancelling performance. Part of implementing an algorithm like LCMP is to find the right balance among the constraints, both linear and quadratic.

Fig. 5 shows the adapted antenna pattern given the point clutter target at 0°. The null is evident, but the increase in the other sidelobes is also easily observed. This is one of the tradeoffs of spatial filtering.

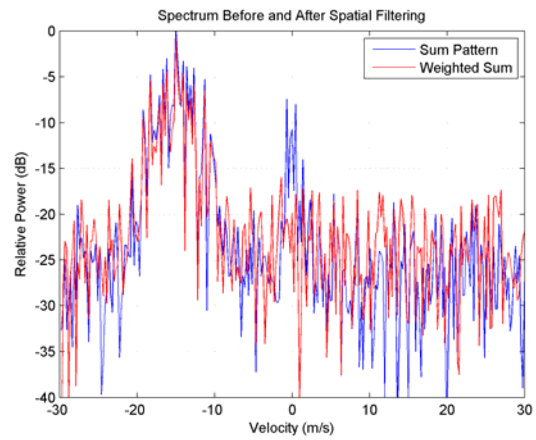

Figure 4. Spectrum showing the performance of spatial filtering for a simple point-source simulation.

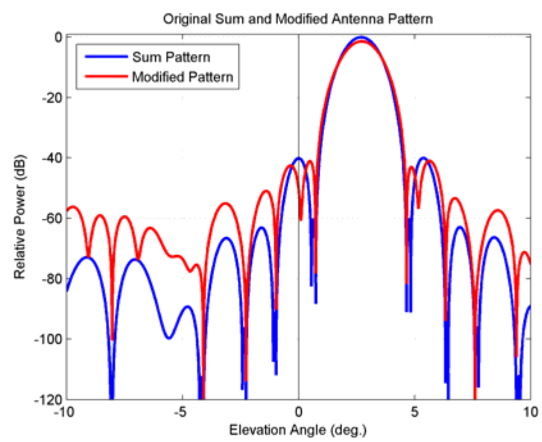

Figure 5. Theoretical antenna patterns for the sum beam and the modified pattern after spatial filtering.

7. CONCLUSIONS

The simulations show that the algorithm can mitigate ground clutter using the sidelobe cancellers, but the performance is limited especially when the clutter is in the sidelobe closest to the mainlobe. Future work will include using the multi-channel receiver to collect both sidelobe canceller antenna patterns and weather data to show the real-world performance of the algorithm.

8. REFERENCES

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Le, K., 2004: Spatial filtering of clutter using phased array radars for observations of the weather. Ph.D. dissertation, University of Oklahoma, 217 pp.

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ACKNOWLEDGEMENTS

This conference paper was prepared by Christopher D. Curtis with funding provided by NOAA/Office of Oceanic and Atmospheric Research under NOAA-University of Oklahoma Cooperative Agreement #NA17RJ1227, U.S. Department of Commerce. The statements, findings, conclusions, and recommendations are those of the authors and do not necessarily reflect the views of NOAA or the U.S. Department of Commerce.