3B.2 A DEMONSTRATION OF MULTIFUNCTION CAPABILITIES ON THE NATIONAL WEATHER RADAR TESTBED PHASED-ARRAY RADAR

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1. INTRODUCTION

The U.S. government operates seven radar networks providing weather and aircraft surveillance for public weather services, air traffic control, and homeland defense. A next-generation, multifunction-phased-array-radar (MPAR) concept has been proposed that could provide enhanced weather and aircraft surveillance services with potentially lower life-cycle costs than multiple single-function radar networks. As critical technology costs decrease, MPAR radars could prove to be a cost-effective alternative to current surveillance radars (Weber et al. 2007).

The National Weather Radar Testbed Phased-Array Radar (NWRT PAR) located in Norman, OK was established to demonstrate the MPAR concept. Since its inception, scientists and engineers at the National Severe Storms Laboratory (NSSL) have been improving the quality of data produced by this system and, more importantly, demonstrating new capabilities in the context of weather and multifunction observations. Unlike conventional radars, which are constrained by inertial limitations of mechanical scanning, the NWRT PAR can exploit electronic beam steering to simultaneously perform weather and aviation functions. This paper presents an overview of the latest improvements to the capabilities of the NWRT PAR to demonstrate this dual functionality. New upgrades include an extension of the signal processor to perform aircraft detection and tracking functions, and modifications to the scan-processing function of the radar real-time controller to allow the interleaved execution of weather and aviation scans.

2. THE NWRT PAR

In a nutshell, the NWRT PAR exploits a passive, 4352-element phased-array antenna to provide stationary, two-dimensional electronic scanning within a given 90° azimuthal sector. The antenna is mounted on a pedestal so that the best overall orientation can be (manually or automatically) selected prior to any data collection exploiting electronic beam steering. The antenna beamwidth is 1.5° at boresite and gradually increases to 2.1° at ±45° from boresite. The peak transmitted power is 750 kW and range resolution cells are produced with a 240-m resolution and a 60-m spacing. In some aspects, such as beamwidth and sensitivity, the NWRT PAR is inferior compared to operational radars such as the Weather Surveillance Radar-1988 Doppler (WSR-88D). However, the purpose of this system is not to achieve operational-like performance or to serve as a prototype for the replacement of WSR-88D radars, but to demonstrate the operational utility of some of the unique capabilities offered by PAR technology that may eventually drive the design of the future MPAR system (Zrnić et al. 2007).

The deployment of new signal processing hardware on the NWRT PAR (Forsyth et al. 2007) marked the beginning of a series of engineering upgrades. Since then, significant hardware, software-infrastructure, and signal-processing upgrades have been completed to support the system’s mission as a demonstrator for the MPAR concept. Using a path of continuous development with an average of two software releases every year, new and improved capabilities have been made available on the NWRT PAR in recent years (Torres et al. 2009, 2010, 2011, 2012, and 2013). The need for these improvements is twofold. On one hand, it is desirable that the NWRT PAR produces data with quality as close as possible to that of the WSR-88D. High data quality leads to better data interpretation and is conducive to the development of more effective automatic algorithms. On the other hand, software-infrastructure and signal-processing improvements are needed to demonstrate new capabilities. Whereas some of these are applicable to both conventional and phased-array radars, others are unique or better suited to PARs. A prime example of the latter is the use of adaptive scanning strategies to perform focused and tailored observations of the atmosphere in a multifunction environment. Whereas adaptive scanning is not unique to PAR, update times can be greatly reduced by using PAR’s electronic beam steering capabilities because scanning strategies are not constrained by the inherent mechanical inertia of reflector antennas (Heinselman and Torres 2011).

3. MULTIFUNCTION ON THE NWRT PAR

In order to demonstrate the multifunction capabilities of a PAR system, an aircraft-detection-and-tracking module was designed and implemented on the NWRT PAR in real-time. Combining weather and aviation functions involves meeting several demanding requirements including sensitivity, coverage, data

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quality, spatial resolution, and temporal resolution. In general, power-aperture, bandwidth, and time can be traded in many different ways to achieve multifunction, but this remains one of the main challenges in the design of an affordable MPAR system. The goal here is not to provide a prototype for an MPAR system, but to use the existing PAR (with its many limitations) as a proof of concept for multifunction and establish a framework for future research. This section describes the first steps taken to upgrade the NWRT PAR in order to demonstrate a combination of weather and terminal aviation functions.

3.1. Multifunction Scanning Strategies

For the initial implementation of multifunction on the NWRT PAR, weather and aviation functions are assigned their own scanning strategies. The weather scanning strategy covers a 90° azimuthal sector and scans discrete elevation angles from 0.5 to 52°. Azimuthal oversampling where adjacent beams are overlapped by 50% is used on all elevations, and up to 19 elevations are chosen in a similar manner as with the operational scanning strategies of the WSR-88D. The pulse repetition times (PRT) are selected to obtain a coverage of up to 460 km in slant range or 70 kft in height. Range oversampling is exploited to reduce the number of samples per beam without increasing the variance of meteorological-variable estimates (for more details about range oversampling the reader is referred to Curtis and Torres 2011). This results in a maximum scan time of ~68 s. Depending on the situation, the scan time can be further reduced by using adaptive scanning techniques. Focused observations provide a means to reduce scan times with no sacrifice in data quality or spatial coverage by devoting less radar time to regions of reduced interest (e.g., clear air). The Adaptive DSP Algorithm for Phased-Array Radar Timely Scans (ADAPTS) performs focused observations by detecting regions with significant weather returns in real time; that is, it classifies individual beam positions within a scanning strategy as active or inactive based on return significance (for more details about ADAPTS the reader is referred to Torres et al. 2013). In addition to focused observations, an auto-PRT algorithm adjusts the pulse repetition time (PRT) in real time to match the maximum range of storms at each beam position; thus, when storms are not too far from the radar, additional time savings are possible by converting multi-PRT dwells into dwells with a single PRT.

The aviation scanning strategy covers a 90° azimuthal sector and scans discrete elevation angles from 0.5 to 20°. Azimuthal and elevation samplings provide full coverage with the minimum number of beams; i.e., unlike with the weather scan, beams are not overlapped. The PRT is set to 800 μs to obtain a coverage of ~120 km in slant range, and only 4 samples are collected at each beam position. This results in a fixed scan time of ~2.4 s. Note that in this initial implementation, the aviation scanning strategy is not adaptive.

3.2. Multifunction Processing

Data acquired with weather and aviation scans are appropriately tagged at the real-time controller (RTC) so that they can be distributed to separate processing modules (Fig. 1). The weather processing mode ("wx dsp" in Fig. 1) produces estimates of radar reflectivity, Doppler velocity, and spectrum width and includes several techniques to mitigate clutter contamination and range-and-velocity ambiguities (Torres et al. 2010). The aviation processing mode consists of detection ("a/c dsp") and tracking ("a/c track") sub-modules; these are described next.

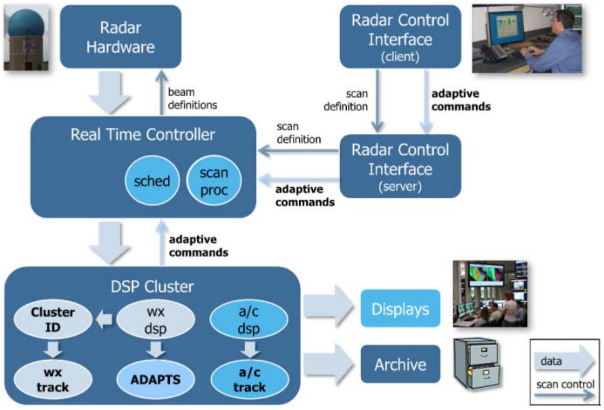


Fig. 1. NWRT PAR functional diagram.

The aircraft detection algorithm identifies moving point targets using data acquired with very short dwell times (recall that the aviation scan uses only 4 pulse transmissions per beam position). Echoes from moving targets are recognized using spatial and temporal (scan-to-scan) features. Spatial processing is facilitated by a range sampling spacing of 60 m (although the transmitted pulse is 240-m long; i.e., returned echoes are oversampled in range by a factor of 4). This approach is robust in the presence of pulsed interference, which causes abrupt changes in received power along range but with a narrower extent compared to true point targets. It is also helpful in the presence of weather returns, which have much larger spatial scales. In addition to using the expected range signature of point targets, the algorithm also searches for changes in power levels from scan to scan as another means for detection. To remove returns from stationary targets (i.e., ground clutter) the time-series data are filtered with a two-pulse canceler; hence, targets with negligible radial velocity are discarded.

The aircraft tracking algorithm uses a short-term history of potential moving targets identified by the aircraft detection algorithm. It compares current detections to previous detections and performs target associations based on maximum and minimum speed thresholds (these are adaptable parameters). If no match is found, the target is labeled as a possible new detection (the "Status" is set to 1). If a match is found with a previous possible new detection, it is marked as a possible valid track (Status = 2). If a match is found with a previous possible valid track (i.e., the target is already being tracked) and the changes in speed and direction from the previous to the current time are not beyond appropriate thresholds, the target is labeled as having a good track (Status = 3). Previous targets that were being tracked (Status = 3) but do not find a match at the current time step are allowed to coast for three time steps (Status = 4 and 5 for coasting steps 1 and 2, respectively) before the track is finally dropped (Status = 0). Previous possible new detections (Status = 1) that do not find a match at the current time step are dropped right away. At the end of a volume (time step), an XML file is written containing the target identification, location (latitude, longitude, altitude), status, speed, direction, and other pertinent information. In summary, the status of the targets is assigned as follows: 0 = Dropped, 1 = Detection, 2 = Track, 3 = Good Track (contains speed and direction), 4 = First Coast, and 5 = Second Coast. Fig. 2 shows an example of terminal aviation tracks produced with the aircraft detection and tracking algorithms on the NWRT PAR.

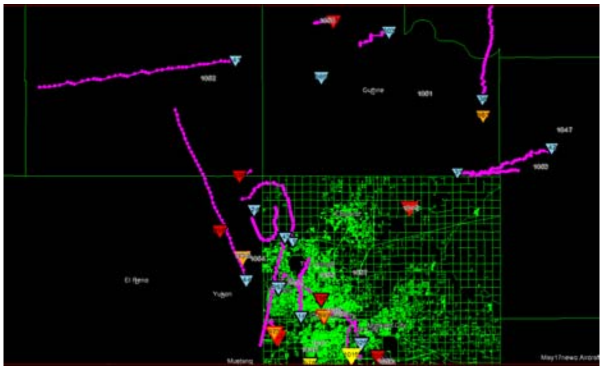


Fig. 2. Example of terminal aviation tracks produced with the aircraft module on the NWRT PAR.

3.3. Multifunction Timeline

One of the goals of the multifunction demonstration on the NWRT PAR is to run aviation scans concurrently with weather scans. Because terminal aviation scans should run at periodic intervals much shorter than typical weather scans (every 4.8 s), an interlaced schedule is needed. In the multifunction schedule, the aviation scan periodically interrupts weather and weather-detection scans at dwell boundaries (Fig. 3).

The scan-processing module in the Real-Time Controller (RTC) was modified to allow the interruption of weather and weather-detection scans so that the aircraft scan can run at the user-controlled frequency. In addition, the radar can operate as a single-function system in which one of the two functions runs exclusively. That is, weather scans can run without aviation scans (as with a typical weather radar) and aviation scans can run without weather scans. When running aviation scans exclusively, the user-defined occupancy for the aviation function is achieved by introducing idle periods of time. With the weather function and ADAPTS running, in addition to the weather scan, a quick, scan-independent, weather-detection scan is periodically scheduled to detect newly formed storms. Thus, whereas multiple weather scans can be scheduled sequentially in a round-robin manner, aviation and weather-detection scans are scheduled in real-time based on user-defined timers.

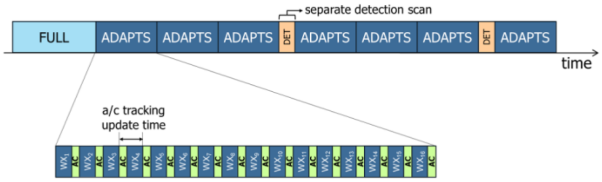
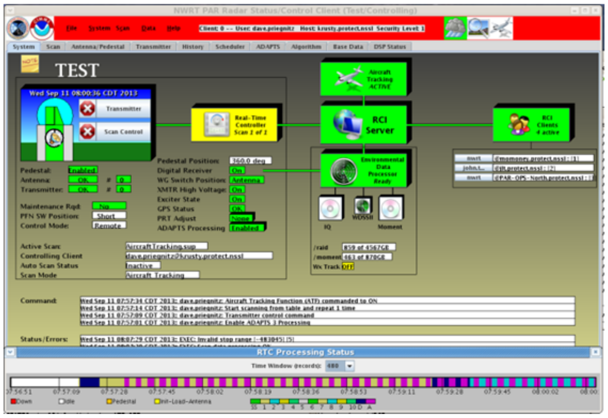


Fig. 3. Multifunction timeline for adaptive weather scans (FULL/ADAPTS) with interleaved deterministic aviation scans (AC) and periodic weather-detection scans (DET).

3.4. Multifunction Control and Monitoring

The occupancy for the aviation function can be controlled from the Radar Control Interface (RCI) as shown in Fig. 4. Since the aviation scan completes in ~2.4 s, a 50-50 share between scan types can be used to obtain an aircraft-tracking update time of ~4.8 s.

The RCI also provides a way to monitor the performance of the multifunction scheduler. The timeline shown at the bottom of the RCI screen in Fig. 4 corresponds to a situation with 2 adaptive weather scans (shown in tan and cyan colors in the timeline) and the aviation scan (shown in magenta). The beginning of the timeline shows an idle period (white) followed by the execution of a weather-detection scan (dark blue), weather scan #1 (tan), another weather-detection scan, and the beginning of weather scan #2 (cyan). As shown in the figure, the aviation scan takes ~2.4 s and interrupts weather and weather-detection scans every ~4.8 s, except for a brief period of time between 7:56:51 and ~7:57:17, where the aviation function is not yet enabled. It is interesting to note that the first weather-detection scan takes ~7 s (between 7:57:17 and 7:57:24) before the aviation function is enabled. However, when the aviation function is running later on, the same scan takes ~14 s to complete (between 7:59:24 and 7:59:38). This makes perfect sense since the occupancy of the weather function is now 50%. Along the same lines, the first weather scan takes ~2 min to complete at 50% occupancy versus the expected ~1 min at 100% occupancy. The weather-detection scan timer is set at 120 s, which is also evident in this timeline. The first weather-detection scan starts at ~7:57:17 and the second one starts at ~ 7:59:24. Since a weather-detection scan is only allowed to run on weather-scan boundaries, this is the earliest it can be scheduled after its timer expires.



Client: 0 -- User: dave.priegnitz Host: krusty.protect.nssl Security Level: 1

Wed Sep 11 08:00:36 CDT 2013

Pedestal: Enabled
Antenna: OK # 0
Transmitter: OK # 0
Maintenance Rqd: No
PFN SW Position: Short
Control Mode: Remote

Pedestal Position: 360.0 deg
Digital Receiver: On
WG Switch Position: Antenna
XMTR High Voltage: On
Exciter State: On
GPS Status: OK
PRT Adjust: None
ADAPTS Processing: Enabled

Active Scan: AircraftTracking.sup
Controlling Client: dave.priegnitz@krusty.protect.nssl
Auto Scan Status: Inactive
Scan Mode: Aircraft Tracking

/raid: 859 of 4567GB
/moment: 463 of 870GB
Wx Track: OFF

nwrt @momoney.protect.nssl : [1]
john.t... @jlt.protect.nssl : [2]
nwrt @PAR-OPS-North.protect.nssl : [3]

Time Window (records): 480

```
Command:       Wed Sep 11 07:57:34 CDT 2013: dave.priegnitz: Aircraft Tracking Function (ATF) commanded to ON
               Wed Sep 11 07:57:14 CDT 2013: dave.priegnitz: Start scanning from table and repeat 1 time
               Wed Sep 11 07:57:09 CDT 2013: dave.priegnitz: Transmitter control command
               Wed Sep 11 07:57:01 CDT 2013: dave.priegnitz: Enable ADAPTS 3 Processing

Status/Errors: Wed Sep 11 08:07:29 CDT 2013: EXEC: Invalid stop range [-483045] [5]
```

Fig. 4. Monitoring and control of the multifunction timeline through the NWRT PAR RCI.

4. SUMMARY

Under the umbrella of the MPAR initiative, scientists at the NSSL have been demonstrating unique PAR capabilities for weather observations. This paper described the latest capabilities of the NWRT PAR to perform simultaneous weather and terminal aviation functions. As such, it is the first step towards the demonstration of multifunction capabilities with phased-array radars. Although the NWRT PAR cannot achieve the performance levels expected of an operational MPAR system, this proof-of-concept demonstration is one of many MPAR risk-reduction activities being conducted by the federal government, industry, and academia. This first step towards multifunction on the NWRT PAR provides a solid framework for future research and development activities. These include the evaluation of scheduling algorithms, the demonstration of advanced adaptive scanning strategies, studies of prioritization and service-degradation schemes, and the definition of critical subsystem interfaces and data formats that may drive the functional requirements and future design of an MPAR system.

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