

Weather Radar Theory and Practice

Signal Processing Assignment #1 *Phased Array Radar: Time-Series and Power*

Due: October 1, 2007 by the end of class

1 Learning Objectives

The following are the learning objectives for this assignment:

- For students to learn the basic design and functionality of the Phased Array Radar (PAR)
- For students to learn how to acquire time-series data, load it into Matlab, and understand its structure
- For students to learn the complexity and stochastic nature of actual Doppler radar data in comparison to theory
- For students to learn the concept of *frequency content* and how to calculate it from time-series Doppler radar data
- For students to learn how to write a simple program in Matlab to analyze Doppler radar data

2 Introduction

The weather radar research community at the University of Oklahoma (OU) is fortunate to have a close collaboration with the National Severe Storms Laboratory (NSSL), which is well known for innovations in Doppler weather radar. In fact, the NSSL was the location for the very first WSR-88D radar! Its latest innovation is the Phased Array Radar (PAR), which uses a AN/SPY-1A phased array antenna. The AN/SPY-1A phased array radar system has been used effectively for years on the Navy's Aegis-class missile guidance systems (Sensi, 1988). Under the auspices of a multi-agency project, including government, private industry, and university groups, the SPY-1A phased array antenna has been adapted for meteorological research under the direction of the NSSL (Zrnic et al., 2007). This advanced weather radar is referred to as the PAR and is the main instrument of the NWRT located in Norman, Oklahoma (Forsyth et al., 2005). The PAR utilizes a WSR-88D transmitter, modified to operate at 3.2 GHz. Both transmit and receive operations are handled by the antenna, which is an array of 4352 elements. Real-time beamforming is used to electronically steer the beam over the desired volume coverage pattern. The data acquisition system allows the storage of raw time-series data (Level-I data) for up to 24 hours of continuous operation. Obviously, the most attractive feature of the PAR system is its agile beam steering capability, which allows complete flexibility in pointing direction from pulse-to-pulse within $\pm 45^\circ$ of broadside. As a result, beam-smearing effects, that are inherent in standard scanning radars



Figure 1: Photograph of the NWRT PAR system during radome installation. The antenna array is housed inside the dome at approximately 12 m above the ground.

such as the WSR-88D due to antenna motion, are eliminated in the PAR system. In addition, it supports adaptable scanning strategies and volumetric scans of a storm on time scales of seconds instead of several minutes (Zrnic et al., 2007). This capability enables the study of rapidly evolving weather phenomena which may potentially improve warning lead-time for severe weather.

A photo of the NWRT PAR is shown in Figure 1. The three-story building houses the array antenna on the top floor, approximately 12 m above the ground, covered with a fiberglass dome. Real-time data processing units and data acquisition equipment are housed on the second floor of the building. The bottom floor stores maintenance tools and test apparatus. During operations, the PAR can be controlled remotely from the National Weather Center (NWC) without the need of human intervention in this building and the radar products are transmitted via a conventional computer network. For this assignment, you will be working with time-series data from PAR for June 5, 2005 (01:05 UTC).

3 Hands-On Activities

The following list provides the basic requirements for this signal processing assignment.

1. Find at least **two references** related to the PAR and provide a short overview of its technical specifications. One of the papers should be related to its use as a naval radar and one for the work here in Norman as a weather radar. Attach the papers to your assignment. Discuss any advantages or limitations of the PAR design.
2. Acquire the PAR data (`mat` format) from the following website using the login (`wxradarstudent`) and password (`metrece5673`).

<http://arrc.ou.edu/~rpalmer/wxradartheory/>

You can use the Matlab command `load filename` to pull the data into the Matlab environment. After loading you should see several variables, including a large double-precision complex array called `X`, which has dimensions of `90x475x50` (for `par_iqdata1.mat`). These

data were collected in a standard PPI fashion at 90 azimuth angles with 475 range gates. Note that these numbers will change for the different data files. The dimension of 50 corresponds to the number of I/Q data samples, i.e., the number of pulses. Use the `whos` command to investigate the other parameters or variables stored in the file. Provide a list of the parameters (or variables) and a short description of each (the size and what it is about).

- Plot the $I(t)$ and $Q(t)$ data for several example azimuth angles and range gates (attach plots). For example, if I wanted to plot gate 100 at the 2nd azimuth angle in the data set, the command would be:

```
plot([1:50]*pri,real(squeeze(X(2,100,:))),[1:50]*pri,imag(squeeze(X(2,100,:))))
```

where `pri` is the PRT (time spacing between pulses). Note that the `squeeze` command was used since Matlab would not accept the first two empty indices. This particular azimuth and range correspond to a strong weather echo for data set `par_iqdata1.mat`. You can find a ground clutter signature at an azimuth and range sample of 50 and 5, which are simply the indices of the `X` matrix. What is the actual range and azimuth angle? Put it on the title of the plot.

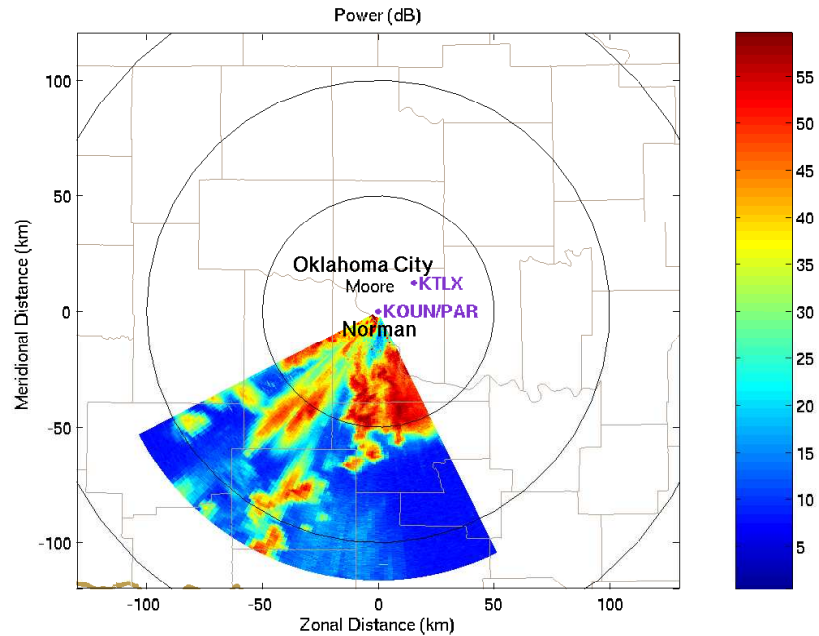
- From your example plots of $I(t)$ and $Q(t)$ data, estimate the Doppler velocity by counting zero crossings (by hand) to estimate the frequency content. Remember that actual time-series data are a stochastic process, corrupted by noise, clutter, etc. In other words, it will not look as perfect as the diagrams drawn on the board in class.
- From the PRT and the number of pulses/scan, determine the time needed for each azimuth angle and for the entire 90° scan. Comment on the scan time in comparison to the temporal evolution of the a typical storm.
- Write an `m`-file to calculate the power for all range gates and azimuth angles. A simple estimator of power is obtained by summing the squares of each of the 50 time-series points.

$$Power = \frac{1}{50} \sum_{n=1}^{50} |v(n)|^2$$

where $v(n)$ is $I(n)+jQ(n)$, which is stored in the matrix `X`. Note that standard radar *reflectivity* is derived from power so you can interpret it in a similar manner.

From the azimuth angle (`az_set`) and range (`delr` and `r_min`) information for each pixel, convert from polar to rectangular coordinates and plot your power estimates using the command `pcolor`. For this first part of the project, example code is provided below with everything needed except the actual calculation of power. Use this code to create your own `m`-file, which you should run in the Matlab environment. **Do not** simply type commands interactively at the Matlab prompt. You should be writing programs (`m`-file). Thoroughly comment your program, including the parts I have provided. Attach a copy of the program.

The following figure is an example plot from the file `par_iqdata1.mat`. Note the fairly obvious second-trip echoes.



```

%
% Simple program to calculate power and plot for PAR data
%     *** it is assumed that you load the data before running ***
%
% Calculate power using the mean of absolute value squared
pow = ?????????????????? *** You need to add code here ***

el_rad = el/180*pi;
[r,az_rad] = meshgrid(([0:num_gates-1]*delr+r_min)/1e3,az_set/180*pi);
x = r*cos(el_rad).*sin(az_rad);
y = r*cos(el_rad).*cos(az_rad);
z = r*sin(el_rad);

pcolor(x,y,pow_dB)
shading flat
colorbar
axis equal
axis([-130 130 -120 120])
xlabel('Zonal Distance (km)')
ylabel('Meridional Distance (km)')
title('Power (dB)')
bmapover2 % Draw map overlay ... not a Matlab command

```

References

- Forsyth, D., J. Kimpel, D. Zrnica, R. Ferek, J. Heimmer, T. McNellis, J. Crain, A. Shapiro, R. Vogt, and W. Benner, 2005: The National Weather Radar Testbed (Phased-Array). in *32nd Conference on Radar Meteorology*, 24-29 October, Albuquerque, NM. American Meteorological Society.
- Sensi, Jr., J., 1988: The AEGIS system. in *Aspects of Modern Radars*, pp. 239–277. Artech House.
- Zrnica, D. S., J. F. Kimpel, D. E. Forsyth, A. Shapiro, G. Crain, R. Ferek, J. Heimmer, W. Benner, T. J. McNellis, and R. J. Vogt, 2007: Agile beam phased array radar for weather observations. *Bull. Amer. Meteor. Soc.*, **accepted**.