Weather Radar Theory and Practice

Signal Processing Assignment #3
The Doppler Spectrum: Radial Velocity Distribution

Due: November 7, 2007 by the end of class

1 Learning Objectives

The following are the learning objectives for this assignment:

- For students to learn the important characteristics of the CASA X-band radars and the major goals of the project.
- For students to appreciate attenuation issues for shorter-wavelength radars.
- For students to make the connection between the time and frequency domains.
- For students to be able to estimate the Doppler spectrum using the periodogram algorithm from raw time series data.
- For students to understand the use and effect of data windows on spectral estimation.
- For students to understand that zero-padding is essentially a frequency interpolation procedure.

2 Introduction

For this laboratory, you will be working with time-series data from an X-band research radar located near Cyril, Oklahoma (KCYR). This radar is one node of a network of radars (see figure below), designed and constructed as part of the NSF-funded CASA (Collaborative Adaptive Sensing of the Atmosphere) project. By having these radars closer together (30 km), the earth curvature problem is mitigated. In addition, one of the major goals of the CASA project is to control the operation of the radars adaptively based on a set of rules designed to respond to input from end-users, such as emergency managers, etc. You can learn more about CASA at `http://www.casa.umass.edu/`.

The Doppler spectrum is defined as the *power-weight distribution of radial velocities within the radial velocity* and is given by

$$S(f) = \lim_{M\to\infty} T_s \sum_{l=-(M-1)}^{M-1} R(l) e^{-j2\pi f T_s l} \tag{1}$$

where T_s and $R(l)$ are the PRT and autocorrelation function, respectively. The *periodogram* is an *estimator* of the Doppler spectrum and is given by

$$\hat{S}(f) = |Z(f)|^2 \left(\frac{T_s}{M}\right) \tag{2}$$

Figure 1: Photograph of the CASA X-band radar system in south-west Oklahoma.

where $Z(f)$ is the DFT (or FFT) given by the following equation

$$Z(f) = \sum_{m=0}^{M-1} V(m) e^{-j2\pi f T_s m}$$

where $V(m)$ is the sampled echo voltage. For this assignment, you will be investigating how to use the periodogram to estimate the Doppler spectrum and how it is related to time-series data and the time-domain, in general. You will also be modifying periodogram code to implement various data windows and zero-padding scenarios. From the Doppler spectrum, it is possible to make logical connections between $\hat{S}(f)$ and the expected radial velocity field.

3 Hands-On Activities

1. Provide a brief list of the technical specifications of the CASA radars. A thesis from a CASA student at the University of Massachusetts has been posted on D2L for your use. This is much more information than you need but is very complete.

2. As was done for the PAR data, acquire the KCYR data (`mat` format) for August 27, 2006 from the class data website using the login (`wxradarstudent`) and password (`metrece5673`).

   `http://arrc.ou.edu/~rpalmer/wxradartheory/`

   As before, you can use the Matlab command `load filename` to pull the time-series data into the Matlab environment. You should be happy to see that the format of the data is the same as for the previous PAR data, except that you now have a full 360° scan. I am only providing data from the lowest elevation angle (0.5°). After loading, you will see, using the `whos` command, the familiar `X` matrix which stores all the azimuth and range samples.

3. As a first step, use your previous program to plot a PPI scan of power. You do not need to convert to dBZ since we will not be estimating rainfall rate. Compare your results to those from KTLX, which are also provided on the class data website for several different elevation angles. Can you tell the difference between your *power* values and the *reflectivity factor* from KTLX? Is attenuation an issue? The figure below provides an example output of power from the CASA radar.

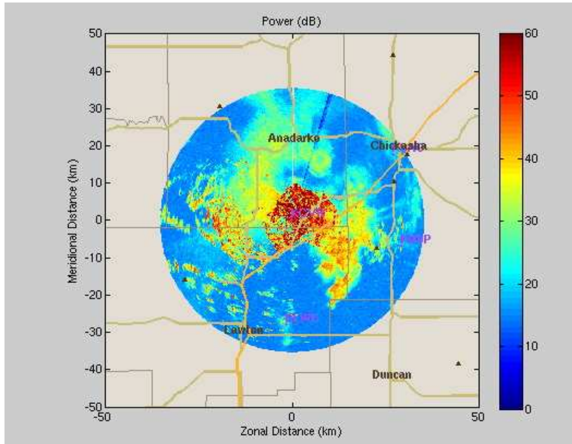

Figure 2: Example power PPI data from the CASA X-band radar.

4. The following code provides a simple example of the use of the *periodogram* algorithm for estimation of the Doppler spectrum. You will also need the subroutine `periodogramse.m` which is provided on D2L in zip format. You simply need to place this subroutine in the same directory as your main program and Matlab should be able to *see* the subroutine.

```
iaz = 130;      % desired azimuth
ir = 300;     % desired range
npts = 64;   % Number of points for DFT (zero-padding)
if ~exist('X','var'), fprintf('No data to process.\n'); end
%
% extract time series data
%
time_series = squeeze(X(iaz,ir,:));
time = [1:length(time_series)]*pri;
va = lambda/4/pri;
vel=-[-npts/2:(npts/2)-1]*2*va/npts; % neg for vf fd neg relationship
%
% data window
%
d=boxcar(num_pulses);
%
% calculate psd
%
S=periodogramse(time_series,d,npts);
S=(pri*abs(fftshift(S)));
%
% plot
%
plot(vel,S);
grid on
```

```
xlabel('Radial Velocity (m/s)')
ylabel('S(f) (arbitrary power units)')
title('Periodogrm')
```

Edit the program and attempt to understand the basic structure and usage. Put additional comments where needed and make any modifications which make the program easier for you to understand or simply make the output more usable. For example, it may be useful to plot the time-series data along with the Doppler spectrum.

5. Use your periodogram program to investigate the change in Doppler spectral characteristics for different regions of the data sets. Provide examples of Doppler spectra from regions which are dominated by noise, ground clutter, and weather echoes. For weather-dominated regions, find examples of velocity aliasing. Compare your Doppler spectra to the corresponding time-series data. Can you find the relationship between the time-domain and the frequency-domain? Which is easier to interpret?

6. Using the built-in Matlab window commands, such as `boxcar`, `bartlett`, etc., describe the effect of a variety of data windows on the spectral estimates. Example plots should be provided.

7. By varying the parameter `npts` in the program, you can study the effect of *zero-padding*. Comment on its usefulness, or lack thereof, using example output.

Graduate Students Only

1. Assuming the 4/3 earth radius model, what is the altitude of the resolution volume of KTLX for the various elevation angles, when it is over the KCYR radar? How does this affect your comparison? What are the approximate sizes of the resolution volumes of the two radars near KCYR.

2. For operational radars, algorithms used to estimate the moments (Level-II) assume a Gaussian-shaped Doppler spectrum. Study the shape of the actual Doppler spectra from your KCYR data. How does the shape change for the different meteorological conditions? Do the spectra have a general Gaussian shape? If not, provide an explanation for this discrepancy.

3. From examples of your Doppler spectra, develop an algorithm to estimate the mean Doppler velocity (first moment of the Doppler spectrum) from the spectrum. Recall that you attempted this in an earlier assignment using the time-series data directly. Compare and contrast your method with direct computation from the time-series data. Compare your KCYR radial velocity estimates to the KTLX data provided on the class data website.