Weather Radar Ambiguity Resolution Using Phase Coding

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Abstract - A weather radar signal simulator that produces an output consisting of a vector of I and Q values representing the radar return permits investigation of the performance of different estimators for the weather signal parameters and their sensitivity when varying radar parameters and precipitation models. The main objective of the project is processing of radar data. It generally involves two distinct steps. The first step, called signal processing, is the extraction of raw radar parameters like reflectivity, spectral width or Doppler velocity from the radar signals coming out of the receiver. The second step, called data processing or product generation, is the further processing of raw radar parameters in order to obtain information that is useful for meteorological or hydrological purposes. The another objective of the project is to implement different algorithms such as systematic phase coding(SZ coding) for separating overlaid echoes in Doppler weather radar to mitigate the effects of range-velocity ambiguities. Evaluate these different algorithms for their effectiveness in mitigating the ambiguity problem in weather Radar. Based on the results obtained on the performance of the algorithms a comparison is made to select a most promising method to recover the velocity of the weaker signal and to effectively mitigate the ambiguity problems in weather radar. The software, MATLAB is used for all simulation work

***Key Words*: Spectral width, Doppler weather radar, range-velocity ambiguities, SZ coding.**

1. INTRODUCTION

Radar or Radio Detecting And Ranging uses the return of transmitted electromagnetic energy from a transmitter to detect and locate objects of interest. The basic function of a radar is provided by a transmitter that emits an electromagnetic signal into space by the means of an antenna. Objects in the signal path scatter or reflect part of the power projected by the transmitter back towards the receiver. By measuring the return in terms of angle of incidence and time to the return, power levels, etc. different factors can be estimated depending on the application. To be able to detect movement or to calculate average power, more than one return pulse must be measured leading to the idea of Pulse Repetition Frequency (PRF). By selecting different PRFs some quantities will be become ambiguous while others become the unambiguous.

1.1 Range ambiguity

The range to scatters is found by measuring the time delay between a transmitted pulse and its echo. If a transmitted pulse is part of an equi-spaced pulse train, the measured range is ambiguous because the echo signal could be due to any one of the pulses transmitted earlier.

One simple method of determining the correct range is to choose T large enough to make $r_a=cT/2$, However, this is not an acceptable solution because it severely curtails the velocity measurement capability of the radar.

1.2 Velocity ambiguity

The radial velocity of scatters is obtained from the measurement of Doppler frequency, f_d. The radial velocity of the scattered is related to the Doppler frequency by

$$v_r=-\lambda f_d/2 \qquad (1)$$

Where λ is the free-space wavelength. By convention, scatters moving away from the radar have a positive velocity, which produce negative Doppler shift. Because the echoes are discrete samples taken at intervals, T, the maximum Doppler frequency that can be unambiguously extracted from the sample sequence is given by

$$f_a = 1/(2T) \qquad (2)$$

which is known as the Nyquist frequency. A fully coherent radar can recover Doppler frequencies within the interval. Any frequency outside this interval is seen by the processor as a measured Doppler frequency, fd within the aliasing interval such that

$$f_d-f_{da} = \pm 2mf_a \qquad (3)$$

Here, f_{da} is the actual Doppler frequency. The integer, m, is the aliasing interval number. Therefore, the actual Doppler frequency is known only within an unknown integer, $\pm m$. Corresponding to the unambiguous frequency interval, $\pm$fa, the unambiguous velocity interval is $\pm v_a$, where $v_d= \lambda/4T$. Since both v_a and r_a are functions of pulse repetition time, T, we can combine them to get

$$r_a v_a = c\lambda/8 \qquad (4)$$

Thus, if r_a, is increased by increasing T, v_a decreases correspondingly. This is a fundamental limitation of a pulsed Doppler radar transmitting uniformly spaced pulses.

2. PROCESSING OF RADAR DATA

The processing of radar data generally involves two distinct steps. The first step, called signal processing, is the extraction of raw radar parameters like echo strength (reflectivity) or Doppler velocity from the radar signals coming out of the receiver. The second step, called data processing or product generation, is the further processing of raw radar parameters. In general, these two steps are done by different computers, signal processing being done at the radar site, while product generation can be done everywhere the data are sent to.

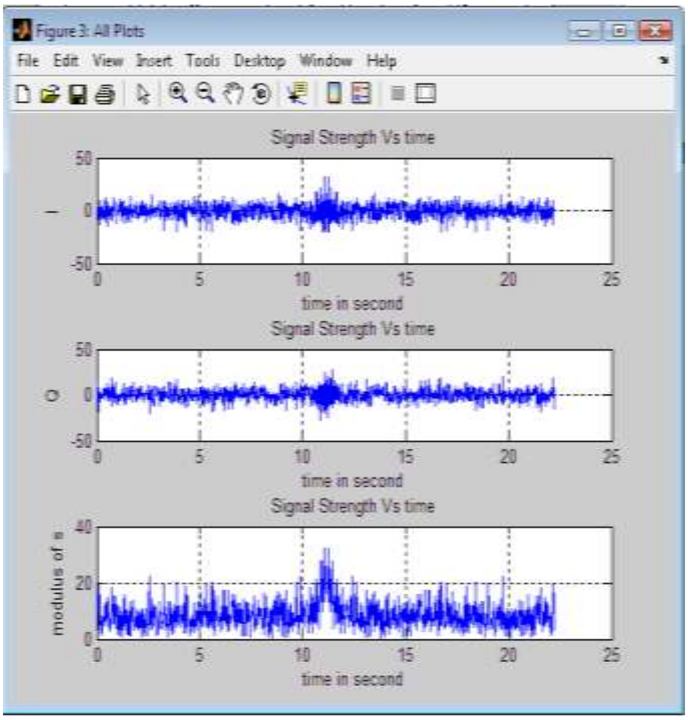

Fig -1: A typical simulated weather signal; time series and frequency spectra. (a) the in-phase component, I, (b) the quadrature component, Q,(c) the magnitude spectrum, |S(the square are root of the power spectrum on linear scale)

Some degree of transmitted energy (power) is likely to be returned to the radar antenna (receiver) as a result of backscattering. Reflectivity is simply a measure of how much power was scattered back to the radar from any targets. Stronger targets have higher levels of reflectivity and return more energy. Thus, stronger targets have higher reflectivity values; that is, higher dBZ levels. This energy is converted into a logarithmic (base10) unit so that a wide range of reflectivity can be expressed with a short number scale. A Radar reflectivity image includes color scales. The color scale on the radar image corresponds to the reflectivity values.

The corrected reflectivity Z is output using a log scale based on the following equation:

$$dBZ = 10 log R0 \qquad (6)$$

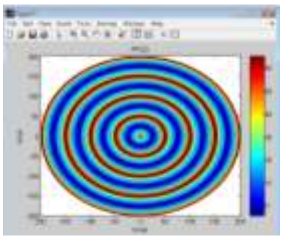

Fig-2: PPI(z, reflectivity)

Radars also measure velocities of targets. These are Doppler radars. Doppler is a means to measure motion. Doppler radars not only detect and measure the power received from a target, they also measure the motion of the target toward or away from the radar. This is called the "Radial Velocity". Radial velocity is determined from Doppler frequency shift of the target. Doppler frequency shift caused by a moving target. Moving targets change the frequency of the returned signal. This frequency shift is then used to determine wind speed.

For a Doppler power spectrum that is symmetric about its mean velocity, the velocity is obtained directly from the argument of the autocorrelation at the first lag, i.e.,

$$V = \frac{\lambda}{2\pi T_s} ar\,g(R1) \qquad (5)$$

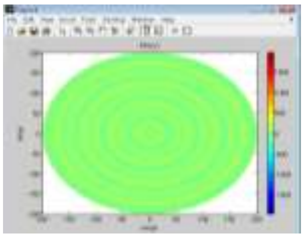

Fig -3: PPI(V, velocity)

Spectrum Width data is a measure of dispersion of velocities within the radar sample volume. In other words, it is the distribution of velocities within a single radar pixel. One pixel on radar represents a volume within which there can be literally millions of individual hydrometeors. Each individual hydrometeor will have its own speed and direction of movement. The radar averages the individual radial velocities with a volume sample to produce a single average radial velocity that is displayed for that pixel. In a situation, where shear and turbulence is small within a pixel, the spectrum width will be small. In a situation, where shear and radial velocity is large within a pixel, the spectrum width will be large. A technical way of defining spectrum width is the standard deviation of the velocity distribution within a single pixel.

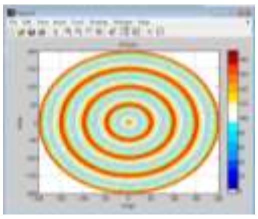

Fig-4: PPI(W, Spectral width)

3. SZ CODING

SZ coding is a kin to the random phase coding except that the code is a periodic phase code instead of a random phase code. The phases of the transmitted pulses are switched in a regular sequence of discrete phase shifts to modify the spectrum of overlaid signal in such a way that its autocorrelation for one pulse lag is zero. Thus, the bias error in the velocity estimate due to the overlaid signal is removed. In this section, we elaborate on the method and evolve a decoding procedure for the signal from discrete phase coded radar. An algorithm is given which can be implemented on radar, the only hardware change needed at the ground level is the addition of a phase shifter in the transmitter path at the low power stage.

A sz code that has the property of zero cyclic autocorrelation for all lags except zero lag. This property is the same as that of the spectrum of the code being perfectly flat, or all spectral coefficients having the same magnitude. The code is given by the expression

$$C_k = \exp(jn\pi k^2/M) \quad k = 0, 1, 2, \dots$$

Where n is prime to M (i.e., M not divisible by n). In fact, for M even, any odd number, n, will produce a flat spectrum and zero autocorrelation, for all lags except zero. The phases progress in a quadratic fashion with the smallest step size determined by (nπ/M), but appear as random when reduced to (0-2π). If n and M are even, only a few of the spectral coefficients are non-zero, and they have equal magnitude.

for n=1, 4, 8 and 11, with M=64. Note that for odd n, the spectrum is flat, and for even n, some of the coefficients are zero. If M is divisible by n, only M/n coefficients are non-zero. For n=1 and 11 the spectra differ only in phase.

If a weather signal is modulated by this phase code, the resulting spectrum is the convolution of the code spectrum and the signal spectrum. Thus, if n/M=l/8, the spectrum of the coded signal would have 8 peaks separated by M/8 coefficients, with one of the peaks at the same location as the original uncoded spectrum. To be able to cohere the weaker signal and recover the velocity, we require at least two of these peaks retained in the spectrum after notch filtering. This will put an upper limit on the maximum notch filter width that can be used for a given n/M.

The code $\mathbf{C_k = exp\ (jn\pi k^2/M)}$, with n/M=8/64, is a sequence of complex numbers with which we have multiplied the 2nd trip signal to change its spectrum, or $\Phi_k = (n\pi k^2/M)$ is the sequence of phase shifts required to be applied to the 2nd trip signal samples when the 1st trip signal is coherent. This is not the phase shift sequence for the transmitted pulses. To obtain the phase switching sequence, proceed as follows: Let Ψ_k k=0, 1, 2,..., be the phase switching sequence for the transmitter pulses. The return samples for the 1st trip will have the same phase shifts, and the 2nd trip signal samples will have phase shifts Ψ_{k-1} , (the same sequence shifted by one pulse). Therefore, when the 1st trip signal is made coherent by multiplying the raw time series by complex numbers Ck*(or phase shifted by - Ψ_k), the resulting phase shifts in the 2nd trip time series is the sequence (Ψ_{k-1} - Ψ_k) = 4,. Given the sequence of phases, Φ_k we can compute Ψ_k as

$$\Psi_k = -\sum_{m=0}^{k} \Phi_m = -\sum_{m=0}^{k} (n\pi m^2/M); \quad k = 0, 1, 2, \dots$$

With M=64 and n=8, this sequence has a periodicity of 32, although Φ_k, has a periodicity of 8. We refer to the code given by equatio as the switching code or the SZ code in general, and specifically the SZ(8/64) code for n=8 and M=64. The phase sequence, Φ_k will be referred to as the modulation code.

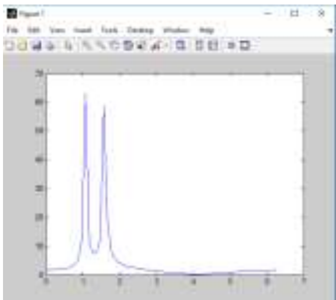

Fig-5: First and second trip signal

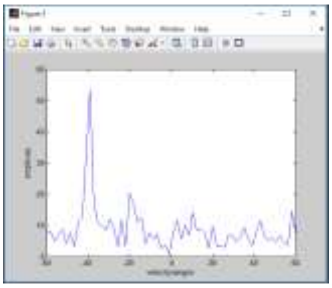

Fig-6: First trip and second trip signal is spreaded

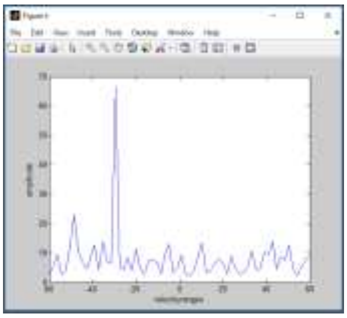

Fig-7: Second trip and First trip signal is spreaded

4. CONCLUSION

SZ coding is efficient code sequences based on numbers m and n which are multiples of each other. Using this coding Doppler radar is able to extract phase without constraint on pulse repetition time.In this manner it is superior to all other phase coding methods.

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