Real-Time Adaptive Data Compression for Weather Radars

1 Learning Objectives:

- *Students will learn about the importance of compressing radar data and how it is accomplished in the modern governmental, industrial, and educational environments.*
- *Historical perspectives will be discussed. Students should understand the genesis of how various compression algorithms have evolved during the last twenty years: from tape drive storage to Internet transfer.*
- *Students will develop their own compression algorithms, which will be a simplified version of the compression algorithms that were developed in the early days of the WSR-88D. Advanced versions of compression algorithms will also be studied.*
- *Students will learn about the spatial correlation of radar data and its relationship to compression. Students will also learn about how different elevations in VCPs may influence the amount of compression associated with each radial.*
- *Various forms of pre-processing will be studied. One example involves setting a threshold so that very weak echoes in the presence of convective storms or other significant events may be zero padded to help maximize compression.*
- *High Resolution (Hi-Res) and Dual Polarization WSR-88D data cases will be studied and analyzed by the students.*
- *Scalability of the techniques will be covered. This will span procedures for the existing, large-scale operational radars to small-scale, futuristic FPGA based digital receivers.*

2 Introduction

A bit (either 0 or 1) is the smallest, most basic form in which information can be measured. The objective of compression is reduce the number of bits required to represent a signal by removing redundant or unnecessary information to reduce the signal.s storage requirements, yet allow its reconstruction [1]. The term "compression ratio" is the key metric that describes the bit savings. It is the ratio of (number of bits employed after compression)/(number of bits before compression). Two different types of compression exist: lossy and lossless. Lossy compression provides the highest level of compression, but the reconstructed data set will have a slightly reduced fidelity since some of the less meaningful bits are actually deleted during the compression scheme. However, in lossless compression, the reconstructed signal will be an exact replica of the original signal. In general, researchers have been experimenting with various compression algorithms for many years, especially in the communications community. A description of a variety of compression techniques applied to radar data can be found in [2–5] and others.

The first form of compression applied to WSR-88D data was known as “run-length-encoding” or RLE. In general, RLE has been known in the digital communications community for many years. By definition, it replaces sequences or runs of consecutive repeated characters with a single character and the length of the run. As of 2001, the image data for most WSR-88D base products and raster- and radial-format derived products were packed in the run length encoded (RLE) format [6]. Ease of implementation is a significant feature of RLE, and its execution speed is considered to be fast. After compression, the WSR-88D image data in RLE format is then unpacked prior to display generation or other processing. Decompressing or unpacking the RLE data consists of determining the data value and length of each RLE segment, and sequentially assigning these data values to the corresponding (length) number of bins or pixels of the full radial or rectilinear data arrays [6]. This compression technique was principally designed for data to be stored in an 8-bit format on tape drives.

The compression ratio and a radar’s volume coverage pattern (VCP) are related in such a manner that different patterns influence the efficiency of compression acheiveable. In other words, data variability impacts compression [7]. As defined in NOAA’s Federal Meterological Handbook [8], a VCP is “an automated method that repetitively scans the atmosphere through a sequence of predefined elevation angles, antenna rotation rates, and pulse characteristics.” A sequence of scans is called a volume scan. In general, the structure of the weather impacts the compression efficiency and different VCP’s are employed to study the atmosphere under various atmospheric conditions.

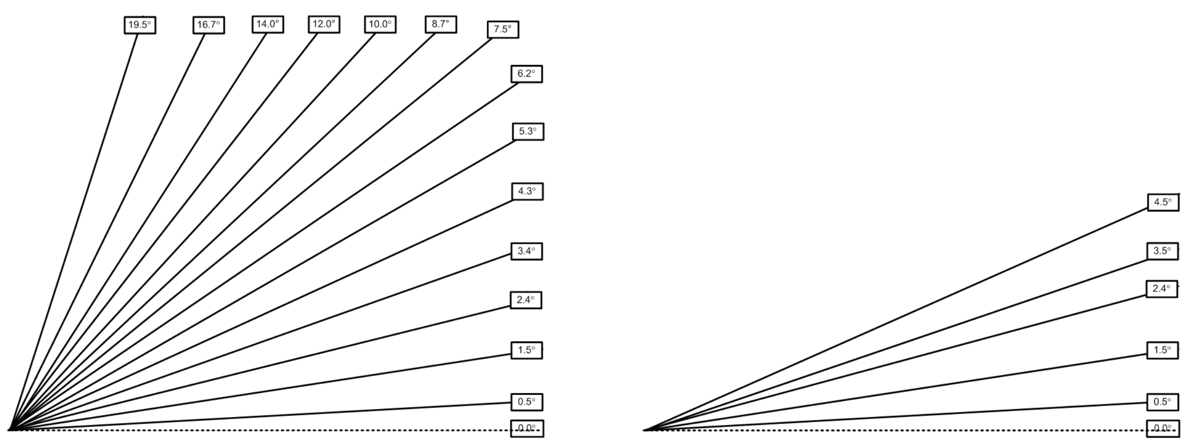

Figure 1: *Two examples of common VCP’s [8]. The one on the left left is known as VCP 11 and was designed for severe and non-severe convective events. The one on the right is known as VCP 31 and was designed to sweep at a slower rate for the radar’s clear air mode. Variability in the data influence the amount of compression that is possible.*

3 Hands-On Activities

- Describe the differences between lossy and lossless compression.

- Download data from http://www.roc.noaa.gov/NWS_Level_2/ and make a meaningful PPI plot of the reflectivity data.

- Prepare a run-length-encoding algorithm and apply it to one radial of data. Different run-lengths should be explored to pack and unpack the data. Various radials of data should also be explored to determine how the compression levels may change as the data become more or less correlated as a function of spatial position.

- Visit five interesting radials to explore the variability of the data in each. Make a pdf of the reflectivity data in each radial and discuss its variability.

- The dynamic range of weather related echoes is known to have a dynamic range of about 60 dBz. As such, to properly represent this data, a sufficient number of bits must be used. What is the "effective number of bits" that are used represent the data in the file above? Next, manually process the data so that one less bit is used to represent the data. How does the compression ratio change when few bits are used to represent the data? Continue this approach so that you can discuss how the dynamic range of the data ultimately influences the compression ratio.

- Next, pre-processing should be implemented with a thresholding technique that has been discussed in class. Explain how this may be implemented and use it to increase the compression ratio for five individual radials. Next apply this to one PPI and explain your findings as you vary the threshold. In a detailed fashion, explain how the compression ratio changes.

- BONUS: can you develop a neural network or fuzzy logic system that will learn from the data in order for it to establish an optimum threshold value for pre-processing so that the compression ratio will be maximum, while minimizing the loss of fidelity in the actual weather data? Use mathematical proofs and data driven graphs to support your claim.

References

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