

Efficient Lossless Compression of Weather Radar Data

Wei-hua Ai, Wei Yan, and Xiang Li

Abstract—Data compression is used operationally to reduce bandwidth and storage requirements. An efficient method for achieving lossless weather radar data compression is presented. The characteristics of the data are taken into account and the optical linear prediction is used for the PPI images in the weather radar data in the proposed method. The next PPI image is identical to the current one and a dramatic reduction in source entropy is achieved by using the prediction algorithm. Some lossless compression methods are used to compress the predicted data. Experimental results show that for the weather radar data, the method proposed in this paper outperforms the other methods.

Keywords—Lossless Compression; Weather Radar Data; Optical Linear Prediction; PPI image.

I. INTRODUCTION

WEATHER radar data is important information sources for weather forecast. It offers continuous, high-resolution, accurate, and multiparameter observation capabilities over large geographical areas, which are of immense value for local as well as synoptic weather information systems. However, these very qualities result in the weather radar data generating huge volumes of digital data that need to be processed, stored, and transmitted in real time [1]. All these operations would be substantially simplified by compressing the weather radar data [1]. Therefore a high efficient data compression algorithm for the data is needed to solve these problems. One volume weather radar data seems be composed of several PPI imaging data and some head information because of the characteristics of the data. Since the size of the other data is negligible in comparison in this study we focus on compression of the PPI imaging data and the other head information data can be compressed by the classic lossless methods such as arithmetic code.

Image compression methods exploit the spatial redundancy to achieve compression [1][2][3]. These schemes can be broadly classified as lossless and lossy methods. Lossy methods exploit the psycho-visual redundancy and are permitted to sacrifice the less observable features of data fields to varying degrees to offer higher compression ratios [4][5], such as JPEG [6], EZW [7], SPIHT [8], and JPEG2000 [9].

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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. While in lossless compression, the reconstructed signal will be an exact replica of the original signal. In general, researchers have been experimenting with various lossless compression algorithms for many years because the original weather radar data needs to be processed for other production without distortion. Some lossless methods [10][11] can achieve moderate degrees of compression for the weather radar data and some classic methods are used, such as RLE, LZW and gzip programs.

The original radar data contain a substantial amount of redundancy and two kinds of redundancy in weather radar data are considered to reduce. One is the high degree of serial correlation between bin values in a ray in one PPI image. Another is the correlation between the PPI images in one volume weather radar data. The former methods only considered reducing the redundancy of bins in one PPI image. For obtaining higher compression ratio two kinds of redundancy in the weather radar data should be take account into. In this paper we present an efficient method for achieving lossless compression for weather radar data by reducing the two kinds of redundancy in the data. Firstly, the redundancy between the PPI images is reduced by the optical linear prediction [12]. Then we use RLE algorithm encode the values of bins in one PPI image. Finally the adaptive arithmetic algorithm is used to compress the processed data. In this study we focus on compression of the PPI imaging data since the size of the other data is negligible in comparison. Experimental results show that for the weather radar data, the method proposed achieves better performance than other methods such as WinZIP, JPEG_LS and JPEG2000. This paper is organized as follows. Section II provides the background and terminology associated with weather radar data generation and introduces the redundancy in the weather radar data. Section III introduces the lossless compression method proposed and the performance is evaluated in Section IV. Conclusion of this paper is drawn in Section V.

II. REDUNDANCY IN RADAR DATA

A radar emits a coherent train of microwave pulses along a directed beam and processes the reflected pulses or echoes to derive the parameters of the scatterers within its detection range[9]. Typical radar collects data as follows: it emits a

coherent train of microwave pulses and coherently processes reflected pulse in a pulse radar processor. To achieve a desired resolution, many pulse measurements must be integrated. Conceptually, one can view the processed and integrated pulses as bins of a radar beam or ray. The radar then moves to the next azimuth and the process is repeated. When one azimuthal sweep is completed, the radar increases the antenna elevation angle and collects the next sweep. A complete set of azimuthal sweeps collected over all elevation angles is called a volume scan, and once a volume scan has been collected the radar moves the antenna to its lowest elevation angle in preparation for base sweep of the next volume scan. The data collection strategy (e.g. number of bins in a ray) and the antenna sweeping strategy (e.g. number of azimuths in an azimuthal sweep, number of sweeps in a volume) depend upon the radar and are in many cases under control of the radar operator.

Weather radar data are usually archived in a format that closely mimics the way the data are collected. Volumes are typically saved one per file, though it is common to store volumes of multiple variables in the same file. Thus, a single volume file may contain pure reflectivity, quality-controlled reflectivity, as well as Doppler velocity information. Each volume file has a header that contains information about the volume such as date, location, number of sweeps, and so on, followed by the rays that make up the volume. The data collected in the certain elevation angle in one volume is the PPI data which may form an image called PPI image. Number of the rays denotes the width of the PPI image and number of bins is height. Each ray is preceded by a ray header that contains information about the ray, such as ray date and time, ray elevation and azimuth, the number of bins for the ray, and so on. Following the header are the data for the ray as a number of bins. Each bin may contain the reflectivity factor or other measurements such as Doppler velocity.

The original radar data contain a substantial amount of redundancy. Some relevant statistics results show that only about 34% of the bins contain data above the signal to noise threshold. There is also a high degree of serial correlation between bin values in a ray, and the bins form runs of similar values which correlation can be reduced by RLE coding algorithm. Besides the correlation of bins there exists high correlation between the PPI images in one volume of weather radar data. So the compression strategy we have developed exploits the two kinds of redundancy in the volume data.

III. LOSSLESS COMPRESSION CODING

A. Optical Linear Prediction

Considering the high correlation between the PPI images, we designed a linear prediction to minimize the approximation error by adjusting the value of it and exploited the correlations between PPI images through optical linear prediction.

An estimate value $x_{n,i,j}$ of the current pixel at location of $p_{n,i,j}$ which denotes the n th PPI image in one volume of the weather data is calculated using linear prediction as:

$$\tilde{x}_{n,i,j} = a_{n-1}x_{n-1,i,j} + b_{n-1} \quad (1)$$

Where n is the number of PPI image in the weather radar data and i, j express the number of row and line respectively in it. a_{n-1} and b_{n-1} are a prediction coefficients of the pixel at location $p_{n,i,j}$. In order to minimize the approximation error, utilize MMSE to optimize prediction coefficients. In other words, we hope $\sigma_n^2 = E\{(x_{n,i,j} - \tilde{x}_{n,i,j})^2\}$ to be minimum. Assuming the size of the PPI image is $M \times N$ and the error of the whole image is calculated as:

$$\sigma_n^2 = \frac{1}{MN} \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} (x_{n,i,j} - a_{n-1}x_{n-1,i,j} - b_{n-1})^2 \quad (2)$$

$$\begin{cases} \frac{\partial \sigma_n^2}{\partial a_{n-1}} = -2[r(n, n-1) - a_{n-1}r(n-1, n-1) \\ \quad - b_{n-1}u(n-1)] = 0 \\ \frac{\partial \sigma_n^2}{\partial b_{n-1}} = -2[u(n) - a_{n-1}u(n-1) - b_{n-1}] = 0 \end{cases} \quad (3)$$

Where

$$r(k, l) = \frac{1}{MN} \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} x_{k,i,j} x_{l,i,j}, u(k) = \frac{1}{MN} \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} x_{k,i,j}.$$

The result of a_{n-1} and b_{n-1} are calculated as:

$$\begin{cases} a_{n-1} = \left[\frac{r(n, n-1) - u(n-1)u(n)}{r(n-1, n-1) - u^2(n-1)} \right] \\ b_{n-1} = [u(n) - a_{n-1}u(n-1)] \end{cases}$$

B. Lossless Compression Flow

By using the optical linear prediction the redundancy between the PPI images is reduced. RLE coding algorithm is used for encoding the rays in one PPI image predicted to reduce the redundancy in one ray. For the data done with optical linear prediction and RLE coding we can use many classic lossless method to compress it, such as LZW, Huffman and arithmetic code, etc. Here we chose the arithmetic code because of its higher compression ratio. So the work flow of lossless compression for weather radar data is shown as Fig.1. Firstly by using the optimal linear prediction for each PPI images and the correlation between them is reduced. Then the RLE coding algorithm is used for bins in one ray. Finally, use the adaptive arithmetic algorithm to encode the residuals data for improving the compression ratio furthermore.

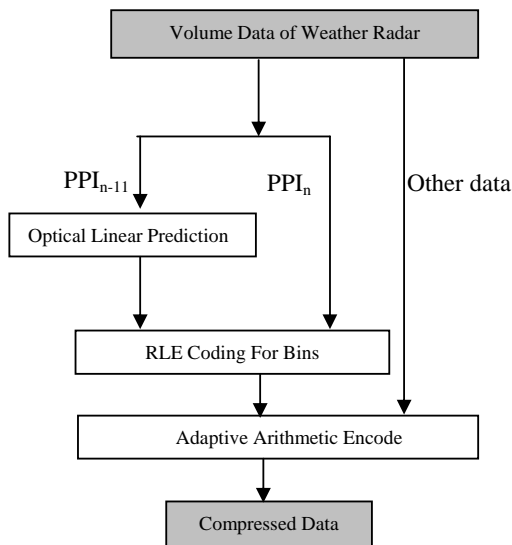


Fig. 1 Lossless compression flow

IV. EXPERIMENTS AND EVALUATION

Fig. 2 shows that there exists 6 PPI images of reflectivity field in one volume data. The images seem similarly and high correlation exists among them. PPI_1 is the data collected in

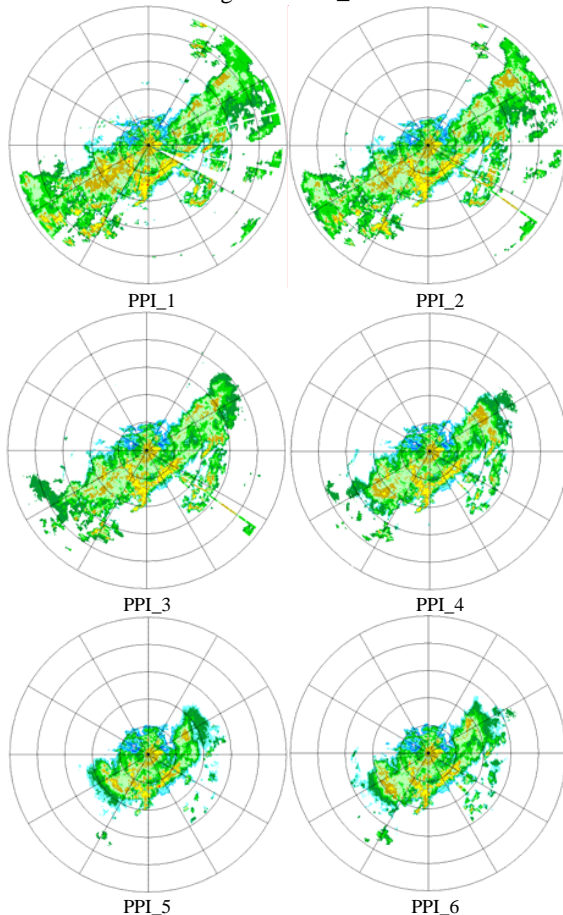


Fig. 2 Images of PPI reflectivity field in one volume data

in the lowest elevation angle, and PPI_6 is the highest.

As an initial attempt to investigate the applicability of our ideas, the proposed method was implemented in software and experimental results were achieved. For reducing the correlation between the PPI images we chose the optical linear prediction presented above. Fig. 3(a) is the original PPI image and Fig. 3(b) is the residual image after optical linear prediction.

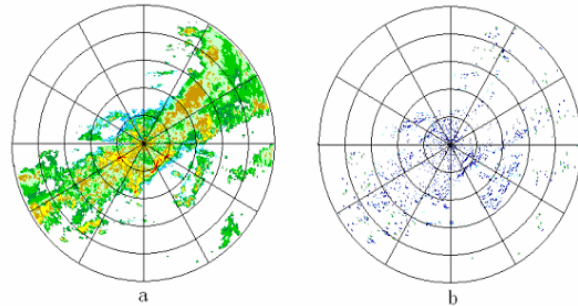


Fig. 3 The original PPI image and the predicted PPI image

Comparing the Fig. 3(a) and Fig. 3(b) we know that the value is decreased and the residual image gets more sparse, which are convenient for improving the lossless compression ratio. Table 1 showed the entropy of each original PPI image and the PPI image after optical linear prediction. It is easy to conclude that the value of entropy is reduced by prediction. For example, the entropy of PPI_1 image is decreased from 3.48 to 2.45, and which provide the probability to obtain higher compression ratio.

TABLE I
COMPARISON OF ENTROPY FOR THE ORIGINAL PPI IMAGE AND THE PREDICTED PPI IMAGE

Entropy	PPI_1	PPI_2	PPI_3	PPI_4	PPI_5	PPI_6
Original Image	3.48	3.39	3.09	2.91	2.78	2.66
Predicted Image	2.45	2.55	2.24	2.10	1.98	2.66

Some lossless compression method LZW, WINZIP, JPEG_LS, JPEG_2000 and the method proposed are used for compressing the weather radar volume data which contains pure reflectivity, quality-controlled reflectivity, as well as Doppler velocity information. The LZW and WINZIP compressed the weather data as a total file and got lower compression ratio. While the compression standard JPEG_LS and JPEG_2000 compressed the PPI images in one volume data, and which contained higher performance. The propose method achieved the highest compression and the compression ratio reached 7.69.

TABLE II
COMPARISON OF THE PERFORMANCE OF DIFFERENT METHODS

Method	LZW	WINZIP	JPEG_LS	JPEG2000	Proposed Method
Ratio	3.89	5.96	6.48	5.52	7.69

V. CONCLUSION

A new efficient and easily to be implemented lossless compression method for weather radar data has been proposed. The method proposed uses the optical linear prediction, RLE coding algorithm and adaptive arithmetic encode algorithm to reduce two kinds of redundancy in the weather radar data, and which achieved higher performance than JPEG_2000 and JPEG_LS.

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