

Studies on a High-Compression Technique for Weather Radar Reflectivity Data

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Abstract—Studies are carried out on a contour-based method for highly compressing voluminous weather radar reflectivity data to optimize the compression and reconstruction parameters. In particular, the effects of the choice of thresholds and the degree of smoothing at encoding and retrieval ends are studied with respect to achievable compression ratios, root-mean-square error of the retrieved contours, and the visual fidelity of the reconstructed reflectivity images. Results are presented for multiple actual Doppler weather radar reflectivity data sets.

Keywords—High data compression, weather radar data compression, contour-based data compression, spline based contour reconstruction.

I. INTRODUCTION

Modern Doppler weather radars are capable of generating accurate high-resolution pictorial weather data at fast update rates [1]. However, by their very nature such data are highly voluminous, overloading communication and storage media. One special situation where this acts as a serious bottleneck occurs when such high-volume data is to be transmitted between ground installations and aircraft in real time, since air-to-ground communication bandwidths are usually highly restricted and hence constitute premium resources. There is thus a need for highly compressing weather radar data in many situations, even at the expense of some loss of picture quality and details.

General purpose compression schemes such as JPEG [2] are not optimized for any particular class of data. It is to be expected that compression techniques that exploit the inherent structures and application-dependent flexibilities of specific data types would have the potential for achieving higher degrees of compression. In particular, in the weather radar context, contour-based compression techniques are highly suitable for encoding reflectivity data since such data are commonly displayed in a contoured format for observation and interpretation purposes. A technique proposed in [3] represents radar reflectivity contours using elliptical or polygonal shapes and transmits the parameters of the individual segments or arcs. The decoder redraws the shapes from these encoded parameters to reconstruct the contours and then fills the enclosed regions. However, the random (jagged) nature of weather contours does not lend itself to neat description in terms of elliptical or polygonal segments. This is also true

for the scheme proposed in [4] which converts bitmapped contour data to polygons, with their vertices determined using a prescribed maximum distance method.

The authors have recently proposed [5] a novel contour-based compression technique which is capable of representing random curves, corresponding to weather contours, in terms of a limited number of control points and reconstructing the contours at the receiving end using a spline interpolation. Here we make further detailed studies on the effects of different data and display parameters on the degrees of achievable compression and suggest ways of optimizing the compression performance of the basic scheme. Specifically, the effects of the following parameters are studied: (1) threshold values for contour generation, (2) variation of the contour smoothing length, and (3) degree of spline interpolation. The first two of these operations are performed at the encoding/transmitting end, and the third one takes place at the receiving/reconstructing end.

To evaluate the performance of compression schemes, it is necessary to quantify both the extent to which data has been compressed (usually defined as the 'compression ratio') and the fidelity of data reproduction. The latter may be expressed in quantitative terms or judged on a qualitative basis [6]. In this paper we compare the original and retrieved contours to quantify the fidelity, and present sample original and reconstructed weather pictures for subjective judgment of the compression scheme.

II. OUTLINE OF BASIC COMPRESSION SCHEME

The chain of data handling from its source (real-time radar operation or storage device) to display (e.g. in the cockpit) has two major parts. At the source end the data is processed using a compression algorithm and transmitted over a data link. At the receiving end the data is processed by a compatible algorithm to retrieve its information content for display to the pilot or other user(s). The two major stages are described in some detail below.

A. Encoding and Transmission

The sequence of operations for converting a weather radar reflectivity field into a compressed data file for transmission or storage is depicted in Fig. 1. The scheme proposed in [5] first converts a two-dimensional reflectivity distribution (Fig. 1(a))

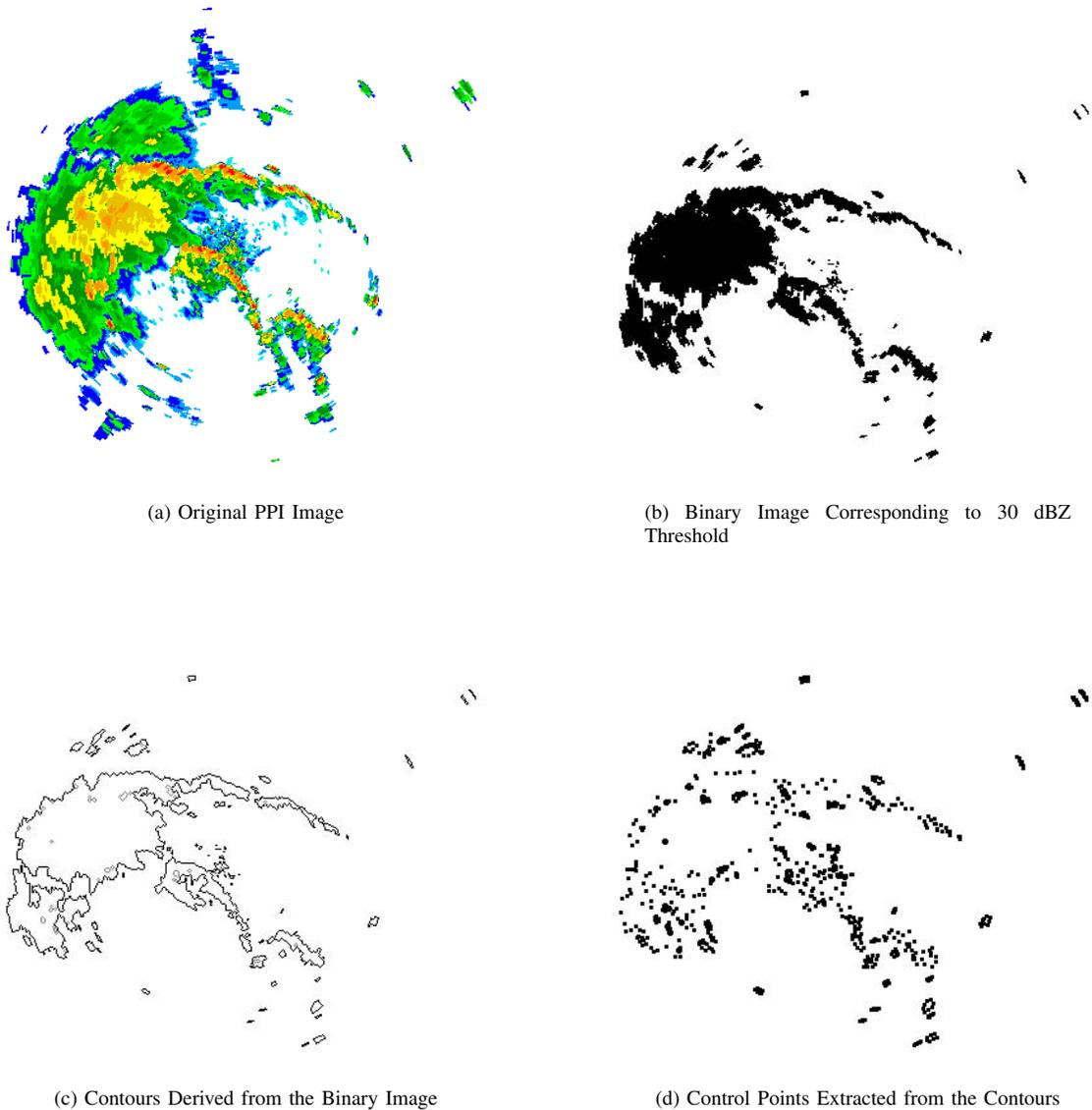


Fig. 1. Steps in Contour Extraction and Encoding Scheme (Reflectivity Field No. 5)

to a binary image (Fig. 1(b)) using an assigned threshold. Any of a set of thresholds can be chosen; however, it is convenient to utilize the thresholds specified by National Weather Service (NWS) or a superset of these thresholds [7]. The selection of thresholds (number as well as values) determines the compression ratio and quality of the reconstructed image. Obviously, the higher the number of thresholds chosen to depict a given data field, the better will be the representation, but at a cost of reduced compression ratio.

The next step is to trace the contours (Fig. 1(c)) in the binary image using a versatile radial sweep algorithm [8]. Contour tracing can be a complex process because of the extreme diversity of weather contour shapes. It is not uncommon to find weather contours of annular shapes, i.e. closed areas with reflectivity below the threshold embedded within zones of higher-than-threshold reflectivity. Two types of contours

are therefore defined. Contours that enclose reflectivity values exceeding the assigned threshold are called *region contours*. Contours of below-threshold areas that are enclosed by a region contour are called *holes*. It is possible to find nested situations wherein region contours occur within holes, and so on. The contour tracing algorithm is therefore required to be capable of tracing region and hole contours [9] and identifying them as such. A tag bit is used to distinguish region and hole contours during transmission and processing.

The prime contribution of the compression scheme proposed in [5] lies in representing each tagged contour by an optimal set of discrete points called *control points* (Fig. 1(d)). Clearly, the smaller the number of points used to represent a given contour, the lower would be the data bandwidth requirement, and hence higher the compression ratio. The choice of points should however, be made such that a suitable reconstruction

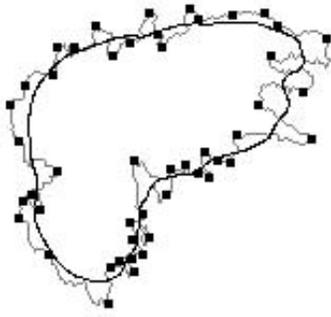


Fig. 2. Example of an Isolated Contour (lighter line), its Smoothed Version (darker line), and Control Points (small black squares)

algorithm can retrieve the original contour from these points with negligible distortion. To achieve both these goals, the scheme in [5] chooses the control points to be the points of local extrema on the contour. To automate the process of detecting such points, an algorithm is devised which first derives a smoothed version of the original contour and then searches for points of maximal distance between the original and smoothed contours (Fig. 2).

The description of each control points is in terms of its x and y coordinates, reckoned from the top-left corner of the minimum bounding rectangle (MBR) of each isolated contour to minimize bit requirements. The control points along with the coordinates of the top-left corner and the height and width of the MBR are transmitted to the receiving end or to a storage device. Control points constitute a major fraction of the data to be transmitted and the fidelity of the scheme can be adjusted by increasing or decreasing the number of control points. However, a drastic reduction in the number of control points can result in poor reconstruction of a contour. The method thus incorporates an explicit mechanism for effecting a tradeoff between the degree of compression and the quality of the reconstructed weather picture.

B. Receiving and Display

At the retrieving end the hole and region contours are identified using their appended tag bits. The control points of each tagged contour are restored to the original coordinate system by adding the coordinates of top-left corner of the MBR to the individual x and y coordinates. The contours are reconstructed from the control points using B-spline interpolation [10]. The degree of spline interpolation and choice of the knot values determine the quality of the reconstructed contour. Our scheme uses uniform knot vector values for spline interpolation.

Following reconstruction of the contours, the interior of the region contours that lies outside the holes is filled by using a boundary fill algorithm [11]. This entire process is repeated for each of the threshold values applied to the reflectivity field at the encoding end. Our filling algorithm minimizes computational effort at the receiving end by selectively filling assigned colors over the areas lying between contours of subsequent thresholds, thus obviating the need for multiple filling of overlapping areas.

III. SCOPE FOR THE STUDY

The proposed scheme has been tested using many Plan Position Indicator (PPI) scan converted WSR-88D data sets available from NOAA [12]. These data fields correspond to a display of dimension 512×512 pixels with 8-bit depth. The quality of the reconstructed image depends on the choice of the thresholds, the degree of spline interpolation and the extent of smoothing of the reference contour. For contour-based compression methods such as the one described here, metrics like signal-to-noise ratio (SNR) do not effectively represent the quality of reproduction. A visual comparison of the original and reconstructed images along with the achieved compression ratios has been adopted to show the variation of quality with the choice of thresholds. Root-mean-square error (RMSE) between the original and reconstructed contours has been used to indicate the fidelity of reconstruction as a function of the degree of spline interpolation.

IV. EFFECT OF SMOOTHING LENGTH

An important parameter affecting the generation of control points is the length of the arc over which the original contour is to be smoothed to act as the reference curve for obtaining the control points. Too small a smoothing length would make the reference curve almost as jagged as the original contour, and the control points obtained by the maximum departure criterion would not be reliable. Over-smoothing would make the reference curve small such that its intersections with the original contour would be minimized, thus missing out many of the valid control points. Tables I and II respectively show the overall compression ratios and the RMSE for four reflectivity fields as function of the smoothing length expressed as percentage of the original contour length while using the NWS thresholds. The results in Table II are based on a second-degree spline interpolation.

TABLE I
COMPRESSION RATIO AS FUNCTION OF PERCENTAGE OF SMOOTHING LENGTH

Percentage	Field 1	Field 2	Field 3	Field 4
5	109.707	103.835	113.784	122.986
10	105.634	100.280	116.173	121.398
15	109.232	103.395	121.977	123.938
20	111.717	105.448	124.927	128.683

TABLE II
RMSE OF CONTOUR RECONSTRUCTION AS FUNCTION OF PERCENTAGE OF SMOOTHING LENGTH

Percentage	Field 1	Field 2	Field 3	Field 4
5	1.249390	1.164300	1.13833	1.52562
10	0.884273	0.884022	1.31600	1.18894
15	1.292630	1.113530	3.78364	3.60833
20	1.405210	1.539360	3.19848	3.53206

An optimal choice of smoothing percentage should be such as to minimize the RMSE while maximizing the compression ratio.

sion ratio. The Tables show that these parameters are data-dependent. However, a smoothing length of 10% is found to be optimum or near-optimum in most cases.

V. EFFECT OF DEGREE OF SPLINE INTERPOLATION

Upon reception at the destination or retrieval from a storage medium, the compressed contour data need to re-composed into an actual contour. As mentioned before, we use a B-spline interpolation to regenerate the contour from the control points. This process offers some freedom of parameters which must be optimally chosen. Of importance here is the degree of the spline. Table III shows the effect of the degree of interpolation (over the range 1 to 5) on the RMSE of reconstruction of the contours for four reflectivity fields obtained at an elevation angle of 0.35° . The standard NWS thresholds have been used together with a smoothing length of 10% for obtaining the respective reference contours.

TABLE III
RMSE OF CONTOUR RECONSTRUCTION AS FUNCTION OF DEGREE OF INTERPOLATION.

Degree	Field 1	Field 2	Field 3	Field 4
1	0.785433	0.816937	1.21413	1.02699
2	0.884273	0.884022	1.31600	1.18894
3	0.993228	0.988289	1.49077	1.29947
4	1.115750	1.094810	1.51259	1.37056
5	1.212050	1.187960	1.62094	1.51071

The error of reconstruction is seen to increase monotonically with the degree of interpolation. This is not unexpected, since the control points lie on the original contour itself, and higher degrees of smoothing takes the reconstructed contour farther from these vertices. However, smoothing of degree 1 is not acceptable because this amounts to joining the successive vertices (control points) by straight-line segments which gives the curve a jagged or saw-tooth-like appearance. We therefore conclude that a spline of degree 2 is the best for reconstructing the contours.

VI. EFFECT OF THE CHOICE OF THRESHOLDS

Although the NWS thresholds are commonly used for contouring reflectivity fields, in many applications these may be considered too coarse, especially in cases where the maximum reflectivity is not too high. In such cases the reconstructed picture may not convey the full visual impact of the original reflectivity field. To obviate this difficulty, one may choose a higher number of thresholds, i.e. space the thresholds closer. Here we augment the number of thresholds by introducing an extra level midway between the consecutive NWS levels.

Table IV shows the overall compression ratios achieved in four different reflectivity fields by using the basic and augmented NWS threshold levels. As expected, the introduction of additional thresholds reduces the compression ratios since more control points would now have to be generated for the same original picture. However, this increase in the compressed data bandwidth is offset by enhancement in the quality of visual reproduction as shown in Fig. 3.

TABLE IV
COMPRESSION RATIOS AS FUNCTION OF THRESHOLDS

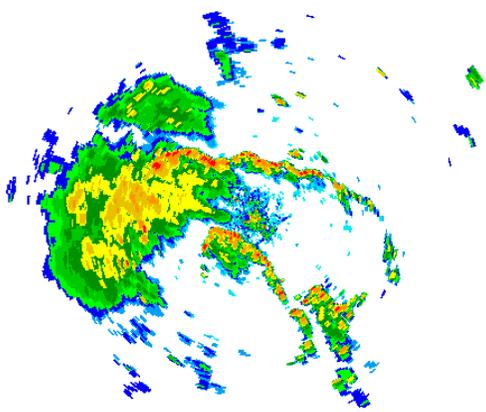
Field	NWS Thresholds	Augmented NWS Thresholds
1	105.634	59.0498
2	100.280	56.4905
3	116.173	63.7161
4	121.398	69.0125

VII. CONCLUSIONS

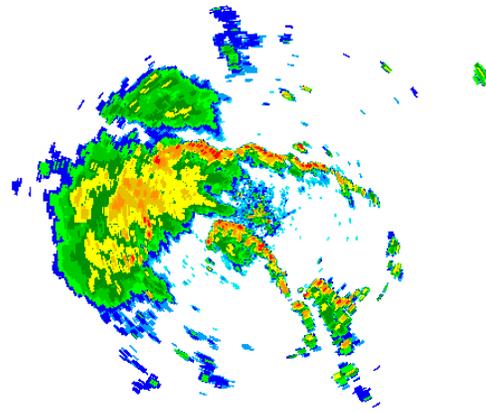
The robustness, sensitivity and fidelity of a contour-based scheme for very high compression of weather radar reflectivity data has been quantitatively and qualitatively assessed in this paper. Specific attention has been devoted to the effects of the choice of thresholds and the degree of smoothing at encoding and retrieval ends. The metrics used for comparing the various parameters are achievable compression ratios, root-mean-square error of the retrieved contours, and the visual fidelity of the reconstructed reflectivity images. It is shown that a 10% smoothing at the encoding end is optimal for most data sets, while a second-degree spline interpolation at the receiving end is desirable. The addition of extra thresholds to the standard National Weather Service thresholds is shown to enhance the quality of reproduction of the reflectivity pictures, but results in significant penalty in terms of reduced compression ratios.

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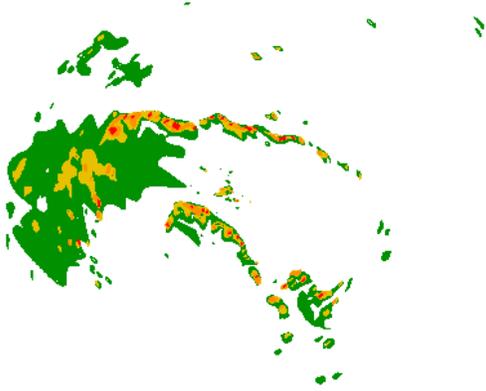
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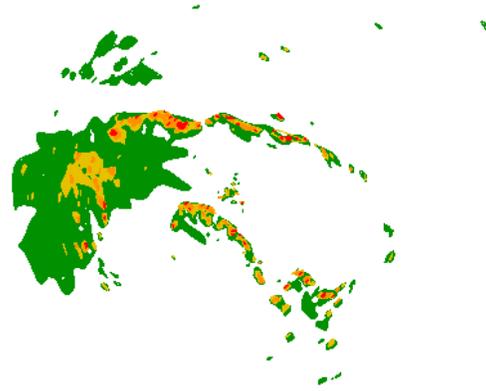
(a) Original Reflectivity PPI (Field 1)



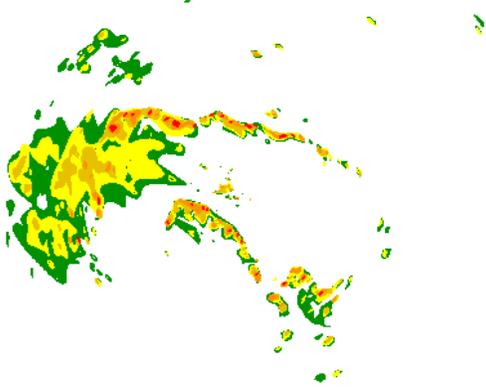
(b) Original Reflectivity PPI (Field 2)



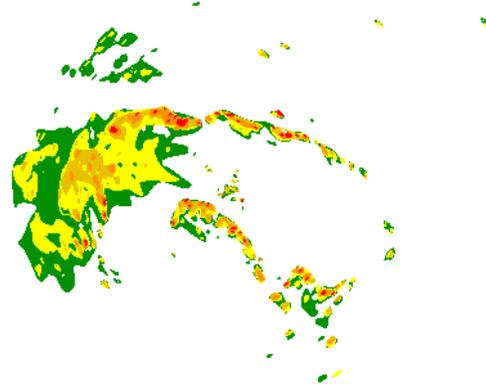
(c) Retrieved Field 1 (NWS Thresholds)



(d) Retrieved Field 2 (NWS Thresholds)



(e) Retrieved Field 1 (Augmented NWS Thresholds)



(f) Retrieved Field 2 (Augmented NWS Thresholds)

Fig. 3. Fidelity of Reconstruction using NWS and Augmented NWS Thresholds