Lossless Compression of Multispectral Images using Spectral Information

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ABSTRACT

Multispectral images are available for different purposes due to developments in spectral imaging systems. The sizes of multispectral images are enormous. Thus transmission and storage of these volumes of data require huge time and memory resources. That is why compression algorithms must be developed. A salient property of multispectral images is that strong spectral correlation exists throughout almost all bands. This fact is successfully used to predict each band based on the previous bands. We propose to use spectral linear prediction and entropy coding with context modeling for encoding multispectral images. Linear prediction predicts the value for the next sample and computes the difference between predicted value and the original value. This difference is usually small, so it can be encoded with less its than the original value. The technique implies prediction of each image band by involving number of bands along the image spectra. Each pixel is predicted using information provided by pixels in the previous bands in the same spatial position. As done in the JPEG-LS, the proposed coder also represents the mapped residuals by using an adaptive Golomb-Rice code with context modeling. This residual coding is context adaptive, where the context used for the current sample is identified by a context quantization function of the three gradients. Then, context-dependent Golomb-Rice code and bias parameters are estimated sample by sample. The proposed scheme was compared with three algorithms applied to the lossless compression of multispectral images, namely JPEG-LS, Rice coding, and JPEG2000. Simulation tests performed on AVIRIS images have demonstrated that the proposed compression scheme is suitable for multispectral images.

Keywords: Lossless compression, image compression, spectral linear prediction

1. INTRODUCTION

Multispectral images have various applications in remote sensing and can now be used in industrial applications including quality control, exact color measurement, and color reproduction. This evolution has been possible due to the development in the multispectral imaging systems. Multispectral data is of enormous size. Transmission and storage of multispectral images require huge time and memory resources. Thus compression methods for multispectral images must be developed. Many lossy compression methods are developed for efficient compression of the multispectral images. Lossy compression cannot reproduce the original data, and, thus, they shouldn’t be applied in compression before the data reaches the end user. Since the final utilization of the images in the databases is not known in advance no metric can describe what information can be discarded, and then only lossless methods can be recommended, even though the compression ratios for the lossless methods are much lower than for the lossy method. Our focus in this paper is on lossless compression. Various lossless compression schemes based on transform coding and predictive coding have been proposed [1-18].

The multispectral images can be modeled as a 3-dimensional matrix composed of two types of coordinates: the spatial coordinates and the spectral coordinate. The spatial coordinates represent the intensity (brightness) of the image at a given point. The spectral coordinate is the wavelength at which the image is acquired. A salient property of multispectral images is that strong spectral correlation exists throughout almost all bands. This could be because, in these bands, the signal associated with these frequencies is greatly attenuated by the atmosphere or the materials being imaged. Correlation coefficient between all bands defined as follows:
\[
\rho(A, B) = \frac{\sum_{m} \sum_{n} (A_{mn} - \bar{A})(B_{mn} - \bar{B})}{\sqrt{\sum_{m} \sum_{n} (A_{mn} - \bar{A})^2 \sum_{m} \sum_{n} (B_{mn} - \bar{B})^2}}
\]

Where \( A \) and \( B \) are two bands in the multispectral image; \( \bar{A} \) and \( \bar{B} \) denote the mean values of the matrices; \( \rho(A, B) \) denotes the correlation coefficient between bands \( A \) and \( B \). Fig. 1 shows the correlation between two consecutive bands of Jasper Ridge scene 1 from the first band to the 224th band. For most bands, the correlation value \( \rho(A, B) \) is close to one.

![Fig. 1 Correlation coefficient between two adjacent bands of Jasper Ridge scene 1.](image)

In this paper, we investigate the use of spectral information for lossless compression of multispectral images. Spectral redundancy is exploited by using the spectral predictor obtained from one spectral band on another spectral band. The idea is that the relationships between a pixel and its neighbors are similar in adjoining spectral bands. Lossless compression algorithms, such as JPEG-LS, CALIC, are not suitable for multispectral images compression. They do not utilize the high correlation between disjoint bands in multispectral images. In this paper, we propose a lossless compression method for multispectral images. The main contribution of the paper is the development of a lossless multispectral images compression which is based on a spectral linear prediction.

The remainder of this paper is organized as follows. The JPEG-LS is reviewed in Section 2. In Section 3 we describe the proposed method for multispectral images using spectral linear prediction. In Section 4 some experimental results are presented and finally the conclusions are drawn in Section 5.

## 2. REVIEW OF THE JPEG-LS

In order to describe the proposed method, we will briefly discuss the latest international standard for lossless and near lossless still image compression developed by JPEG, JPEG-LS. The main compression techniques proposed in JPEG-LS can be summarised as: (1) run-length coding; (2) nonlinear prediction; (3) context-based statistics modelling; and (4) Golomb-Rice coding [19-21].

As it will be evident from the notation, we consider here a raster-scan order for the pixels, from top to bottom and from left to right. For an input image, a prediction scheme is first operated to decide whether the run-length compression mode or the predictive coding mode should be selected to encode the current pixel, depending on the values of those
previously encoded pixels in a surrounding neighbourhood. The neighbourhood is represented by a predictive template of four pixels as illustrated in Fig. 2. To reduce the computational cost for statistical modeling and for selection of an appropriate coding mode, JPEG-LS proposed the following three $\Delta$ values to implement the local texture analysis.

$$\Delta_1 = d - b; \quad \Delta_2 = b - c; \quad \Delta_3 = c - a$$

As a result, the consideration of the four pixel intensity values can be reduced to the consideration of three $\Delta$ values.

$$\begin{array}{ccc}
  b & c & d \\
  a & x & \\
\end{array}$$

Fig 2 JPEG-LS predictive template

If all four neighbouring pixel values are the same, it is indicated that the local region surrounding the pixel to be encoded is of smooth texture. Hence, run-length coding is selected to encode the next sequence of pixels until the run is broken. Otherwise, the texture may not be that smooth and thus a prediction-based entropy coding is selected. The selection of its coding mode in JPEG-LS can be summarized below

$$\text{coding mode} = \begin{cases} 
\text{run length} & \text{if } \Delta_1, \Delta_2, \Delta_3 = 0 \\
\text{predictive coding} & \text{otherwise}
\end{cases}$$

Prediction is designed by exploiting a simple local texture analysis among the three context pixels, $a$, $b$, and $c$, inside the predictive template given in Fig. 2. The detailed design of the prediction can shown below

$$\hat{x} = \begin{cases} 
\min(a,b), & c \geq \max(a,b) \\
\max(a,b), & c < \min(a,b) \\
a + b - c, & \text{otherwise}
\end{cases}$$

Where $\max(a,b)$ and $\min(a,b)$ stand for the maximum and minimum pixel values among pixels $a$ and $b$, respectively.

JPEG-LS also include a run mode procedure to code image regions with constant pixel values. We will also consider these procedures in this paper.

### 3. THE COMPRESSION SCHEME

In this section, we propose a scheme for lossless compression of multispectral images. We exploit the fact that the JPEG-LS can achieve improving compression performance with low complexity. An extension of the JPEG-LS scheme to take into account 3-D information was considered in this paper. The proposed scheme is based on fundamental blocks similar to those described for JPEG-LS, with the difference that the prediction is built by considering the pixels form previous bands. Linear prediction predicts the value for the next sample and computes the difference between predicted value and the original value. This difference is usually small, so it can be encoded with less its than the original value. The technique implies prediction of each image band by involving number of bands along the image spectra. Each pixel is predicted using information provided by pixels in the previous bands in the same spatial position. An estimate for each pixel value is calculated in the following way:

$$\hat{p}_{x,y,z} = \sum_{j=1}^{N} a_{z,j} p_{x,y,z-j}$$

Where $p_{x,y,z}$ is the value of the pixel at band $z$ in spatial location $(x, y)$, $a_{z,j}$, $j = 1…N$ denote prediction coefficients, $N$ is the predictor order.
For each band, the optimal spectral linear prediction coefficient vector $a = [a_1, ..., a_N]^T$ can be calculated in such a way that the prediction coefficients minimize the expected value of the squared error. Note that, if we do not want to send the predictor coefficients to the decoder, we have to compute the prediction (2) for the current pixel using information in the past. We will therefore determine the optimal prediction coefficients that minimize the expected value of the squared error for each band

$$ P = \sum_{x,y} (\hat{p}_{x,y} - p_{x,y})^2 $$

In normal mode, as done in the JPEG-LS, the proposed algorithm also represents the mapped residuals by using an adaptive Golomb-Rice coding with context modeling. This residual coding is context adaptive, where the context used for the current pixel is identified by a context quantization function of the three $\Delta$ values. In run mode, the assumption is that in current band a number of consecutive pixels are all likely to have the same value. The run length is coded by using Golomb-Rice coding.

4. EXPERIMENTAL RESULTS

We experimented with multispectral images produced by an airborne visible/infrared imaging spectrometer (AVIRIS). The Spectrometer measured reflected radiance of 20x20 meter pixels in 224 narrow spectral bands, most of which are outside the visual range. The resulting image consisted of 614 samples/columns by 512 lines/rows by 224 spectral bands using wavelengths between 400 and 2500 nm. There are three areas from Cuprite, Nevada, Jasper Ridge, California and Lunar Lake, Nevada that have been used for testing of the algorithms described in this paper [22].

Table 1 contains results for the 1997 AVIRIS datasets. Our algorithm is labeled “proposed’. The “JPEG-LS” column contains lossless compression results for JPEG-LS applied to the spectral bands independently. The Rice compressor used in the Universal Source Encoder for Space (USES) chip using the multispectral predictor option mentioned in [23]. JPEG-LS applied to the differences between the successive spectral bands.

Table 1. Bit rate achieved for AVIRIS datasets. Results are given in bits/sample

<table>
<thead>
<tr>
<th></th>
<th>Proposed algorithms</th>
<th>JPEG-LS</th>
<th>Rice</th>
<th>$\triangle$-JPEG-LS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cuprite 1</td>
<td>5.27</td>
<td>7.13</td>
<td>6.00</td>
<td>5.44</td>
</tr>
<tr>
<td>Cuprite 2</td>
<td>5.40</td>
<td>7.50</td>
<td>6.13</td>
<td>5.58</td>
</tr>
<tr>
<td>Cuprite 3</td>
<td>5.29</td>
<td>7.16</td>
<td>6.00</td>
<td>5.45</td>
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<tr>
<td>Cuprite 4</td>
<td>5.34</td>
<td>7.16</td>
<td>6.05</td>
<td>5.51</td>
</tr>
<tr>
<td>Jasper Ridge1</td>
<td>5.45</td>
<td>7.72</td>
<td>6.17</td>
<td>5.62</td>
</tr>
<tr>
<td>Jasper Ridge2</td>
<td>5.42</td>
<td>7.76</td>
<td>6.12</td>
<td>5.59</td>
</tr>
<tr>
<td>Jasper Ridge3</td>
<td>5.50</td>
<td>7.90</td>
<td>6.19</td>
<td>5.67</td>
</tr>
<tr>
<td>Jasper Ridge4</td>
<td>5.50</td>
<td>7.87</td>
<td>6.22</td>
<td>5.67</td>
</tr>
<tr>
<td>Jasper Ridge5</td>
<td>5.43</td>
<td>7.75</td>
<td>6.14</td>
<td>5.60</td>
</tr>
<tr>
<td>LunarLake 1</td>
<td>5.32</td>
<td>6.98</td>
<td>6.02</td>
<td>5.49</td>
</tr>
<tr>
<td>LunarLake 2</td>
<td>5.27</td>
<td>6.96</td>
<td>5.97</td>
<td>5.44</td>
</tr>
<tr>
<td>Average</td>
<td>5.38</td>
<td>7.44</td>
<td>6.09</td>
<td>5.55</td>
</tr>
</tbody>
</table>

Table 1. Compression ratio for AVIRIS datasets.

<table>
<thead>
<tr>
<th></th>
<th>Proposed</th>
<th>JPEG2000</th>
<th>$\triangle$-JPEG2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cuprite</td>
<td>3.00</td>
<td>1.91</td>
<td>2.92</td>
</tr>
<tr>
<td>Jasper Ridge</td>
<td>2.93</td>
<td>1.80</td>
<td>2.82</td>
</tr>
<tr>
<td>LunarLake</td>
<td>3.02</td>
<td>1.82</td>
<td>2.94</td>
</tr>
<tr>
<td>Average</td>
<td>2.98</td>
<td>1.84</td>
<td>2.89</td>
</tr>
</tbody>
</table>
In table 2, we compare our proposed algorithm to JPEG2000 compression standards and JPEG2000 [24]. JPEG2000 uses only spatial decorrelation. JPEG2000 refers to the computation of the spectral differences between consecutive bands decorrelation before applying JPEG2000 as an intra-band compressor.

5. CONCLUSION

In this paper, we proposed a lossless compression technique for multispectral images. Since spectral correlation is much stronger than spatial correlation, prediction should be done only in the spectral direction. Spectral linear prediction predicts the value for the next sample and computes the difference between predicted value and the original value. The prediction error is then represented using Golomb-Rice coding.

The proposed scheme was compared with three algorithms applied to the lossless compression of multispectral imagery, namely JPEG-LS, Rice coding, and JPEG2000. Simulation tests performed on AVIRIS images have demonstrated that the proposed compression scheme is suitable for multispectral images.

REFERENCES