IMPROVED VECTOR QUANTIZATION FOR LOSSLESS COMPRESSION OF AVIRIS IMAGES

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ABSTRACT

In this paper, we present a modification to the back end of vector quantization (VQ), which improves the compression ratio of the lossless compression of multispectral images. By introducing a small change to the back end of VQ, the compression ratio improve significantly. In our expreriments, images were compressed from the original image entropies of between 10.73 and 11.55 bits/pixel to between 5.13 and 5.33 bits/pixel.

1 INTRODUCTION

Recently, several new methods for the lossless [7][8] and lossy compression [1] of multispectral images have been proposed. Application scientists should be able to get the essential information from the images. Therefore, it is important to develop lossless compression methods.

Vector quantization (VQ) is a popular asymmetric technique also suitable for data compression [2][3][6][9]. While VQ compression is normally computationally demanding, decompression is a computationally inexpensive table lookup process. The performance of the VQ techniques depend largely on the quality of the codebook used in coding the data. Although there exist several methods for generating a codebook [2] we used the most popular one known as the Generalized Lloyd Algorithm (GLA) [5] that produces a locally optimal codebook. Following vector quantization, the reconstructed image is subtracted from the original image in order to obtain a residual image. The difference between consecutive bands in the residual image is calculated and a difference image is formed. The residual image can be reconstructed using the first band of the residual and all the bands of the difference image.

This paper is organized as follows. In Section 2, the VQ operation is reviewed. The experimental results and conclusions are given in Sections 3 and 4, respectively.

2 METHODS

Figure 1 shows three stages of vector quantization. The first step is the decomposition of the image into a set of vectors. The second step is codebook generation. The last stage is index selection.

For the codebook generation phase we used the GLA.

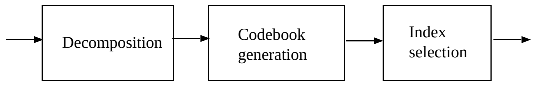


Figure 1: The Vector Quantization Algorithm.

The codebook generation phase can be formally defined as follows: given M k-dimensional input vectors, $v_i = (v_1, v_{2,}, ..., v_k)$, $(i = 1, ..., M)$, we are looking for a set of N k-dimensional codebook vectors, $u_j = (u_{1,} u_2, ..., u_k)$, $(j = 1, ..., N)$, that minimize the sum of the squared distances of every input vector to its closest code vector:

$$D(v, u) = \sum_{i=1}^{M} d(v_i, u_{m(i)}), \quad (1)$$

where $m(i)$ is the index of the closest code vector of the input vector with index i under the distance metrics, $d(v, u)$.

For the distance metrics $d(v, u)$, we used the Euclidean distance:

$$d(v, u) = \|v - u\|^2 = \sum_{i=1}^{k} (v_i - u_i)^2. \quad (2)$$

The GLA algorithm iteratively generates the codebook, which is only a locally optimal solution to Eq. 1. Initially, the size of the codebook is one and its only codevector is set to the arithmetic mean of all the input vectors, v_i $(i = 1, ..., M)$. At every iteration step, r, the size of the codebook is doubled by duplicating all the codebook vectors and adding a small perturbance, $\varepsilon \in R^k$, to the duplicates. For every input vector v_i, the nearest code vector, u_j, under distance metrics, $d(v, u)$ is determined. Then, each code vector, u_j, is a assigned the arithmetic mean of all input vectors, v_i, the closest code vector of which is u_j. If there exists a codebook vector, u_j, that is not the nearest to any input vector, v_j, the codebook vector is reassigned in such a way that the unused codebook vector is moved to the neighborhood of often used codebook vector. The codebook error, $D^p(v, u)$, during the iteration, p, is calculated. If the relative error of the codebook errors between two iterations,

$$\frac{D^p(v-u) - D^{p-1}(v-u)}{D^p(v-u)}, \tag{3}$$

is smaller than a given tolarance, the local optimum for a codebook of size 2^r has been found.

In the index selection phase, for each input vector, v_j, the closest code vector in the codebook, u_j, is found and an image containing the indices formed.

In order to form a difference image, the difference between consecutive bands in the residual image is calculated:

$$d_i = b_{i-1} - b_i, \tag{4}$$

where i is the band number, and b_i the value of band i.

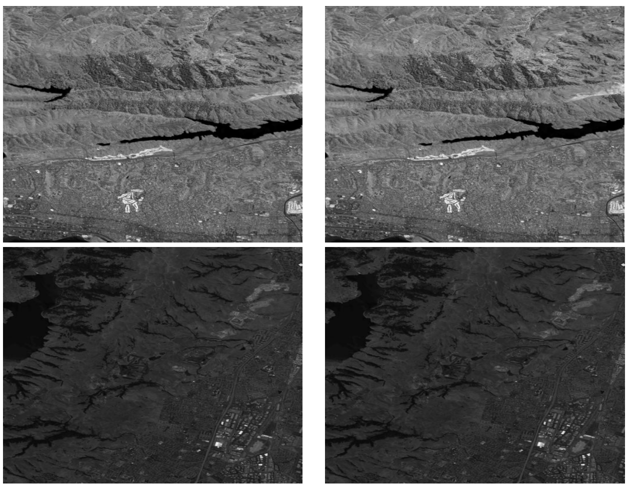
The residual image can be reconstructed using the first band of the residual image and all the bands of the difference image:

$$b_i = b_{i-1} - d_i. \tag{5}$$

The first band's residuals and other bands' differences are entropy coded, one band at a time. Also both the index and codebook values are separately entropy coded, which means that 226 separate entropy coders are used. The frequency tables, that are used by entropy coders are grouped into one data set and are entropy coded by an 8-bit entropy coder.

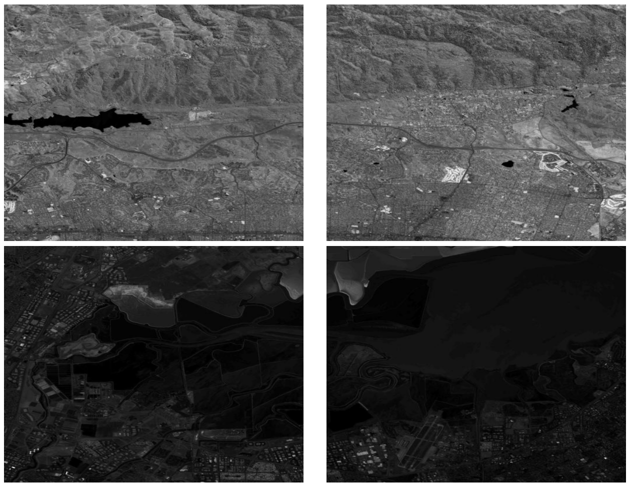
3 EXPERIMENTAL RESULTS

The data used in this research consisted of AVIRIS images from the Jasper Ridge and Moffet Field [10], shown in figures 2 and 3. The images had 608 columns and 512 in the spatial dimension, and each pixel consisted of 224 bands, ranging from 369 nm to 2504 nm with a resolution of 9 nm in the spectral dimension.



(a) (b)
(c) (d)

Figure 2: (a)-(b) Bands 80-81 of the Jasper Ridge no. 1, (c)-(d) Bands 30-31 of the Moffet Field no. 1.



(a) (b)
(c) (d)

Figure 3: (a)-(b) Band 80 of the Jasper Ridge no. 2 and 3, (c)-(d) Band 30 of the Moffet Field no. 2 and 3.

The results in Table 1 contain both the entropies after the different phases and the final compression ratio calculated as a ratio between the sizes of the files containing the original image and the coded data.

The entropy is defined as

$$H(X) = -\sum_i P(x_i) \lg_2(P(x_i)), \tag{6}$$

where $P(x_i)$ is the probability of the occurrence of symbol x_i and X is the input vector with values x_i.

The second column's original entropy (OE) is the entropy of the uncompressed image. The effect of VQ can be accounted for by the entropy of the vector quantized data, which is presented in the third column (VQ entropy). The lower the entropy, the better the decorrelation. The fourth column's final entropy (FE) is defined as :

$$H_C = 16(bits/pixel)/CR, \tag{7}$$

where CR is the compression ratio.

The compression ratio (CR) is calculated by dividing the size of the original image by the size of the compressed file. The last column's entropy ratio (ER) refers to the ratio between the entropy of the original image and the final entropy. This ratio describes how well the method can reduce the entropy of the original image.

Using the best parameters values, a vector length of 224 and a codebook size of 4096, four Jasper images as well as three Moffet Field images were compressed. The results from the experiments can be found in Table 1.

4 CONCLUSIONS

The comparison of our results with the results from literature is not straightforward, since different images have been

Table 1: The Results from Jasper Ridge and Moffet Field Images.

image	OE	VQ entropy	FE	CR	ER
jasper 1	11.19	6.60	5.17	3.09	2.16
jasper 2	11.20	6.34	5.09	3.12	2.20
jasper 3	11.19	6.38	5.16	3.10	2.17
jasper 4	11.27	6.46	5.20	3.08	2.17
moffet 1	11.55	6.58	5.33	3.00	2.17
moffet 2	11.09	6.44	5.25	3.05	2.11
moffet 3	10.73	6.11	5.15	3.13	2.08

used. A comprehensive set of AVIRIS images were compressed in [8]. We used similar images but newer versions. Table 2 shows some results that we have collected from [8]. Unfortunately, the actual compression ratios were not calculated in [8]. Based on the comparison of the entropies, our new method seems to give better results: the entropy ratio is between 22 and 29 percent higher with our method. We also compared the results to Kaarna's method [4] (ER-K) and our earlier method [6] (ER-M) in Table 3 which lists the entropy ratios for both methods. Both of these research projects used exactly the same images which makes their use for comparison more meaningful. Entropy ratio with our method is between 9 and 14 percent higher than the ones in Table 3. By introducing a small change to the back end of VQ, we were able to improve the compression ratio significantly. The method works because there exists a correlation between the bands in the residual image. In the difference image, there is small but sufficiently significant difference in the frequencies of values at different bands, which can be exploited by using several entropy coders. The VQ is an asymmetric compression method; therefore, this technique is well suited to applications where decompression is more frequent than compression.

Table 2: The Results from [8].

image	orig. entropy	final entropy	entropy ratio
jasper	9.79	5.73	1.71
moffet	9.64	5.63	1.71

Table 3: The Results from [4] and [6].

image	orig. entropy	ER-K	ER-M
jasper 1	11.19	1.99	1.90
moffet 1	11.55	2.01	1.93

References

[1] P. L. Dragotti, G. Poggi and A. R. P. Ragozini, Compression of Multispectral Images by Three-Dimensional SPIHT Algorithm, *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 38, No. 1, Jan. 2000, pp. 416–428.

[2] A. Gersho and R. M. Gray, *Vector Quantization and Signal Compression*. Boston, MA: Kluwer, 1992.

[3] R. Gray, and D. Neuhoff, Quantization. *IEEE Transactions on Information Theory*, Vol. 44, Oct. 1998, pp. 2325–2383.

[4] A. Kaarna, Integer PCA and Wavelet Transforms for Multispectral Image Compression, *IEEE 2001 International Geoscience and Remote Sensing Symposium*.

[5] Y. Linde, A. Buze, and R. M. Gray, An algorithm for vector quantizer design, *IEEE Transactions on Communication*, Vol. 28, Jan. 1980, pp. 84–95.

[6] J. Mielikainen, A. Kaarna, P. Toivanen, and Heikki Kälviäinen, Lossless Compression of AVIRIS Images by a Combination of Vector Quantization and Burrows-Wheeler Transform. *Proceedings of the Third International Conference on Multispectral Color Science MCS'01*, pp. 81–84.

[7] R. E. Roger and M. C. Cavenor, Lossless Compression of AVIRIS Images, *IEEE Transactions on Image Processing*, Vol. 5, No. 5, May 1996, pp. 713–719.

[8] M. J. Ryan and J. F. Arnold, The Lossless Compression of AVIRIS Images by Vector Quantization, *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 35, No. 3, May 1997, pp. 546–550.

[9] K. Sayood, *Introduction to Data Compression*, San Francisco, CA, 1996.

[10] www-site: http://makalu.jpl.nasa.gov/aviris.html, Sept. 21, 1998.