Multispectral Image Coding Using Lattice VQ and the Wavelet Transform

Jacques Vaisey*, Michel Barlaud** and Marc Antonini**
**Simon Fraser University, Burnaby, BC, V5A 1S6, CANADA*
***Laboratoire I3S, Les Algorithmes/Bâtiment Euclide*
2000 Route des Lucioles, 06560 Valbonne, FRANCE

vaisey@cs.sfu.ca, barlaud@cs.sfu.ca, Marc.Antonini@i3s.unice.fr

Abstract

This paper examines the problem of compressing multispectral images using the wavelet transform and stack-run entropy coding. Our goal is to explore various ways of coding the wavelet coefficients in order to see which techniques can best exploit the correlation between the multispectral bands to produce an efficient coding algorithm. The results of our study indicate that applying the KLT to each subband followed by lattice VQ on Z^n and subsequent independent entropy coding of each of the lattice dimensions is an effective and fairly simple coding technique. We also demonstrate the importance of proper bit-allocation or, equivalently, the correct choice of the lattice scale parameter for each subband.

1. 0 Introduction

The compression of multispectral images is an important problem due to the tremendous amount of data that these types of images can contain. In addition, standard image coding techniques such as JPEG and SPIHT [7] cannot be applied directly, since they are not designed to work in a multispectral environment where the coding effort must be partitioned between the bands in an optimal way and the interband correlation must be accounted for. Also, the multispectral environment requires that the images be coded with very high fidelity. Techniques like SPIHT tend to suppress high frequencies even at fairly large bit-rates [3], resulting in a smearing of important image details. Recently, Amato et al. [1] have proposed a technique that decomposes the multispectral components into subbands using the wavelet transform and then uses a combination of the KLT and a vector version of the SPIHT algorithm to code the result. These authors avoid the use of VQ due to its computational complexity.

In this paper, we explore a family of techniques to that avoids the "low-pass" effect of the SPHIT algorithm. As in [1], we first take the wavelet transform; however, instead of the SPIHT algorithm, we then apply lattice VQ using and follow it by a stack-run coding [8] of the resulting indices. In the variants considered, we explore the use of the Z^n lattice, which has been shown to perform very well in comparison with other lattices [4], as well as the "rectangular Z^n" lattice, where we allow independent scaling of the lattice in each dimension. We also explore the use of the KLT as well as different techniques for bit allocation, which must be done carefully to get good performance.

2.0 Coding Algorithms

The algorithms examined in this paper all have the basic structure shown in Fig. 1; i.e., we start with a 3-level wavelet transform (using the standard 9-7 filters [2]) and then follow this by a quantization block that produces a set of indices describing the quantized data. These indices are then entropy coded using the effective stack-run algorithm. Our algorithms are tested using the 10m resolution 3-component multispectral image (courtesy of CNES, France) shown in Fig. 2. One of the important characteristics of these images is that, although very correlated, they have distinctly different variances.

2.1 Lattice VQ

The quantization block shown above was implemented using various flavors of lattice VQ. In the first sequence of tests, we experimented with using a "rectangular lattice"; i.e., we started with the Z^n lattice, but used different quantization step-sizes (or lattice scaling) in each dimension. The number of points in each dimension was also fixed with simple truncation occurring on large inputs. The method used here was straightforward; however, in order to be able to apply the stack-run coder, we needed to assign an index to each quantization point.

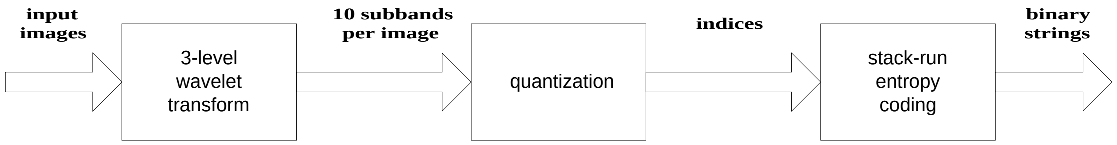

Figure 1: Algorithm Block Diagram

C1 **C2** **C3**

Figure 2: The Test Multispectral Image

We tried two methods: 1) a "Euclidean" assignment, where the index was assigned according to the distance from the origin of the lattice, and 2) an "Entropy" assignment where the most popular lattice point was assigned to have index "0", the next most popular index "1", et cetera. The "Entropy" assignment was done in this way, since zeros are the by far the most popular coefficient in image subbands and the stack-run technique does well when there are large runs of them. We found that the "Entropy" method worked much better than the "Euclidean" one and the "Entropy" method is thus used in subsequent tests. Note, that although we have not included the cost of sending the index assignment in our bit-rates, the issue is moot, as we shall see later.

In our tests on scaling the lattice dimensions differently, we took the largest "vertical" subband and quantized each of its components using step-sizes from 0.75 to 6, with the number of quantization steps/dimension equal to 3, 5 and 7. The results of this semi-exhaustive test are shown in Fig. 3 for the case when the number of levels, *N*, equals 5 in each dimension – the stars indicate what happens when the lattice scaling is constrained to be identical in each dimension, and these results are shown for all three values of *N*. The interesting conclusion to be drawn here is that there is no penalty in using the Z^n lattice, provided that one is willing to increase the number of quantization levels. Similar results were found when using a multi-dimensional Gauss-Markov source having different variances in each component. As a result of these tests, we decided to use the same lattice scaling in all dimensions for the subsequent work.

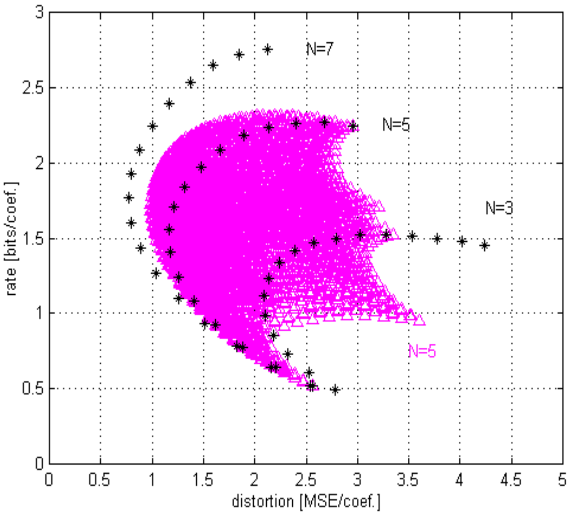

Figure 3: Quantizing Subband V1

2.2 Bit Allocation

Bit allocation is extremely important in data compression. In the problem at hand, the goal is to allocate bits between the different subbands after the wavelet transform. Since we quantize the multispectral components together as a vector, we have avoided the problem of bit allocation between the spectral bands altogether. In this study, we consider two methods of bit allocation. The first of these techniques is based on the approach of Huang and Schultheiss [5] and consists of assuming similar distributions for the sources, high-rate quantization and optimal non-uniform step-sizes to obtain a distortion formula than can be minimized under a constraint on the total bit-rate.

The second method that we considered is the BFOS algorithm [6]. In this technique, we generate a rate-distortion table for each of the sources (subbands) when quantized in isolation, weight them according to their probability (size). A pruning approach is then used to find a point on the convex hull of the rate-distortion curve for the combined source that is close to the target bit rate. Although the allocation is done in the subband domain, we expect the results to be close to optimal in the "image" domain as well, since the error only changes slightly.

2.3 The KLT

Although VQ is an effective technique for exploiting inter-component dependence, an alternative approach is to remove the correlation through an application of the KLT. In this formulation, each of the subband vectors (one dimension for each component) is considered as a sample of the source and the entire subband is used to create the necessary correlation matrix. After application of the transform, we are left with one very strong component and two much weaker ones. The main disadvantage of the KLT is that side-information must be sent to describe the transform; however, this is manageable as long as the number of multispectral components is fairly small.

3.0 Comparisons

Various combinations of quantization strategies were tried on our three-band test image, as is outlined in Table 1. The PSNR results are given in Table 2 for a bit rate of (approximately) 1 bit per pixel per component. Such a high rate was chosen, since the compression must be essentially transparent to be acceptable in this application. Despite the high rate, we found that the stack-run algorithm was able to code the quantization indices at a rate very close to the 0^{th} order entropy of the data. In tests of our coding technique done on single still images, we obtained results 0.7dB below that of the SPIHT algorithm [7] for "Lena" at 0.4bpp. Even better performance can be achieved by using an alternative method for the coding of the low-pass subband, which lacks zero-runs and is thus not really appropriate for stack-run coding.

From these results, we see first of all that optimal bit allocation, using something like the BFOS algorithm, makes a big difference in the performance; indeed, the only reason to adopt the Huang-Schultheiss approach would be a need for speed. In addition, we see that it is important to treat the lattice points as vectors in the absence of the KLT. Applying the KLT first, however, allows us to approach the vector performance at much less complexity and without the need to send the index assignment table to the decoder; this is the recommended technique.

As an additional comparison, we coded the three components using the SPIHT algorithm, each at a rate of 1bpp. The results obtained were 42.41 dB, 37.91 dB and 42.79 dB for C1, C2 and C3 respectively. It is not surprising that these results are inferior to the LVQ results, since a direct application of the SPIHT algorithm does not exploit the inter-component correlation; however, even in the cases that are close in terms of PSNR, a viewing of the coded images confirms that SPIHT does worse at preserving important fine details.

4.0 Conclusions

This study has allowed us to draw several conclusions regarding the quantization of multispectal images. The first is that despite the differing variance of the components, it is sufficient to quantize the data using a lattice with equal step-sizes in each dimension, providing that there are a sufficient number of quantization points prior to truncation. This is an important result, since it greatly simplifies the bit allocation procedure. Our next result is that bit allocation is very important. Simply allocating bits according to the variances of the subbands gives distinctly inferior performance. Finally, we have shown that it is sufficient to independently entropy code the vector dimensions in the case where the KLT is used to decorrelate the input vectors. The result is a fairly simple codec that performs well.

Table 1: Quantizer Configurations

Label	**Description**
LVQ	Lattice VQ using the Z^n lattice and "Entropy" index assignment
SQ	Lattice VQ using the Z^n lattice, but with independent entropy quantization (stack-run coding) of each of the vector dimensions. In this case, we lose the benefit of entropy coding a vector; however, the stack-run algorithm works better for scalars**.** In the scale case, we use the simple "natural" code to index the quantization points.
KLT-LVQ	Lattice VQ using the Z^n lattice and "Entropy" index assignment, but with the vector components decorrelated prior to the quantization.
KLT-SQ	Lattice VQ using the Z^n lattice, but with independent entropy quantization (stack-run coding) of each of the vector dimensions and with the vector components decorrelated prior to the quantization.

Table 2: PSNR Results [dB]

		Comp.	**LVQ**	**SQ**	**KLT-LVQ**	**KLT-SQ**
bit allocation	**Huang-Schul.**	**C1**	39.76			
		C2	38.81			
		C3	39.74			
	BFOS	**C1**	42.13	41.02	42.94	42.81
		C2	40.75	39.56	41.29	41.14
		C3	42.20	41.15	42.27	42.11

References

[1] F. Amato, C. Galdi and G. Poggi, "Embedded Zerotree Wavelet Coding of MultiSpectral Images," Proceedings ICIP'97, pp. I.612-I.615, Oct. 1997.

[2] M. Antonini, M. Barlaud, P. Mathieu and I. Daubechies, Image Coding Using Wavelet Transform," IEEE Trans. on Image Processing, vol. 1, pp. 205-220, 1992.

[3] M. Effros, "Zerotree Design for Image Compression: Toward Weighted Universal Zerotree Coding," Proc. ICIP'97, pp. I.616-I.619, Oct. 1997.

[4] Z. Gao, F. Chen, B. Belzer and J.D. Villasenor, "A Comparison of the Z, E8 and Leech Lattices for Image Subband Quantization," Proc. IEEE Data Compresssion Conf., pp. 312-321, March 1995.

[5] J. Huang and P. Schultheiss, "Block Quantization of Correlated Gaussian Random Variables," IEEE Transactions on Communications, vol. 11, pp. 289-296, 1963.

[6] E. Riskin, "Optimal Bit Allocation via the Generalized BFOS Algorithm," IEEE Transactions on Information Theory," vol. 37, pp. 400-402, March 1991.

[7] A. Said and W.A. Pearlman, "A New Fast and Efficient Image Codec Based on Set Partitioning in Hierarchical Trees," IEEE Trans. on CAS for Video Tech., vol. 6, pp. 243-250, June 1996.

[8] M.-J. Tsai, J.D. Villasenor and F. Chen, "Stack-Run Coding for Low Bit Rate Image Communication," IEEE Trans. on CAS for Video Tech., vol. 6, pp. 519-521, October 1996.