DETECTION FROM HYPERSPECTRAL IMAGES COMPRESSED USING RATE DISTORTION AND OPTIMIZATION TECHNIQUES UNDER JPEG2000 PART 2

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ABSTRACT

This paper studies the effect of different bit rate allocation strategies in JPEG2000 part 2 compression of Hyperspectral data on the results of background classification. We compare traditional bit rate allocation approach based on the high bit rate quantizer approach with the Rate Distortion Optimal (RDO) approach that produces a bit rate allocation optimal in the mean squared error (MSE) sense. The experiments show that for relatively low bit rates both rate allocation strategies perform with excellent and almost similar accuracy (96 % at 0.125 bpppb). However at a very low bit rates RDO outperforms (90 % at 0.0375 bpppb) the high bit rate quantizer approach in terms of detection. The experiments also confirm that RDO bit rate allocation achieves a lower MSE than the high bit rate quantizer model approach.

1. INTRODUCTION

The theme of this paper is to investigate two different bit allocation strategies based on their perfomance on background classification over Hyperspectral Imagery. Some of the experiments over the past few years have proved that a good accuracy of the detection results can be achieved with the use of JPEG2000 lossy compression on hyperspectral imagery, therefore lossy JPEG2000 compression becomes useful alternative to the lossless compression for this data.

The paper by Pal, Brislawn and Brumby [3] describes such experiments and compares the classification performance and 3D-SNR of three approaches: the wavelet transform decorrelation, KLT transform decorrelation, and no component decorrelation at different bit rates (from 0.125 to 4 bpppb, where bpppb stands for bits per pixel per band) using the high bit rate quantizer approach. The results were also compared by using different classification algorithms. One of the conclusions obtained in their paper is that KLT

decorrelation approach produces the largest gain (in dB) among the three decorrelation approaches. However in their experiments they do not consider very low bit rates (less than 0.125 bpppb). We incorporate this idea in our research to further investigate the performance of background classification on the recently developed approach to bit rate allocation called as the Rate Distortion Optimal (RDO). In this research we also are performing lossy JPEG2000 compression and applying only the KLT transform decorrelation preprocessing before compressing the data. Since the classification accuracy obtained in [3] is good (99.5 %) even at low bit rates of 0.125 bpppb, we decided to consider low and very low bit rates in our experiments.

For bit rate allocation, we have a choice in what bits we allocate to different bands. The JPEG2000 Part 2 standard (where the 3-D data compression is described), does not specify any particular method (algorithm) for bit allocation. Traditionally, bit allocation is done using the high bit rate quantizer approach that leads to the bit rates computed using logarithms of variances of the bands [7].

The RDO approach was motivated by Post Compression Rate Distortion (PCRD) algorithm used in JPEG2000 for selection of the optimal truncation points for the bit streams of the code-blocks [5]. This approach makes use of experimentally obtained rate distortion curves. It allows optimal bit allocation in terms of minimization of MSE (see Section 3 for detailed description).

After performing the bit allocation by these two different strategies we compare their MSE and background classification performance. In the Section 2 we describe the specifications of the Hyperion instrument and the description of the data which we are using as a case study in our experiments, acquired by this instrument. In Section 3 we review the JPEG2000 compression approach and describe the PCRD approach which serves as a basis for the RDO approach. Section 4 gives an evaluation of the two bit allocation strategies followed by conclusions in Section 5.

2. DESCRIPTION OF DATA

The Hyperion Hyperspectral Imager instrument provides a high resolution hyperspectral image capable of resolving 220 spectral bands (from 0.4 to 2.5 μm) with a 30 meter pixel resolution. The Instrument can image a 7.5 km by 100 km land area per image and provide detailed spectral mapping across all 220 channels with high radiometric accuracy. The Hyperion instrument along with Advanced Land Imager (ALI) instrument (which provides accurate radiometric calibration on orbit using precisely controlled amount of Solar irradiance) is used as an integrated camera system on the Earth Observatory-1 satellite(EO-1) [10].

The analysis of Hyperspectral Imagery by means of such spectrometers (Hyperion) exploits the fact that each material radiates different amount of electromagnetic energy throughout all the spectra. This unique characteristic of the material is commonly known as a spectral signature which can be read using such airborne or space borne-based detectors.

As we are interested in evaluating the performance of background classification, we notice that there are two major applications that use the spectral signature to separate materials (in our experiments they are minerals). They are Classification and Target detection. Classification is focused on assigning each pixel in the hyperspectral image into land cover classes or themes. The central idea of target detection is to search pixels for a presence of a particular material predetermined as a target. Notice that the classification is performed by means of a set of training fields which are circled in white as shown in the Figure 1.

The data used for experiments were collected by the Hyperion over the semiarid Mount Fitton area which is located in the Northern Flinders Ranges of South Australia. Centered at $-29°55'S, 139°25'E$, and about 700 kms NW of Adelaide. This Hyperion image consists of 194 atmospherically corrected contiguous spectral bands. Each band has dimensions of 6702 x 256 pixels.

3. THE RDO APPROACH TO BIT RATE ALLOCATION

In the RDO method ([6], [1]) designed to distribute bit rates optimally among the bands we use the approach similar to PCRD optimization used in JPEG2000 for the selection of the optimal truncation points for the bit streams of the code-blocks [5]. We use the same concepts when we go from single image/bands to multiple images/bands.

In this section we briefly describe the PCRD approach. The JPEG2000 Part 1 baseline or simply JPEG2000 [5] brings a new paradigm to image compression standards. It provides among other advantages superior low bit-rate performance, bit rate scalability and progressive transmission by
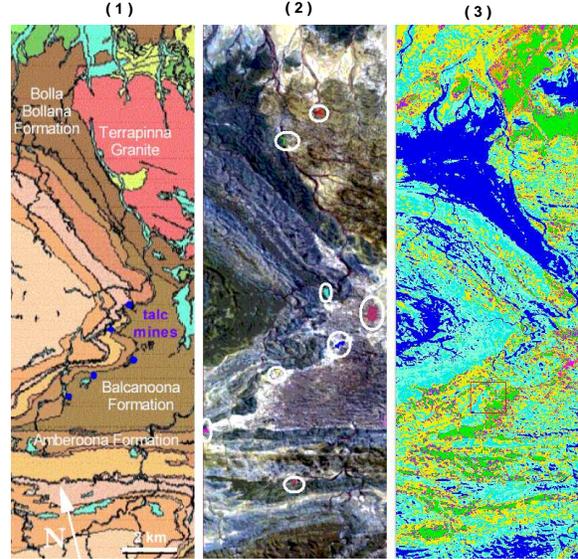
Fig. 1. (1) Published 1:100 000 scale geology [9] of the Mount Fitton test site. (2) Hyperion color composite image showing color-coded training fields. (3) Classified image using minimum Euclidean distance algorithm.

quality or resolution.

Quality scalability is achieved by dividing the wavelet transformed image into codeblocks. After each codeblock is encoded, a post-processing operation determines where each code-block's embedded stream should be truncated in order to achieve a pre-defined bit-rate or distortion bound for the whole image. This bitstream rescheduling module is referred to as the Tier 2. It establishes a multi-layered representation of the final bitstream, guaranteeing an optimal performance at several bitrates or resolutions.

The Tier 2 component optimizes the truncation process, and tries to reach the desired bit-rate while minimizing the introduced distortion, utilizing Lagrangian rate allocation principles.

The following procedure is known as PCRD optimization [5].

Assuming that the overall distortion metric is additive, i.e.,

$$D = \sum_{i=1}^{N} D_i(n_i), \qquad (1)$$

it is desired to find the optimal selection of bit stream truncation points n_i^λ such that the overall distortion metric is minimized subject to a constraint

$$R^{max} \geq R = \sum_i R_i(n_i). \qquad (2)$$

To solve the problem, the Lagrange multiplier method is

used. It leads to the unconstrained optimization problem

$$Q = (D(\lambda) + \lambda \cdot R(\lambda)) \to \min. \qquad (3)$$

The resulting objective function Q depends on N variables n_i, but can be represented as a sum of N terms

$$Q_i = D_i(n_i) + \lambda \cdot R_i(n_i). \qquad (4)$$

Therefore, to minimize the sum, we must find, for each code-block i, a truncation point n_i^{λ} that minimizes the corresponding term Q_i. This fact is a particular case of the general result proven in [4].

The determination of the N optimal truncation points for any given λ is performed efficiently based on the experimental information about rate distortion dependence collected during generation of each code-block's embedded bitstream. Basically, the algorithm finds the truncation points where each rate distortion slope is closest to the fixed λ.

4. EXPERIMENTS AND RESULTS

This section shows the evaluation of two bit rate allocations based on their MSE as shown in Figure 2, and background classifications as shown in Tables 1, 2 and Figure 3. The classification is performed using the Minimum Euclidean Distance algorithm.

The traditional approach (based on the high bit rate quantizer model) is used without the standard constraint which forces bit rates to be integers. Instead, any non-negative bit rate in an acceptable range can be achieved on each slice.

For the RDO approach we generate experimental data for a set of bit rates in an acceptable range (0.0375 bpppb to 2 bpppb) and compute the corresponding distortion (MSE) at each point using the JPEG2000 coder and decoder. Thus, we acquire pairs $(R_z, MSE_z(R_z))$ for each band z. Once the rate distortion curves are determined, the optimal bit rates are determined by finding all the points on rate distortion curves of the same slope such that the corresponding bit rate average is the desired target rate (similar to PCRD approach described in Section 3). Thus for the given average bit rate, RDO provides bit rate allocation that minimizes the MSE. After allocating bits based on the two strategies we perform the classification.

Under the supervised classification task we employ training data in our experiments. The classification algorithm assigns each pixel in the image to one of the classes (determined by the spectral signature of the training fields) using minimum Euclidean distance (between the reference spectra and the image spectra) as a threshold criteria. The training fields were created by selecting eight regions of interest [9]as shown in Figure 1.

Classification was performed using the Minimum Distance classifier wherein the algorithm classifies pixels using

a training class. A pixel is considered in-class if the Euclidean distance from the pixel vector to the nearest class mean vector is the smallest.

Table 1. Results obtained using high bit rate quantizer approach, 0.0625 bpppb. Overall accuracy 93.0415 %

MINERALS	Hits	Misses	False alarm
Al-Poor Mica	97.33	2.67	6.01
Vegetation	98.99	1.01	2.26
Tremolite	95.41	4.59	13.63
Chlorite	87.25	12.75	14.11
Talc	99.08	0.92	9.11
Dolamite	83.02	16.98	3.12
Kaolinite	84.03	15.97	12.23
Al-Rich Mica	97.14	2.86	3.92

Table 2. Results obtained using RDO approach, 0.0625 bpppb. Overall accuracy 93.4861 %

MINERALS	Hits	Misses	False alarm
Al-Poor Mica	97.39	2.61	6.64
Vegetation	97.56	2.44	1.4
Tremolite	91.41	8.59	14.94
Chlorite	90	10	10.71
Talc	96.28	3.72	1.15
Dolamite	82.63	17.37	3.46
Kaolinite	89.95	10.05	11.01
Al-Rich Mica	97.37	2.63	5.85

Figure 2 compares the MSE results for the two rate allocation methods. Notice that at lower bit rates the difference in the MSE's keeps on increasing, with RDO outperforming the traditional approach.

Figure 3 compares the classification performance of the two rate allocation methods. Observe that at lower bit rates RDO comparatively shows better classification performance than the traditional approach.

Table 1 shows the Target Hits, Misses and False Alarm of various minerals detected in the region at 0.0625 bpppb using the Log of Variances rate allocation method.

Similarly Table 2 shows the Target Hits, Misses and False Alarm of the same minerals detected in the region at 0.0625 bpppb using the Rate Distortion Optimal technique. Notice that the overall accuracy of correctly classified pixels using RDO is better than the traditional rate allocation strategy.
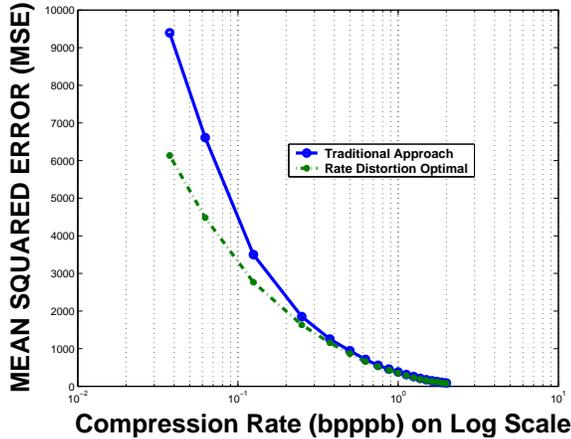
Fig. 2. MSE comparison of RDO vs. high bit rate quantization approach.
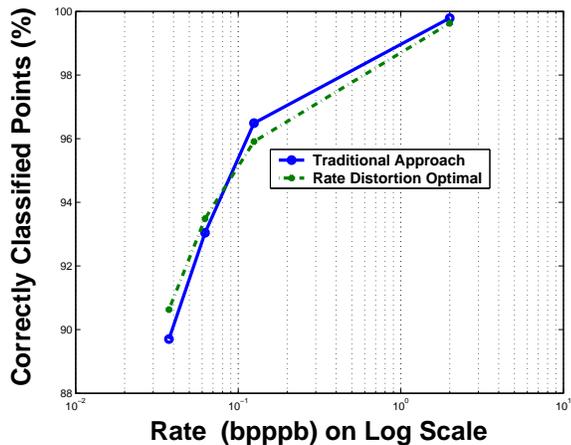

Fig. 3. Detection performance of RDO vs. high bit rate quantization approach.

5. CONCLUSION

The results of this paper shows that at higher bit rates we observe that both rate allocation strategies produce similar detection results. While at lower bit rates Rate Distortion Optimal has better detection performance. It is also observed that the RDO approach has an added advantage of lower MSE over the traditional high bit rate quantizer model approach. This confirms the results from [6] that the high bit rate model approach is not adequate for assigning bit allocation for very low bit rates. The RDO approach allows for the use of the more adequate model with the unavoidable disadvantage of paying a price in terms of implementation complexity.

6. REFERENCES

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