OPTIMIZED RATE ALLOCATION OF HYPERSPECTRAL IMAGES IN COMPRESSED DOMAIN UNDER JPEG2000 PART 2

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Abstract

This paper studies the application of bit allocation using JPEG2000 for compressing multi-dimensional remote sensing data. Past experiments have shown that the Karhunen-Loève transform (KLT) along with rate distortion optimal (RDO) bit allocation produces good compression performance. However, this model has the unavoidable disadvantage of paying a price in terms of implementation complexity. In this research we address this complexity problem by using the discrete wavelet transform (DWT) instead of the KLT as the decorrelator. Further, we have incorporated a mixed model (MM) to find the rate distortion curves instead of the prior method of using experimental rate distortion curves for RDO bit allocation. We compared our results to the traditional high bit rate quantizer bit allocation model based on the logarithm of variances among the bands. Our comparisons show that by using the MM-RDO bit rate allocation method result in lower mean squared error (MSE) compared to the traditional bit allocation scheme. Our approach also has an additional advantage of using DWT as a computationally efficient decorrelator when compared to the KLT.

1 Introduction

The Hyperion (Hyperspectral Imager) provides a high resolution hyperspectral image capable of resolving 220 spectral bands (0.4 - 2.5 μm) with a 30 meters pixel resolution. The data used in these experiments is the Mt. Fitton scene in southern Australia. The layers or bands of this Hyperion data are highly correlated to each other in the spectral direction. Decorrelation of these bands allows a more compact representation of an image by packing the energy into fewer numbers of bands. Part 2 of the JPEG2000 standard recommends the use of either the KLT or the DWT for decorrelation. Past results have shown that the KLT RDO combination works very well for bit allocation [2]. Due to the good accuracy of the results achieved in this method has become a very useful alternative to the lossless compression for this capacious data set. Nevertheless, due to the high computational complexity KLT is not a very attractive option as a decorrelator. Therefore, we use DWT decorrelation instead of the KLT. Our research refers to past experiments [1] which have implemented the mixed model for the bit allocation using the KLT and no decorrelation at different rates.

The high bit rate quantizer model performs bit allocation using the log of variances (of the bands). The major problems of this high bit rate quantizer model are non integer rates, negative allocations and when these are forced to non-negative integer rates it leads to suboptimal solutions. Moreover the present day challenges lies in looking at low and very low bit rates where this model fails. To overcome this our past research [2] implemented the approach of experimentally obtained rate distortion curves, which allows optimal bit allocation with minimized MSE. However, this method has an unavoidable complexity of generating rate distortion curves for each band. This problem is addressed in our current research by using the mixed model which mathematically models each band's rate distortion curves using two distinct regions to get a distortion model that suits both high and low bit rates.

2 Description of Data

The Hyperion instrument can image a 7.5 km by 100 km land area per image and provide detailed spectral mapping

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across all 220 channels with high radiometric accuracy. The Hyperion instrument, in conjunction with Advanced Land Imager (ALI) instrument which provides accurate radiometric calibration on orbit using precisely controlled amount of Solar irradiance, forms the standalone camera system on the Earth Observatory-1 (EO-1) satellite [15]. 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 spectral signature which can be read using such airborne or space borne-based detectors.

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 $-29°55'S$ and $139°25'E$, about 700 kms NNW of Adelaide. This Hyperion image consists of 194 atmospherically corrected contiguous spectral bands. Each band has dimensions of 6702 x 256 [12].

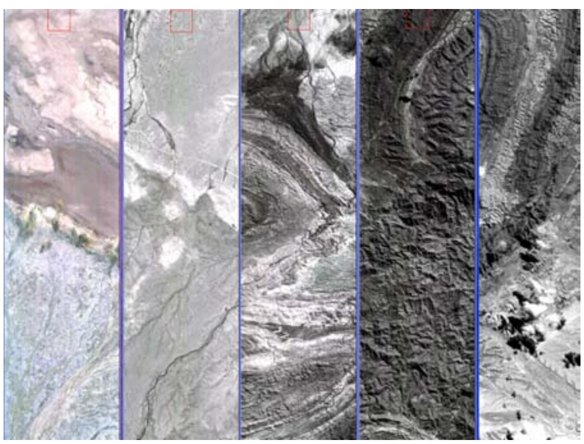

Figure 1. Hyperion color composite image of Mount Fitton test site.

3 The JPEG2000 Standard

The JPEG2000 standard has many advantages compared to the earlier compression standards. Such advantages include superior low bit rate performance, bit rate scalability and progressive transmission by quality or resolution. The coder and decoder for JPEG2000 use a wavelet based compression method which implements the Embedded Block Coding with Optimized Truncation (EBCOT) [4] scheme. Quality scalability is achieved by dividing the wavelet transformed image into code-blocks. After each code-block 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 entire data. This bit-stream rescheduling module is referred to as Tier 2. It establishes a multi-layered representation of the final bit-stream, guaranteeing an optimal performance at several bit-rates or resolutions. Figure 2 illustrates the general flowchart of the JPEG2000 architecture.
The Tier 2 component optimizes the truncation process, and tries to reach the desired bit-rate while minimizing the introduced distortion (MSE), utilizing Lagrangian rate allocation principles. This following procedure is known as Post-Compression Rate-Distortion (PCRD) optimization [4] and the basic principles behind it are extensively discussed in [7].

4 Description of our approach

Due to the computationally inefficient nature of the KLT we employed DWT for decorrelating the bands. The DWT can be implemented by either a convolution or a lifting scheme. We have used the lifting scheme implementation of DWT due to its lesser computations and memory requirements. Here the $9/7$ Daubechies filter is used as we are performing the lossy compression.

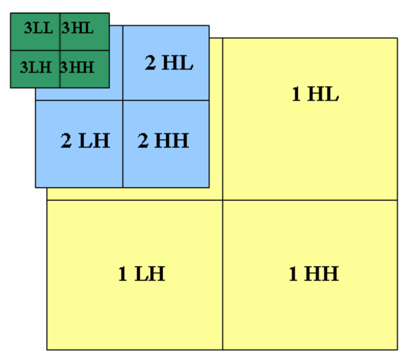

Figure 3. 2-D Wavelet Decomposition

Once the data is decorrelated by the use of the transform, all of the energy or information is packed into just a few bands instead of all the bands. Figure 4 is a hypothetical portrayal of energy distributions: before and after decorrelation. The right plot clearly shows that we cannot just allocate the same number of bits for each band. Assigning the same bit rate for every band neglects the information importance of each band. To avoid this we allocate bits optimally to the separate slices or image bands. The individual bands were compressed and reconstructed depending on the different rate allocation strategies. We performed experiments using several different approaches to bit rate allocation for individual

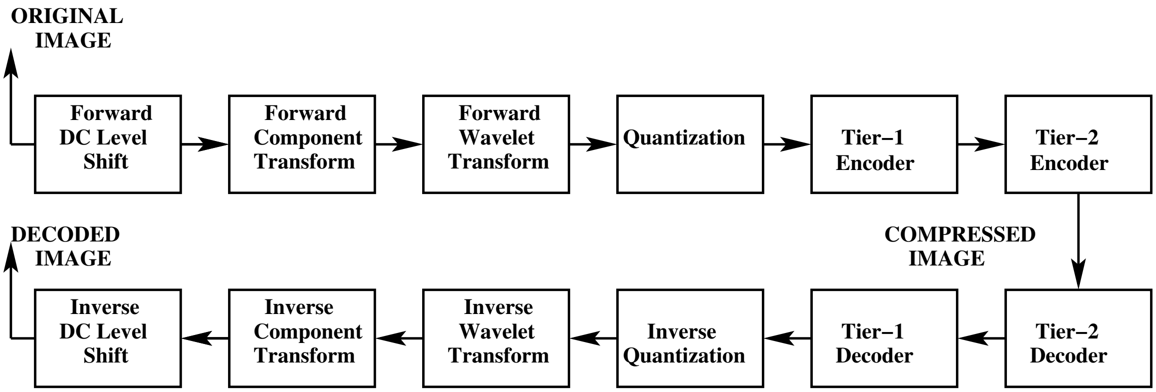

Figure 2. JPEG2000 architectural flowchart

bands. One of them is the traditional bit rate allocation approach based on logarithm of variances of individual bands (see [9] for more details). In this model the MSE's in each band can be approximated as function of rate R and variance σ^2. Assumptions of a high bit rate model lead to a quantizer distortion given by:

$$MSE(R) \cong \sigma^2 \cdot 2^{-2R} \quad (1)$$

where σ^2 is the variance (of the bands) and R being the average rate for each band.

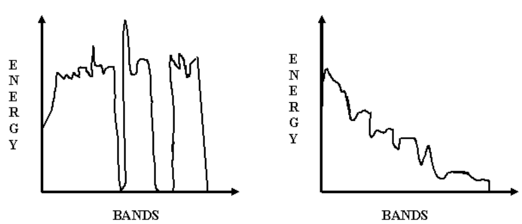

Figure 4. Original band energy Vs. Transformed band energy

The traditional or the log of variances bit allocation scheme is not fully compatible, since this high bit rate quantizer distortion model breaks down at low bit rates. Instead we use the mixed model and the RDO [8], which is based on post compression rate distortion (PCRD) extensively used in JPEG2000, for bit allocation. Our research implemented the RDO by using RD curves that have been obtained by using the mixed model. The mixed model is essentially a hybrid splicing of the low and the high bit rate models. The low bit rate of the model follows the results of Mallat and Falzon [5] . Past research [1] tried modifying this so that we can make it work for our problem incorporating lower bit rates [1]. The relation between the MSE and the bit rate corresponding to the information about the data can still be described by a modified Mallat-Falzon model,i.e.,

$$MSE(R) = \begin{cases} A\frac{1}{(R+R_o)^\alpha} & \text{if } R \leq \tilde{R}, \\ B \cdot 2^{-2R} & \text{if } R \geq \tilde{R} \end{cases} \quad (2)$$

where A, R_o, α come from the low rate model and B which is nothing but the variance of each band is the parameter from the high rate model (same as 1). To find R_o, we use the fact that the MSE of each band is nothing but its entropy when $R_o = 0$. $\tilde{R}$ is the cross over bit rate between the low and the high rate models. The determination of these mixed model parameters are derived in [1].

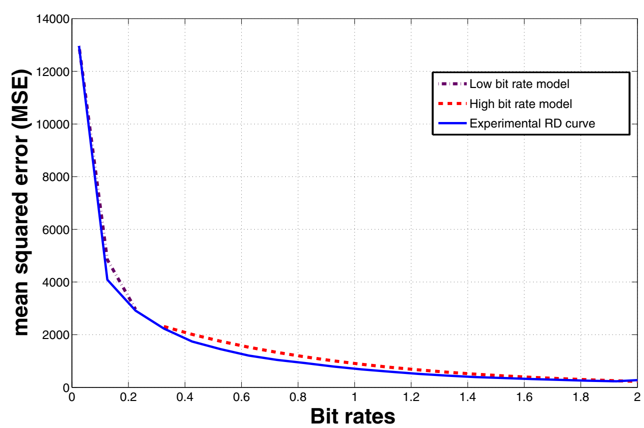

Figure 5. Comparison of experimental RD curve with Mixed model. Notice that the hybrid splicing of mixed model shown as 2 dotted curves is close to the RD curves (solid lines) obtained experimentally.

Advantages of the mixed model approach are that it can give performance nearly identical to the RDO approach with a much lower implementation complexity. Here we have generated this approach for the data at bit rates in the range 0.0375 bpppb to 4 bpppb (where bpppb stands for bits per pixel per band) and further compute the corresponding distortions (MSE) at each average bit rate using JPEG2000 coder and decoder. Results show that the mixed model approach gives distortion results that are nearly identical to the RDO approach on this data, while significantly reducing complexity of implementation. We notice from Figure

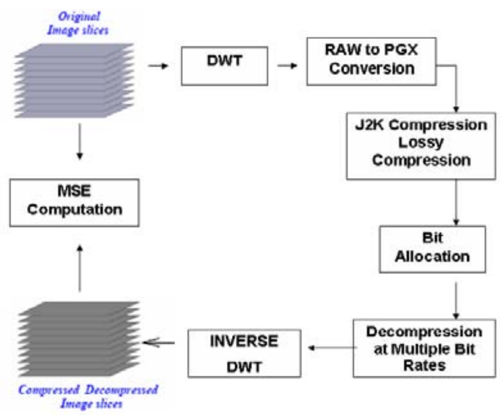

Figure 6. 2-D band-wise compression.

5 that the mixed model approach gives distortion results that are nearly identical to the experimental RDO approach on this data, while significantly reducing the complexity. Further, our experiments are performed as shown in Figure 6. Each band of the Hyperspectral cube were compressed at 16 bpppb and decompressed at bit-rates obtained from the two bit allocation schemes. Next we computed the MSE's by comparing the original set of bands to the compressed decompressed bands for the given set of average bit rates.

5 Results

Figure 7 shows a comparison of MSE's obtained for each average bit rates corresponding to traditional and the MM-RDO bit allocation schemes using DWT as a decorrelator. Our results confirm that MM-RDO has lower MSE's compared to the traditional model. Moreover, MM-RDO when used in conjunction with DWT as decorrelator further produces lower MSE's compared to KLT decorrelation with traditional bit allocation for lower bit rates. Figure 8 shows a comparison our past experimental results [2] that employed KLT docorrelation followed by RDO bit allocation with the present DWT mixed model. In spite of KLT's advantage of an optimum compaction transform, the DWT manages to match up with its MSE performance and also does slightly better compared to the KLT traditional bit allocation in the low bit rate region as seen in Figure 8.

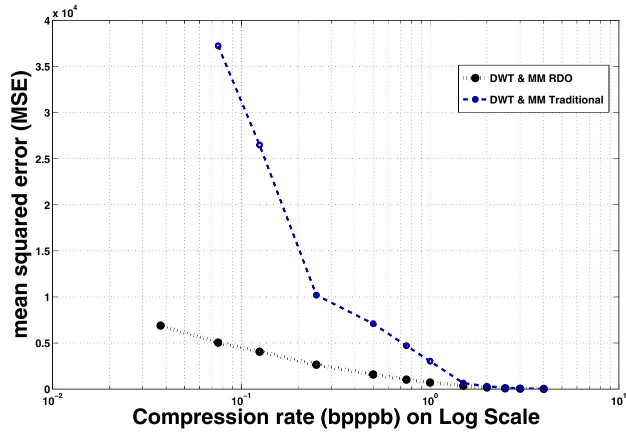

Figure 7. MSE comparison of mixed model RDO and the high rate quantizer model.

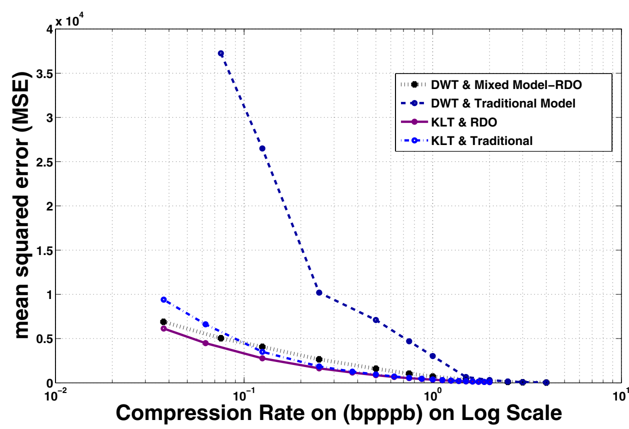

Figure 8. MSE comparisons of DWT mixed model, DWT traditional model, KLT RDO and KLT traditional model.

6 Conclusions

In the case of KLT the computation time and memory requirements is very high (about 8 times higher) when compared to DWT. One other main advantage of DWT, that it allows to divide a huge data set into parts and pre-process each of these independent of the other. This enables parallel processing which cannot be done with KLT. At higher bit rates we observe that both rate allocation strategies produce similar MSE results. The rate distortion curves obtained from the Mixed Model are very close to the R-D curves obtained experimentally. The Mixed Model and RDO approach gives lower MSE than the traditional model and also slightly out performs our past KLT traditional method at lower rates.

However, we do see that KLT-RDO provides lower MSE's in most cases compared to the present DWT approach. This is because of the fact that the KLT is a better decorrelator than a DWT. The KLT is theoretically the ideal transform and is expected to give better results for both classification performance and compression. Nevertheless, its biggest disadvantage is that it is computationally expensive.

7 Acknowledgment

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