Analysis of CCSDS-ILDC for Remote Sensing Data Compression[1]

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Abstract: This paper deals with the encoding of high resolution images for remote sensing and geographic information systems applications. We are currently investigating the suitability of several still image coding techniques for this kind of applications. We present results for an adapted and modified version of the CCSDS-ILDC technique. In addition to evaluate its compression factor and quality of recovery with respect to the latest still image coding standard JPEG2000, we also consider whether this technique may fulfill the particular functionalities requested by remote sensing users.

Key-Words: Lossy Data Compression, CCSDS-ILDC, JPEG2000, DWT, Remote Sensing, High Resolution Images, Geographic Information Systems

1 Introduction

In relation to Remote Sensing (RS) and Geographic Information Systems (GIS) applications, multispectral and hyperspectral images have been successfully used for, among many others, image classification and segmentation. Nevertheless, inherent to these images is their huge size, so that it seems reasonable to look for a compression approach both for storage and transmission scenarios.

Approaches based on the Discrete Wavelet Transform (DWT): EZW [10], IC [12], SPIHT [7], and JPEG2000 [11] for lossy encoding natural and hyperspectral images have been recently reported [9]. However, among the revised techniques, results are not always compared within the same setting, or techniques are not always applied to the same corpus of test images. To overcome this impediment, and to take into account the particular features requested by RS and GIS applications, we are currently developing a unified framework to comprehend all these requirements [8].

The ultimate goal is to design and implement a coding system with the following capabilities: high compression ratios; monoband and multiband compression; regions of interest support; lossy to lossless compression; high speed of data recovering in any image area; fast and efficient zoom and panning; respect of no-data regions; and watermarking.

2 Still Image Coding

The components of the encoder in a typical lossy compression system consist mainly of six basic stages: first, a pre-processing stage, where a color model conversion or a dimension reduction is performed if needed. Second, a transform is applied to the pre-processed data in order to obtain de-correlated coefficients and a higher compactness of energy in a few coefficients. Third, a quantization stage removes information considered unnecessary for user purposes. Fourth, a bit plane encoding is applied to account for the significance of the quantized coefficients and to allow for an embedded encoding. Fifth, an entropy coding scheme such as Huffman coding or arithmetic coding is used to reduce the amount of bits needed to send the significant quantized coefficients through the transmission channel. Last, a post-processing stage as a post compression rate distortion may be carried out. At the receiver side, the decoder performs the inverse operations in reverse order. The overall goal is to produce a recovered image as close as possible to the original image while preserving the bit rate needed to transmit the compressed stream as low as possible.

Table 1 presents a comparison of some of the most used products in the Remote Sensing and Geographic Information Systems communities. We analyze here their suitability for fulfilling the desired features. Besides of JPEG2000, the tools considered are: Enhanced Compressed Wavelet (ECW) from ER Mapper (http://www.ermapper.com), MultiResolution Seamless Image Database (MrSID) from LizardTech (http://www.lizardtech.com), and last a Geographic extension of the Tag(ged) Image File Format (GeoTIFF), a completely open, public domain, and non-proprietary format. As may be appreciated, it seems that the single standardized technique that may incorporate most of the RS and GIS requirements is JPEG2000, the last international standard designed and developed by the

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image coding community.

With this consideration in mind, we are currently developing a unified framework for designing and implementing still image coding algorithms, in order to evaluate whether other well-known coding techniques may be an alternative to the proposed standard JPEG2000. Our application is mainly intended to lossy compress natural, multispectral and hyperspectral images. Table 2 shows the already implemented methods. With the exception of JPEG2000, some of the most important techniques used in image compression schemes have already been implemented and tested.

2.1 CCSDS-ILDC

Following this motivation, we study here the capabilities of another technique in restricted computational scenarios. Some applications use scanning sensors that create images (possibly unconstrained in length) row by row and have limited amounts of processing memory. These applications need full scan-based coding where only the minimum number of bytes is retained in memory at any given time without significant loss in performance. Example implementations of such a scan-based coding systems have been demonstrated [5, 2].

The first of such approaches conforms to a Recommendation of the Consultative Committee for Space Data System Standards (CCSDS) [1]. The main goal of such Recommendation is to provide a common data compression algorithm, pointed to Image Lossy Data Compression (ILDC), to be used by the different CCSDS-related agencies. One of the advantages of this method is the adaptation to the memory limitation required to the management of data in satellites, remote sensing applications, etc, working with data using a local working memory.

CCSDS was created on 1982. It is composed of significant space agencies and industrial associates worldwide, working together to provide well-engineered, standardized solutions for common space data handling needs. To date more than 250 missions have elected to fly with CCSDS protocols and realized the benefits: reduced cost, risk and development time, as well as enhanced interoperability and cross-support.

The coding scheme of the CCSDS-ILDC Recommendation is the following: a wavelet transform to decorrelate coefficients, a rearrangement of coefficients in blocks and a bit plane encoding step that includes (unlike EZW, SPIHT or JPEG2000) an own entropy coding. The appropriate wavelet transforms to this method are the 9/7 and an integer modified version of 9/7M DWT. In both cases, it should be a three level wavelet transform. To avoid buffering overhead, there is a variant of the wavelet transform called the Local Wavelet Transform (LWT). LWT does not implement the transform in the whole image but on the minimum coefficients needed to obtain a 8x8 block, according to the family tree structure shown in Fig. 1. The number of blocks to be processed together is determined depending on the available RAM memory; the set of these blocks is called a segment (see Fig. 2). As soon as a whole segment is completed with the blocks obtained from the LWT, it is processed by the bit plane encoder.

The first value in each block, called DC component, is expected to be the most significant coefficient. In fact, all DC components corresponds to the residual subband where the energy of the image is concentrated. Thereby, DC components in each segment are coded separately of the rest of the components (called AC values) and are the first values to be transmitted. Nevertheless, only the most significant bits are coded, the rest of the bits will be coded with the rest of the values of the image. Significant DC bits are those such that there exist an important difference between them and the maximum bit in AC values. Shifted DC values (the most significant bits) are passed through a nearest neighbor predictor (DPCM operation) and a k-sample split entropy code (fundamental sequence or comma code).

To obtain the coded output stream for each bit plane, all the family tree structure of every block in the segment is scanned. Each bit plane defines a threshold. Coefficients greater than or equal to this threshold, but smaller than the previous threshold, are called significant. The significance of a coefficient is signaled with a single bit.

The processing of the AC components is based on patterns. According to the family tree structure of a block, we consider the following sets: 3 parents, 3x4 children and (3x4)x4 grandchildren, each one signaled by a pattern. For example, the pattern corresponding to parent coefficients indicates whether each parent in the block is significant or not. But these are not the only patterns. In order to avoid coding non significant descendants, there exist auxiliary patterns that indicate which family has significant coefficients and, if needed, which set of children and grandchildren has to be scanned. Once a coefficient is found to be significant, it will not be considered again. In this way, we obtain 4, 3, 2 and 1 bit patterns in each bit plane in a block, according to the set represented and the previous scanned values. Encoding AC components is, in fact, encoding such bit patterns, using a mapping function (depending on the different probability density function of each pattern) and an optimal entropy coding by truncated sample split code.

Coded data in each block and each bit plane is organized and interleaved. The output data is not organized by blocks but by bit planes, in order to first send the values corresponding to higher bit planes. Just before starting to code a new bit plane, least significant DC bits are appended when needed, then the coding proceeds by sending bits corresponding to the significance assessment, and afterwards follow the refinement bits of previous bit planes.

Notice that this method of bit plane encoder is also embedded and based on entropy coding. In this case, nevertheless, the entropy coding is specific for the output data stream and the methods used are based on sample split code. Due to the fact that the encoder has to compare and select the optimal k-sample split code (for the DC values) and has to select the truncated sample split code (for the bit patterns) and it has to signal these choices to the decoder, the coder algorithm is computationally more complex than the decoder one, although the decoder algorithm may require less memory than its coder counterpart (the coder algorithm is block-oriented, but the decoder algorithm is segment-oriented).

To simplify the two commented selections, we have implemented two estimators in the case of k-sample split code for DC values and we are trying to obtain a good one in the case of truncated sample split code.

Even though the scanning of family tree structure is similar to the EZW bit plane encoder, the significance of a coefficient is established like in the SPIHT method. In CCSDS-ILDC, on one hand we analyze the significance of a coefficient and, on the other hand, we analyze the significance of its descendants.

CCSDS-ILDC was especially motivated for panchromatic images (monoband) by the need of a dual operating mode: low compression ratio (3 or 4 at most, quasi-lossless mode) for ordinary situations; and higher compression ratio (10 or more) for emergency situations, in which monitoring of large regions was required. Nevertheless, due to its promising performance for much larger compression ratios, we are now investigating extensions of this technique to any number of DWT decomposition levels. Results obtained are reported in the following section.

2.2 JPEG2000

The second approach of a scan-based coding system conforms to the International Standard JPEG2000 [3], which defines a set of lossless and lossy compression methods for coding many kinds of images, among which, remote sensing images. JPEG2000 is the most recent standard developed by the Joint Photographic Experts Group, intended as the successor to classical JPEG, and motivated primarily by the need for compressed image representations which contemplate a whole range of requirements that no other coding technique or commercial format has considered.

A scan-based approach of JPEG2000, where a row-based transform is followed by a scan-based rate allocation, may also be devised. We are still implementing Part 1 of the standard, but with the objective of considering a scan-based approach, and also of implementing Part 9, JPIP or JPEG2000 Internet Protocol, that seems well fitted to the particular requirements of RS and GIS applications.

3 Experimental Results

Extensions to the original CCSDS-ILDC technique have been implemented in JAVA language and incorporated to our unified framework. In order to compare the results obtained, we also provide results produced by SPIHT (own implementation) and by the new Joint Photographic Experts Group 2000 (JasPer JPEG-2000 Encoder, version 1.700.5, compliant with ISO/IEC 15444-1, i.e., JPEG-2000 Part 1, 25 December 2001). All techniques have been tested on a Linux platform.

Evaluation of the different coding techniques is performed based on the trade-off between the compression ratio (given in bits per pixel, bpp), and the quality (given in PSNR). The Peak Signal to Noise Ratio (PSNR), is a measure accounting for the similarity between the original image I and the recovered image I^*, given in dB; for images with a B bpp resolution, $PSNR = 10\,log_{10}\frac{(2^B-1)^2}{MSE}$, where the Mean Square Error (MSE) is given by $MSE = \frac{1}{N_x}\frac{1}{N_y}\sum_i^{N_x}\sum_j^{N_y}(I_{ij}-I^*_{ij})^2$.

3.1 Landsat Image

The Landsat Program is a joint effort of the U.S. Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA) to gather Earth resource data using a series of satellites. NASA was responsible for developing and launching the spacecrafts. The USGS is responsible for flight operations, maintenance, and management of all ground data reception, processing, archiving, product generation, and distribution. A primary objective of the Landsat Program is to ensure a collection of consistently calibrated Earth imagery. The Landsat Project is the longest-running enterprise for acquisition of moderate resolution imagery of the Earth from space. The Landsat 1 satellite was launched in 1972; the most recent, Landsat 7, was launched in 1999. The instruments on the Landsat satellites have acquired millions of images.

The chosen images taken for the experiments correspond to a Landsat 7 flight on 19 May 2002. The sensor producing these images is an Enhanced Thematic Mapper Plus (ETM+). The ETM+ instrument provides image data from eight spectral bands. The spatial resolution is 30 meters for the visible (band 1: blue; band 2: green; band 3: red), for the near-infrared (band 4), and for the mid-infrared (bands 5 and 7); resolution for the thermal infrared (bands 6 and 9) is 60 meters. The sensor also allows a panchromatic band (band 8) with 15 meters resolution. The satellite orbits at an altitude of 705 km and provides a 16-day, 233-orbit cycle.

The original images belong to path 197 and row 31. They are 11292 columns times 13350 rows of spatial size, but they have been cut off to 2048 times 2048 pixel scenes, with 8 bits per pixel resolution. Images have been ortocorrected and an atmospheric correction has also taken place. Compression experiments have been carried out on all eight spectral bands.

Fig. 3 shows the rate distortion curves obtained for all three visible bands for bit rates running from 0.008 bpp (compression ratio 1024:1) to 1 bpp (compression ratio 8:1). Fig. 4 shows the rate distortion curves obtained for all three infrared bands for the same bit rates.

The figures plot results obtained with the 5 level 9-7 Discrete Wavelet Transform.

The results achieved for the implemented embedded codecs: SPIHT and CCSDS-ILDC, as well as for JPEG2000 standard (Jasper implementation), are very similar from low bit rate (1 bpp, compression ratio 8:1) to very low bit rate (below 0.1 bpp, compression ratio 100:1 or higher). This is consistent with results applied to different corpora of images, as reported elsewhere [9].

Fig. 5 displays achievements of CCSDS-ILDC for several DWT decomposition levels for the two thermal infrared bands. The original Recommendation only considers 3 levels, which is appropriate for moderate bit rate transmission. When the compression ratio has to be increased, it pays off to extend the method to 5 decomposition levels.

We are still discussing the obtained results with a group of GIS experts who will perform both a visual analysis and a digital analysis to establish the proper quality of such coding techniques. Their criteria and statements will be more meaningful than a simple MSE-like measure.

4 Conclusion

High resolution images are a growing source of data for applied technologies involving scientists from a broad range of disciplines. Because of the increasing use of these applications, and the huge size of the images they manage, a compression process of these images has to be adopted before transmission or before storage. Lossy coding is preferred over lossless coding (see [4]) to account for a higher compression ratio, but assuring at the same time a high quality image recovering.

Remote sensing and geographic information systems are examples of such applications, since they use hyperspectral images of huge size and high bit per pixel, spatial, and spectral resolution. These applications have some specific demands that are not addressed by the commonest still image coding techniques, so that new paradigms have to be devised.

This paper provides an experimental evaluation of a modified version of the CCSDS-ILDC Recommendation. This technique was originally intended for low compression ratios, but its promising performance has led us to extend the predefined 3-level DWT to any number of decomposition levels, to account for a competitive coding performance at much higher compression ratios when compared to other well-know lossy coding techniques as SPIHT and JPEG2000.

All these image coding algorithms are based on the wavelet transform. Wavelet or subband image coding is an efficient method of image compression, because subbands of the same level have little interband correlation. However, some spatially varying interband energy dependence is often visible in an image subband decomposition across the levels (or scales) of the wavelet pyramid. All reviewed methods are motivated by such significant statistically dependence and all yield an embedded encoder, which fits nicely with the following requirements of RS and GIS applications. At least JPEG2000 and CCSDS-ILDC may provide high compression ratios; monoband and multiband compression; regions of interest support; lossy to lossless compression; high speed of data recovering in any image area; and fast and efficient zoom and panning. We have to note that the freely available Kakadu implementation of JPEG2000 by D.Taubman (http://www.kakadusoftware.com/) does already provide such capabilities.

Although the analyzed wavelet-based methods present important structural differences, experimental results carried out on Landsat images show that all the techniques produce similar performances from very low bit rate (0.0078125 bpp, compression ratio of 1024:1) to low bit rate (1 bpp, compression ratio of 8:1).

In regard to future research, and concerning the reviewed techniques, it is our interest to: a) investigate JPEG2000, in particular Part 9 of the proposed standard; b) adapt CCSDS-ILDC to readily provide most of the desired features, as JPEG2000; and c) review SPIHT, because it is the single technique that produces competitive results without the expensive arithmetic coding step, as has been demonstrated in [13]. We should also state that we have not addressed here the performance of the currently recognized state-of-the-art still image coding technique [14], nor the impressive results of the recent [6].

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Table 1: Common Remote Sensing and Geographic Information Systems products.

	ECW	**MrSID**	**GeoTIFF**	**JPEG2000**
Price	Free to 21 *k*€	2.9 *k*€ to 4.9 *k*€	Free	155 *k*€ to 6.8 *k*€
Compression ratios	10:1 to 50:1	n.a.	n.a.	any
Mono/multiband compression	gray and RGB	n.a.	gray and RGB	yes
Lossy to lossless	lossy	lossy or lossless	n.a.	yes
Region of interest	n.a.	n.a.	n.a.	yes
Zooming and panning	n.a.	yes	no	yes
Random access	n.a.	yes	no	yes
Respect of no-data regions	n.a.	n.a.	n.a.	n.a.
Watermarking	n.a.	yes	no	yes

Table 2: Implemented methods in our application.

Stage	**Implemented**	**Foreseen**
Pre-processing	Color Convers., Level Shift, Normalization	
Transform	DWT: Haar, Shore, D4, 5/3, 9/7, 9/7M, Integer	Local DWT, DCT
Quantization	Scalar quantization, Lattice Vector Quan.	Embedded LVQ, Trellis
Bit Plane Encoding	EZW, IC, SPIHT (1-D, 2-D), CCSDS-ILDC	JPEG2000, 3-D SPIHT, SBHP
Entropy Coding	Arithmetic coding	Huffman, Golomb-Rice
Optimization	Bit Allocation	

Figure 1: 8x8 block obtained from the tree structure for CCSDS-ILDC.

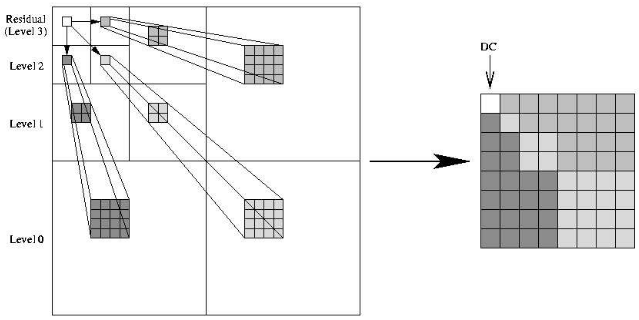

Figure 2: A segment in CCSDS-ILDC is the input data to be processed by the bit plane encoder.

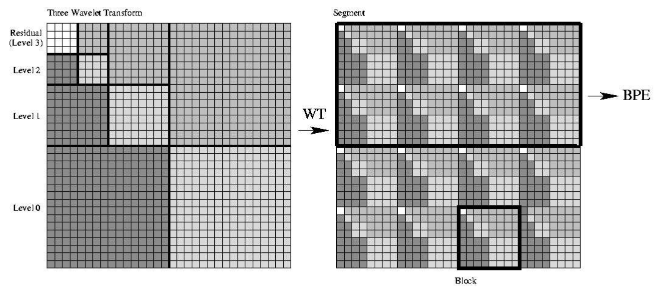

Figure 3: Rate-distortion curves for 2048×2048 Landsat Image. Visible bands.

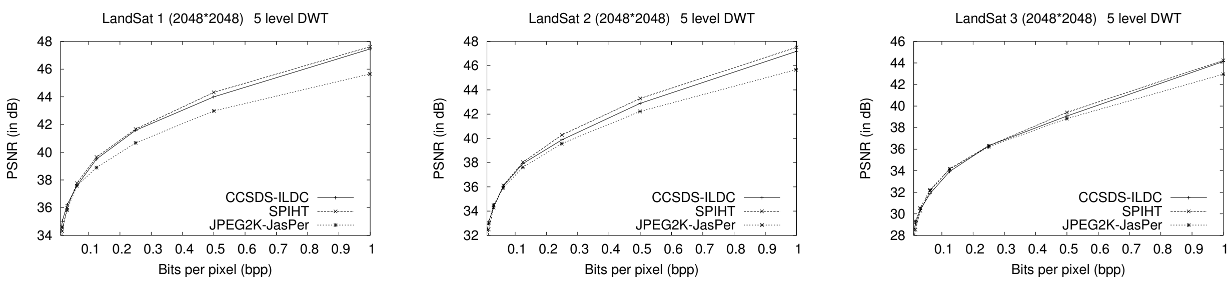

Figure 4: Rate-distortion curves for 2048×2048 Landsat Image. Infrared bands.

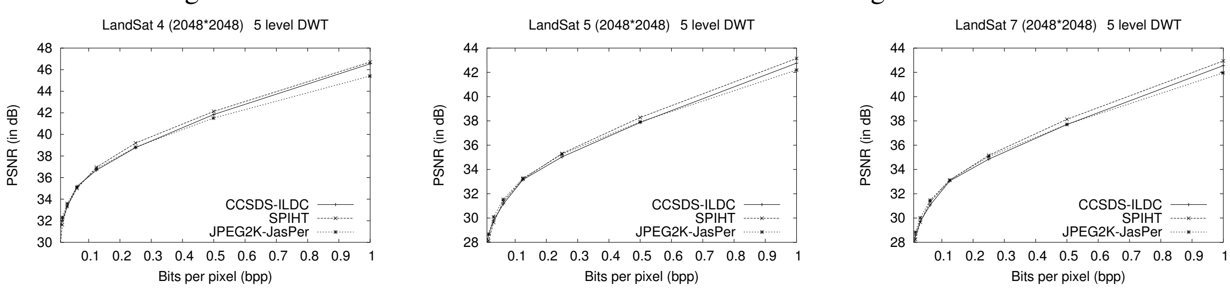

Figure 5: Rate-distortion curves for 2048×2048 Landsat Image. Thermal bands. DWT decomposition levels.