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# COMPRESSION THROUGH DECOMPOSITION INTO BROWSE AND RESIDUAL IMAGES


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**Abstract.** Economical archival and retrieval of image data is becoming increasingly important considering the unprecedented data volumes expected from the Earth Observation System (EOS) instruments. For cost effective browsing the image data (possibly from remote sites), and retrieving the original image data from the data archive, we suggest an integrated image browse and data archive system employing incremental transmission.

We produce our browse image data with the JPEG/DCT lossy compression approach. Image residual data is then obtained by taking the pixel by pixel differences between the original data and the browse image data. We then code the residual data with a form of variable length coding called diagonal coding.

In our experiments, the JPEG/DCT is used at different quality factors (Q) to generate the browse and residual data. The algorithm has been tested on band 4 of two Thematic Mapper (TM) data sets. The best overall compression ratios (of about 1.7) were obtained when a quality factor of Q=50 was used to produce browse data at a compression ratios of 10 to 11. At this quality factor the browse image data has virtually no visible distortions for the images tested.


## 1. Introduction

Economical archival and retrieval of image data is becoming increasingly important considering the unprecedented data volumes expected from the Earth Observation System (EOS) instruments. The challenges EOS present to the information scientist are providing a cost effective mechanism for: (i) browsing the image data (possibly from remote sites), and (ii) obtaining the original image data from the data archive. We suggest that these two mechanisms be integrated, *i. e.*, the lossless image data should be reconstructed from the browse image data by incremental transmission.

The data archive's integrity is maintained as long as every bit of the original image data can be reliably reconstructed from compressed form without loss. Nevertheless, lossless compression is not very effective in reducing data volume. Maximum compression ratios of 2.0 to 2.5 are typical for the type of image data expected from EOS instruments. Lossy compression, on the



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other hand, can typically provide compression ratios of as high as 30 to 50 without significant visible degradation of the image data. However, because the original image data cannot be perfectly reconstructed from this highly compressed data, it can only be used for data browsing and, possibly, certain preliminary analysis.

In most data archive schemes, highly compressed data is kept in on-line storage and used to efficiently browse the data to determine potentially useful data set(s) for further processing. Once this decision is made, the original data is obtained from off-line storage. The browse quality image data and the corresponding original image data contain redundant information, causing a fraction of the information to be transmitted twice.

If incremental data is stored off-line instead of original data, data transmission to users can be made more efficient. In this approach the image data is decomposed into browse and residue so information is not duplicated either in data archival or in transmission to users across the computer networks.

In this paper we address the problem of decomposing image data into browse and residual data in a manner that is most appropriate for image data archival. Browse data should take only a small fraction (typically 1/30 to 1/50) of the storage required for original data with quality that is adequate for deciding whether the data is useful or not for an intended application. The residual data, normally kept off-line, should have relatively high compressibility using a carefully designed lossless compression technique. Thus, the key problems are to select a lossy compression approach that provides the best compression with quality that is nearly lossless visually, and to select the most effective lossless compression approach for the residual. In addition, we also determine the browse data compression ratio that leads to the best overall compression.

## 2. JPEG/DCT Approach for Browse Quality Image Generation

Any of several lossy compression techniques, such as subband/wavelet coding and vector quantization, could be used to produce the browse quality image. We chose to use the JPEG/DCT lossy compression approach for the following reasons.

i. The JPEG/DCT lossy compression approach has become an industry-wide standard compression approach.
ii. Special hardware boards are available commercially for various machines including the ubiquitous IBM/PC.
iii. The image quality of the browse data can be fine tuned until it is visually lossless.

JPEG lossy compression is based on the Discrete Cosine Transform (DCT) of 8x8 blocks of the input image [1-2]. In the encoding process, the samples in the input image are grouped into 8 x 8 blocks, and each block is transformed by the forward DCT (FDCT) into a set of 64 coefficients referred to as the DCT coefficients. The first coefficient corresponds to the DC coefficient, and the remaining 63 are AC coefficients. Each of the AC coefficients is then quantized using one of 64 corresponding values from a quantization table. The DC coefficients of different blocks undergo differential coding. The AC coefficients are then ordered by a one-dimensional zigzag sequence. Finally, the quantized coefficients are compressed using either a Huffman table or arithmetic coding.

The baseline JPEG/DCT accepts 8-bit images and uses two Huffman tables for coding DC and AC coefficients. However, the other JPEG lossy standards allow 8-bit to 12-bit precisions with either Huffman or arithmetic coding of coefficients. At the decoding end the 64 coefficients are used to reconstruct 8 x 8 coefficient image which then is mapped back to image space by Inverse DCT (IDCT).

JPEG/DCT approach provides a fine tuning factor, $Q$, which corresponds to different qualities of the compressed images. For typical NASA image data, a low value of $Q$, such as 20, provides high compression with poor image fidelity. As the $Q$ factor increases the fidelity improves at the expense of compression ratio. For $Q$ = 80, the compressed images are generally visually indistinguishable from the input images, with a compression ratio typically in the range of 6.0 to 7.0. For data from the Landsat TM instrument, a general image quality rating for different $Q$ values and corresponding compression ratios ($C_R$) is:

| $Q$ | $C_R$ | Image Quality |
|---|---|---|
| 25 - 40 | 25 - 12 | moderate to good quality |
| 40 - 70 | 12 - 8 | good to very good quality |
| 70 - 80 | 8 - 6 | excellent quality |
| 80 - 90 | 6 - 4 | indistinguishable from original |

Several EOS instruments are expected to have a dynamic range of 0 - 4095, that is, the pixel brightness level can be represented by 12 bits. However, the human perceptual system cannot even resolve 256 gray scale levels (*i. e.*, a range of 0 - 255), which can be represented by 8 bits. Therefore, the first stage of producing the browse data can be described as follows: Determine the actual dynamic range of the data (which can be less than, but no more than 12 bits), and retain only the 8 most significant bits in that dynamic range. Then compress this 8-bit data with JPEG/DCT at the optimal quality factor. For lossless compression, the remaining bits, as well as the residual from JPEG compression are separately compressed using an appropriate lossless compression approach. Such an approach is described in the following section.

## 3. Residual Compression using Diagonal Codes

Residual image data is that which is obtained through taking the pixel by pixel differences between the original data and the image reconstructed after lossy compression. We have observed that the residual image data obtained from JPEG/DCT compression is low entropy data that is compressible to a greater degree than the original image data. The better the browse data approximates the original data, the more compressible is the residual image data. Thus, a better quality browse results in a residual that can be compressed better in lossless mode.

However, a better quality browse image requires more bits per pixel. Since the overall lossless representation is sum of the bits per pixel for browse data and residual data, producing maximum overall lossless compression requires finding the optimal balance between the bits allocated to the browse data and the bits consequently required for the residual data.

For remote browsing applications, the browse data bit rate (bits/pixel) must be kept very low to ensure efficient transmission of the data across the computer networks. This requirement leads to choosing the lowest JPEG/DCT quality factor without significant visual degradation of the reconstructed image data, which we have found to be a quality factor of about 50. Fortunately, our experiments have found that a quality factor of about 50 also corresponds closely to the browse bit rate that produces the optimal overall lossless compression in combination with the residual image data.

The residual image data exhibits a Laplacian distribution with a smaller variance of data values than the original image data. This property suggests that a form of variable length encoding would be most appropriate for lossless compression of this data. We have found specifically that a type of variable length encoding, called diagonal coding [3,4], is most appropriate.

For images with $n$ bits/pixel, straightforward representation of the residual image data requires $n$+1 bits. However, through using Golomb codes [5], the residual data requires just $n$ bits/pixels (prior to diagonal coding).

In our approach, the residual image data is divided into two parts. The first part contains the lower order two bits, while the second part contains the remaining higher order six bits. The frequency distribution of the lower order bits exhibits no particular structure, and thus can be compressed very little. However, the frequency distribution of the higher order bits exhibits a narrow Laplacian distribution. For this type of distribution, Rice, *et. al.*, [3] have shown the diagonal code is asymptomatically optimal. In this code, each value is represented by number of zeros corresponding to that value, terminated by a one. For six bit data, the diagonal code for "000101" is "000001", and the diagonal code for "010100" is "000000000000000000001." Since higher values in the residual data occur less frequently, this code turns out to be optimal. This representation is very efficient for coding as well as decoding.

The diagonal code we propose is as follows. The frequency distribution is divided into sets of four pixels centered about the zero axis such that each set contains two negative and two positive residual values except the first one that contains zero. If the residual value belongs to set 1, it is represented by 1, if the value belonged to set 2, it is represented by 01, if the value belongs to set 3, it is represented by 001, and so on. In general, if the residual value belongs to $i^{th}$ set, the representation is series of $i$-1 zeros followed by 1. Typical sets and their representations are shown below:

| Set | Range | Diagonal code | |
|---|---|---|---|
| 1 | (-1,0,1,2) | = 1 | followed by two bits for identification of actual value |
| 2 | (-2,-3,2,4) | = 01 | |
| 3 | (-5,-4,5,6) | = 001 | |
| 4 | (-7,-6,7,8) | = 0001 | |
| 5 | (-9,-8,9,10) | = 00001 | |
| 6 | (-11,-10,11,12) | = 000001 | |
| 7 | (-13,-12,13,14) | = 0000001 | |
| 8 | (-15,-14,15,16) | = 00000001 | |
| 9 | (-17,-16,17,18) | = 000000001 | |
| 10 | (-19,-18,19,20) | = 0000000001 | |
| 11 | (-21,-20,21,22) | = 00000000001 | |
| 12 | (-23,-22,23,24) | = 000000000001 | |
| 13 | (-25,-24,25,26) | = 0000000000001 | |
| 14 | (-27,-26,27,28) | = 00000000000001 | |
| 15 | (-29,-28,29,30) | = 000000000000001 | |
| 16 | (-31,-30,31,32) | = 0000000000000001 | |

## 4. Experimental Results and Conclusions

We have tested our compression approach on band 4 of Landsat Thematic Mapper Images of Washington, DC and of Davidsonville, LA (northwest of New Orleans, LA). The browse data was generated using JPEG/DCT at quality factors of 25, 50, and 75. Table 1 shows the frequency distribution of residual data at these quality factors:

Table 1. Washington, DC residual data image statistics.

| Diagonal Code Set # | Q = 25 | Q = 50 | Q = 75 |
|---|---|---|---|
| 1 | .3393 | .4101 | .4911 |
| 2 | .2556 | .2883 | .3055 |
| 3 | .1794 | .1686 | .1381 |
| 4 | .1102 | .0819 | .0487 |
| 5 | .0599 | .0339 | .0127 |
| 6 | .0311 | .0118 | .0030 |
| 7 | .0138 | .0036 | .0005 |
| 8 | .0060 | .0010 | .0001 |
| 9 | .0026 | .0002 | .00004 |

The compression performance of the algorithm is summarized in Tables 2 and 3 for the two data sets we have used in our experiments. For three different Quality factors, the browse compression ration ($CR_B$), the overall lossless compression (CR), and the ratio of CR to the first order entropy ($CR_e$) are tabulated. From the table we see that the best compression ratio in lossless mode corresponds to a quality factor, Q = 50.

Table 2. Washington D.C. (Band 4)

| Q | $CR_B$ | CR | $CR/CR_e$ |
|---|---|---|---|
| 25 | 20.0 | 1.63 | 0.972 |
| 50 | 11.6 | 1.67 | 0.985 |
| 70 | 7.5 | 1.64 | 0.977 |

Table 3. New Orleans (Band 4)

| Q | $CR_B$ | CR | $CR/CR_e$ |
|---|---|---|---|
| 25 | 16.1 | 1.599 | .9198 |
| 50 | 10.3 | 1.653 | .9901 |
| 75 | 6.9 | 1.633 | .9774 |

We have described a method of decomposing image data into a browse image and residual image data for active archival and distribution of data. We have found that a variant of diagonal code proposed by us gives the best compression ratio for a residual corresponding to the browse data generated by JPEG/DCT for a quality factor of 50. This quality factor provides browse quality that has very little visible distortions for the images tested.

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