Image Compression for Progressive Transmission

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Abstract

In this work several different strategies for image compression and progressive transmission are analyzed and evaluated. It will be shown that the simplest wavelet transform (Unitary Sequential Transform, UST) with a spatial predictor (U(S+P)T) followed by the so-called Set Partitioning In Hierarchical Trees (SPIHT) coder is a very good lossless compressor providing compression rates similar to CALIC or LOCO-I. In addition, U(S+P)T+SPIHT is an optimal solution for image progressive transmission because the most relevant information is concentrated in a small amount of data.

1 Introduction

Progressive image transmission is a method which allows to obtain a high quality version of the original image from the minimal amount of data. It also must be able to refine the image based on the new received data until the image is an exact replica of the original image.

Progressive image transmission is an interesting feature in many practical applications such as telemedicine, teleastronomy or database retrieval among others. Some of the advantages of a progressive image transmission are that it allows to interrupt the transmission when the quality of the received image has reached a desired accuracy or when the receiver recognizes that the image is not interesting or only needs a specific portion of the complete image or images.

The requirements for a progressive image transmission environment are the following, although they depend on the specific application:

- The information visually most relevant must be sent first. In general, the transmission strategy should minimize the reconstruction error.

- At any time, the size of the reconstructed image at the receiver is the same that the original image. This is important in applications where the distance between several objects must be measured; e.g. in teleastronomy.
- The code-stream must be compressed as much as possible. In this way the time spent in the transmission process is minimum.
- There exist many applications (telemedicine, teleastronomy) where at the end of the transmission the reconstructed image must be equal to the original one, so the compressor must be a lossless compressor.
- The receiver should be able to refine the reconstructed image when a new bit or group of bits arrives.

With these constraints in mind, a progressive image transmission system must be designed using the following elements: (1) a reversible transform which is able to represent the most relevant information with the minimal amount of data or bits, (2) a mechanism which allows to determine the most relevant information and (3) a lossless compressor which permits to reduce the size of the code-stream. In Section 2 the Discrete Cosine Transform (DCT), the Walsh-Hadamard Transform (WHT) and a Discrete Wavelet Transform (Sequential + Prediction Transform, (S+P)T) as well as three different schemes to select the ordering of data for transmission are analyzed and evaluated. In Section 3 the Set Partitioning In Hierarchical Trees (SPIHT) coder is briefly described. Finally in Section 4 an evaluation of (S+P)T + SPIHT as a lossless compressor and a progressive image transmission mechanism is performed.

2 DCT and WHT versus Wavelet Transforms

An spectral representation of an image allows to concentrate most of the energy of the image within a small number of the transform coefficients. In this work the Walsh-Hadamard Transform (WHT) [8, 10], The Discrete Cosine Transform (DCT) [1, 8, 9] and a Discrete Wavelet Transform (Unitary Sequential + Prediction Transform, U(S+P)T) [5, 2, 12, 14] unitary are evaluated.

Both, WHT and DCT kernels consist of periodical basis functions and the transformation matrices are dense while U(S+P)T consists of local basis functions with a sparse transformation matrix.

This feature makes U(S+P)T more appropriate for progressive transmission because the relevant information can be described with less coefficients than using DCT or WHT transform and, moreover, U(S+P)T is faster than DCT and WHT. It should be noticed that the Discrete Cosine Transform does not guarantee an exact reconstruction of the original image due to the rounding error of floating point operation, however we have used it in this analysis because it is well known its good spectral compactation properties. In Figure 1 Cosine, Walsh-Hadamard and U(S+P) transforms for "lena" are shown.

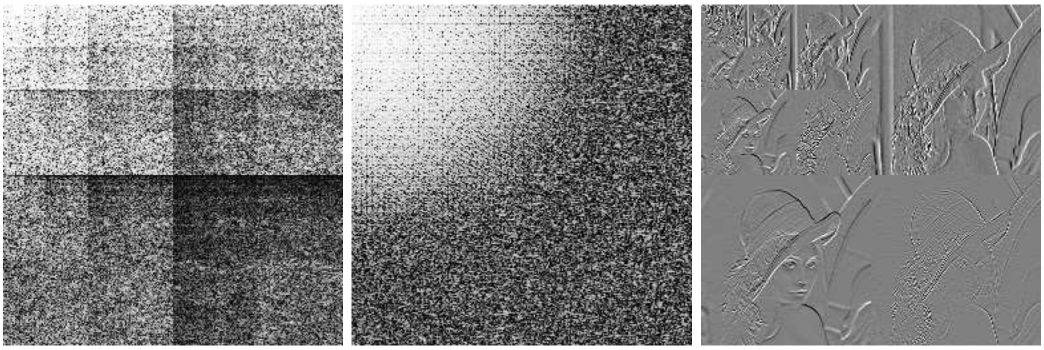

Figure 1: Walsh-Hadamard (left), Cosine (center) and U(S+P) (right) transforms for "lena".

As a particular case of a Discrete Wavelet Transform, U(S+P)T is a separable transform, so it is possible to compute the 2D-U(S+P)T by applying the 1D transform to each column of the image and then a second 1D transform is taken along each row of the first transformation. This procedure is shown in Figure 2.

For a progressive image transmission when the two-dimensional transform has been computed, it is necessary to determine which data from the transformed image should be sent first. We have tested three different transmission ordering strategies: (1) coefficients with larger magnitude first (hereinafter known as Magnitude Ordering), (2) Triangle Ordering (lower frequencies first) and (3) Square ordering (lower frequencies first). In Figure 3 these policies are graphically described.

The main advantage of a magnitude ordering transmission strategy is that the reconstruction error decreases quadratically with the value of the received coefficient. In this way, if c is the value of the received data the mean square error between the original and the reconstructed images is decreased by c^2/N, where N is the size of the image [4]. However, transmitting in decreasing order of magnitude implies that information about the spatial location of each sent data must be explicitly

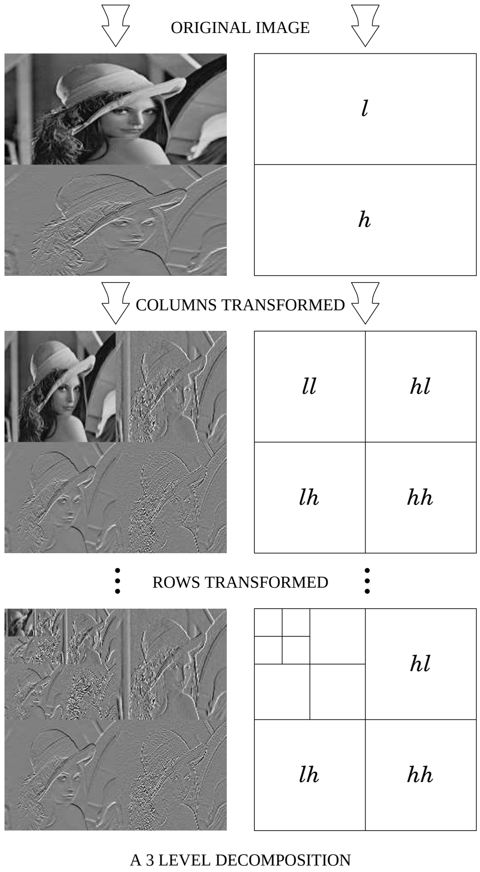

Figure 2: Computation of the DWT-2D using the DWT-1D. l=low frequency band and h=high frequency band.

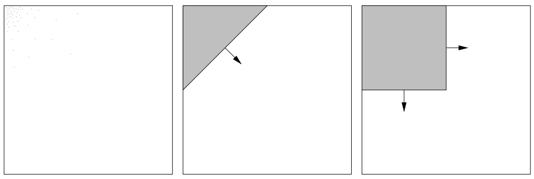

Figure 3: Incremental transmission ordering strategies: (left) Magnitude Ordering (MAG), (center) Triangle Ordering (TRI) y (right) Square Ordering (SQU).

described. Using the triangle and square transmission strategies the spatial location of each received data is implicitly defined and both strategies are relatively efficient because the coefficients with larger magnitude are usually located at the upper left corner of the transformed image (low frequency coefficients).

The nine possible combination of the three transforms and the three ordering transmission strategies have been analyzed and values of the PSNR for the original and the reconstructed images have been measured as a function of the number of coefficients transmitted. In Figure 4 values of PSNR as a function of the number of transmitted coefficients are graphically shown for the 256×256 pixels version of “lena” image. Similar results were obtained for other standard images. Results clearly show that U(S+P) transform is the most efficient and that magnitude ordering transmission provides the minimum error for the reconstructed image, mainly at the beginning of the transmission when only

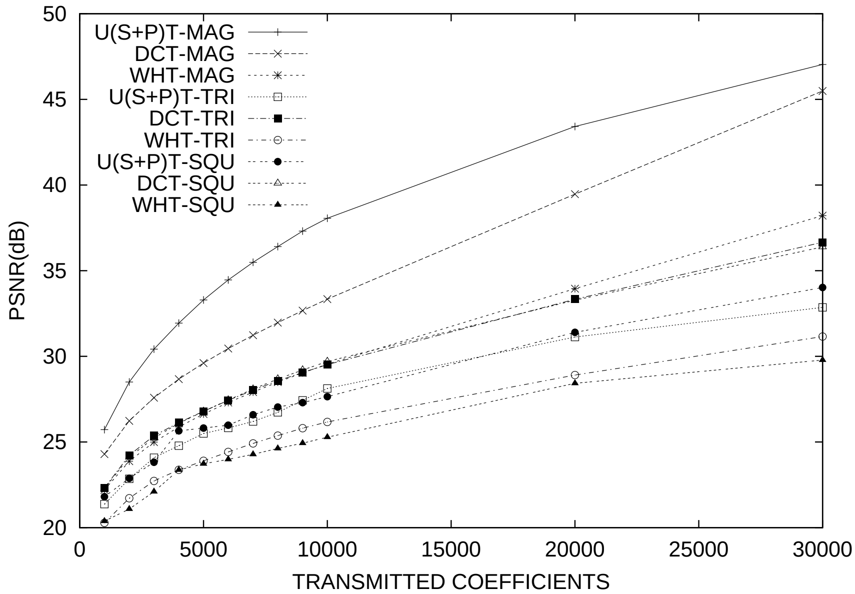

Figure 4: PSNR values as a function of the amount of data received for WHT, DCT and U(S+P)T and the three methods for transmission (magnitude (MAG), triangle (TRI) and square (SQU) orderings).

5,000 or 10,000 coefficients have been received.

3 Bit-Plane Compression using SPIHT

Transmitting wavelet coefficients in a bit-plane ordering has a behaviour similar to the transmission in decreasing order of magnitude, in terms of the reconstruction distortion. However, it presents two additional interesting properties:

- Coefficients need not be ordered according to their magnitude before being transmitted, which allows to reduce the time to start the transmission.
- The reconstruction error is minimized since the most significant bits are transmitted first.

The wavelet multiresolution spectrum has the property that there exists a spatial self-similarity relationship among the coefficients at different levels and frequency subbands. This spatial relationship is defined in a hierarchical pyramid constructed with recursive four-subband splitting, as shown in Figure 5: A coefficient (i, j) in the wavelet representation has four direct descendants (offsprings) at the locations $\mathcal{O}(i, j) = \{(2i, 2j), (2i, 2j + 1), (2i + 1, 2j), (2i + 1, 2j + 1)\}$, and each of them recursively maintains a spatial similarity to its corresponding four offspring. That kind of pyramid structure is commonly known as *spatial orientation tree*.

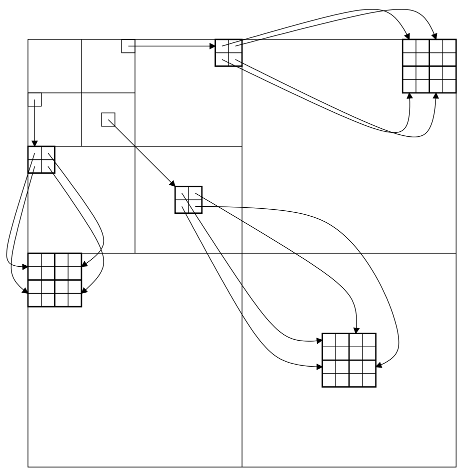

Figure 5: Examples of parent-offspring dependencies in the spatial orientation trees created in the DWT-2D.

The SPIHT (Set Partitioning In Hierarchical Trees) algorithm takes advantage of the spatial similarity present in the wavelet space to efficiently compress the coefficients in a bit-plane ordering. As an example, Figure 1 shows the similarity among subbands within a level or between bands at adjacent levels present in the wavelet space. More specifically, if a given coefficient (i, j) is significant at the bit-plane p (i.e., its value is greater than or equal to 2^p), then some of its descendants $\mathcal{O}(i, j)$ will probably be significant, and viceversa. SPIHT takes into account this fact to optimally find the location of the wavelet coefficient that are significant in every bit-plane by means of a binary search algorithm.

One of the main features of SPIHT is that the ordering data is not explicitly transmitted. Instead, the encoder (transmitter) and the decoder (receiver) synchronously execute the same search algorithm based on the results of comparisons on the branching points. The encoder transmits the results of each comparison with only one bit whereas the decoder receives them from the code-stream and can then duplicate the path followed by the encoder.

The SPIHT algorithm generates an efficient code-stream since the result of every binary comparison is equally likely [13]. The code-bits that are transmitted allow to find the exact location of the coefficients that become significant in every bit-plane. Nevertheless, SPIHT does not code those bits that did become significant in previous bit-planes (those bits are commonly known as *refinement* bits at the present bit-plane). This behaviour allows to increase the efficiency, mostly in terms of speed and memory usage, because the spatial correlation among the refinement bits within a bit-plane is not enough to justify that encoding. For the same reason, SPIHT does not encode the sign bits of the coefficients either.

4 Evaluation of SPIHT as Compressor and Transmitter

In a lossless compressor fashion, two implementations of the SPIHT algorithm have been evaluated: "SPIHT" and "SPIHT+arith", together with a set of lossless image compressors. Differences between both implementations are: (1) "SPIHT+arith" uses arithmetic coding to slightly compress the SPIHT's code-stream and (2) while "SPIHT" does not encode the low significant bit-planes (because they are usually expanded), "SPIHT+arith" performs an entropy encoding of these bit-planes [13].

Figure 6 shows the performance of the lossless compressors that have been evaluated. This measure relates the compression ratio to the transmission ratio in both compression and decompression processes. The compression ratio is computed as $\mathrm{TC} = 1 - \frac{\beta}{\alpha}$, where α is the size of the image before the compression and β is the size of the compressed image. Transmission ratios are computed according to $\mathrm{TT}_c = \frac{t_{cp}}{t_c}$ and $\mathrm{TT}_d = \frac{t_{cp}}{t_d}$, where t_{cp} is the time that the "*cp*" command spends in copying the image, t_c is the compression time and t_d is the decompression time. As can be seen, SPIHT is an excellent lossless image compressor.

Figure 7 presents the reconstructions of the "lena" image for "SPIHT", "SPIHT+arith" [11, 13], JPEG [7, 15] and "Wave03" [3]. This last compressor (available from the Internet) tries to improve the best compression ratio but it is lossy for each bit-rate. Only "SPIHT" and "SPIHT+arith" allow a true progressive reconstruction. "Wave03" and "JPEG" have been evaluated to see the performance of the SPIHT progressive transmission. The results also demonstrate that SPIHT is very competitive as a lossy compressor.

Finally, to perform a subjective evaluation, Figure 8 shows the reconstruction of "lena" using SPIHT and JPEG at 0.14 bpp. At this compression ratio, SPIHT is clearly better than JPEG.

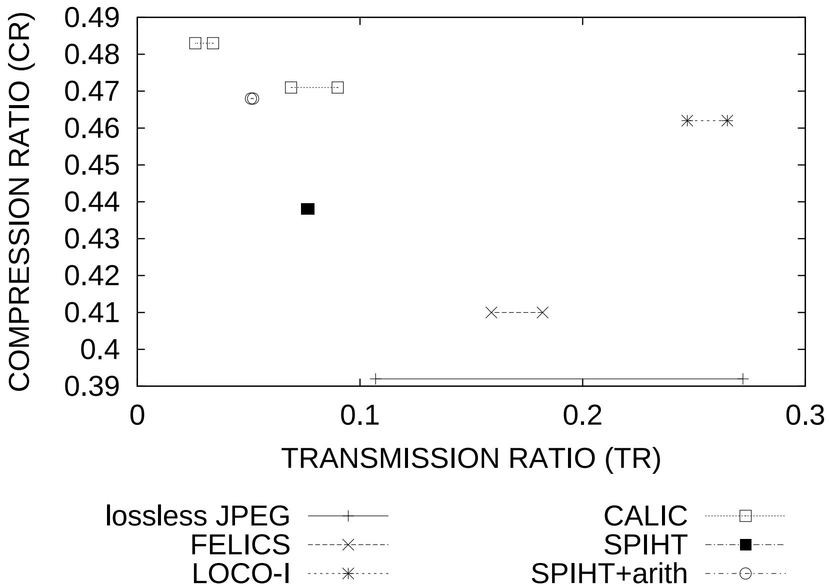

Figure 6: SPIHT's performance versus other lossless compressors. The test images are ("lena", "barb", "boats" y "zelda", all with 512×512 points and 8 bits/point). The results shown here are the averaged values. Lossless JPEG (Joint Photographic Experts Group), FELICS (Fast, Efficient, Lossless Image Compression System), LOCO-I (Low COmplexity, context-based, lossless image compression algorithm), CALIC (Context-based, Adaptive, Lossless Image Coding).

5 Conclusions

The wavelet lossless/lossy image compression is nowadays the state of the art in efficient image coding and, as a matter of fact, the new JPEG-2000 image compression standard [6] already bears in mind this fact. Wavelet image compression presents several advantages: (1) excellent transmission ratios, (2) competitive compression ratios and (3) progressive image transmission. This last feature is the most important one for telecontrol purposes. The U(S+P)T wavelet transform is a perfect couple for SPIHT to solve this kind of problems.

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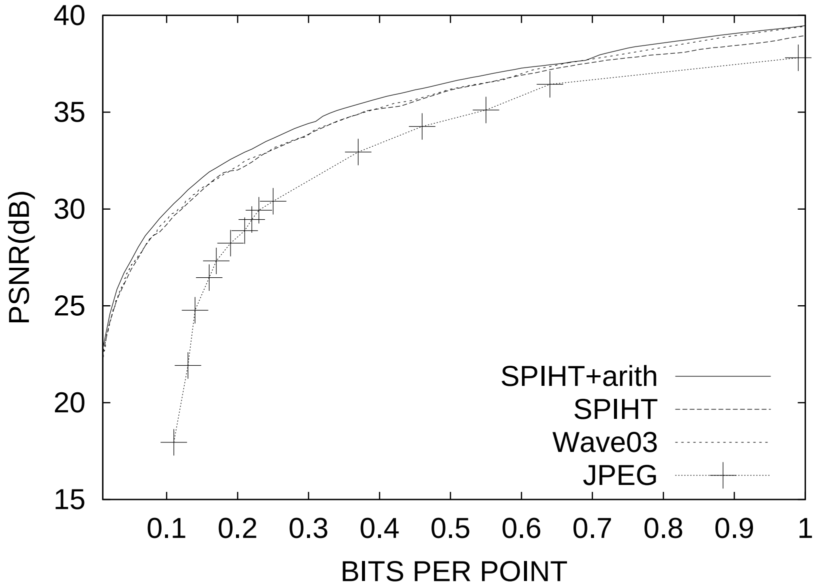

Figure 7: Progressive reconstruction of the "lena" image.

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Figure 8: A JPEG-lossy (left) versus SPIHT (right) comparative for “lena” ($512 \times 512 \times 8$). The compression ratio is 0.14 bpp (51:1).

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