Wavelet and JPEG Based Image Compression: An Experimental Analysis

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ABSTRACT
The paper attempts a comparison between JPEG and JPEG2000 –wavelet- based image compression based on the output from different images. Also the PSNR values are compared for different images. The paper also reviews the recent advancements in this area after the introduction of JPEG2000 so as to bring out the further research prospects in the field of image compression.

General Terms
Image compression, Huffman coding, low bit rate transmission, JPEG, JPEG 2000, wavelet, PSNR

Keywords
JPEG, JPEG2000, image compression, wavelet, DCT,

1. INTRODUCTION
Image compression is an established and well researched segment which has been undergoing significant advances over the period of time. Keeping in view the on-going advancements taking place in this field, the paper focuses on the recent advances in this field starting with the two latest image compression standards, such as JPEG and JPEG2000 the distinguishing feature of JPEG2000 being wavelet based image compression. After comparing the theoretical differences vis-à-vis the experimental results of these key standards, the paper also details some of the recent studies in the field of wavelet based image compression.

2. JPEG IMAGE COMPRESSION
JPEG (Joint Picture Expert Group) corresponds to the ISO/IEC International Standard 10928-1(ISO/IEC, 1991). JPEG standard defines three different coding systems, such as loss baseline coding system based on DCT, an extended coding system for greater compression, higher precision, or progressive reconstruction of applications and lossless independent coding system for reversible compression[16]. The process flow of general image compression and JPEG Image compression are given in Fig 1. The image is first divided into 8 by 8 blocks of pixels. For the sake of explaining the process, the process involved in a block can be explained on account of the fact that each block is processed without reference to the others. Let us assume that that the colour of each pixel as represented by a three-dimensional vector *(R,G,B)* consisting of its red, green, and blue components. A significant amount of correlation exists between these components. Therefore, a *colour space transform* can be used to produce a new vector whose components represent *luminance, Y,* and blue and red *chrominance,* C_b and C_r. Thus, the three quantities are typically less correlated than the components (*R, G, B*). Further, the human eye is more sensitive to luminance than chrominance, which can support us to neglect larger changes in the chrominance without affecting image perception[17].

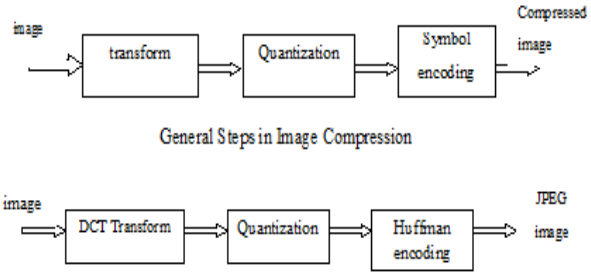

Fig 1: Process Flow of JPEG image compression

Since this transformation is invertible, we will be able to recover the *(R,G,B)* vector from the *(Y,* C_b*,* C_r*)* vector. This is important when we wish to reconstruct the image. When we apply this transformation to each pixel in our block we obtain three new blocks, one corresponding to each component.

3. JPEG2000
Though JPEG has been a very successful method, the extensive use of digital imageries in the day to day life has necessitated the need for high performance image compression. Thus, JPEG2000 encompasses not only new compression algorithms, but also flexible compression architectures and formats. Further, the standard intends to compliment and not to replace the current JPEG standards. It addresses areas where current standards have limitations in producing the best quality or performance. JPEG2000 provides low bit rate operation (below 0.25 bits/pixel) with subjective image quality performance superior to existing standards, without sacrificing performance at higher bitrates. The key differentiator is that the JPEG2000 uses a *wavelet* transform in place of the DCT. Thus, as part of this review, after explaining the JPEG 2000, we shall explain the wavelet transform, which is the integral part of JPEG2000 standard.

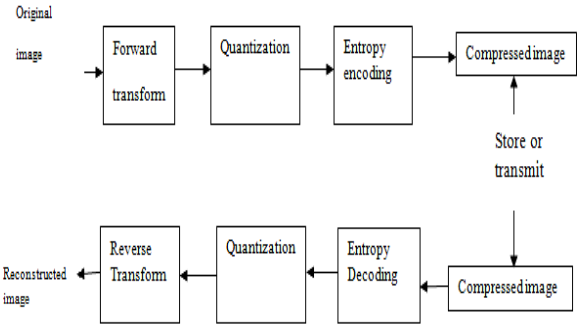

Fig 2 : Block Diagram of JPEG-2000 image compression

Though the diagram looks like the one for the conventional JPEG, there are radical differences in all of the processes of each block of the diagram. The JPEG2000 image compression processes can be split into three parts, they are preprocessing, the core processing, and the bit-stream formation, although there exists high interrelation between them[18]. In the preprocessing part the image tiling, the dc-level shifting and the component transformations are covered. The core processing part consists of the discrete transform, the quantization and the entropy coding processes. The areas such as the precincts, code blocks, layers, and packets are included in the bit-stream formation.

3.1.Core processing – Wavelet Transform.
Wavelet transform is used for the analysis of the tile components into different decomposition levels. These decomposition levels contain a number of subbands, which consist of coefficients that describe the horizontal and vertical spatial frequency characteristics of the original tile component. The pre-requisites of the wavelet's history begin in 1910, when Alfred Haar, a German mathematician, developed the now called *Haar function* and associated *Haar matrix* [19].

Wavelets are used successfully for signal processing. Most prominent field is compression of digital signals. Quite established are wavelet algorithms in digital image processing. The ability of the WT to extract the main features (most important for the eye) results in high compression without losing much quality. The compression quality showed to be superior to the usual JPEG compression, which is based on a FT. The FBI adopted wavelet compression for their archive of digital fingerprint images [20]. Also for video compression, wavelets are used successfully. Noise reduction works well for similar reasons: low coefficients are likely to contain uncorrelated wide-spectrum noise. By setting coefficients below a certain *threshold* to 0, the image can be denoised. Other fields of signal processing, where the WT is efficient, include detecting of singularities or breaks, determining long-term evolution of the signal, and pattern recognition. For sound processing, experiments have been done as described in[20] and [21]. Also compression of sound has been successfully developed with good results. Furthermore, wavelets can be used for linear algebra shows an application for solving linear systems efficiently by using the wavelet transform, demonstrates its application for fast multiplication of large matrices.

4. Comparison of JPEG and JPEG2000

Having explained the major image compression standards such as JPEG and JPEG 2000, it would be also desirable to explain the major differences between JPEG and JPEG 2000. The lossy baseline JPEG is the very well known and popular standard for compression of still images. In the JPEG the source image is divided into 8 X 8 blocks and each block is transformed by using DCT. The data compression is achieved by variable length coding. The quantization step size for each of the 64 DCT coefficients is specified in a quantization table, which remains the same for all blocks in the image. In JPEG the degree of comparison is determined by a quantization scale factor [18]. The DC coefficients of all blocks are coded separately using a predictive scheme.

Therefore, the block based segmentation of the source image is a fundamental limitation of the DCT-based compression system. This degradation is known as "blocking effect" and depends on compression ratio and image content. The performance of the block-based DCT scheme degrades at high compression ratio. On the other hand, DWT offers adaptive spatial frequency resolution, that is, better spatial resolution at high frequencies and better frequency resolution at low frequencies. This can provide better image quality than DCT, especially at higher compression ratio.

JPEG 2000 is based on DWT, which is applied on image tiles. DWT tiles are decomposed into different decomposition (resolution) levels. After transformation, all transform coefficients are quantized. Scalar quantization is used in Part I of the standard. Arithmetic coding is employed in the last part of the encoding process.

Table 1. Major differences between JPEG and JPEG2000

Sr.No	JPEG	JPEG2000
1	DCT	DWT
2	Block based segmentation of source image	Tile based
3	Less computational complexity	High computational complexity
4	Less compression ratio	More compression ratio (20% to 50% or more)
5	The quality of image is less at a low bit rate	Improvement in image quality at a low bit rate
6	PSNR is low	PSNR is high

JPEG2000 integrates the benefits of all four JPEG modes in a single compression architecture and a single code stream syntax. Any image quality or size can be decompressed from the resulting code-stream, upto and including those selected at

encode time. Thus, JPEG2000 supports progression in four dimensions, that is, quality, resolution, spatial location and component. As more and more data are received, image quality is improved. Apart from supporting resolution and spatial location, JPEG 2000 supports images with upto 16384 components. Generally images with more than four components are from scientific instruments.

In a relevant study, [16] the authors have compared the results of four images with different spatial frequency characteristics. The characteristics of test images are evaluated in spatial domain using Spatial Frequency Measure (SPM) and in frequency domain using Spectral Activity Measure (SAM). The paper observed that for typical natural image, the largest value of SFM implies smaller value of SAM. Further, the authors have also used the measures such as Mean Square Error (MSE) and Peak Signal to Noise Ratio (PSNR). The authors have concluded that JPEG 2000 provides image quality than JPEG for all test images and all bitrates. But in cases where visual image quality quantified by Picture Quality Scale (PQS), the conclusions are different. At high and moderate bitrates (above 1bpp) for all test images, JPEG performs better than JPEG 2000. At low bitrates image quality of JPEG degrades below image quality of JPEG 2000 because of the artifacts resulting from the block-based DCT scheme. On the other hand, JPEG 2000 provides better image quality at low bit rates for all test images because of overlapping basis functions and better energy compaction property. Such results assume importance in practical applications.

5. Experimental Results

The comparative analysis of JPEG and wavelet based image compression in terms of PSNR is analysed in this section. Further, the performance analysis of JPEG and JPEG2000 for different images with PSNR parameters are also discussed.

5.1 JPEG and Wavelet Compression Results

5.1.1. JPEG-Compression Results

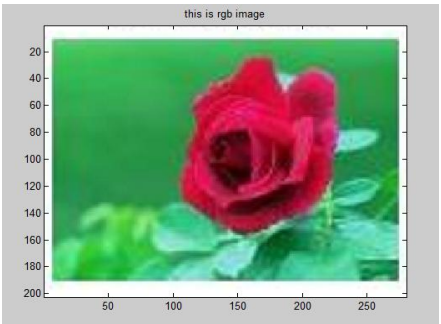

Fig 3: Original Image with RGB (Size 4.72 KB)

The JPEG compression with Huffman encoding is performed for the original image (Fig 3). The compressed image gives a DC coefficient after Huffman coding at 5085 bits and AC coefficient at 30378 bits. We have chosen the compression rate as 0.54112 Bits / pixel and the compression ratio of 14.7841 : 1. The PSNR of the image after the transmission and reception is 8.9873. The analysis has done for the gray scale image; the original image has been converted to gray scale image to reduce the complexity in the process (Fig 4) and the reconstructed image is shown at Fig 5.

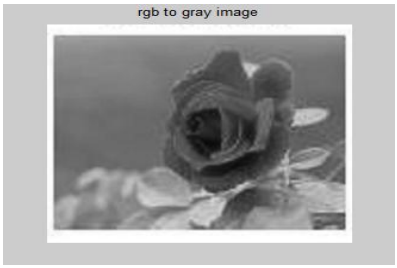

Fig 4: Original Image after converting to gray

Fig 5: Reconstructed Image

5.1.2. Wavelet based image compression results.

The wavelet based compression is performed for the same image used for JPEG compression and different level of approximation has been attempted. Here the two level decomposition of discrete wavelet transform are performed and approximated images in different levels are shown under for the same compression ratio and compression rate of JPEG.

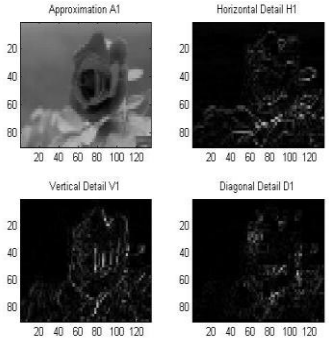

Fig 6: The level 1 approximation using wavelet based transform

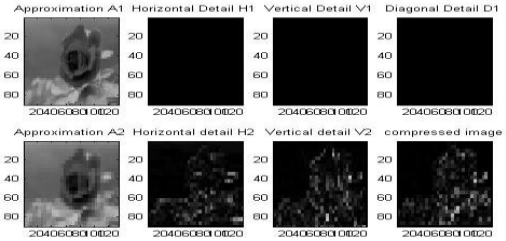

Fig 7: The level 2 approximation using wavelet based transform

Fig 8: Reconstructed Image size 4.72 KB

Fig 9: Original Image size 134KB

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Fig 10: Gray Image

5.2. JPEG and JPEG2000 Results

The comparison has done with a flower image of size 134KB. The original image has converted into gray scale image for both JPEG and JPEG2000 to reduce the complexity in the process, the JPEG compression with DCT and Huffman coding have applied.

5.2.1. JPEG Compression

After performing the JPEG compression, the DC coefficient after Huffman coding has 5997 bits and AC coefficient has 85608 bits. The compression rate of 1.3978 Bits / pixel has choosen and the compression ratio of 5.7234 : 1. The PSNR value calculated after reconstructing the image in the receiver side is 5.9739. The reconstructed image is shown at Fig.11.

Fig 11: Reconstructed Image

5.2.2. JPEG2000 Compression

The JPEG 2000 with DWT followed by Huffman coding has performed for the same flower image with the same compression rate and compression ratio. The PSNR value as per the result at the receiving end is 25.4164. The PSNR value of JPEG2000 is better than JPEG, which is in conformity with the results of the prevailing literature.

Fig 12: Gray Image

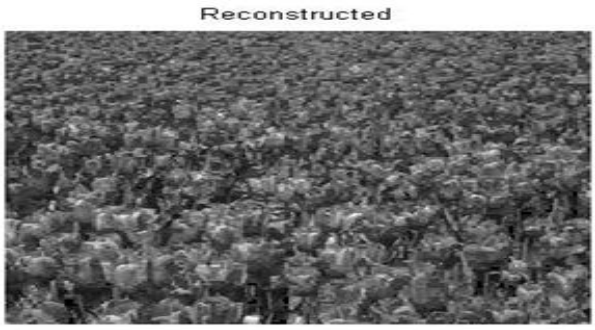

Fig 13: Reconstructed Image

6. POST JPEG2000 DEVELOPMENTS

After the introduction of JPEG 2000 standard, researchers have carried out several studies in this area. Julien and others [1] in their paper stated that the 'integer wavelet transform' is one of the alternative to the DWT because of its rate – distortion performances is similar and the differences can be predicted. This methodology is verified using simulations with random noise as input. Barraniuk[22] and others introduced a new image texture segmentation algorithm based on wavelet and hidden Markov tree (HMT). The paper highlighted that the statistical properties of the coefficients of wavelet and HMT is well suited to image containing singularities (edges and ridges). Since HMT segment works on WT of the image, it can directly segment WT compressed images without the need for decompression into the space domain. The paper demonstrated the performance of HMT segment with synthetic, aerial photo and document image segmentation. Gobbers et. al [2] in their paper used a simple and efficient technique for designing translation invariant dyadic WTs in two dimensions. This technique relies on an extension of the work of Duval – Destin, where dyadic decomposition are constructed starting from continuous wavelet transform. The main advantage of this framework is that it allows for a lot of freedom in designing 2-D dyadic wavelets, whose orientation filtering capabilities are very important in image processing. In another paper [3] it was shown that sometimes image processing units inherit images in raster bitmap format only, so that processing is to be carried without knowledge of past operations that may compromise image quality (e.g. compression). To carry further processing, it is useful to not only know whether the image has been previously JPEG compressed but to learn what quantization table was used. After detecting compression signature, the paper estimated parameters specifically, and developed a method for the maximum likelihood estimation of JPEG quantization steps. In order to remove possible artifacts, it first has to determine whether the image has been compressed in the past and estimate its quantization table. The information is then used to remove possible compression artifacts. Michael and others[4] applied a wavelet basis of L2 to which a unitary Fresnel transform was applied. The method presents an efficient multi resolution Fresnel transform algorithm, which allows for the reconstruction of complex scalar waves at several user defined, wavelength independent resolutions. The transform separates the image to reconstruct from the unwanted zero-order and twin image terms. Marcus [5] in their paper focussed on to visual significant information. Here Contrast Sensitivity Function (CSF) can be exploited to regulate the quantization step size to minimize the visibility of compression artifacts. Existing CSF for wavelet based image compression uses the same quantization step-size for a large range of spatial frequencies. Blu[6] provided an approximation theoretic quantities such as the asymptotic constant for the L^2 error and the angle between the analysis and synthesis spaces which characterizes the loss of performance with respect to an orthogonal projection.

In a related study, Li et. al [7] investigated the problem of how to exploit geometric constraint of edges in wavelet based image coding. The potential coding gain brought by improved probabilistic models of wavelet high-band coefficients. Novel phase shifting and prediction algorithm are derived in the wavelet space. After resolving the phased uncertainity, high band wavelet coefficients can be better modelled by biased-mean probability models rather than the existing zero-mean probability models. In lossy coding, the coding gain brought by the biased mean model is quantitatively analysed within the conventional DPCM coding framework. Experiment results have shown that the proposed phase shifting and prediction scheme improves both subjective and objective performance of wavelet –based image coders. In another paper,[8] the authors have applied the latest technologies in image compression, such as JPEG 2000 for managing the storage of massive image data within cultural heritage databases. The paper has presented an application of the latest image compression standard in managing and browsing image databases focusing on the image transmission. The paper has combined the technologies of JPEG 2000 image compression with client server socket connections and client browser plug-in as to provide with an all –in-one package for remote browsing of JPEG2000 compressed image databases, suitable for the effective dissemination of cultural heritage.

Ng and others[9] addressed the design of a novel complex steerable wavelet construction, the generation of transform – space feature measurements associated with corner and edge presence and orientation properties, and the application of these measurements directly to image denoising. Ning and others[10] showed that the challenge of image denoising is how to preserve the edges of an image when reducing noise. By modeling the intensity surface of a noisy image as statistically self-similar multi fractal processes and taking advantages of the multi-resolution analysis with wavelet to exploit the local statistical self similarity at different scales, the point-wise singularity strength value characterizing the local singularity at each scale was calculated. Wavelet coefficient at each scale was classified into regular and irregular coefficients for smoothed using fuzzy weighted mean and minimum mean-squared error respectively.

An image compression algorithm based on the efficient construction of wavelet coefficient lower trees was proposed in another paper[11]. It grouped the coefficients and also a fast

way of coding them. Here fast execution is achieved by means of a simple two-pass coding and one-pass decoding algorithm. By taking note of the excellent visual quality and compression rate of fractal image coding have limited applications due to exhaustive inherent encoding time, the paper [12] present a new fast and efficient image coder that applied the speed of the wavelet transform to the image quality of the fractal compression. Here encoding using Fisher's domain classification is applied to the Low pass subband of the wavelet image and a modified set partitioning in hierarchical trees coding, on the remaining coefficients. The proposed scheme has an average of 94% reduction in encoding – decoding time comparing to the pure accelerated fractal coding results.

In an important study carried out by Mahul and others [13] the paper has proposed that a similarity index for images should account for both intensity variations and geometric distortions. In the proposed index, complex wavelet structural similarity index is used as a general purpose image similarity index. In this method, the similarity in two images are to be compared to find the position of similar coefficients. The objective is to discern that certain image distortions lead to consistent phase shift of the coefficients does not change the structural content of the image.

In yet another paper[14], an iterative algorithm was proposed, which not only results in a compressed bit stream completely compatible with existing JPEG and MPEG decoders, but is also computationally efficient when tested over standard test images. It achieves the best JPEG compression results to the extent that its own JPEG compression performance even exceeds the quoted PSNR results of some state of the art wavelet based image coder such as Shapiro's embedded zero tree wavelet algorithm at the common bit rates under comparison. Rahul and others [15] in their paper discusses the effects of resolution scalable features and present two efficient methods to improve resolution scalability for bi level imagery in JPEG 2000. By analyzing the sequence of rounding operations performed in the JPEG 2000 lossless compression pathway the paper introduced a simple pixel assignment scheme that improves image quality for commonly occurring types of bilevel imagery based on the JPIP protocol, which enables efficient interactive access of compressed bilevel imagery. It may be noted that both proposed methods are fully compliant with part of the JPEG 2000 standard. As evident, the recent review as briefly explained above, makes clear that, the researchers are continuing further into the JPEG2000 domain.

7. CONCLUSION

The paper has attempted a comparison between JPEG and JPEG 2000 standards through experimental results. The results reconfirms the position that, for different images with different compression ratio and compression rate, the PSNR value for JPEG2000 is far better than JPEG, which is in line with the existing literature. The review of the recent researches reveals that, the studies are further progressing exploring for better image compression methods. Such studies offer promises of emergence of further image compression methods and algorithms either in the field of wavelet or other new areas, which may outperform the existing image compression methods.

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