JPEG2000: A Review and its Performance Comparison with JPEG

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Abstract— **The JPEG2000 standard is a wavelet based image compression system that is capable of providing effective lossy and lossless compression. This standard is motivated primarily by the need for compressed image representations that offer new features increasingly demanded by modern applications and also offering superior compression performance especially at low bit rates. Embedded lossy to lossless coding, progressive transmission by pixel accuracy and resolution, error resilience, region of interest coding are some of the key features of JPEG2000.This paper provides a review of the JPEG2000 standard, explaining the technology on which it is based. A performance comparison of JPEG2000 with JPEG is also shown in terms of image quality and compression ratio. A brief survey on rate control algorithms suggested for JPEG2000 is also presented. At very low bit rates, ringing artifact is observed in JPEG2000 coded images. A brief discussion of ringing artifact and various methods already suggested in previous papers is also reviewed.**

***Keywords*— JPEG2000, wavelet transform, rate-distortion, EBCOT, JPEG, ringing artifact.**

I. INTRODUCTION

In the mid 80's , the joint collaboration of International Telecommunication Union (ITU) and International organization for Standard (ISO) introduced the standard for the compression of gray scale and colour still image. Their joint effort results in JPEG, the Joint Photographic Experts Group. The intensive research effort since the development of JPEG evolved a new imaging standard JPEG2000 [3] for coding still images. This new standard has been developed to meet the demand for efficient, flexible and interactive image representations.JPEG2000 is much more than a compression algorithm, opening up new paradigms for interacting with digital imagery. It is developed to compliment the JPEG standard and not to replace it. It addresses areas where JPEG fails to produce the best quality or performance. The original JPEG compression standard is efficient at medium to high levels of compression with relatively low levels of loss in visual image quality and has found widespread use in the imaging industry. Excessive compression using JPEG however, results in well-known "blocking" artifacts [31]. JPEG 2000 has been developed to improve JPEG in terms of functionality and image quality at lower bit rates. One of the more fundamental changes is the use of a discrete wavelet transform instead of a discrete cosine transform, which provides several advantages both in terms of the way in which the image is encoded and overall image quality.

The core encoding algorithm of JPEG2000 is EBCOT (Embedded block coding with optimized truncation) [4]. EBCOT is comprised of two parts as tier-1 and tier-2 coding. Tier-1 coding stage includes a fractional bit plane coder and the MQ arithmetic coder to encode each code block into embedded bit stream. The responsibility of tier-2 is to optimize rate control to minimise the image distortion for a given bit rate and packet the final code stream. This optimized rate control algorithm is named as post compression rate distortion (PCRD) optimization algorithm. The JPEG2000 standard provides a set of features that are of importance to many high-end and emerging applications by taking advantage of new technologies. Some of the most important features that this standard possesses are the following:

- Improved compression efficiency
- Lossy to lossless compression
- Multiple resolution representation
- Progressive transmission by pixel accuracy and resolution
- Region of interest coding
- Error resilience
- Random access and processing
- Continuous and bi-level compression

In JPEG2000, quality scalability [34] is also incorporated by the use of quality layers that are formed in the encoder through rate-distortion optimization techniques. Quality scalability is an important feature that allows the transmission and/or decoding of compressed code streams at several bit rates without sacrificing coding performance.

JPEG2000 is inherently more complex than its predecessor JPEG. Its reliance on discrete wavelet transform (DWT) and coding of wavelet coefficients in block, together imply a significantly higher cost in memory consumption than baseline JPEG. The complexity of the entropy encoder (EBCOT) is most significant in JPEG2000 which alone consumes 70% execution time in compression of an image. The principle advantage of EBCOT is that it produces highly scalable bit stream which can be accessed randomly.

This study involves a comparison of subjective image quality between JPEG and JPEG 2000 to establish whether JPEG2000 does indeed demonstrate significant improvements in visual quality. This paper is organized as follows. Section II

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provides a brief overview of JPEG and JPEG2000.Section III discusses architecture and the entropy coder (EBCOT) used in JPEG2000. .Section IV gives the issues related to JPEG2000. Section V presents the implementation of JPEG2000 and experimental results of comparison between JPEG and JPEG2000 and Section VI gives the conclusion of the paper.

II. OVERVIEW OF JPEG AND JPEG2000

For the purpose of comparison between the two technologies a brief review of the concepts of JPEG and JPEG2000 is shown in this section.

A. *JPEG*

This is very well known ISO/ITU-T standard created in the late 1980's. JPEG (Joint Photographic Expert Group) is an international compression standard for continuous- tone still images for both gray scale & color. This standard is designed to support a wide variety of applications for continuous-tone still images. Because of the distinct requirement for each of the applications; JPEG standard has two basic compression methods. The DCT based methods are specified for lossy compression and the predictive methods is specified for lossless compression. In this article we use lossy compression of JPEG standard.

The discovery of DCT in 1974 is an important achievement for the research community working on image compression. The DCT can be regarded as a discrete time version of the Fourier cosine series. JPEG standard use DCT which represents image as a superposition of cosine functions with different discrete frequencies [5]. The transformed signal is a function of two spatial dimensions and its components are called DCT coefficients or spatial frequencies.DCT provides excellent energy compaction & a number of fast algorithms for calculating the DCT. The DCT of a discrete signal x (n) is defined as:

$$\mathrm{X(u)} = \sqrt{\frac{2}{N}}\,c(u)\sum_{n=0}^{N-1} \mathrm{x(n)} * \cos\left(\frac{(2\mathrm{n}+1)\mathrm{u}\pi}{2\mathrm{N}}\right)$$

Where c(u) = 0.707 for u=0 and
= 1 otherwise.

The JPEG standard specifies three modes namely sequential, progressive and hierarchical for lossy encoding and one mode for lossless encoding. The 'baseline JPEG codec' which is the sequential encoding in its simplest form is briefly discussed here. The following is the general overview of the baseline JPEG process.

1. The image is broken in to 8×8 block of pixels.
2. Working from left to right, top to bottom, the DCT is applied to each block.
3. Each block is compressed through quantization.
4. The array of compressed blocks that constitute the image is stored in a drastically reduced amount of space.
5. When desired the image is reconstructed through decompression, a process that uses Inverse Discrete Cosine Transform. (IDCT).

DCT introduces no loss to the source image samples; it merely transforms them to a domain in which it can be more efficiently encoded. The basic components of the JPEG standard are DCT transform, scalar quantization, zigzag scan and Huffman coding. To achieve the compression, DCT coefficients should be quantized so that the near zero coefficients are set to zero and the remaining coefficients are represented with reduced precision that is determined by quantizer scale. The quantization results in loss of information, but also in compression. Increasing the quantizer scale leads to loss of information, but also increases in compression. Entropy encoding achieves additional compression losslessly by encoding the quantized DCT coefficients more compactly based on their statistical characteristics. The JPEG proposal specifies both Huffman coding and arithmetic coding, but codecs with both methods are specified for all modes of operation. Arithmetic coding, though more complex, normally achieves 5-10% better compression than Huffman coding.

One of the major drawbacks of the block-based DCT (JPEG) compression methods, mainly at low bit rates, is that they result in visible artifacts at block boundaries due to coarse quantisation of the coefficients. To cope with the blockiness problem, different types of post processing techniques [30] are developed till now.

B. *JPEG2000*

It is the next ISO/ITU-T standard for still image coding. The JPEG2000 standard consists of five processing steps: image transformation and codeblock segmentation, quantization, embedded block coding with optimal truncation (EBCOT) tier-1 coding, optimal truncation, and EBCOT tier-II coding. Discrete Wavelet transform (DWT) is used as image transform in the standard. This processing step losslessly (excluding rounding errors in computation) reduces the entropy of the original image to aid in compression performance, The codeblock segmentation takes the transformed image components and separates them into independent data blocks for coding. The quantization process is a lossy process, which reduces the dynamic range of the transformed image components, reducing the output file size as well as the quality of the reconstructed image. The tier-I coding process takes the processed codeblocks and losslessly compresses each independently. The optimal truncation process is a lossy process, which further reduces the size of each compressed codeblock until the desired file size is achieved. After the optimal truncation process, the independently coded blocks are ordered and arranged into the JPEG2000 file format by the EBCOT tier-II coder. In this, the

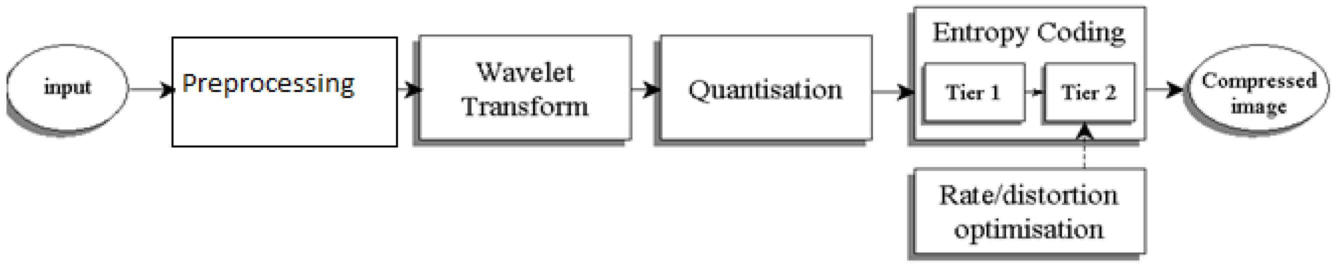

Fig. 1 JPEG2000 general processing architecture.

coded data is organized into so called layers, which are quality levels, using the post compression rate allocation (PCRD) approach. The JPEG2000 bit stream is scalable in terms of resolution and quality. JPEG2000 supports number of functionalities including Region of Interest (ROI) coding, random access error resilience, lossless and lossy compression in single bit stream and so on.

III. ARCHITECTURE OF THE JPEG2000 STANDARD

JPEG2000 is a standard for image compression and transmission .The input in JPEG2000 encoding system can be still image of different types (gray scale, color...) and different characteristics (natural, scientific, computer generated...). The different blocks in JPEG2000 encoding system as illustrated in fig.1 is discussed in this section.

A. Pre-processing

The input image needs to be processed by some form before the start of compression process. The first step in pre-processing is image tiling. In image tiling, the original image is partitioned into rectangular non-overlapping blocks (tiles) to be compressed independently. This tiling is due to the limited memory available to the codec. The next form of pre-processing is DC level shifting. This is done only for images of unsigned type. For multi-component (color) images, a component transform is performed to decorrelate the components. For example, a color image with RGB (red, green and blue) components can be transformed to the YCbCr (Luminance, Chrominance red and Chrominance blue) or RCT (reversible component transform) component space. Each tile of each component is then processed separately.

B. Wavelet Transform

Most existing high performance image coders in application are transform based coders, and this exists for a very good reason: the transform coder provides good compression performance with reasonable complexity. In the transform coder, the image pixels are converted from the space domain to the transform domain through a linear orthogonal or bi-orthogonal transform. The transform decorrelates the pixels and compacts their energy into a small number of coefficients, and results in efficient coding of the transform coefficients. Since most of the energy is compacted into a few large transform coefficients, we may adopt entropy coding scheme that easily locates those coefficients and encodes them. Because the transform coefficients are decorrelated, the subsequent quantizer and entropy coder can ignore the correlation among the transform coefficients, and model them as independent random variables. The optimal transform of an image block can be derived through karhunen-loeve (k-l) decomposition. However, the k-l transform lacks fast computation, and the transform is content dependent. It is thus not suited for the compression purposes. Popular transforms used in image coding include block based transform, such as DCT, and wavelet transform (DWT). DCT transform of the image block can be quickly computed. It achieves very good energy compaction and coefficient decorrelation. In the earlier section DCT based JPEG standard was described. However, the DCT is calculated on block of pixels independently, therefore, coding error causes discontinuity between the blocks which leads to annoying blocking artifact. On the contrary, the wavelet transform operates on the entire image, (or a tile of a component in the case of large color image). It offers better energy compaction than the DCT, and no blocking artifact after coding. The multi-resolution capability of the wavelet transform lends it ideally to scalable image coding. To apply wavelet transform to an image which is represented as 2D array, it is a common practice to apply the wavelet transform in the horizontal and vertical direction separately. The approach is called 2D-separable wavelet transform. Although it is possible to design a 2D *non*-separable wavelet, which directly uses the 2D filtering and sub sampling operation, the computational complexity is greatly increased, while the gain on additional energy compaction is very limited. The 2D data array of the image is first filtered in the horizontal direction, which results in two subbands, - a horizontal low and a horizontal high pass subband. Each subband then passes through a vertical wavelet filter. The image is thus decomposed into four subbands, - subband LL (low pass horizontal and vertical filter), LH (low pass vertical and high pass horizontal filter), HL (high pass vertical and low pass horizontal filter) and HH (high pass horizontal and vertical filter). Because the wavelet transform is a linear transform, we may switch the order of the horizontal and vertical wavelet filter, and still reach the same effect. A multi-scale dyadic wavelet pyramid shown in Fig.2 can be obtained by further decomposing the subband LL with another 2D wavelet.

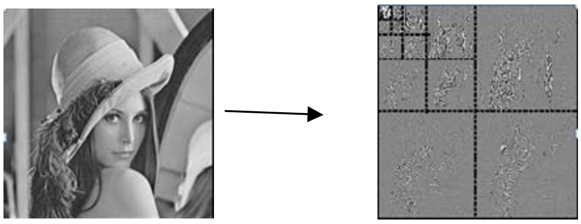

Fig. 2 Wavelet Transform: effect of frequency filtering on a grayscale image.

A number of different wavelet filters is allowed by the standard for both lossy (irreversible) and lossless (reversible) compression. The standard supports CDF 9-tap/7-tap wavelet filter for lossy mode and 5-tap/3-tap for lossless compression mode. Lossy filters usually give better results but they involve floating point operations. Due to floating point approximation, the correct reconstruction of the input signal is not guaranteed using these filters. Filters involving only integer operations are also allowed to overcome this problem.

C. Quantisation

After wavelet transform, all coefficients are quantized. It is the process by which the coefficients are reduced in precision. The quantization process converts the wavelet coefficients from floating number into integer number. Scalar quantisation is used in the standard. Scalar quantization consists of a simple truncation of less significant bits, often obtained by right shifting wavelet coefficients' magnitude. Coefficients differing only in the digits being cut off will be undistinguishable after dequantisation. Scalar quantization suffers from the so-called dead-zone problem. Namely, if a quantization step Δ_b is used for a sub-band b, the coefficients whose magnitude falls below that threshold are clamped to zero. Thus the information on coefficients in a ball of radius Δ_b around zero will be completely lost.

D. Entropy coding- Embedded block coding with optimized truncation (EBCOT)

It is the core coding algorithm in JPEG2000. The EBCOT algorithm is related in various degrees to much earlier work on scalable image compression. In EBCOT, each subband is partitioned into relatively small blocks of samples, which we call *code-blocks*. EBCOT generates a separate highly scalable (or *embedded*) bit-stream for each code-block. The bit-stream associated with each codeblock may be independently truncated to any of a collection of different lengths. An enabling observation leading to the development of the EBCOT algorithm is that it is possible to independently compress relative small code-blocks (say 32×32 or 64×64 samples each) with an embedded bit-stream consisting of a large number of truncation points, such that most of these truncation points lie on the convex hull of the corresponding rate-distortion curve. The EBCOT algorithm is conceptually divided into two layers called Tiers. The tier-I coding process takes the codeblocks and losslessly compresses each independently. The optimal truncation process is a lossy process, which further reduces the size of each compressed codeblock until the desired file size is achieved. After the optimal truncation process, the independently coded blocks are ordered and arranged into the JPEG2000 file format by the EBCOT tier-II coder.

1) *Tier-1 coding:* The block diagram of tier-1 coding is shown in the fig. 3.

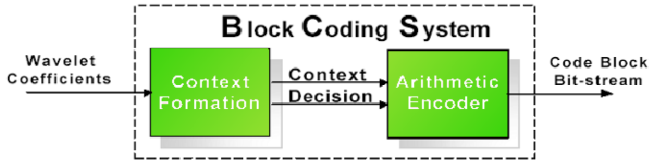

Fig. 3 Schematic representation of EBCOT Tier 1

The block coding system generates a separate embedded bit stream for each code block. The algorithm relies upon the use of classical context adaptive arithmetic coding to efficiently represent a collection of binary symbols. The coder is essentially a bit-plane coder, in which the most significant bits are coded first, then low order bits are coded in descending order. By coding the more significant bits of all coefficients first, and coding the less significant bits later, the output compressed bit stream is said to have the embedding property, as a lower rate bit stream can be obtained by truncating a higher rate bit stream, which results in a partial decoding of all coefficients. EBCOT encodes each bit-plane in three coding passes. The three coding passes in the order in which they are performed on each bit-plane are *significant propagation pass, magnitude refinement pass,* and *cleanup pass.*

All three types of coding passes scan the samples of a code block in the same fixed order. The code block is partitioned into horizontal stripes, each having a nominal height of four samples. The stripes are scanned from top to bottom. Within a stripe, columns are scanned from left to right. Within a column, samples are scanned from top to bottom. Each coefficient bit in the bit plane is coded in only one of the three coding passes and for each coefficient in a block is assigned a binary state variable called its significance state that is initialized to zero (insignificant) at the start of the encoding. The significance state changes from zero to one (significant) when the first nonzero magnitude bit is found. The context vector for a given coefficient is the binary vector consisting of the significance states of its eight immediate neighbor coefficients For each pass, contexts are created which are provided to the arithmetic coder. In the following each coding pass is described:

Significance propagation pass: During the significance propagation pass, a bit is coded if its location is not significant, but at least one of its eight-connect neighbors are significant.

Magnitude refinement pass: During this pass, all bits that became significant in previous Biplanes are coded. The magnitude refinement pass includes the bits from coefficients that are already significant.

*Clean-up pass***:** The clean-up pass is the final pass in which all bits not encoded during the previous passes are encoded (i.e. Coefficients that are insignificant and had the context value of zero during the significance propagation pass).The very first pass in a new code block is always a clean-up pass.

The symbol to be encoded and the relative context are passed to the arithmetic coder, which "loads" the current state relative to the given context and uses it to encode the given symbol. The state is then updated in order to refine probability estimates for the current context. The arithmetic coding engine in JPEG2000 (MQ-Coder) was developed for the JBIG standard for bi-level image compression. It is slightly different from standard arithmetic coders. The MQ-Code is an adaptive Binary Arithmetic Coder (BAC). Generally, a BAC encodes a code stream consisting of a sequence of symbols. Each symbol (logic '0' or logic '1') is classified into one of these categories: the More Probable Symbols (MPS), and the Less Probable Symbols (LPS), based on the probability of their occurrence. In BAC an interval is considered as a probability model. This interval is divided into two subintervals, each one, corresponding to the probability of each symbol. When a symbol occurs (either MPS or LPS), the subinterval associated with that symbol becomes the new interval. The recursive splitting of the current interval continues until all symbols are received. When the last symbol is received the characteristics of the last subdivided interval represents the encoded data.

2) *Tier-2 coding:* In JPEG2000, the bit-stream is organized as a succession of layers. The second tier coding engine of JPEG2000 is responsible for efficiently identifying the contribution of each code-block to each bit-stream layer, along with other summary information for the code-blocks. For each code-block, a separate bit-stream is generated. No information from other blocks is utilized during the generation of the bit stream for a particular block. Truncation points to each code block are allocated using rate distortion optimization. If the bit-stream is truncated exactly on a layer point, it will be optimal in the rate distortion sense. If the bitstream is truncated part way through a layer, then it will not be optimal, but since many layers are used, the result will be close to optimal. Once the entire image has been compressed, a post compression rate distortion optimization (PCRD) operation passes over all the compressed code-blocks. This operation determines, the extent to which each code-block's embedded bitstream, should be truncated in order to achieve a, particular target bit-rate or distortion. The first, lowest layer (of lowest quality), is formed from the optimally truncated code-block bit-streams in the manner described above. Each subsequent layer is formed by optimally truncating the code-block bit-streams to achieve successively higher target bit-rates.

IV. Issues in JPEG2000

A. *Rate control in JPEG2000*

One valuable capability of the coding system is the ability to create a code stream at a target bit rate providing the best recovery. Typically the code stream construction is controlled by the rate control method of the encoding process.JPEG2000 uses post-compression rate-distortion (PCRD) optimization scheme to control the bit rate. The PCRD method is applied in two steps: the first one uses the distortion contribution and the bit-rate of each coding pass to calculate the set of feasible truncation points of code-blocks. The second step uses the generalized optimal Lagrange multiplier to estimate the set of truncation points for a target bit rate. This process approximates the optimal solution and has a low computational complexity. However this optimization scheme is not efficient because it compels to encode the whole image even if only some coding passes are included in the final code stream. Since it requires encoding all the data and storing the entire encoded bit stream, even though a large portion of the data need not to be sent out, most of the computation and memory usage is considered redundant in this process. In the past few years much research has been done in alleviating this problem. Some other rate control methods related to JPEG2000 is reviewed in this section. The different rate control approaches suggested in [12]-[23] are classified under the following categories:

Deterministic: methods that use distortion measures based on the original image. These measures are used by PCRD like methods [17] to assess the rate distortion of each coding pass of code blocks.

Model based: methods based on theoretical model that characterizes the rate-distortion contributions of the truncation points. The model described in the [23],[18] is used before or during the sample data coding stage to predict the coding passes that are likely to be included in the final code stream. Model based rate allocation is an attractive approach for fast rate control as it can provide the optimal quality when the coefficients follow the model assumption. However the major drawback is the degree of model accuracy.

Quantized: methods based on the calculation of adequate step sizes for each sub-band in order to attain a target bit rate is used in the.

Opt-Lagrange: methods focussed on the search of the set of optimal truncation points using approaches different from the generalize Lagrange multiplier [33].

The quality scalability in JPEG2000 is supplied by the quality layers. These quality layers provide a good recovering when decoding only a segment of the whole code stream, and they allow retrieving selected spatial regions at different qualities. All the rate control methods described above allow the construction of quality layers. The rate control method described in the [34] is devised to provide quality scalability to JPEG2000 code streams containing a single or few quality layers. In [20] an efficient rate control system is introduced which consists of three (precoding, tier-1 coding, post coding) stages to reduce the computational complexity and memory usage, as well as maintaining high image quality comparable with PCRD. In [23], a compression quality prediction model is proposed for gray image that is to be coded by JPEG2000. With this model, the compression quality (PSNR) could be estimated according to the given compression ratio (CR) and the image activity measures (IAM) without coding images. The prediction error is lower than 3dB for more than 70% sample images when CR is higher than 15.The lack of quality scalability of code streams containing single or few quality layers and the rate-distortion optimality of window of interest (WOI) transmission is addressed in [22].Its main key feature is a novel characterization of the code-blocks rate-distortion contribution that does not use distortion measures based on the original image, or related with the encoding process.

B. Post-processing techniques for JPEG2000 decoded images

At low bit rates, wavelet based (JPEG2000) image coding performs significantly better than the traditional block based (JPEG) methods in terms of image quality. However, if the quantization errors of wavelet coefficients in coded images are very large, than the reconstructed image still carry obvious artifacts among smooth regions and around sharp edges[24]-[31]. Specifically, the quantization errors in high frequency sub-bands generally result in the ringing effect near the sharp edges. Ringing effect can also be regarded as a kind of Gibb's phenomena caused by heavy truncation of high frequency components during compression, which manifests itself as local irregularities around major edges. This section primarily focuses on post processing techniques for removal of ringing artifacts in JPEG2000 decoded images.

Post processing techniques can be classified according to their solution approach that can be derived from two different principles: image enhancement and image restoration. In [32] the post processing technique for removal of ringing artefact uses optimization functions similar to DCT oriented post processing. These methods achieve certain PSNR gains but do not deblur edges blurred by the quantisation errors. Edge reconstruction methods were used in [28] that can recover distorted edges based on edge model and a degradation model. In [29] the edge degradation is discussed under the over complete wavelet expansion and interpreted as the distortion of wavelet modulus maxima i.e... magnitude decays. The author enhances the image quality for low bit rate wavelet coding by reconstructing the coded image using the WMMR (Wavelet Modulus Maximum Representation) with improved visual quality and image fidelity (PSNR). In [25], [27] the proposed method counter intuitively employs further compression to achieve image enhancement. The objective of the authors is to construct at the decoder a version of the decompressed image with approximately shift-invariant statistics. The idea is to apply compression to the shifted version of the received image and average the results. The results show perceptual improvement in the image quality at very low bit rates. Block wise edge-preserving adaptive smoothing algorithm is suggested in [30] to suppress the spurious edge features for alleviating ringing in JPEG2000 images. In this paper quad tree decomposition followed by block shift filtering is applied to each block to suppress the ringing artefact. The algorithm is very suitable for hardware implementation and parallel processing due to regularity and the block based nature. The drawback of the method is that some textures are unavoidably smeared away by the block shift filter which results in low image quality.

V. EXPERIMENTAL RESULTS

In this section, the compression performance of JPEG2000 is briefly demonstrated and its performance comparison with traditional JPEG standard has been tabulated. To obtain results, the test image Lena of size 512×512 is taken. The image taken is a gray scale image. For lossy compression, the distortion is characterized by peak signal to noise ratio (PSNR) which is defined as:

$$PSNR\ (dB) = 10log_{10}\,[(255)^2\,/MSE]$$

where MSE refers to the mean squared error between the original image and the reconstructed image.

The compression performance of JPEG2000 in terms of bits per pixel and PSNR is tabulated in table 1. The software used for the purpose is MATLAB. The gray scale images taken are Lena and Boat of size 512×512.

Image	Rate (bpp)	PSNR	MSE
Boat.bmp	0.5	52	0.40
	0.2	41.93	4.16
	0.1	36.63	14.10
	0.08	34.55	22.77
	0.04	32.11	40.12
Lena.bmp	0.46	54.26	0.24
	0.24	46.32	1.51
	0.12	41.82	4.27
	0.08	39.83	6.75
	0.04	37.27	12.17

TABLE I: Comparison of JPEG2000 performance for different test images

The TABLE I show that the reconstructed image quality depends on the image content and its characteristics.

	JPEG2000	JPEG
Bits per pixel (bpp)	PSNR	PSNR
0.46	54.26	49.8
0.24	46.32	41.32
0.12	41.82	39.33
0.08	39.83	37.22

TABLE II: Comparison of JPEG2000 with JPEG

Table II shows the performance comparison of JPEG with JPEG 2000 in terms of bits per pixel and PSNR. The tabulation is for the case of low bit rates i.e. below 0.5 bpp. The figures in the table shows that JPEG 2000 outperforms JPEG at low bit rates.

VI. CONCLUSION

In this paper, a comprehensive review of the existing JPEG2000 compression standard has been done and its performance for different images is tabulated. The work in this paper aims at providing a comparison of performance of two most popular still image coding algorithms JPEG and JPEG2000 for low bit-rate compression. The result presented in previous section shows that JPEG2000 improves the compression performance of JPEG especially at low bit rates i.e. less than 0.5bpp.

It is also being observed that the conventional PCRD algorithm in JPEG2000 can provide excellent rate-distortion performance for an image but it is not sufficiently efficient in terms of high computation complexity and large memory requirements. A brief review of rate control algorithms suggested for JPEG2000 in past few years is also presented.

This paper also focuses on post processing techniques for JPEG2000 decoded images to achieve higher compression ratio while maintaining better perceptual quality. There has been a significant number of research activities in the post processing of wavelet based compressed image over the last few years. Therefore a review of recent developments in post processing techniques for JPEG2000 decoded image is also presented.

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