JPEG2000: The New Still Picture Compression Standard

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Abstract: *This paper presents an overview of the upcoming JPEG2000 still picture compression standard. JPEG2000 is not only intended to provide rate-distortion and subjective image quality performance superior to existing JPEG standard, but to also provide functionality that the current JPEG standard can either not address efficiently nor address at all. Lossless and lossy compression, encoding of very large images, progressive transmission by pixel accuracy and by resolution, robustness to the presence of bit-errors and region-of-interest coding, are some representative examples of its features.*

Keywords: *JPEG, colour image coding, data compression, source coding, subbabnd coding, wavelet transform.*

1. INTRODUCTION

With the increasing use of multimedia technologies, picture compression requires higher performance as well as new features. In March 1997 a new call for contributions were launched for the development of a new standard for the compression of still pictures, the JPEG2000. This project, JTC 1.29.14 (15444), was intended to create a new image coding system for different types of still pictures (bi-level, grey-level, colour, multi-component), with different characteristics (natural images, scientific, medical, remote sensing, text, rendered graphics, etc) allowing different imaging models (client/server, real-time transmission, image library archival, limited buffer and bandwidth resources, etc) preferably within a unified system. This coding system should provide low bit-rate operation with rate-distortion and subjective image quality performance superior to existing standards. And all this, without sacrificing performance at other points in the rate-distortion spectrum, and at the same time incorporating many contemporary features. The standard is intended to complement and not to replace the current JPEG standards. The standard is expected to reach the International Standard (IS) stage in December 2000 [1].

The JPEG2000 standard provides a set of features that are of vital importance to many high-end and emerging applications, by taking advantage of new technologies. It addresses areas where current standards fail to produce the best quality or performance and provides capabilities to markets that currently do not use compression. The markets and applications better served by the JPEG2000 standard are Internet, colour facsimile, printing, scanning (consumer and pre-press), digital photography, remote sensing, mobile, medical imagery, digital libraries / archives and E-commerce. Some of the features that this standard possesses are the following [2]:

- **Superior low bit-rate performance**: This standard offers performance superior to the current standards at low bit-rates (e.g. below 0.25 bpp for highly detailed grey-scale images). This significantly improved low bit-rate performance is achieved without sacrificing performance on the rest of the rate-distortion spectrum.
- **Continuous-tone and bi-level compression**: It is desired to have a coding standard that is capable of compressing both continuous-tone and bi-level

images. The standard strives to achieve this with similar system resources.

- **Lossless and lossy compression**: It is desired to provide lossless compression naturally in the course of progressive decoding. Examples of applications that can use this feature include medical images, image archival applications, network applications and pre-press imagery.
- **Progressive transmission by pixel accuracy and resolution**: Progressive transmission that allows pictures to be reconstructed with increasing pixel accuracy or spatial resolution is essential for many applications. This feature allows the reconstruction of images with different resolutions and pixel accuracy, as needed or desired, for different target devices.
- **Region of Interest Coding**: Often there are parts of a picture that are more important than other parts of it. This feature allows user-defined Regions-Of-Interest (ROI) in the image to be compressed with better quality than the rest of the image.
- **Robustness to bit-errors:** It is desirable to consider robustness to bit-errors while designing the codestream. This is an important feature for wireless communication applications.

In this paper, the structure of the JPEG2000 standard is presented together with a description of its advanced features and functionalities. The paper is organized in the following way: In Section 2, the structure of the standard is described. The file format aspects, as well as other interesting features of the standard, like region-of-interest coding, error resilience and scalability, are presented in Section 3. Finally, some performance comparisons are reported in Section 4 of the paper.

2. THE STRUCTURE OF THE STANDARD

The block diagram of the JPEG200 encoder is illustrated in Fig. 1a. It is similar to every transform-based coding scheme. The discrete transform is first applied on the source image data. The transform coefficients are then quantised and entropy coded, before forming the output codestream (bitstream). The decoder is depicted in Fig. 1b. The codestream is first entropy-decoded, dequantised and undergone the inverse discrete transform to produce the reconstructed image. It is worth mentioning that, unlike other coding schemes, the JPEG2000 can be both lossy and lossless. This depends on the wavelet transform and the quantisation applied. The standard allows tiling of the image. Tiles are encoded independently.

Prior to computation of the forward discrete wavelet transform (DWT) on each tile, all samples of the image tile component are DC level shifted by subtracting the same quantity (i.e. the component depth) from each sample.

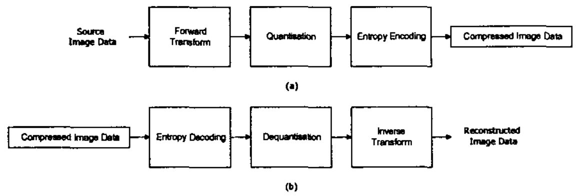


Figure 1 Block diagram of the JPEG2000 (a) encoder and (b) decoder.

2.1. Wavelet Transform

For the forward DWT the standard uses a 2-D separable filtering for subband decomposition of a 2-D set of samples into low-pass samples, representing a downsampled low-resolution version of the original set, and high-pass samples, representing a downsampled residual version of the original set, needed for the perfect reconstruction of the original set from the low-pass set. In general, any user supplied wavelet filter bank may be used (Part II of the standard). The DWT can be *irreversible* (not exact reconstruction of image samples) or *reversible (which can result in exact reconstruction of the image samples).*

Table I Daubechies 9/7 analysis and synthesis filter coefficients

Analysis Filter Coefficients		
i	Lowpass Filter $h_L(i)$	Highpass Filter $h_H(i)$
0	0.6029490182363579	1.115087052456994
±1	0.2668641184428723	-0.5912717631142470
±2	-0.07822326652898785	-0.05754352622849957
±3	-0.01686411844287495	0.09127176311424948
±4	0.02674875741080976	
Synthesis Filter Coefficients		
i	Lowpass Filter $g_L(i)$	Highpass Filter $g_H(i)$
0	1.115087052456994	0.6029490182363579
±1	0.5912717631142470	-0.2668641184428723
±2	-0.05754352622849957	-0.07822326652898785
±3	-0.09127176311424948	0.01686411844287495
±4		0.02674875741080976

Table II 5/3 analysis and synthesis filter coefficients

Analysis Filter Coefficients		
i	Lowpass Filter $h_L(i)$	Highpass Filter $h_H(i)$
0	6/8	1
±1	2/8	-1/2
±2	-1/8	

Synthesis Filter Coefficients		
i	Lowpass Filter $g_L(i)$	Highpass Filter $g_H(i)$
0	1	6/8
±1	1/2	-2/8
±2		-1/8

The default *irreversible transform* is implemented by means of the Daubechies 9-tap/7-tap filter [3]. The analysis and the corresponding synthesis filter coefficients are given in Table I. The default *reversible transformation* is implemented by means of the 5-tap/3-tap filter, the coefficients of which are given in Table II [4]. Two filtering modes are supported by the standard: the *convolution-based* and the *lifting-based* [4, 5].

2.2. Quantisation

Quantisation is the process by which the coefficients are reduced in precision. This operation is lossy, unless the quantisation step is 1 and the coefficients are integers, as produced by the reversible integer 5/3 wavelet. Each of the transform coefficients $a_b(u,v)$ of the subband b is quantised to the value $q_b(u,v)$ according to the formula:

$$q_b(u,v) = \mathrm{sign}(a_b(u,v)) \left\lfloor \frac{|a_b(u,v)|}{\Delta_b} \right\rfloor \quad (1)$$

The quantisation step $_b$ is represented relative to the dynamic range R_b of subband b, by the exponent $_b$ and mantissa $_b$ as:

$$\Delta_b = 2^{R_b-\varepsilon_b}\left(1+\frac{\mu_b}{2^{11}}\right) \quad (2)$$

The dynamic range R_b depends on the number of bits used to represent the original image tile component and on the choice of the wavelet transform. All quantised transform coefficients are signed values even when the original components are unsigned. These coefficients are expressed in a sign-magnitude representation prior to coding.

2.3. Entropy Coding

Each subband of the wavelet decomposition is divided into rectangular blocks, called *code-blocks*, which are coded independently using arithmetic coding. These code-blocks are coded at a bit-plane at a time, starting with the most significant bit-plane with a non-zero element to the least significant bit-plane. For each bit-plane in a code-block, a special code-block scan pattern is used for each of three passes (significance propagation pass, magnitude refinement pass and clean-up pass). Each coefficient bit in the bit-plane is coded in only one of the three passes. A rate distortion optimisation method is used to allocate a certain number of bits to each block. The recursive probability interval subdivision of Elias coding is the basis for the binary *arithmetic coding* process. With each binary decision, the current probability interval is subdivided into two sub-intervals, and the codestream is modified (if necessary) so that points to the base (the lower bound) of the probability sub-interval assigned to the symbol, which occurred. Since the coding process involves addition of binary fractions rather than concatenation of integer codewords, the more probable binary decisions can often be coded at a cost of much less than one bit per decision.

3. Some Remarkable Features of the Standard

The JPEG2000 standard exhibits a lot of features, the most significant being the possibility to define regions of interest in an image, the spatial and SNR scalability, the error resilience and the possibility of intellectual property rights protection. Interestingly enough, all these features are incorporated within a unified algorithm.

Region-of-Interest (ROI): One of the features included in JPEG2000 is the ROI coding. According to this, certain ROI's of the image can be coded with better quality than the rest of the image (background). The ROI approach defined in the JPEG2000 Part I is called MAXSHIFT method and allows ROI encoding of arbitrary shaped regions without the need of shape information and shape decoding [6]. The ROI coding method scales-up the coefficients so that the bits associated with the ROI are placed in higher bit-planes. During the embedded coding process, those bits are placed in the bit-stream before the non-ROI parts of the picture. Thus, the ROI will be decoded, or refined, before the rest of the picture. Regardless of the scaling, a full decoding of the bit-stream results in a reconstruction of the whole picture with the highest fidelity available. If the bit-stream is truncated, or the encoding process is terminated before the whole image is fully encoded, the ROI will have a higher fidelity than the rest of the image.

Scalability: Scalable coding of still pictures means the ability to achieve coding of more than one resolution and/or quality simultaneously. Scalable image coding involves generating a coded representation (bitstream) in a manner which facilitates the derivation of images of more than one resolution and/or quality by scalable decoding. Bitstream scalability is the property of a bitstream that allows decoding of appropriate subsets of a bitstream to generate complete pictures of resolution and/or quality commensurate with the proportion of the bitstream decoded. If a bitstream is truly scalable, decoders of different complexities, from low performance to high performance can coexist. While low performance decoders may decode only small portions of the bitstream producing basic quality, high performance decoders may decode much more and produce significantly higher quality. The most important types of scalability are signal-to-noise (SNR) scalability and spatial scalability [5].

SNR scalability involves generating at least two image layers of same spatial resolution, but different qualities, from a single image source.

Spatial scalability is intended for use in systems with the primary common feature that a minimum of two layers of spatial resolution is necessary. Spatial scalability involves generating at least two spatial resolution layers from a single source such that the lower layer is coded by itself to provide the basic spatial resolution and the enhancement layer employs the spatially interpolated lower layer and carries the full spatial resolution of the input image source.

Error Resilience: To improve the performance of transmitting compressed images over error prone channels, error resilient bit stream syntax and tools are included in this standard. The error resilience tools deal with channel errors using the following approaches: data partitioning and resynchronisation, error detection and concealment, and Quality of Service (QoS) transmission based on priority.

Multicomponent Images: JPEG2000 supports multiple-component images. Different components need not have the same bit-depths; nor need they have all been signed or unsigned. For reversible systems, the only requirement is that the bit-depth of each output image component must be identical to the bit-depth of the corresponding input image component. Two different component transformations are supported by the standard: an *irreversible component transformation* (ICT) and a *reversible component transformation* (RCT) [5].

New File Format with IPR Capabilities: An optional file format (JP2) for the JPEG2000 compressed image data has been defined by the standard. This format has got provisions for both image and metadata, a mechanism to indicate the tonescale or colourspace of the image, a mechanism by which readers may recognise the existence of intellectual property rights (IPR) information in the file and a mechanism by which metadata (including vendor specific information) can be included in the file.

4. PERFORMANCE OF THE STANDARD

Up to now we have been dealing with the description of the main blocks of the JPEG2000 algorithm. In this section we will have a look at the efficiency of the algorithm in comparison with existing lossless and lossy compression standards.

The rate-distortion behaviour of the lossy (non-reversible) JPEG2000 and the progressive JPEG is depicted in Fig. 2 for a natural image. It is seen that the JPEG2000 significantly outperforms the JPEG scheme. We can easily conclude that for similar PSNR quality, the JPEG2000 compresses almost twice more than JPEG. The superiority of the JPEG2000 can be subjectively judged with the help of Fig. 3, where the reconstructed image *'goldhill'* (720x576) is shown. Both images were compressed at a rate of 0.125 bpp using the existing JPEG and the upcoming JPEG2000.

One of the interesting and unique features of JPEG2000 is its capability in defining ROI's, that are coded at a better quality than the rest of the image. The regions can be one or more and of any shape and size. In Fig. 4 an example of a circular ROI is given. Experiments have shown that for lossless coding of images, the ROI feature results in an increase in the bitrate of approximately 1 to 8 percent in comparison to lossless coding without using the ROI feature [6].

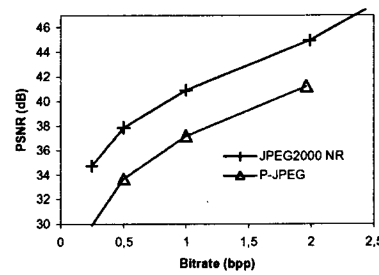
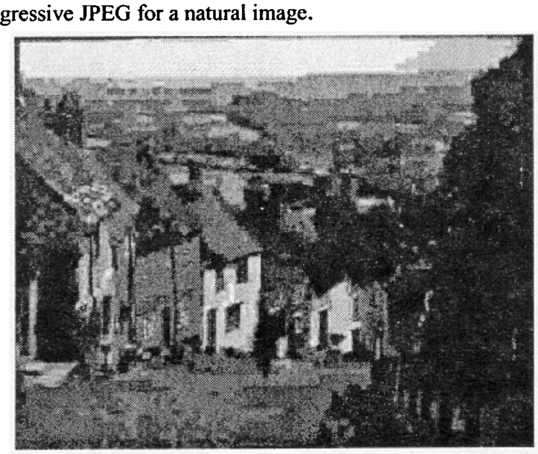


Figure 2 Rate-distortion results for the JPEG2000 versus the progressive JPEG for a natural image.



(a)

(b)

Figure 3 Reconstructed images compressed at 0.125 bpp by means of (a) JPEG and (b) JPEG2000.

The lossless compression efficiency of JPEG2000 versus the lossless mode of JPEG and JPEG-LS [7] for a natural and a compound image (that contains both text) is reported in Table III. It is seen that JPEG2000 performs equivalently to JPEG-LS in the case of the natural image, with the added benefit of scalability. JPEG-LS, however, is advantageous in the case of the compound image. Taking into account that JPEG-LS is significantly less complex than JPEG2000, it is reasonable to use JPEG-LS for lossless compression. In such a case though, the generality of JPEG2000 is sacrificed [8].

Figure 4 Reconstructed image at 0.0625 in which a rectangular ROI has been defined.

Table III Lossless compression results (in bpp)

Image	lossless JPEG	JPEG-LS	JPEG2000
Lena (512x512, 24bpp)	14.75	13.56	13.54
Cmpnd1 (512x768, 8bpp)	2.48	1.24	2.12

Comparative results of JPEG, JPEG-LS and JPEG2000 from the functionality point of view are shown in Table IV. A plus (minus) sign indicates that the corresponding functionality is supported (not supported). The more the plus signs the greater the support. The parentheses indicate that a separate mode is required. It becomes evident from Table IV, that the JPEG2000 standard offers the richest set of features in a very efficient way and within a unified algorithm [8].

5. CONCLUSIONS

JPEG2000 is the new standard for still picture compression that is going to be in use by the beginning of next year. Lossless and lossy coding, embedded lossy to lossless, progressive by resolution and quality, high compression efficiency, error resilience and lossless colour transformations are some of its features. Performance comparisons have shown that JPEG2000 is indeed superior to existing still picture compression standards.

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Table IV Summary of functionalities supported by each standard

Compression Algorithm	Lossless	Lossy	Embedded bitstream	ROI	Error resilience	Scalability	Complexity	Random access	Generic
JPEG	(+)	++	-	-	-	(+)	++(+)	+	+
JPEG-LS	++++	+	+	-	-	-	+	-	+
JPEG2000	+++	+++	+++	++	++	++	+++	++	+++