COMPARISON OF JPEG IMAGE CODERS

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Abstract: *In this paper we report results from our comparative study of JPEG and JPEG2000 image coders using two image quality measures: Peak Signal to Noise Ratio (PSNR) as traditional objective picture quality measure, and Picture Quality Scale as perception based quantitative picture quality measure. Coders are evaluated in rate-distortion sense. The influences of different image contents and compression ratios are assessed. The objective of this paper is to provide a quantitative and qualitative comparison of JPEG and JPEG2000 image coding focusing on low bitrates.*

Key words: *Image Coding, JPEG, JPEG2000, Picture Quality Measures*

1. INTRODUCTION

With the continual expansion of multimedia and Internet applications, the needs and requirements of the technologies used, grew and evolved. To address these needs and requirements in the specific area of still image compression, many efficient techniques with considerably different features have recently been developed for both lossy and lossless compression [1]-[5]. The evaluation of lossless techniques is a simple task where compression ratio and execution time are employed as standard criteria. Contrary, the evaluation of lossy techniques is difficult task because of inherent drawbacks associated with the objective measures of image quality, which do not correlate well with subjective quality measures.

Since the mid-80s, members from both the International Telecommunication Union (ITU) and the International Organization for Standardization (ISO) have been working together to establish an international standard for the compression of greyscale and colour still images. This effort has been known as JPEG, the Joint Photographic Experts Group. Officially, JPEG corresponds to the ISO/IEC international standard 10928-1, digital compression and coding of continuous-tone (multilevel) still images [6]. After evaluating a number of coding schemes, the JPEG members selected a Discrete Cosine Transform (DCT) based method. JPEG became a Draft International Standard (DIS) in 1991 and an International Standard (IS) in 1992 [1]- [3].

Much research has been undertaken on still image coding since JPEG standard was established. JPEG2000 is an attempt to focus these research efforts into a new standard for coding still images. The standardisation process has already produced the Final Draft International Standard (FDIS) [7]. One of the aims of the standardisation committee has been the development of Part I, which could be used on a royalty and fee free basis. This is important for the standard to become widely accepted, in the same manner as the original JPEG is now. The scope of JPEG2000 includes not only new compression algorithms, but also flexible compression architectures and formats. The standard intends to compliment and not to replace the current JPEG standards. It addresses areas where current standards fail to produce the best quality or performance. JPEG2000 should provide low bitrate operation (below 0.25 bits/pixel) with subjective image quality performance superior to existing standards, without sacrificing performance at higher bitrates. Image compression scheme in JPEG2000 Part I is based on discrete wavelet transform (DWT).

In this paper we attempt to evaluate and compare image quality in two mentioned still image coding system: lossy baseline JPEG [8] and JPEG2000 image coding standard Part I [9]. JPEG and JPEG2000 use different compression techniques, which introduce different types of impairment in the reconstructed images. To describe image distortions of dissimilar nature, we used four test images with different spatial and frequency characteristics. Image quality is measured using peak signal-to-noise ratio (*PSNR*) [10] as most common objective measure, which does not correlate well with subjective quality measure, and picture quality scale (*PQS*) [11], which incorporates model of human visual system (HVS) and leads to better correlation with the response of the human observers.

2. JPEG AND JPEG2000 IMAGE COMPRESSION TECHNIQUES

Because theoretical analysis of JPEG and JPEG2000 image compression techniques is widely available, in this section the main focus is given to explanation relying on experimental results.

Lossy baseline JPEG is the very well known and popular standard for compression of still images. In baseline JPEG mode, the source image is divided in 8×8 blocks and each block is transformed using DCT. The data compression is achieved via quantization followed by variable length coding (VLC). 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 compression is determined by a quantization scale factor. Increasing the quantization scale factor leads to coarser quantization, which gives higher compression and lower decoded image quality. The DC coefficients of all blocks are coded separately, using a predictive scheme. The block-based segmentation of the source image is fundamental limitation of the DCT-based compression system. The degradation is known as "blocking effect" and depends on compression ratio and image content. JPEG is very efficient coding method but the performance of block-based DCT scheme degrades at high compression ratio.

In recent time, much of the research activities in image coding have been focused on the Discrete Wavelet Transform (DWT) which has become a standard tool in image compression applications because of their data reduction capability [12], [13]. DWT offers adaptive spatial-frequency resolution (better spatial resolution at high frequencies and better frequency resolution at low frequencies) that is well suited to the properties of HVS. It can provide better image quality than DCT, especially at higher compression ratio [13].

JPEG2000 Part I coding procedure is based on DWT, which is applied on image tiles. The tiles are rectangular non-overlapping blocks, which are compressed independently. Using DWT tiles are decomposed into different decomposition (resolution) 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. In JPEG2000 Part I power of 2 decompositions are allowed (dyadic decomposition) and two types of wavelet filters are implemented: Daubechies 9-tap/7-tap filter and 5-tap/3-tap filter. Due to its better performance for visually lossless compression, the 9-tap/7-tap filter is used by default. 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.

3. TEST IMAGES

The fundamental difficulty in testing image compression system is how to decide which test images to use for the evaluations. The image content being viewed influences the perception of quality irrespective of technical parameters of the system [14]. Normally, a series of pictures, which are average in terms of how difficult they are for system being evaluated, has been selected.

We used four types of test images (512×512, 8 bits/pixel) with different spatial and frequency characteristics: Baboon, Fingerprint, Goldhill and Lena, Fig. 1. Characteristics of test images are evaluated in spatial domain using spatial frequency measure (*SFM*) [10] and in frequency domain using spectral activity measure (*SAM)* [12]. *SFM* is defined as follows:

$$SFM = \sqrt{R^2 + C^2}\ ,\ R = \sqrt{\frac{1}{MN}\sum_{j=1}^{M}\sum_{k=2}^{N}\left(x_{j,k} - x_{j,k-1}\right)^2}\ ,\ C = \sqrt{\frac{1}{MN}\sum_{k=1}^{N}\sum_{j=2}^{M}\left(x_{j,k} - x_{j-1,k}\right)^2}\ , \qquad (1)$$

where R is row frequency, C is column frequency, $x_{j,k}$ denotes the samples of image, M and N are numbers of pixels in horizontal and vertical directions respectively. *SAM* is a measure of image predictability. It is defined as the ratio of the arithmetic and the geometric mean of the Discrete Fourier Transform (DFT) coefficients:

$$SAM = \frac{\frac{1}{M \cdot N}\sum_{j=0}^{M-1}\sum_{k=0}^{N-1}\left|F(j,k)\right|^2}{\left[\prod_{j=0}^{M-1}\prod_{k=0}^{N-1}\left|F(j,k)\right|^2\right]^{\frac{1}{M \cdot N}}}, \qquad (2)$$

where $F(j,k)$ is (j,k)-th DFT coefficient of image. *SAM* has a dynamic range of $[1, \infty)$. Higher values of *SAM* imply higher predictability. Active images (*SAM* close to 1) are in general difficult to code. These images usually contain large number of small details and low spatial redundancy.

a) Baboon	b) Fingerprint	c) Goldhill	d) Lena
SFM=36.515	*SFM*=24.925	*SFM*=16.167	*SFM*=14.019
SAM=24.93	*SAM*=352.65	*SAM*=126.77	*SAM*=227.43

Fig. 1. Test images

Test image Baboon has a lot of details and consequently large *SFM* and small *SAM*. Large value of *SFM* means that image contains components in high frequency area and small value of *SAM* means low predictability. It returns that Baboon presents low redundant image, which is difficult for compression. Test image Fingerprint is not typical natural image because this image has relatively large *SFM* but also large *SAM*. For typical natural image largest value of *SFM* implies smaller value of *SAM*. Image Fingerprint is easier for coder to handle than Baboon. Images Goldhill and Lena are images with less detail (smaller *SFM*) than Baboon. Image Goldhill has higher *SFM* and lower *SAM* than Lena. It indicates that image Lena has higher predictability than Goldhill.

4. PICTURE QUALITY MEASURE

The image quality can be evaluated objectively and subjectively [15]. Objective methods are based on computable distortion measures. A standard objective measures of image quality are Mean Square Error (*MSE*) and Peak Signal-to-Noise Ratio (*PSNR*) which is defined as

$$PSNR(dB) = 10\log_{10}\left(\frac{255^2}{MSE}\right), \tag{3}$$

for the common case of 8 bits per picture element of input image. *MSE* and *PSNR* are the most common methods for measuring the quality of compressed images, despite the fact that they are not adequate as perceptually meaningful measures of picture quality. In fact, in image compression systems, the truly definitive measure of image quality is perceptual quality [16]. The distortion is specified by mean opinion score (*MOS)* or by picture quality scale (*PQS*). *MOS* is result of perception based subjective evaluation described in ITU-R BT Rec. 500 [17]. *PQS* methodology was proposed in [11] as perception based objective evaluation. It has been developed in the last few years for evaluating the quality of compressed images.

In addition to the commonly used *PSNR*, we chose to use a perception based objective evaluation that is quantified by *PQS*. It combines various perceived distortions into a single quantitative measure and perfectly responds to a mean opinion score. To do so, *PQS* methodology uses some of the properties of HVS relevant to global image impairments, such as random errors, and emphasises the perceptual importance of structured and localised errors. *PQS* is constructed by regressions with *MOS*, which is 5-level grading scale developed for subjective evaluation. (5-imperceptible, 4-perceptible, but not annoying, 3-slightly annoying, 2-annoying, 1-very annoying).

5. RESULTS

Four test images are coded and decoded using JPEG and JPEG2000 compression algorithms. For each test image, nine different bitrates were selected: 0.10, 0.20, 0.30, 0.40, 0.50, 0.75, 1.00, 1.50 and 3.00 bpp (bits per pixel). Table 1 presents *PSNR* results and Table 2 *PQS* results for all images in our experiment. Fig. 2 compares *PSNR* and *PQS* values for JPEG and JPEG2000 compression methods at different bitrates. At lowest bitrates *PQS* is out of range. It means that images have very low quality, which can not be evaluated using *PQS*.

If we consider only *PSNR* values (Table 1) we can conclude that JPEG2000 provides better image quality than JPEG for all test images and all bitrates. The JPEG2000 results are significantly better than the JPEG results. Typically JPEG2000 provides a few dB improvement over JPEG. But if we take into account visual image quality quantified by *PQS* (Table 2), the conclusions are quite different. At high and moderate bitrates (above 1 bpp) for all test images JPEG performs better that JPEG2000. At lower bitrates image quality of JPEG degrades below image quality of JPEG2000 because of the artifacts resulting from the block-based DCT scheme. On the other hand JPEG2000 wavelet-based coding provides better image quality at low bitrates (below 0.5 bpp) for all test images because of overlapping basis functions and better energy compaction property. At bitrates lower than 0.1 bpp JPEG images are not recognisable while JPEG2000 produces recognisable images.

Table 1. *PSNR* results (in dB)

Test image	Baboon		Fingerprint		Goldhill		Lena	
bitrate (bpp) \ coder	JPEG	JPEG 2000	JPEG	JPEG 2000	JPEG	JPEG 2000	JPEG	JPEG 2000
0.10	19.0083	21.3211	18.9223	22.9362	22.0284	27.8901	21.9289	29.9702
0.20	20.8713	22.6913	21.1548	25.3899	26.8679	29.9359	28.8961	33.0524
0.30	22.0333	23.6591	22.6390	27.3952	29.2333	31.1425	31.6818	34.9189
0.40	22.8200	24.6781	25.3741	28.9198	30.3571	32.3101	33.4328	36.2176
0.50	23.6726	25.5832	26.9922	29.9333	31.3103	33.2441	34.6446	37.3362
0.75	25.0003	27.4183	29.4432	32.2384	32.7882	35.0119	36.1753	39.0222
1.00	26.4469	29.1106	31.7714	33.9338	34.4045	36.5728	37.7603	40.4310
1.50	28.6416	32.0164	34.5683	37.6364	36.4777	39.1898	39.6584	42.8391
3.00	34.7708	40.0833	41.0423	46.6267	41.9067	47.0935	43.5956	48.8186

Table 2. *PQS* results

Test image	Baboon		Fingerprint		Goldhill		Lena	
bitrate (bpp) \ coder	JPEG	JPEG 2000	JPEG	JPEG 2000	JPEG	JPEG 2000	JPEG	JPEG 2000
0.10	--	0.2131	--	0.1574	--	--	--	--
0.20	0.5940	1.1196	--	1.5407	--	0.4708	--	2.2229
0.30	1.4209	1.5474	0.9679	2.4801	0.6550	1.3854	2.0837	3.0911
0.40	1.9773	2.0634	2.1430	3.0656	1.6563	2.0740	3.0251	3.5029
0.50	2.5376	2.3254	2.7635	3.4748	2.3950	2.5858	3.5790	3.8659
0.75	3.2787	2.8650	3.5809	4.0541	3.3240	3.3767	4.1603	4.2822
1.00	3.8788	3.4603	4.1846	4.3363	4.0406	3.7204	4.6120	4.5345
1.50	4.4227	3.9683	4.7308	4.6908	4.6137	4.3449	4.9588	4.7892
3.00	5.0659	4.8119	5.2661	5.1878	5.1577	4.9053	5.2779	5.1586

An observation made in evaluating *PSNR* is that images with higher *SFM* produces larger reconstruction error (smaller *PSNR*) for a given compression technique and a given bitrate. The highest *PSNR* values are associated with test image Lena that has the lowest *SFM*. So, *SFM* can be used as an indicator of the test image activity level if we evaluate image quality using *PSNR*. But the image quality evaluated using *PQS* does not depend on original image spatial frequency. *PQS* depends on *SAM* and for a given bitrate and a given compression method images with higher *SAM* provide better visual quality than images with lower *SAM*. It means that if we want to measure visual image quality, test material should be evaluated and classified using *SAM*.

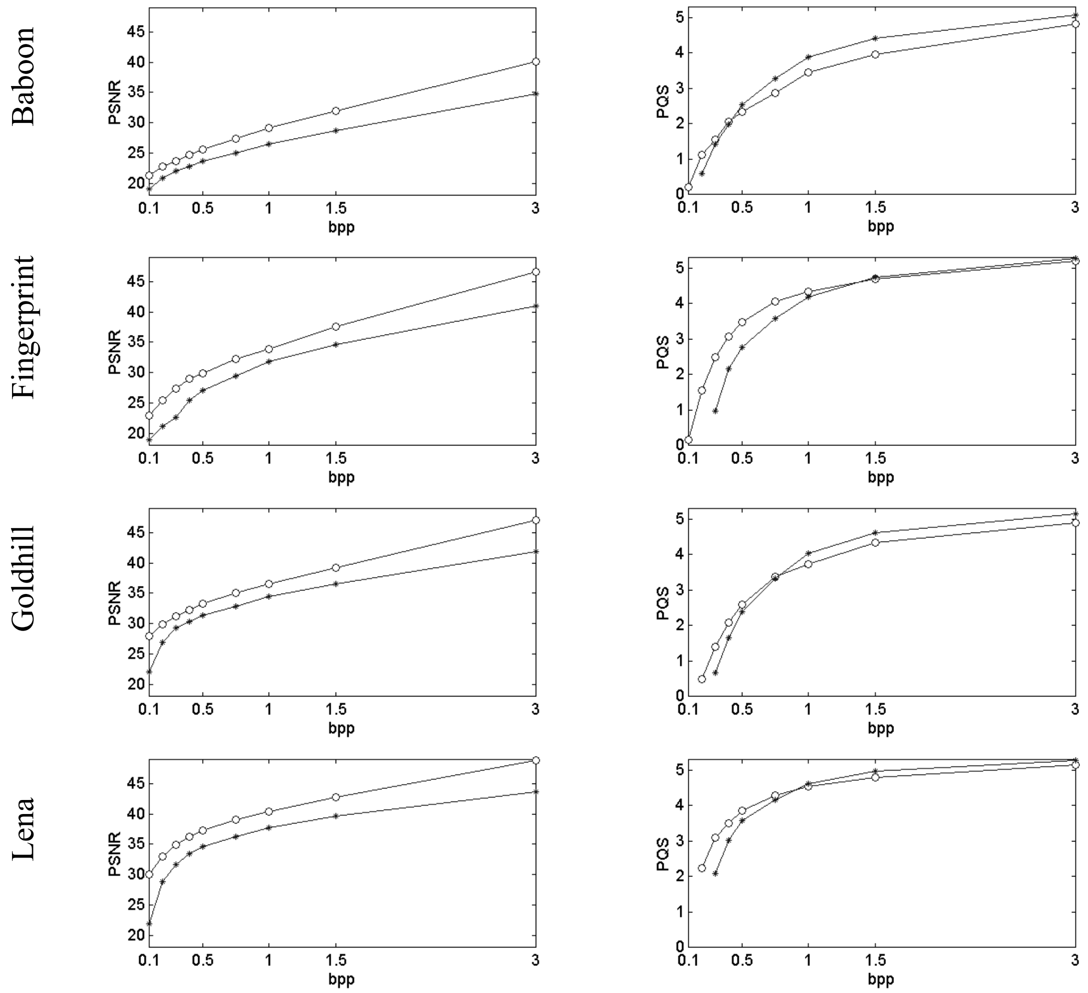

Fig. 2. *PSNR* and *PQS* results: —*— JPEG, —o— JPEG2000

6. CONCLUSION

Comparison of JPEG and JPEG2000 using *PSNR* as image quality measure shows that JPEG2000 achieves higher picture quality than JPEG for all bitrates and test images. But visual image quality quantified by *PQS* shows different results. JPEG offers better compression performance in the mid- and high bitrates (above 1 bpp) than JPEG2000. We propose the application of JPEG for moderate bitrates because of good image quality and lower computational complexity in comparison with JPEG2000. At low bitrates (below 0.25 bits/pixel) the JPEG image distortion becomes unacceptable compared with more modern algorithms such as JPEG2000 based on DWT. Corresponding to DCT as used in JPEG, DWT is able to achieve advantages of low bitrate coding. JPEG2000 wavelet-based technique provides significantly lower distortion than JPEG at low bitrates. Computational complexity of JPEG2000 is higher than complexity of JPEG. For low bitrates, improvements in image quality give good reason for utilisation of JPEG2000.

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