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MEDICAL IMAGE COMPRESSION USING JPEG-2000 AND JPEG: A COMPARISON STUDY

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Due to the constrained bandwidth and storage capacity, medical images must be compressed before transmission and storage. However, compression will reduce image fidelity, especially when the image is compressed of lower bit rate, which cannot be tolerated in medical field. In this paper, the compression performance of the new JPEG-2000 and the more conventional JPEG is studied. The parameters used for comparison include the compression efficiency, peak signal-to-noise ratio (PSNR), picture quality scale (PQS), and mean opinion score (MOS). Three types of medical images are used — X-ray, magnetic resonance imaging (MRI) and ultrasound. Overall, the study shows that JPEG-2000 compression is more acceptable and superior compare to JPEG for lossy compression.

Keywords: Medical images compression; JPEG-2000; JPEG; lossy compression.

1. Introduction

Digital imagery is spreading fast in our world today from ordinary digital images to high-tech satellite images. With the increasing use of multimedia techniques, image compression requires higher performance as well as new features. This is especially so in telemedicine applications.

Consequently, standards for the efficient representation and inter-change of digital images are essential. Christopoulos *et al.*[3] said that since the mid-80s, members from both the International Telecommunication Union Standardization Sector (ITU-T) and the International Standardization for Organization (ISO) have been working together to establish a joint international standard for the compression of grayscale and color still images. This effort has been known as JPEG, the Joint Photographic Experts Group (The word "joint" in JPEG refers to the collaboration between ITU and ISO). Wallace,[19] ISO/IEC 10918-1[8] and ISO/IEC, ISO/IEC

14495-1[9] showed that both the JPEG and JPEG-LS standards were the results from the effort of the JPEG committee.

For the last few years, the JPEG committee has been working towards the establishment of a new standard known as JPEG-2000 (i.e., ISO/IEC 15444). Effort has been made not only to make this new standard suitable for applications of today and tomorrow by providing features unavailable in previous standards, but also by providing more efficient support for features that are covered by them.

A new call for contributions were launched in March 1997 for the development of a new coding standard for the compression of still images, the JPEG-2000. This project, JTC 1.29.14 (15444), was intended to create a new image coding system for different types of still images (bi-level, gray-level, color, multi-component), with different characteristics (scientific, rendered graphics, medical, remote sensing, natural images, text, etc) allowing different imaging models (client/server, real-time transmission, image library archival, limited buffer and bandwidth resources, etc) to work 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, without sacrificing performance at other points in the rate-distortion spectrum, incorporating many interesting features at the same time.

To address a need in the specific area of still image encoding, a new standard, JPEG-2000 is currently being developed, with its Part 1 has already been approved as international standard. Some representation features are very useful for medical image coding. For example, lossless and lossy coding, progressive embedded by pixel accuracy and by resolution robustness to the presence of bit-error, and region of interest (ROI).

The standard is intended to compliment and not to replace the current JPEG standards, even though it is superior to the existing standards in terms of subjective image quality and rate-distortion with a number of additional functionalities, which are either inefficiently adressed or not addressed by the current standards. Some of these include lossless and lossy compression, sequential build up and tiling, region of interest (ROI) coding, spatial and quality (SNR) scalabilities, content-based description, random bit-stream access and processing, bit stream parsing, improved error resilience, human visual system weighting line based transforms, open architecture, protective image security (intellectual property rights) and a common compression technique for binary and continuous tone images.

One of the aims of the standardization committee has been the development of Part 1 (the core system), which could be used on a royalty and fee-free basis. This in the same manner as the original JPEG with Huffman coding is now. The fruits of these hardship has now come to bear, as JPEG-2000 Part 1 (i.e., ISO/IEC 15444-1) has been approved as a new international standard in December 2000.

Following this introduction is the experimental theory related to this study. The results from this study is then presented and followed by a discussion. After that, some conclusions are made based from the results and discussion.

2. Experimental Theory

The range of acceptable compression rates with different methods and on different types of images differs between imaging modalities and has always raised questions and doubts on what is the ideal compression ratio for each type of image. This is especially important for medical images, which is considered critical data, and any loss of information is unacceptable. Thus, acceptable compression rates in any medical images type are widely undetermined.

There are two main different general methods for digital image compression — lossy and lossless. Lossy compression tries to take advantage of psycho-visual effects to optimize compression results but loses certain image information, while lossless compression reconstructs the original image in a numerically identical manner.

Medical images are usually compressed losslessly because they are considered as critical data and any loss of information is intolerable. Lossless coding techniques are well understood, readily available and typically yield compression ratios of between 2:1 and 4:1. Although physicians and scientists prefer to work with uncorrupted data, the modest compression offered by lossless coding is often inadequate for storage facilities and transmission.

Netravali and Haskell[13] showed that although lossy coding does not permit perfect reconstruction of the original image, it can provide excellent quality at a fraction of the original bit-rate. Lossy coding is unavoidable if the original image is analog, as in one ordinary X-ray film. An advantage of a well-designed lossy compression system is that it works to minimize information loss or image distortion for a given allotted storage space or transmission rate. When bits are scarce, good compression schemes devote the available bits to the information of greatest importance. As a result, lossy compression schemes are capable of enhancing specific structures of importance to the viewer.

Utility depends critically on the quality of the processed images, but quality is itself an attribute with many possible definitions and interpretations, depending on the use to which the image will be put. A "well" processed image might be one that is perceptually pleasing or useful in a specific application. No single approach to quality measurement has gained universal acceptance, but a few approaches have become common:

(1) Computable objective distortion measure such as peak signal-to-noise measure (PSNR) and root mean squared error (RMSE).
(2) Perception-based quantitative distortion measure (subjective evaluation), quantified by picture quality scale (PQS) and mean opinion score (MOS).
(3) Simulation and statistical analysis of a specific application of the images, e.g., the usage of clinical simulation and statistical analysis to measure diagnostic accuracy in medical images.

The intent of this study is to compare and contrast the first two types of distortion measures mentioned above for lossy compression of medical images. This application is a controversial one, because physicians often will not accept images that are compressed lossily because of liability issues or mainly because of fear of impaired quality. The psycho-optical properties of the human visual system (HVS), however, limit the capability of an observer to detect these information loss. Thus, compression rates with resulting images that are accepted by the medical experts are used besides the objective measurements, to determine the usability and reliability of a processed image for diagnosis. However, the compression rates vary considerably between imaging modalities and compression techniques. As a result, lossy compression may not be recognized by the medical experts below a critical threshold of compression.

Sayre *et al.*[15] showed that many in the medical image compression community argue that lossy compression is both necessary and helpful in the long run. It is necessary in order to preserve rapid access for follow-up and recall studies because the overwhelming quantity of medical images data requires the remote storage of hard-copy films, which frequently will result in loss or damage, and will always require significant time to locate and transfer. It is helpful because it permits efficient storage and rapid communication of images amongst hospitals, clinics, and medical experts and officers. Image transmission can be within a local area network (LAN) or to remote locations via satellite, ISDN or ordinary phone links. However, wide application of inter-hospital exchange as well as between physicians in private practice is still limited by various technical factors, such as inadequate networks connectivity, security concerns (confidentiality) and cost-effectiveness for minor cases.

In series 1, a total of 10 images with the dimension of 256×256 and 8-bit depth for each image type (brain-MRI, Ultrasound and chest-X-ray) are used for compression at 10 different levels, resulting a set of 100 images for each image type. In series 2, the same number of images is used for each image type, but the images are processed at 4 different bit rates. Two lossy compression algorithms are employed — JPEG-2000 and JPEG.

2.1. *Compression algorithms*

2.1.1. *JPEG*

JPEG baseline system divides the image data into 8×8 blocks and these blocks are transformed with Discrete Cosine Transform (DCT) into frequency spectrums. JPEG baseline supports lossy compression only. The transformed blocks are then quantized with a uniform scalar quantizer, zig-zag scanned and entropy coded with Huffman coding (Fig. 1). The quantization step size for each of the 64 DCT coefficients is specified in a quantization table, which is same for all blocks. The coefficients of all blocks are coded separately, using predictive coding. JPEG is a symmetric algorithm. Therefore, decompression runs the other way round, and the calculation time is same for compressing and decompressing an image.

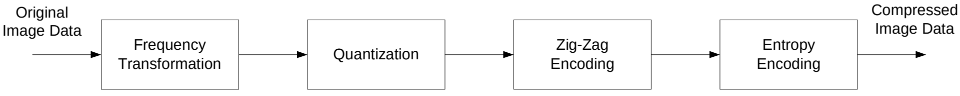


Fig. 1. JPEG fundamental building blocks.

2.1.2. *JPEG-2000*

JPEG-2000 is based on Discrete Wavelet Transform (DWT), scalar quantization, context modeling, arithmetic coding and post-compression rate allocation. The wavelet compression method works globally on the image and tries to replace sequences of pixels with recursively assembled small parts of waveforms (wavelets). The DWT is dyadic and can be either lossy or lossless compression. The quantizer follows an embedded dead-zone scalar approach and is independent for each subband, which is divided into blocks (typically 64×64), and entropy coded using context modeling and bit-plane arithmetic coding (Fig. 2). JPEG-2000 also supports error-resilience, random access, palletized color, arbitrarily shaped region of interest and simple rotation, etc. Skodras *et al.*[16] and Rabbani and Joshi[14] provide more detailed explanation about JPEG-2000 compression standard.

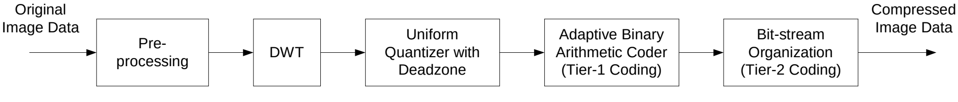


Fig. 2. JPEG-2000 fundamental building blocks.

2.2. *Compression process*

A total of 30 medical images of 3 modalities (10 for each) — MRI, X-ray and ultrasound — are compressed with both algorithms at 10 different compression rates, starting from the ratio of 10:1, and an increment on 10 after that until the maximum ratio of 100:1.

IrfanView v3 is used for the DCT compression while JasPer v1.500.4 is used for DWT. Ten compressed images with linearly progressing quality settings are generated and stored for each image for both compression algorithms. Matlab® is used to calculate the PQS of the original and the after processed images for comparison. For PSNR measurement, JasPer is used.

2.3. *Image quality evaluation*

According to Drury,[5] the image quality generally can be evaluated objectively and subjectively. Cosman[4] said that objective methods are based on computable distortion measures. A standard objective measure of image quality is reconstruction error. We are often interested in the way that PSNR varies with compression ratio, measured in bits/pixel (bpp), producing what is known as the rate-distortion curve.

Signal-to-noise ratio is not adequate as a perceptual meaningful measure for the digitized image quality in whole. According to Bauer *et al.*,[1] this is because the reconstruction errors in general do not have the character of signal independent additive noise and seriousness of the impairments cannot be measured but a simple power measurement. In addition to the commonly used PSNR, we choose to use the perception-based subjective evaluation, quantified by MOS, and the perception-based objective evaluation, quantified by PQS. In this study, five medical experts were asked to assess the quality of the compressed images. A more elaborated explanation of both image quality evaluations can be found in the paper by Grgic.[6]

3. Results and Discussions

Tables 5 and 6 show the dynamic ranges of the original images' histograms that are used in this study. The histogram of a digital image represents the discrete function of the number of gray level and the number of pixels in an image. Table 5 shows the dynamic range of the original images and Table 6 shows the dynamic range of the reconstructed images at different bit rates. The components of the histogram of the MRI images are concentrated on the low (left) side of the gray scale as expected since MRI images are considered dark images. Ultrasound images in contrary, are biased toward the high (right) side of the gray scale because they are bright images. X-ray images cover a broad range of the gray scale compared to the other two image types. This shows that X-ray images are high in contrast.

The tabulated results as shown in Table 2 are the average PSNR (dB) values of the 10 images for each image type. Comparison of PSNR of MRI image for 8×8

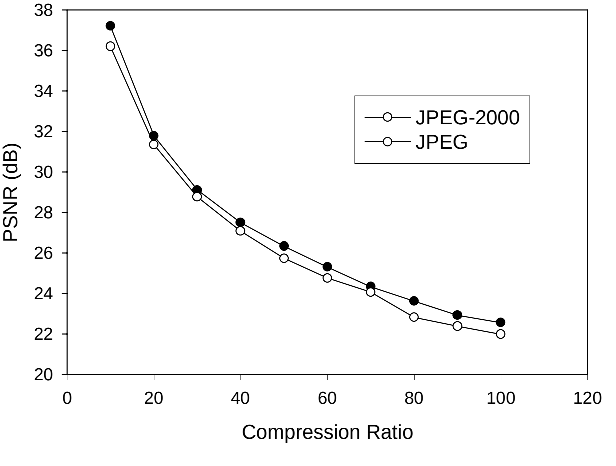


Fig. 3. Comparison of DWT and DCT compression of the MRI images.

DCT JPEG and DWT JPEG-2000 is shown in Fig. 3, ultrasound in Fig. 4 and X-ray in Fig. 5. As expected, the PSNR decreases with the increasing compression rates as seen in Figs. 3–5. Wavelet compression produced generally less reduction in PSNR compared to JPEG (DCT-based) at comparable compression rates, as seen in the figures.

In MRI images, JPEG shows its compatibility with JPEG-2000, with the DWT-based JPEG-2000 outperforming JPEG by less than 1 dB only in average for the PSNR. As in ultrasound images, at low compression rate (10:1), JPEG-2000 outperforms JPEG by as much as more than 4 dB. But after that, JPEG seems to

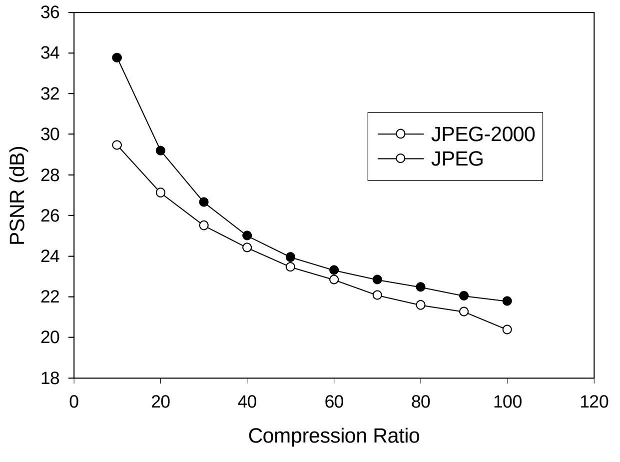


Fig. 4. Comparison of DWT and DCT compression of the ultrasound images.

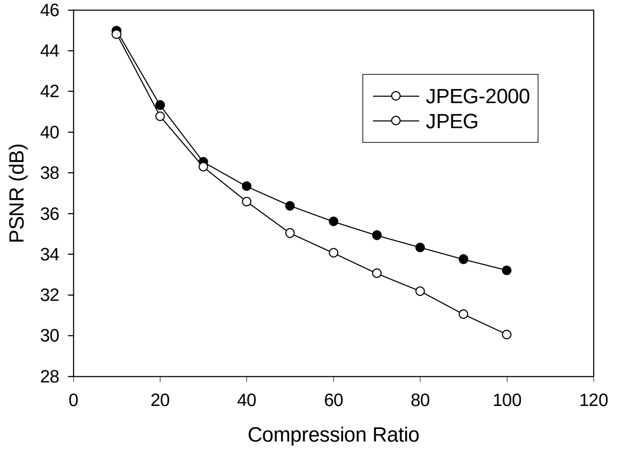


Fig. 5. Comparison of DWT and DCT compression of the X-ray images.

degrade slower compare to JPEG-2000, whereby after the compression rate of 30:1, the difference is less than 1 dB (Fig. 4). This is uncommon because JPEG usually degrades faster than JPEG-2000 when compression rate increases, just as in the X-ray images (Fig. 5). In X-ray images, the PSNR expectedly decreases with increasing compression rate, starting at an infinum (identical images) and going down to a few decibels, especially at high compression ratios (>50:1).

The compression performance of DWT is superior to that of DCT and the visual quality of reconstructed images is better even if the PSNR are the same. There are noticeable blocking artifacts in the DCT images. Figure 6 shows the visual quality for DCT and DWT compressed MRI image with the same PSNR ($\approx$25 dB), in comparison to the original image. Take note of the blocking artifacts in Fig. 6(b). The comparison demonstrates that even at relatively high compression ratios (>50:1), DWT based compression shows better results in both visual quality and PSNR than DCT.

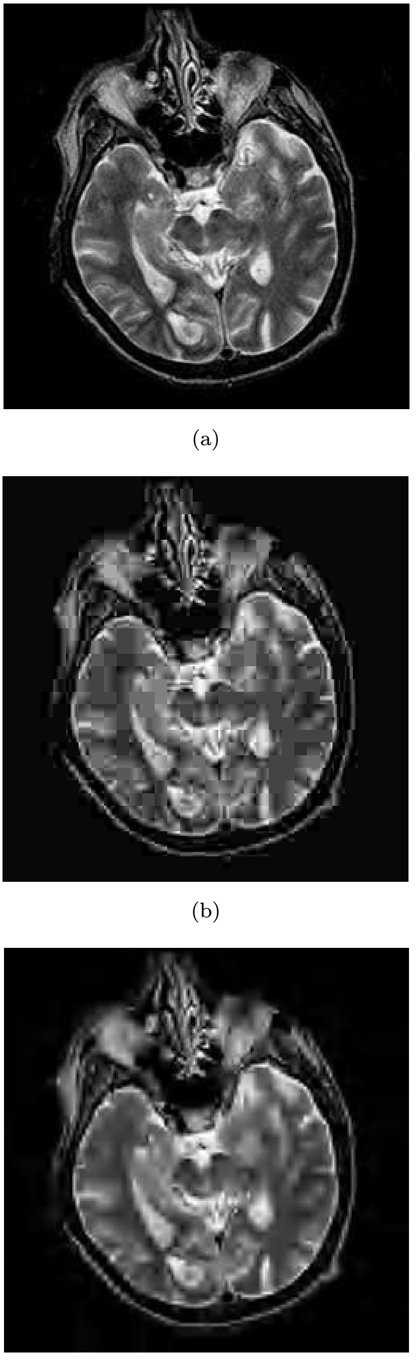
The PSNR criterion also suggests that the image quality from a mathematical point of view is better when using wavelet compression algorithm because it keeps the image distortions low far into high compression rates where JPEG degrades rapidly, especially the X-ray images. While PSNR of the ultrasound and MRI images are slightly different, the PSNR of the X-ray images are exceptionally high.

As PSNR is an objective distortion measurement, which can be done through mathematical calculation, subjective assessments of image quality are experimentally difficult and lengthy. Furthermore, the results may vary depending on the test conditions. For subjective assessments, we use PQS and MOS as the measuring parameters.

The rating of medical experts is used as the gold standard to define the usability and the compression thresholds of the medical images from different modalities. We refer the rating by the experts as the mean opinion score (MOS) here. The 5-grade impairment scale is shown in Table 1. As for the PQS, it combines various perceived distortions in image coders into a single quantitative measure and it correlates well with the subjective evaluation quantified by a MOS. Since that it is possible to obtain negative values at the low end of the quality scale, we have excluded high compression rates (>50:1) because the images will be too low in quality and will obtain negative PQS values (meaningless values). We use a range of bit rates for

Table 1. 5-grade impairment scale.

Grade	Description
5	Imperceptible
4	Perceptible, but not annoying
3	Slightly annoying
2	Annoying
1	Very annoying



(a)

(b)

(c)

Fig. 6. Reconstructed sample MRI image using (a) original; (b) JPEG and (c) JPEG-2000 (PSNR ≈ 25 dB).

Table 2. PSNR (dB) values of the reconstructed images.

Compression ratio (CR)	JPEG-2000 MRI	JPEG-2000 ultrasound	JPEG-2000 X-ray	JPEG MRI	JPEG ultrasound	JPEG X-ray
10	37.21	33.76	44.98	36.19	29.46	44.81
20	31.78	29.19	41.31	31.35	27.11	40.77
30	29.11	26.65	39.53	28.77	25.50	38.29
40	27.50	25.00	37.33	27.08	24.41	36.58
50	26.33	23.94	36.37	25.73	23.46	35.02
60	25.31	23.30	35.60	24.76	22.83	34.06
70	24.33	22.83	34.92	24.06	22.07	33.06
80	23.62	22.47	34.33	22.82	21.58	32.18
90	22.92	22.04	33.74	22.38	21.26	31.04
100	22.56	21.78	33.20	21.98	20.38	30.05

Table 3. PQS for the reconstructed images at different bit rates.

Bit rate	JPEG-2000 MRI	JPEG-2000 ultrasound	JPEG-2000 X-ray	JPEG MRI	JPEG ultrasound	JPEG X-ray
0.250	−2.94	−0.80	−3.12	−26.28	−0.91	−4.45
0.500	−0.12	1.15	0.32	−25.38	0.96	0.60
1.000	2.30	2.97	2.34	−24.45	2.82	2.54
2.000	3.97	4.26	3.91	−23.99	4.22	2.88

Table 4. MOS for the reconstructed images at different bit rates.

Bit rate	JPEG-2000 MRI	JPEG-2000 ultrasound	JPEG-2000 X-ray	JPEG MRI	JPEG ultrasound	JPEG X-ray
0.250	1.68	1.88	1.76	1.54	1.89	1.24
0.500	2.34	2.56	2.39	1.86	2.44	1.86
1.000	2.96	3.47	3.17	2.09	3.06	2.97
2.000	3.88	4.15	3.63	3.45	4.02	3.58

the MOS and PQS purpose, from 0.25 bpp to 2.00 bpp, which are equivalent to the compression rates of 4:1 to 32:1, for 8-bit depth image.

The results of visual image quality measurements are tabulated in Table 3. The results show that the DWT-based JPEG-2000 totally outperforms DCT-based JPEG, especially in the MRI images. The shaded boxes in the table indicate meaningless results because they are negative in value. For MRI JPEG, all the values obtained for the varying bit rates are negative. The results show that, the barrier of acceptable PQS values for the three types of medical images is basically at 0.50 bpp. Any value below this bit rate is considered unacceptable. Figure 7 shows an example of X-ray image compressed at 0.25 bpp and 1 bpp. As for the JPEG compressed MRI images, although the PQS values did not much agree with the acceptability of the images, the images themselves show otherwise (Fig. 8(a)). For comparison

Table 5. Dynamic range of the original images.

Original image	Dynamic range
MRI	78
Ultrasound	156
X-ray	194

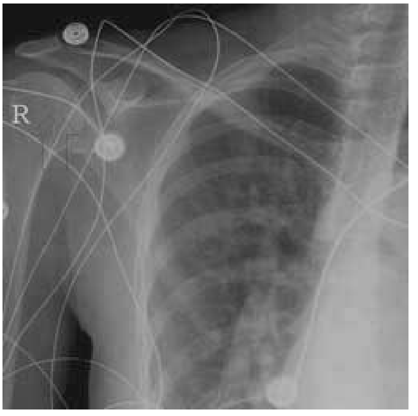
Table 6. Dynamic ranges of the histograms for the 3 image types.

	MRI		Ultrasound		X-ray	
Bit rate	JPEG-2000	JPEG	JPEG-2000	JPEG	JPEG-2000	JPEG
0.25	255	255	159	167	195	196
0.50	255	255	170	197	195	194
1.00	255	255	191	233	195	197
2.00	255	255	221	241	196	197

purpose, we have included the JPEG-2000 image at the same compressed bit rates (Fig. 8(b)). Although the PQS value of JPEG is negative (−24.45), the picture quality is compatible to that of JPEG-2000 at the same bit rate, which has a PQS value of 2.30. But at lower bit rate (0.25 bpp), if we look closely (Fig. 8), we can see that the blocking artifacts are quite obvious in the JPEG compressed image, compared to the JPEG-2000, which appears much smoother.

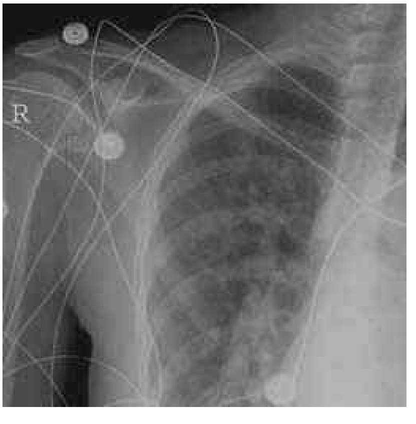
The MOS values of each image type are contained in Table 4. Unlike PQS, MOS will not obtain negative values since the grade selection of an image quality by the assessors varies between 1 and 5 only. The MOS show that the ultrasound image gives higher grades than X-ray and MRI at lower bit rate (higher compression). It is more obvious in the JPEG DCT-based compression. This is probably because the contents of the X-ray and MRI images are very hard for DCT coder to handle, especially at high compression. Compared to ultrasound, both MRI and X-ray images contain large number of details and small variations of luminance component. For higher compression ratios, the variations are lost inside the 8×8 image blocks. The result is typically noise and blocking artifacts in the picture. Comparison of MOS presented in Table 4 indicates that DWT-based JPEG-2000 coder works better than DCT-based JPEG coder at higher compression ratios for all image types.

As for the histograms, after the compression and decompression processes, it appears that the number of gray level in each image type has increased drastically, especially in MRI, with a maximum 255 number of gray level in every bit rate for both JPEG-2000 and JPEG, compare to just 78 gray levels in the original image. Ultrasound and X-ray images also experienced the same results, with every gray scale at each bit rate larger than that of the original (Table 6). Although the gain is small compared to that in MRI, the number of gray levels seems to increase with the increment of the bit rate for both ultrasound and X-ray, respectively (Table 6). The histograms of the image type are shown in Fig. 9. The gray level gain in X-ray image is so small that no different can be spotted from the histogram itself (Fig. 9(c)).



(a)

(b)



(c)

Fig. 7. Reconstructed sample X-ray image at (a) original; (b) 0.25 bpp and (c) 1 bpp.

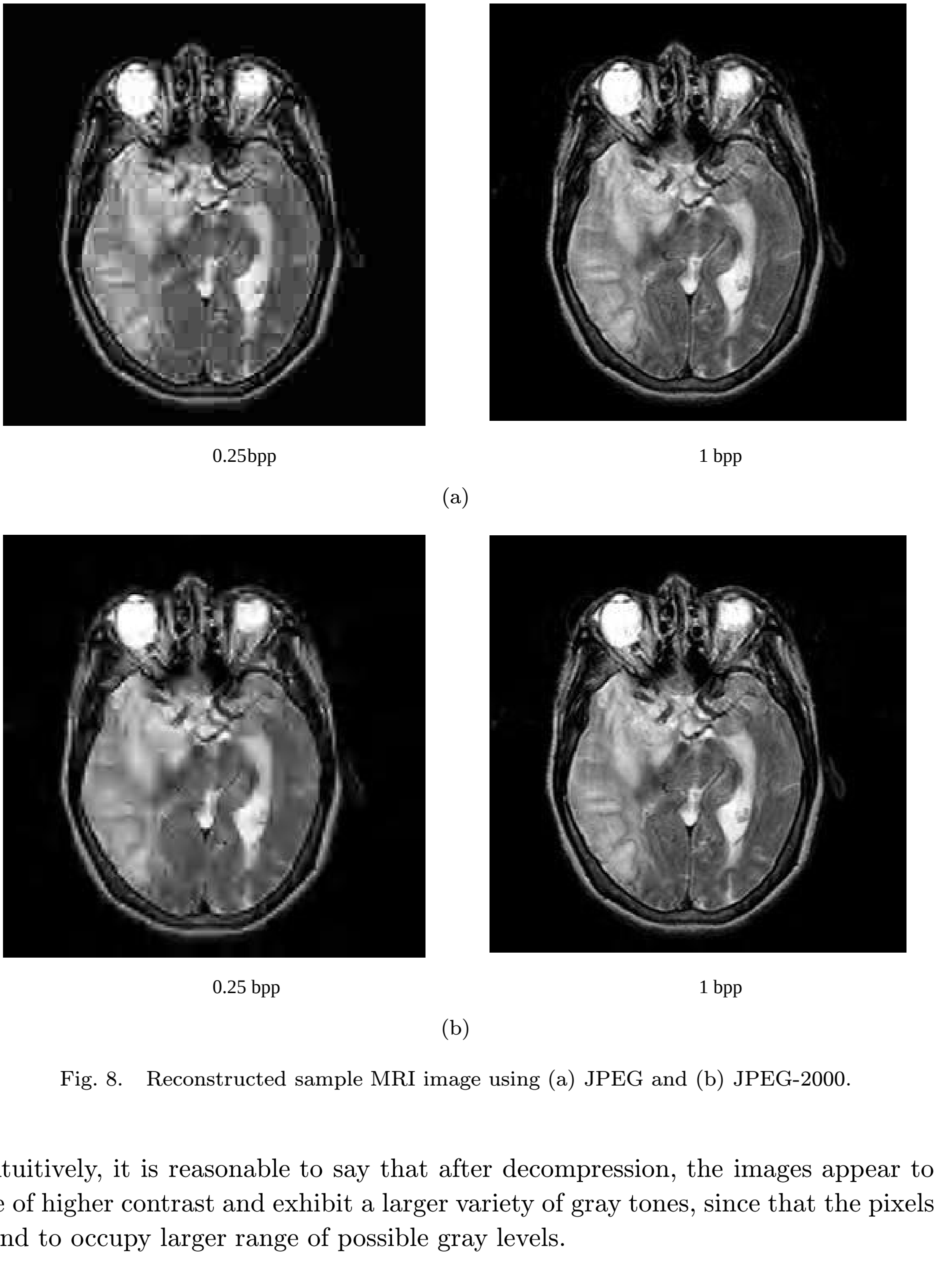


Fig. 8. Reconstructed sample MRI image using (a) JPEG and (b) JPEG-2000.

Intuitively, it is reasonable to say that after decompression, the images appear to be of higher contrast and exhibit a larger variety of gray tones, since that the pixels tend to occupy larger range of possible gray levels.

4. Conclusion

No single image compression algorithm can be expected to work well for all types of images. The quality of the reconstructed image depends heavily on the content

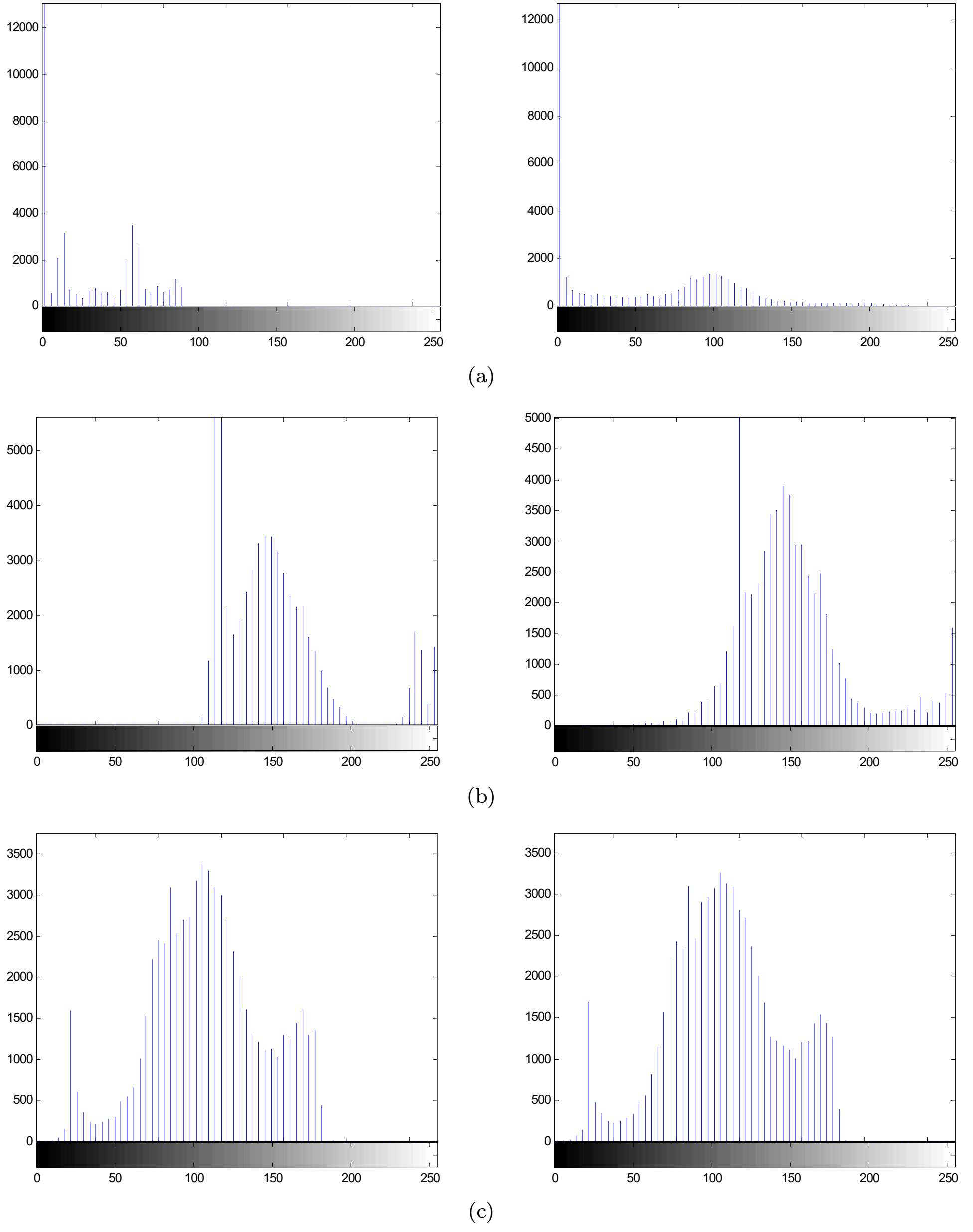


Fig. 9. Histograms of (a) MRI; (b) Ultrasound and (c) X-ray, with the original on the left and decompressed on right.

of an image. Although DCT processing speed and compression capabilities are good, there are noticeable blocking artifacts at high compression ratios. But in the wavelet-based method, there are no blocking artifacts in the reconstructed images at all.

Since the PSNR values are not directly related to the psycho-visual impression of the image quality throughout imaging modalities, the values alone cannot be used solely as indicators of acceptable compression rates for an automated compression process in a telemedicine application. A more precise determination of acceptable image quality has to be used. PQS and MOS values are defined by taking into account known image impairments due to coding, and by weighing their quantitative perceptual importance. With the inclusion of both values here for the image quality evaluation besides referring to the mathematical PSNR values alone, the coding techniques are more confidently compared.

Systematic studies using the objective evaluation of images, as well as their subjective assessment, are always difficult. The rapid increase in the range and use of digital imaging and coding and their increasing economic importance justifies renewed attention and specialization of perceptually relevant image quality metrics as a critical missing component for efficient compression and for providing the quality of service needed in telemedicine applications.

Precise information on clinically allowable compression rates for several imaging modalities is scarce or even unavailable in literature. Results from the present study indicate that the filed brain MRI compression rates of 20:1 using JPEG or wavelets are acceptable, while other imaging modalities like renal MR-angiograms, are more responsive to wavelet algorithms (40:1 — 80:1).

These series here indicate that compression of digitized medical images is possible to a considerable degree without recognizable loss of quality from a medical perspective. Moreover, investigation on different imaging modalities shows that considerable compression rates may be acceptable for clinical decision-making. Sneiderman *et al.*[17] showed that image compression up to 40:1 (JPEG) was reported to result in sufficient image quality in dermatology. However, this does not mean that this is the same for other applications. According to Brenecke,[2] in cardioangiography, JPEG compression up to 6:1 was found to be equivalent to original images, whereas higher compression rates induced major reductions in diagnostic accuracy.

Image compression will therefore be a valuable adjunct for future tools in telemedicine application, provided that efficient compression process does not deteriorate the image quality to an unacceptable level.

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