Performance Comparison of the JPEG and Full Frame Bit Allocation Techniques for Medical Image Compression

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ABSTRACTS

The discrete cosine transform (DCT)-based progressive coding standard proposed by the International Standardization Organization (ISO) Joint Photographic Experts Groups (JPEG) is investigated for medical image compression and the performance of the JPEG is compared to that of the full-frame bit-allocation (FFBA) technique. From the comparison, the JPEG standard appears superior to the FFBA technique in the following aspects: 1) JPEG achieves higher compression than the FFBA technique with less mean square error. 2) Less Gibb's artifact is observed in the compressed images by the JPEG. 3) Computational time for the JPEG is about one-fourth of the FFBA technique. Other attractive points of the JPEG include: Implementation of the JPEG with VLSIs is commercially available in relative low price and the JPEG compression format can easily be interchangeable with other applications.

I. INTRODUCTION

The Joint Photographic Experts Group (JPEG) standard has been developed by the ISO/IEC JTC1/SC29/WG10 in a close coordination with the CCITT SGVIII. The standard provides requirements and implementation guidelines for encoding and decoding digital continuous-tone still images, and for the coded representation of compressed image data for interchange between applications [1]. The algorithm is currently at the level of draft international standard (DIS), and will soon be promoted to an international standard (IS).

Four modes of operation are defined in the JPEG standard, , i.e., lossless, sequential DCT-based, progressive DCT-based, and hierarchical coding. The simplest DCT-based sequential coding is referred to as the baseline process. The additional DCT-based progressive and hierarchical processes and lossless mode are called extend coding. In any decoder using extended coding, the baseline decoding process is required as a default capability.

In this paper, the JPEG standard is briefly reviewed, and is investigated for medical image compression [2,3]. Some compression results using JPEG standard are shown for magnetic resonance images (MRI) and are compared to existing radiological image compression method such as full-frame bit-allocation technique [4,5]. Advantages of the JPEG-based compression are also discussed.

II. REVIEW OF THE JPEG STANDARD

DCT-based Sequential Coding

For the discrete cosine transform (DCT) - based encoding, input image is segmented into 8x8 blocks, and each block is transformed by the forward DCT [6]. After the forward DCT, 64 DCT coefficients are quantized by a uniform quantizer. The quantizer step size for each coefficient is given by the quantization table. In the JPEG standard, no default quantization tables are specified. An example of quantization tables considering human psycho-visual effects for luminance and chrominance components is shown in Table 1.

Table 1 Quantization tables for luminance and chrominance components based on the psycho-visual thresholds.

(a) Luminance quantization table.

16	11	10	16	24	40	51	61
12	12	14	19	26	58	60	55
14	13	16	24	40	57	69	56
14	17	22	29	51	87	80	62
18	22	37	56	68	109	103	77
24	35	55	64	81	104	113	92
49	64	78	87	103	121	120	101
72	92	95	98	112	100	103	99

(b) Chrominance quantization table.

17	18	24	47	99	99	99	99
18	21	26	66	99	99	99	99
24	26	56	99	99	99	99	99
47	66	99	99	99	99	99	99
99	99	99	99	99	99	99	99
99	99	99	99	99	99	99	99
99	99	99	99	99	99	99	99
99	99	99	99	99	99	99	99

The quantized DCT coefficients are, then, entropy coded. Since there are correlations in the d.c. coefficients between adjacent blocks due to small transform size (8x8), the previous quantized d.c. coefficient is used to predict the current value, and the difference is entropy coded. All the other a.c. coefficients are directly entropy coded. For the entropy coding, the baseline sequential process uses Huffman code [7], while the extended coding uses either Huffman or arithmetic codes [8]. It has been known that the arithmetic coding outperforms the Huffman coding, especially at low bit rates, but it has higher complexity.

The decoding process is essentially the inverse of encoding process. After multiplication of the step size specified by the quantization table (dequantization) the DCT coefficients are inversely transformed to reconstruct an 8x8 block of sample image.

Progressive and Hierarchical Coding

For the progressive DCT-based mode, 8x8 image block is also transformed in the same sequential order, but the encoding order of the DCT coefficients is different from that of the sequential mode. Two procedures for the encoding the quantized DCT coefficients are defined in the standard, i.e., spectral selection and successive approximation. In the spectral selection, only a specified band of coefficients are first encoded, and in subsequent scans additional bands are encoded repeatedly. At the receiver end, reconstruction will be progressively carried out by the addition of the inverse DCT of the received band of the coefficients to the previously reconstructed image, therefore the reconstructed image quality will be progressively improved. In the successive approximation, a specified number of most significant bits is first encoded, and in subsequent scans the less significant bits are encoded.

In the hierarchical mode, an image is encoded as a sequence of frames with different resolutions. These frames provide reference for the prediction in subsequent frames. Downsampling and upsampling filters are, therefore, used to provide a pyramid of spatial resolutions. Reconstructed image in the hierarchical mode is also progressively improved, similar to the progressive coding, from low resolution to high resolution.

Lossless Coding

Unlike the previous DCT-based lossy modes, the JPEG standard defines lossless mode. Predictor in the JPEG is composed of up to three previously reconstructed neighborhood samples. The predicted value is then subtracted from the actual value, and the difference is losslessly entropy-coded by either Huffman or arithmetic coding. Although the compression efficiency of the lossless mode is not as high as the DCT-based lossy modes, the lossless mode is used when preserving original image values is of prime importance.

III. COMPARISON OF THE JPEG STANDARD WITH THE FULL-FRAME BIT-ALLOCATION TECHNIQUE

The performance of the JPEG compression algorithm is compared to the full-frame bit-allocation (FFBA) technique which has been proposed for radiological image compression [4,5]. The FFBA technique is also based on the discrete cosine transform, but the transform size is identical to the whole image matrix size (transform size is 8x8 for the JPEG). Detailed description for the FFBA technique is found in reference 4. Advantage of the full-frame transformation is free from block artifact by avoiding segmentation of the original image matrix. Disadvantages of the full-frame transformation are: Gibb's phenomena, large overhead bit allocation table, and large computational time. These aspects will be considered in the performance comparisons with the JPEG.

For the JPEG, the DCT-based progressive mode with spectral selection is employed. The quantization table shown in Table 1(a) is used with Huffman code optimized for the test image. For the FFBA technique, since the full-frame is transformed, the bit allocation table is the same size as the image matrix. Thus a large amount of overhead information is needed for the bit allocation table. Although the amount of the bits for the table is relatively small (~1% of the original image) in large image matrix such as 2048 x 2048 containing simple structures, it becomes fairly large (> 25%) for the matrix of 256 x 256 and compression ratio is relatively small. Some smoothing of the bit allocation table and run-length coding for dominant values such as 0 and 1 are helpful for a reduction of the bits for the table, which, however, introduces additional distortion (in addition to the quantization noise) due to the modification of the table. A predetermined table based on a statistical model such as two-dimensional Markov field or a table optimized for a set of images may reduce the amount of bits for the table substantially, however, the image distortion due to the mismatch of the table to actual data will increase considerably.

For a head section of MR image with 256 gray levels, compressed images by the JPEG and FFBA techniques are shown in Fig.1. Error images which were obtained by the subtraction of compressed images from the original image are shown in Fig.2 with a magnification factor of 5. The MR images are in the format of 256 x 256 obtained by a two-dimensional multi-slice spin echo technique [9]. For a quantitative evaluation, compression ratio (CR), the ratio of the amount of computer storage space required for the original image to that of the compressed image, and signal-to-noise ratio (SNR) are evaluated and are shown in Table 2. The SNR is defined as

$$\mathrm{SNR} = \sqrt{\frac{\sum_{x=1}^{N}\sum_{y=1}^{N} I^2(x,y)}{\sum_{x=1}^{N}\sum_{y=1}^{N}\{I(x,y)-\hat{I}(x,y)\}^2}} \qquad (1)$$

where N is image matrix size, $I(x, y)$ and $\hat{I}(x, y)$ are the original image and reconstructed image, respectively. Note that the transmission time or the disk access time can also be reduced by the same factor as that of CR.

Table 2 A summary of compression ratio and signal-to-noise ratio for the JPEG and FFBA techniques. Some smoothing and run-length coding for 0 and 1 are employed for a reduction of bit allocation table in the FFBA method.

JPEG progressive			FFBA	
Max. freq.	CR	SNR	CR	SNR
2	42	13.4	19	16.8
4	25	14.9	13	18.1
8	15	17.9	9.7	19.0
16	10	21.5	5.4	22.0
64	7.1	28.9	3.3	23.8
Lossless	1.7	∞		

From Fig.1 and Table 2, the JPEG achieves higher compression with higher SNR. For example, the SNR of the compressed image by the JPEG is 28.9 when CR is 7.1, while the SNR of the image compressed by the FFBA technique is 22.0 even with a lower CR of 5.4. As compression ratio increases, the Gibb's phenomena (ringing artifact near edges) becomes more evident as observed in some compressed images in Fig.1 or error images in Fig.2. This is due to the lack of high frequency components with high compression. The Gibb's phenomena is more serious in the compressed images by the FFBA technique compared to those by the JPEG (compare (a) and (c); and (b) and (d) in Figs.1 and 2). In the JPEG, since the image is segmented into 8 x 8 blocks, image intensities are more likely to be stationary in this segments. The propagation of ringing artifact is also limited to maximum 8 pixels in the JPEG due to the transform size of 8x8. The block artifact due to the small block size in the JPEG is, on the other hand, minimized by the assignment of a small quantization step size for the d.c. component as shown in Table 1, although a uniform level quantization table is optimal in the sense of minimization of total mean square error [10].

Finally computational times for the JPEG and FFBA are shown in Table 3. In general, if N-point data is segmented into M-point data and M-point DCT is performed N/M times instead of N-point DCT (M<N), total computational time is reduced approximately by a factor of $(\log N - \alpha) / (\log M - \alpha)$, where α is a constant depending on the computational algorithm. For example α is 1.0 for the algorithm proposed by Narasimha and Peterson [11], and α is 1.5 for the Chen's algorithm [12]. From Table 3, computational time for the JPEG is almost one fourth of the full-frame bit-allocation technique. Since the implementation of the JPEG with very large scale integrated circuit (VLSI) is commercially available in relative low price, the computational time for the JPEG can be further reduced.

Table 3 Computational times for the two-dimensional DCT are shown with and without segmentation corresponding to the JPEG and FFBA techniques, respectively. The DCT is implemented in the SUN SPARC station 2 without special hardware and the computational times were measured in seconds.

Image matrix size	JPEG	FFBA
256	0.617	2.95
512	2.50	12.6
1024	9.97	53.3
2048	40.9	227

IV. CONCLUSION

The JPEG DCT-based progressive coding provides high compression yet maintaining good image quality for gray scale medical tomographic images. A compression ratio of about 10 is obtained for the test MR images without noticeable image distortion. Features of the progressive image build-up of the JPEG progressive coding appear useful for medical image archiving and communication where fast search of medical data base and urgent interpretation of patient images examined in remote site are often in need. Compared to the existing full-frame bit-allocation technique, the JPEG standard is not only a computational efficient algorithm, but it also achieves higher compression ratio with higher SNR. Furthermore the Gibb's artifact in the JPEG is much smaller than that in the FFBA technique. The block artifact in the JPEG is minimized by the assignment of a small quantization step size for the d.c. component. In addition to these scientific merits, other advantages of the JPEG include: implementation of the JPEG with VLSI is commercially available in relative low price and the JPEG compression format can easily be interfaced with other system or applications.

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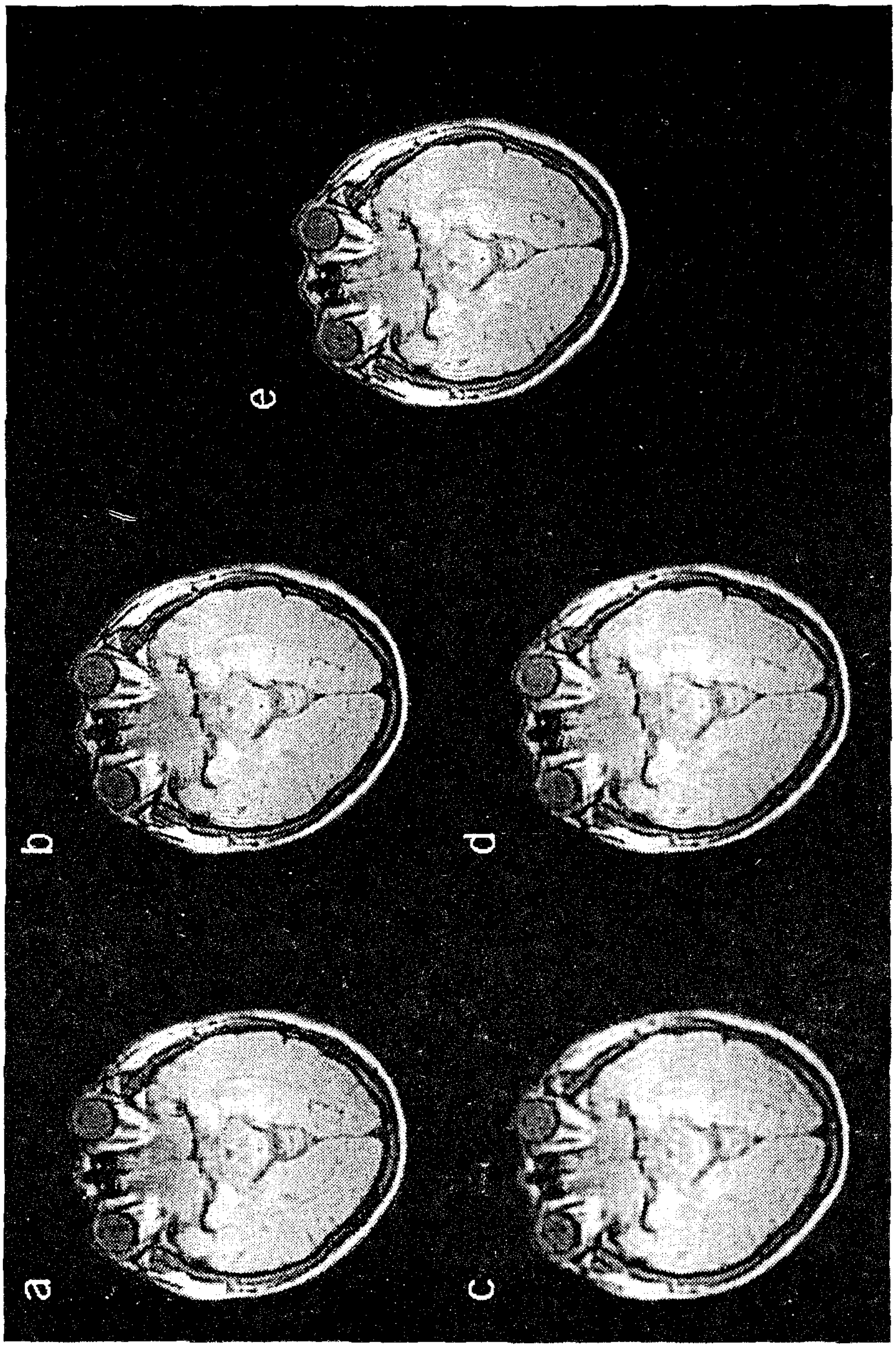

Fig.1 Compressed images by the JPEG progressive and the FFBA techniques: (a) JPEG progressive mode with encoded frequency up to 16 (CR=10 and SNR=21.5). (b) JPEG progressive mode with encoded frequency up to 64 for the final stage (CR=7.1 and SNR=28.9). (c) FFBA (CR=9.7 and SNR=19.0). (d) FFBA (CR=5.4 and SNR=22.0). (e) Original.

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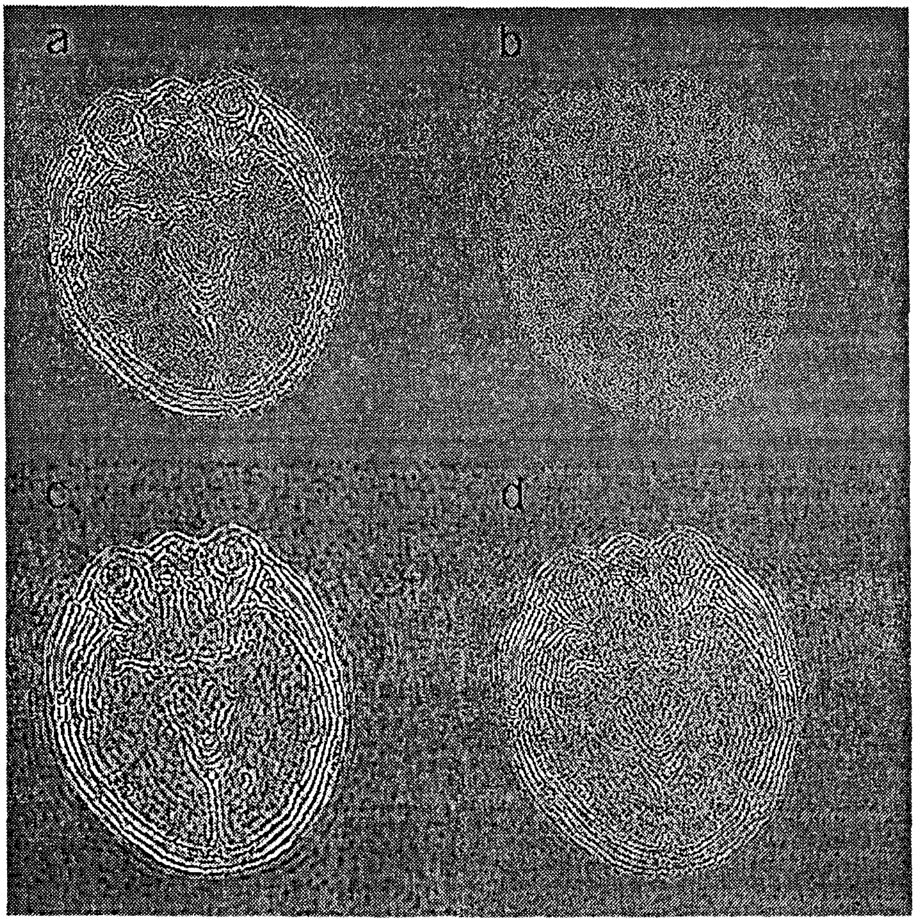

Fig.2 Error images of Fig.1 obtained by the subtraction of compressed images from the original image. They are displayed in the same order as in Fig.1 and the error images were multiplied by a factor of 5 for a better visualization. Note *the serious Gibb's artifact in the error images by the FFBA technique* (c and d) due to the lack of high frequency components.