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Comparative Performance Analysis of Image Compression by JPEG 2000: A Case Study on Medical Images

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Abstract: JPEG 2000 is a new and improved, image-coding standard developed for compression of images. JPEG 2000 is the state-of-the-art image-coding standard that resulted from the joint efforts of the International Standards Organization (ISO) and the International Telecommunications Union (ITU); JPEG in JPEG 2000 is an acronym for Joint Picture Experts Group. The new standard outperforms the older JPEG standard by approximately 2 dB of Peak Signal to Noise Ratio (PSNR) for several images across all compression ratios. Reasons behind JPEG 2000's superior performance are the wavelet transform and Embedded Block Coding with Optimal Truncation (EBCOT). This study describes the performance comparison of JPEG 2000 against its predecessor JPEG, by evaluating image compressions for medical images. The present research further describes the most important parameters of this new standard in order to help resolve design tradeoffs.

Key words: JPEG, JPEG 2000, medical image compression

INTRODUCTION

As high quality digital imagery becomes more and more common in Internet applications that range from simple websites to multimedia messages over the new generation mobile phones, there is the need to manipulate increasing amount of data. Thus, image compression must not only reduce the necessary storage and bandwidth requirements, but also allow extraction for editing, processing and targeting relative devices and applications. The JPEG 2000 image compression system has advantage over the original JPEG because it allows extraction of different resolutions, pixel fidelities, regions of interest, components and more, from a single compressed bitstream of images[1]. JPEG 2000 has the following features[2]:

- State-of-the-art low bit-rate compression performance;
- Progressive transmission by quality, resolution, component, or spatial locality;
- Lossy and lossless compression (with lossless decompression available naturally through all types of progression);
- Random (spatial) access to the bitstream;
- Pan and zoom (with decompression of only a subset of the compressed data);
- Compressed domain processing (e.g., rotation and cropping);
- Region of interest coding by progression and
- Limited memory implementations.

JPEG 2000-part I has become an International Standard in December 2000, which is a royalty and fee free-and it is both ITU-T standard (ITU-T.800) and an ISO standard (IS 15444 Part I). It was designed to address a wide spectrum of still images (binary, continuous gray level, color, multilevel components) having different characteristics (natural, medical, scientific, remote reusing, text, compound rendered graphics)[3].

Image compression: Image compression, briefly stated is minimizing the size in bytes of graphics file without degrading the quality of the image to an unacceptable level. Compressed images require less space to be saved and can be sent conveniently over the Internet.

A text file or program can be compressed without the introduction of errors, but only up to a certain extent. This is called lossless *compression*. Beyond this point, errors are introduced. In text and program files, it is crucial that compression be lossless because a single error can seriously damage the meaning of a text file, or cause a program not to run. In image compression, a small loss in quality is usually not noticeable. There is no

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"critical point" up to which compression works perfectly, but beyond which it becomes impossible. When there is some tolerance for loss, the compression factor can be greater than it can when there is no loss tolerance. For this reason, graphic images can be compressed more than text files or program.

JPEG 2000 standard and codec: JPEG 2000 is designed to compliment the current JPEG instead of replacing it. JPEG 2000 is wavelet-based and can be implemented in fixed point, floating point and integer formats. It has both reversible (lossless) and irreversible (lossy) modes that include corresponding component transformations. JPEG 2000 comprises of 6 parts as outlined below[3]:

Part 1: JPEG 2000 Image Coding System (core).
Part 2: Extensions (adds more features and sophistication to the core).
Part 3: Motion JPEG 2000.
Part 4: Conformance.
Part 5: Reference Software.
Part 6: Compound Image File Format for pre-press and fax like applications.
Part 7: Technical Report.

Figure 1 shows the components of JPEG 2000 compression and decompression. It also depicts that decompression stages are opposite in operation to that of compression.

DC level shifting if unsigned: All DC component values are shifted by same value by subtracting the same value. For example subtracting 128 from each pixel.

Component transformation: These are of two types, irreversible for lossy or lossless and reversible for only lossless[4].

Tiling: Here image is divided into rectangular nonoverlapping equal size blocks. All operations including component mixing, DWT, quantization, entropy coding etc. are performed independently on each block.

DWT: At this stage block components are mapped into the wavelet domain using irreversible, Daubechies 9/7 filter or reversible, 5/7 filter.

Quantization: All DWT coefficients $a_b(u, v)$ are quantized to $Q_b(u,v)$ by using the following equation[5]:

$$Q_b(u,v) = \text{sign}(a_b(u,v))\left[\frac{a_b(u,v)}{\Delta_b}\right]$$

$$\Delta_b = 2^{R_b - \varepsilon_b}\left[\frac{1+\mu_b}{2^{11}}\right]$$

The quantized coefficients are then stored into arrays of blocks. These blocks are then entropy coded using context based arithmetic coding in the next step.

Performance parameters: Two of the error metrics used to compare the various image compression techniques are the Mean Square Error (MSE) and the Peak Signal to Noise Ratio (PSNR). The MSE is the cumulative squared error between the compressed and the original image, whereas PSNR is a measure of the peak error[6].

$$MSE = \frac{1}{MN}\sum_{y=1}^{M}\sum_{x=1}^{N}[I(x,y)-I'(x,y)]^2$$

$$PSNR = 20*\log10\,(225/\text{sqrt}(MSE))$$

where, I (x, y) is the original image, I' (x, y) is the approximated version (which is actually the decompressed image) and M, N are the dimensions of the images. A lower value for MSE means lesser error and as

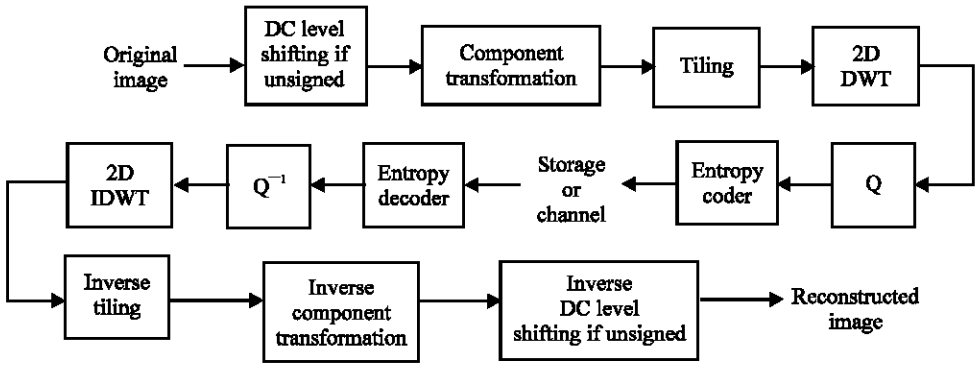

Fig. 1: JPEG 2000 encoder and decoder

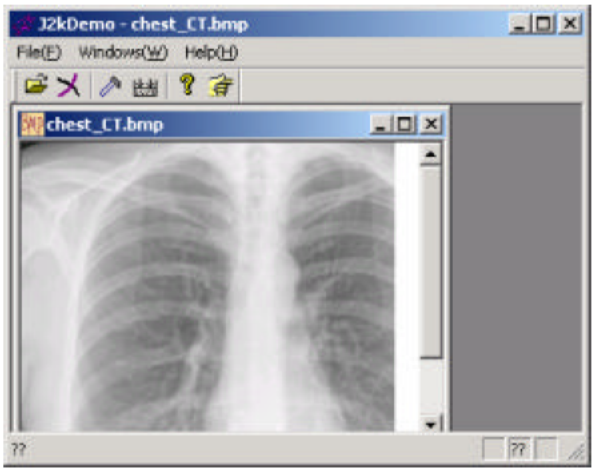

Fig. 2: Interface with a bitmap image

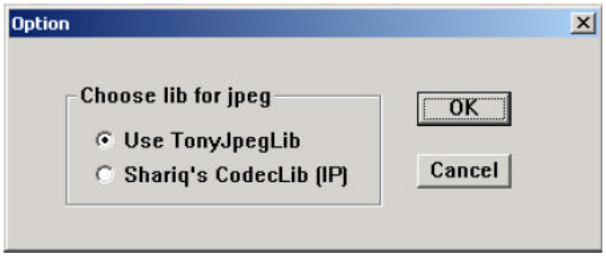

Fig. 3: Library selection window

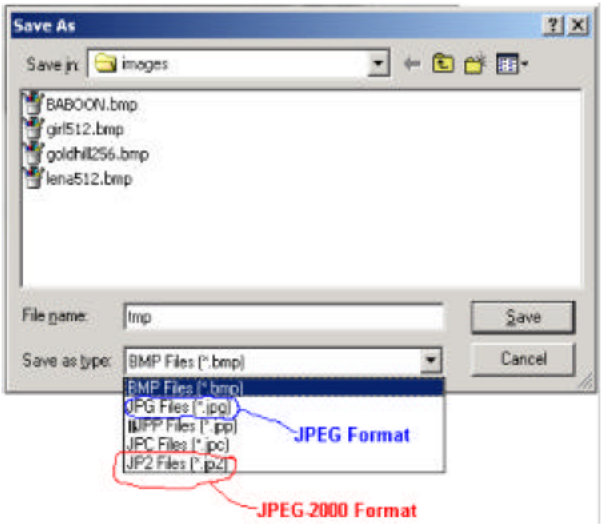

Fig. 4: Compressor window

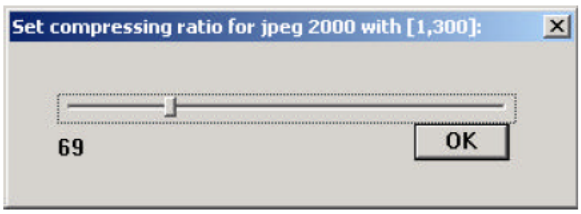

Fig. 5: Ratio selector

seen from the inverse relation between the MSE and PSNR, this translates to a high value of PSNR. Logically, a higher value of PSNR is good because it means that the ratio of Signal to Noise is higher. Here, the signal is the original image and the noise is the error in reconstruction. So, we can observe JPEG 2000 compression scheme having a lower MSE (and a high PSNR). Thus, we can recognize with utmost certainty that it is a better algorithm for compression of medical images.

Experimental compressor: To test the performance of the JPEG 2000 algorithm, we designed a software library, written in Microsoft Visual C++ 6.0. In the design of this software, guidance was taken from Dr. Tony Lin's form National Laboratory on Machine Perception, Peking University, Bejing, China.. The interface of the software is shown in Fig. 2.

The compression process is simple. The first step is to select the library for compression by clicking on the options button, which opens up the window (Fig. 3).

From this window, users can select either one of the libraries to use for their compression process. Once the library has been selected, the compression can begin by pressing the compression button of Fig. 4.

When we select JPEG 2000 from the options, a new window asking for the compression ration was displayed, as shown in Fig. 5.

Once we have selected the compression ratio between 1 and 300, the program compresses and saves the new image on a desired location.

RESULTS

Several medical bitmap images were selected for the experiment. These images include CT scans and x-ray images of different parts of human body. We compressed the images starting from a ratio of 1:10 to 1:110 with an increment of 20 because after the ratio of 110, the images became unrecognizable. The compressed images were then converted back to bitmap for calculating MSE and SNR for each image by comparing them to original bitmap image. Partial results of different images are shown in Fig. 6-10.

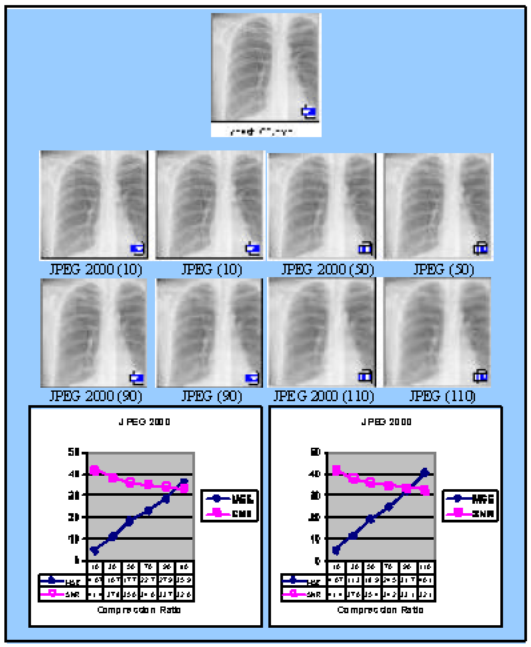

Fig. 6: Compression of chest CT scan

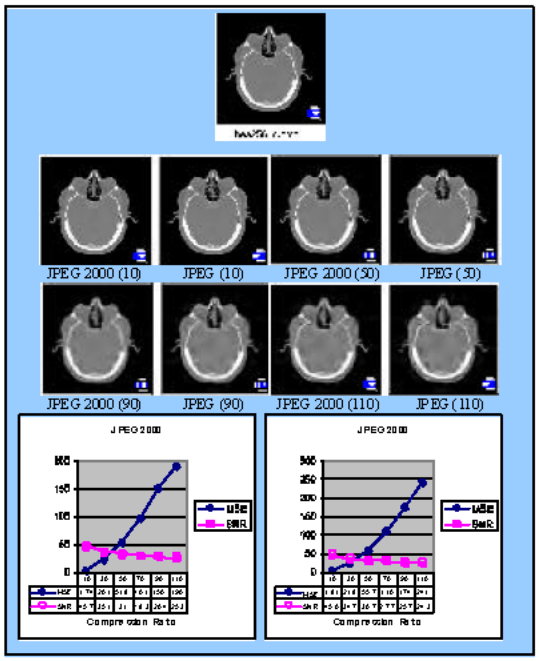

Fig. 8: Compression of skull CT scan

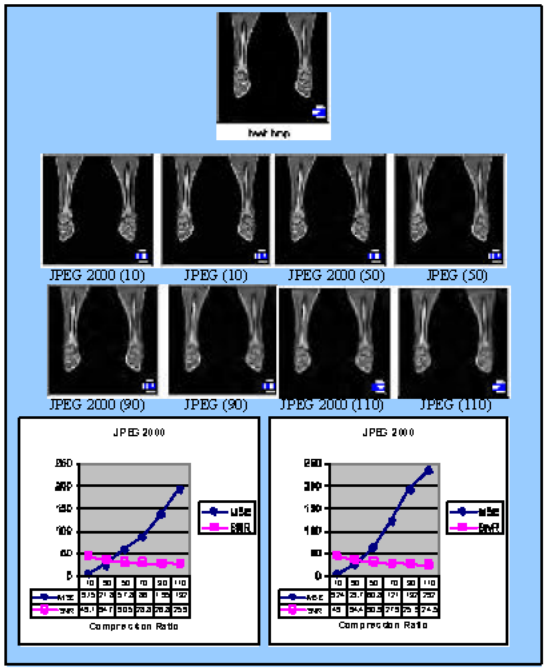

Fig. 7: Compression of feet X-Ray

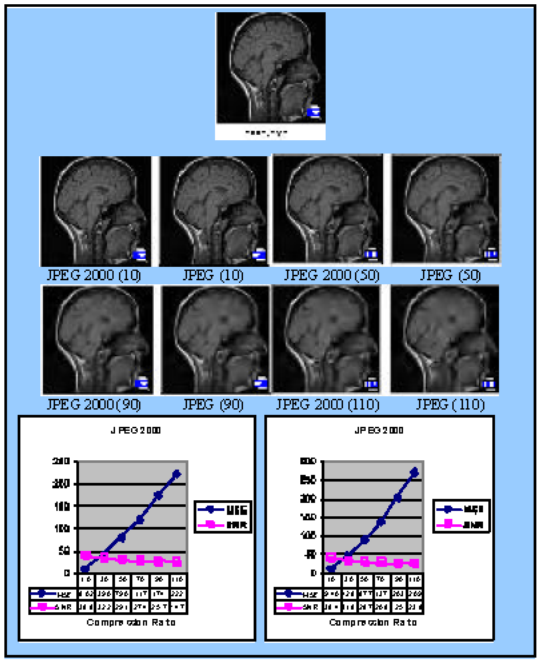

Fig. 9: Compression of head CT scan

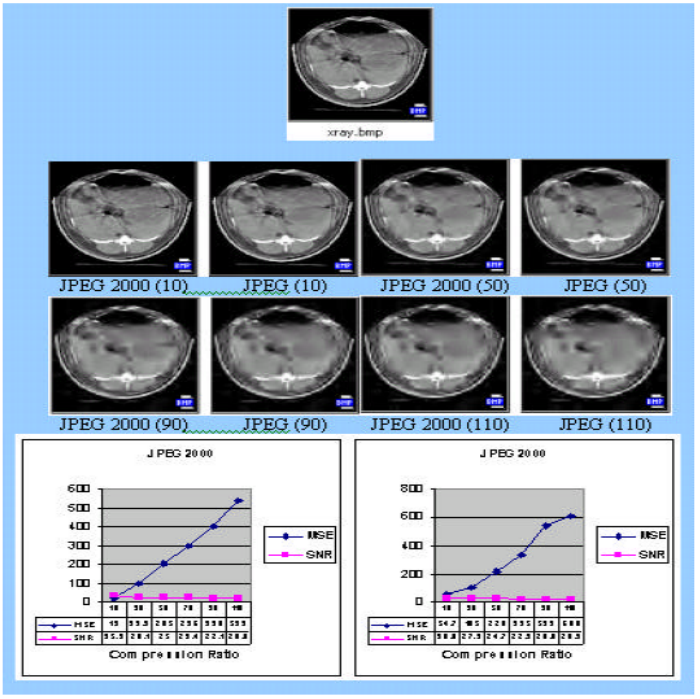

Fig. 10: Compression of X-Ray image

DISCUSSION

The results obtained show that JPEG 2000 outperforms the JPEG compression in SNR and MSE performance parameters at all compression ratios. JPEG 2000 provides only a few dB improvement for lower compression ratios but substantial improvement at higher compression ratios.

At lower compression ratios (below 1:50), the difference between the JPEG 2000 compressed image and the original image is negligible. However, at the same compression ratio, the difference between the JPEG compress image and the original is perceivable.

CONCLUSIONS

The comparison between JPEG 2000 and JPEG compression algorithm on medical images leads us to conclude that JPEG 2000 gives a better Peak Signal to Noise Ratio and Mean Square Error. We cannot claim that experimentation on only 5 images proves the superiority of the algorithm. However, it gives us a general trend towards the difference in performance of JPEG 2000 and JPEG. Future work would require more fine-tuning of the compression library and experimentation on a larger population of diverse images for a more meaningful claim.

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