Pertanika J. Sci. & Technol. 11(2): 191 - 203 (2003)
ISSN: 0128-7680

A Comparison of JPEG and Wavelet Compression Applied to CT Images

Amhamed Saffor, Abdul Rahman Ramli & Kwan-Hoong Ng[1]
Multimedia and Imaging Systems Research Group,
Department of Computer and Communication System Engineering,
Universiti Putra Malaysia, 43400 UPM, Selangor, Malaysia
[1]Department of Radiology, Universiti of Malaya Medical Center,
59100 Kuala Lumpur, Malaysia
E-mail: saffor@hotmail.com

Received: 18 September 2001

ABSTRAK

Satu kajian mampatan imej menjadi lebih penting kerana satu imej yang tidak boleh mampat memerlukan satu jumlah ruang storan/simpanan yang besar dan lebar jalur transmisi yang tinggi. Makalah ini memfokuskan kepada perbandingan kuantitatif kaedah kehilangan mampatan yang digunakan ke atas pelbagai jenis imej 8-bit Computed Tomography (CT). Algoritma mampatan Joint Photographic Experts Group (JPEG) dan Wavelet telah digunakan ke atas satu set imej CT, iaitu otak, dada, dan abdomen. Semua algoritma tersebut digunakan ke atas setiap imej untuk mencapai nisbah mampatan maksimum (CR). Setiap imej yang dimampatkan kemudiannya telah dinyah mampat dan analisis kuantitatif dilakukan untuk membandingkan setiap imej mampatan-dinyah mampat dengan kesesuaian imej asal. Enjin Mampatan Wavelet (edisi piawaian 2.5), dan Bestari JPEG (Versi 1.1.7) telah digunakan dalam kajian ini. Indeks statistik terkira adalah min ralat kuasa dua (MSE), nisbah isyarat-hingar (SNR) dan nisbah isyarat-hingar puncak (PSNR). Keputusan menunjukkan bahawa mampatan Wavelet menghasilkan kualiti mampatan yang lebih baik berbanding JPEG untuk mampatan tinggi. Daripada nilai-nilai berangka yang diperoleh kami perhatikan bahawa PSNR untuk imej dada dan abdomen adalah bersamaan dengan 24 dB untuk nisbah mampatan sehingga 31:1 dengan menggunakan JPEG dan 18 dB untuk nisbah mampatan sehingga 33:1 dengan menggunakan Wavelet. Untuk imej otak, PSNR adalah bersamaan dengan 26 hingga 30 dB untuk nisbah mampatan di antara 40 hingga 125:1 dengan menggunakan JPEG, manakala dengan menggunakan Wavelet, PSNR adalah bersamaan dengan 22 hingga 34 dB untuk nisbah mampatan di antara 52 hingga 240:1. Darjah mampatan juga didapati bergantung pada struktur anatomi dan kerumitan imej-imej CT.

ABSTRACT

A study of image compression is becoming more important since an uncompressed image requires a large amount of storage space and high transmission bandwidth. This paper focuses on the quantitative comparison of lossy compression methods applied to a variety of 8-bit Computed Tomography (CT) images. Joint Photographic Experts Group (JPEG) and Wavelet compression algorithms were used on a set of CT images, namely brain, chest, and abdomen. These algorithms were applied to each image to achieve maximum compression ratio (CR). Each compressed image was then decompressed and quantitative analysis was performed to compare each compressed-then-decompressed image with its corresponding original image. The Wavelet Compression Engine (standard edition 2.5), and JPEG Wizard (Version 1.1.7) were used in this study. The statistical indices computed were mean square error (MSE), signal-to-noise ratio (SNR) and peak signal-to-noise ratio (PSNR). Our results show that Wavelet compression yields better compression quality compared with JPEG for higher compression. From the numerical values obtained we observe that the PSNR for chest and abdomen images is equal to 24 dB for compression ratio up to 31:1 by using JPEG and 18 dB for compression ratio up to 33:1 by using wavelet. For brain image the PSNR is equal to 26 to 30 dB for compression ratio between 40 to 125:1 by using JPEG, whereas by using wavelet the PSNR is equal to 22 to 34 dB for compression ratio between 52 to 240:1. The degree of compression was also found dependent on the anatomic structure and the complexity of the CT images.

Keywords: Image compression, Computed Tomography (CT), wavelet compression, JPEG, medical images

INTRODUCTION

Image compression is fundamental to the efficient and cost-effective use of digital medical imaging technology and applications. There are two methods of image compression: lossless compression enables an exact reproduction of the original image from the compressed file. However, this scheme achieves relatively low compression rates of about 3:1. The second, lossy compression eliminates the redundant and high frequency data from an image, which is usually outside the range of human visual perception. This results in much higher compression ratios, typically 20:1 or greater, but with some data loss (Saffor *et al.* 2001). There are a number of techniques or compression algorithms for producing lossy or lossless images (Slone *et al.* 2000). It is quite important that the method used is based on an adopted medical imaging standard. Standards ensure simplified and long-term interoperability with other imaging devices; they also minimize the risk of diagnostic data being rendered obsolete over time (Erickson *et al.* 1998). Digital Imaging and Communications in Medicine (DICOM) is a medical imaging standard for all imaging modalities. The DICOM standard supports RLE (Run Length Encoding) lossless compression, and JPEG lossy compression for both static and dynamic clips. RLE lossless compression is good for static images, typically achieving ratios of 3:1 for grayscale images (Iyriboz *et al.* 1999). A variety of lossy compression techniques are available, with some of them standardized e.g. JPEG, which has the advantage of being available as commercial products, but also has the disadvantage of creating block artifacts at respectable compression ratios, i.e., over 10:1. This is a consequence of its 8 x 8 discrete cosine transform (DCT) coding scheme (Persons *et al.* 2000). Most current research efforts in lossy compression that appear promising involve the discrete wavelet transform (DWT), after the pioneering work by Daubechies (1988). The reasons for this are that the DWT operates on the whole image as a single block thereby avoiding blocking artifacts typical in JPEG, while dynamically adjusting its spatial/frequency resolution to the appropriate level in various regions of the image (Savcenko *et al.* 2000). Wavelet compression methods appear to perform better than JPEG, particularly for large-matrix images such as radiographs using the dual pathology approach, compression ratios as high as 80:1 (Bradley and Erickson 2000). The goal of this paper is to compare Wavelet and JPEG lossy compression methods applied to a set of CT images by using Wavelet Compression Engine (standard edition 2.5) available at Wavelet Compression Engine, 2000, and JPEG wizard version (1.1.7) available at Pegasus Imaging Corporation. The size of each image before compression is 512 x 512 x 8 bit.

IMPLEMENTATION

Techniques commonly employed for image data compression result in some degradation of the reconstructed image. A widely used measure of reconstructed image fidelity for an N x M size image is the mean square error (MSE) as given by Stephen *et al.*(2000).

$$MSE = \frac{1}{N.M}\sum_{i=0}^{N-1}\sum_{j=0}^{M-1}\left(\left|f(i,j)-f'(i,j)\right|^2\right) \quad (1)$$

Where $f(i,j)$ is the original image data and $f'(i,j)$ is the compressed image value. Signal-to-Noise Ratio (SNR) is widely used in the signal processing literature (since it is related to the signal power and noise power), and is perhaps more meaningful because it gives 0 dB for equal signal and noise power. SNR is used more commonly in the image-coding field. So, the SNR that is used corresponding to the above error is defined as

$$SNR = 10\log\left\{\frac{\sum_{i=0}^{N-1}\sum_{j=0}^{M-1} f(i,j)^2}{\sum_{i=0}^{N-1}\sum_{j=0}^{M-1}\left(f(i,j)-f'(i,j)\right)^2}\right\} \quad (2)$$

Another quantitative measure is the peak signal-to-noise ratio (PSNR), based on the root mean square error of the reconstructed image. The formula for PSNR is given by

$$PSNR = 10\log\left(\frac{(255)^2}{MSE}\right) \quad (3)$$

where RMSE, is calculated as

$$RMSE = \sqrt{MSE} \tag{4}$$

Values for these quantities were obtained using LuraWave Smart Compression software (version 1.7.1) available at Lura Tech Gmblt, 2000.

METHOD

By using the formulas in the previous section, some parameters were calculated for JPEG and Wavelet respectively. Signal-to-Noise-Ratio (SNR) measures are estimates of the quality of a reconstructed image compared with the original image. Mean Square Error (MSE) is the cumulative squared error between original and compressed image. Lower value of MSE means lesser error, and these values give higher Peak Signal-to-Noise Ratio (PSNR). PSNR is another qualitative measure based on the root-mean-square-error of the reconstructed image. In our study we calculate the compression ratio, MSE, SNR and PSNR for various sets of CT images: - 18,20 and 17 image sequence for brain, chest and abdomen respectively.

RESULTS AND DISCUSSION

Fig. 1 shows three different CT images, which are for brain, chest and abdomen. Tables 1 and 2 represent the results for compression ratio (CR), MSE, SNR and PSNR for CT-brain by using JPEG and Wavelet compression respectively. These results were also plotted in *Figs. 2, 3* and *4*. The results for chest and abdomen images are given in Tables 3 - 6 respectively. These results were also plotted in *Figs. 5 - 10*. The images in *Fig. 11* provide a subjective comparison between JPEG and Wavelet for compressed different CT images in terms of PSNR. The comparisons between the results are given in Table 7.

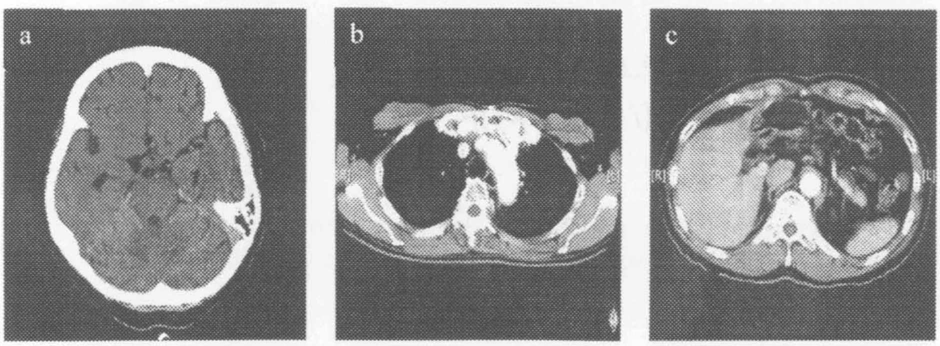

Fig. 1: (a) CT-brain image, (b) CT- chest image, and (c) CT-abdomen image

TABLE 1
Analysis of CT-brain images by using JPEG

JPEG					
Image No	Anatomical Structure	Maximum Compression ratio	MSE	SNR dB	PSNR dB
Image01	Orbit +Sinus air cells +brain +skull bone	40	147.0	18.82	26.45
Image02	Orbit +Sinus air cells +brain +skull bone	41	151.44	18.19	26.32
Image03	Orbit +Sinus air cells +brain +skull bone	41	143.78	18.50	26.55
Image04	Air cells +brain +skull bone	45	128.94	19.45	27.02
Image05	Brain +skull bone	52	112.55	18.42	27.61
Image06	Air cells +brain +skull bone	55	107.52	19.18	27.81
Image07	Brain +skull bone + ventricle	56	106.73	19.08	27.84
Image08	Brain +skull bone + ventricle	56	105.69	19.27	27.89
Image09	Brain +skull bone + ventricle	55	107.96	19.17	27.79
Image10	Brain +skull bone + ventricle	74	66.31	22.52	29.91
Image11	Brain +skull bone + ventricle	78	63.7	22.52	30.08
Image12	Brain +skull bone + ventricle	79	63.21	22.56	30.12
Image13	Brain +skull bone + ventricle	73	65.72	22.53	29.95
Image14	Brain +skull bone	77	62.19	22.77	30.19
Image15	Brain +skull bone	81	60.72	22.73	30.29
Image16	Brain +skull bone	88	59.38	22.57	30.39
Image17	Brain +skull bone	104	57.9	22.17	30.50
Image18	Skull bone	125	55.64	18.34	30.67

TABLE 2
Analysis of CT-brain images by using Wavelet compression

Wavelet compression					
Image No	Anatomical Structure	Maximum Compression ratio	MSE	SNR dB	PSNR dB
Image01	Orbit +Sinus air cells +brain +skull bone	52	383.82	14.66	22.29
Image02	Orbit +Sinus air cells +brain +skull bone	55	381.52	14.18	22.32
Image03	Orbit +Sinus air cells +brain +skull bone	57	394.50	14.12	22.17
Image04	Air cells +brain +skull bone	63	327.37	15.40	22.98
Image05	Brain +skull bone	76	254.27	15.89	24.08
Image06	Air cells +brain +skull bone	83	219.97	16.08	24.71
Image07	Brain +skull bone + Ventricle	83	211.05	16.12	24.89
Image08	Brain +skull bone + Ventricle	83	211.05	16.27	24.89
Image09	Brain +skull bone + Ventricle	82	232.85	15.84	24.46
Image10	Brain +skull bone + Ventricle	125	114.76	20.14	27.53
Image11	Brain +skull bone + Ventricle	136	97.47	20.68	28.24
Image12	Brain +skull bone + Ventricle	136	96.09	20.74	28.31
Image13	Brain +skull bone + Ventricle	114	107.97	20.38	27.80
Image14	Brain +skull bone	120	95.27	20.92	28.34
Image15	Brain +skull bone	129	83.25	21.36	28.93
Image16	Brain +skull bone	142	68.46	21.95	29.77
Image17	Brain +skull bone	185	42.04	23.56	31.89
Image18	Skull bone	240	26.04	21.64	33.97

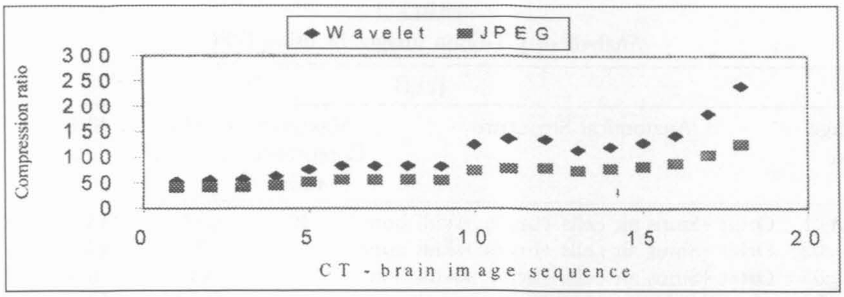

Fig. 2: Compression ratio against CT-brain image sequence for JPEG and Wavelet compression

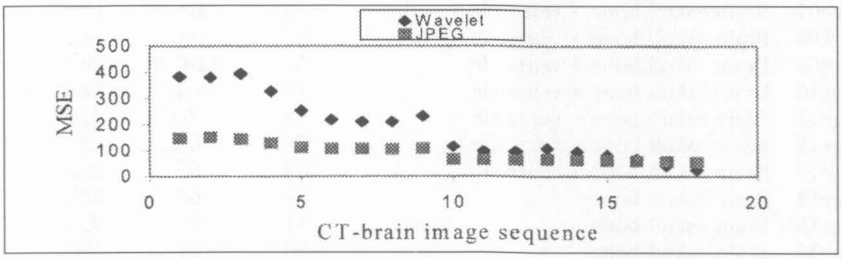

Fig. 3: MSE against CT-brain image sequence for JPEG and Wavelet compression

TABLE 3
Analysis of CT-chest images by using JPEG

		JPEG			
Image No	Anatomical Structure	Maximum Compression ratio	MSE	SNR dB	PSNR dB
Image01	Small vessels + esophagus + more tissues	27	271.68	15.11	23.79
Image02	The same + lungs	27	264.02	15.52	23.91
Image03	The same + lungs	28	258.07	15.48	24.01
Image04	The same + lungs is bigger	28	253.12	15.44	24.09
Image05	The same + superior vena cave + bigger lungs	29	248.50	15.35	24.18
Image06	Less tissues +bigger lungs	28	250.76	15.03	24.19
Image07	The same as above + aortic arch	29	248.48	14.98	24.18
Image08	The same + less tissues	28	253.56	15.18	24.09
Image09	The same + division of aorta	26	198.23	15.61	25.16
Image10	Lungs bigger + pulmonary vessel	28	253.12	14.89	24.09
Image11	Less tissues + more pulmonary vessel	29	249.78	15.03	24.16
Image12	Heart (upper border) + lungs bigger	28	253.29	14.64	24.09
Image13	The same as above	28	256.37	14.78	24.04
Image14	The same + more heart	28	250.53	14.60	24.14
Image15	Much less tissues + more heart	28	255.48	14.68	24.06
Image16	No aorta + bigger lungs + less tissues	28	253.70	15.08	24.08
Image17	Inferior vena cave	29	248.25	15.04	24.18
Image18	The same as above	28	252.42	15.29	24.11
Image19	The same as above + liver	28	252.95	15.34	24.10
Image20	Bigger liver + less heart +spleen bowels	27	251.34	15.54	24.13

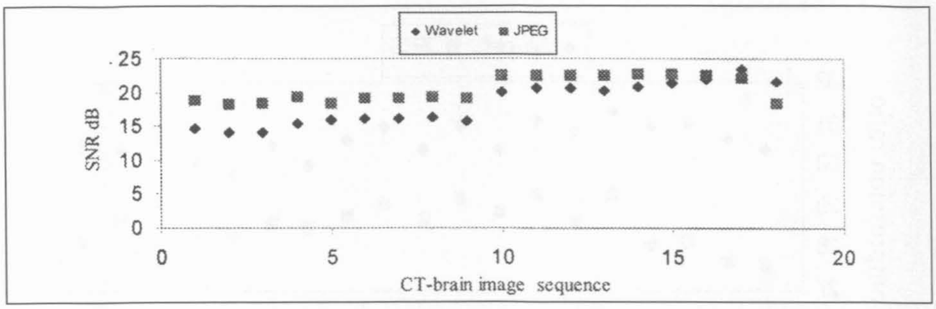

Fig. 4: SNR against CT-brain image sequence for JPEG and Wavelet compression

TABLE 4
Analysis of CT-chest images by using Wavelet compression

Wavelet compression					
Image No	Anatomical Structure	Maximum Compression ratio	MSE	SNR dB	PSNR dB
Image01	Small vessels + esophagus + more tissues + bones	30	1099.00	9.25	17.72
Image02	The same + lungs	30	1075.08	9.62	17.82
Image03	The same + lungs	31	1060.19	9.55	17.88
Image04	The same + lungs is bigger	31	1058.02	9.45	17.88
Image05	The same + Superior vena cave + bigger lungs	31	1040.56	9.32	17.96
Image06	Less tissues +bigger lungs	30	1048.37	9.01	17.93
Image07	The same as above + aortic arch	31	1039.98	8.95	17.96
Image08	The same + less tissues	30	1067.82	9.13	17.85
Image09	The same + division of aorta	30	1033.06	8.64	17.99
Image10	Lungs bigger + pulmonary vessel	30	1071.52	8.83	17.83
Image11	Less tissues + more pulmonary vessel	30	1048.68	8.98	17.92
Image12	Heart (upper border) + lungs bigger	30	1057.48	8.63	17.88
Image13	The same as above	30	1094.81	8.67	17.74
Image14	The same + more heart	30	1070.48	8.50	17.84
Image15	Much less tissues + more heart	29	1078.03	8.64	17.80
Image16	No aorta + bigger lungs + less tissues	30	1082.35	8.97	17.78
Image17	Inferior vena cave	31	1058.16	8.91	17.88
Image18	The same as above	30	1066.75	9.13	17.85
Image19	The same as above +liver	30	1077.87	9.22	17.80
Image20	Bigger liver+ less heart +spleen bowels	30	1080.32	9.38	17.79

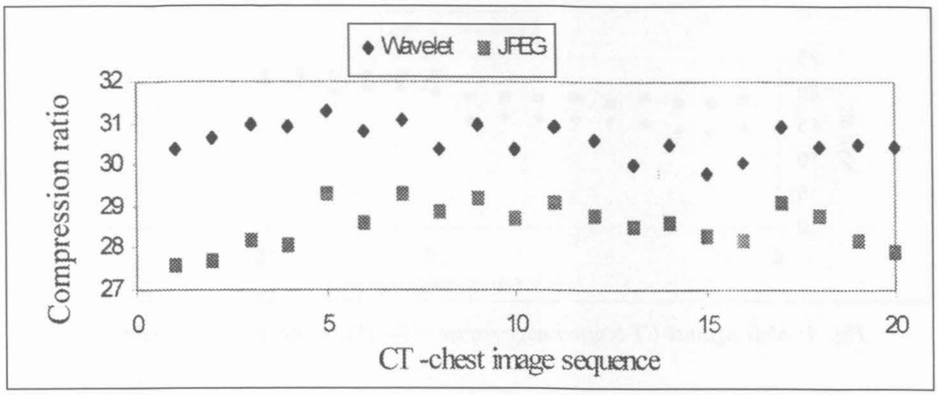

Fig. 5: Compression ratio against CT-chest image sequence for JPEG and Wavelet compression

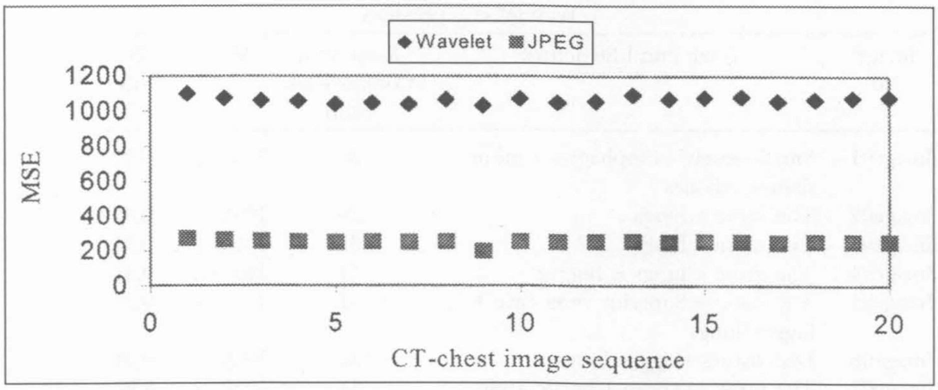

Fig. 6: MSE against CT-chest image sequence for JPEG and Wavelet compression

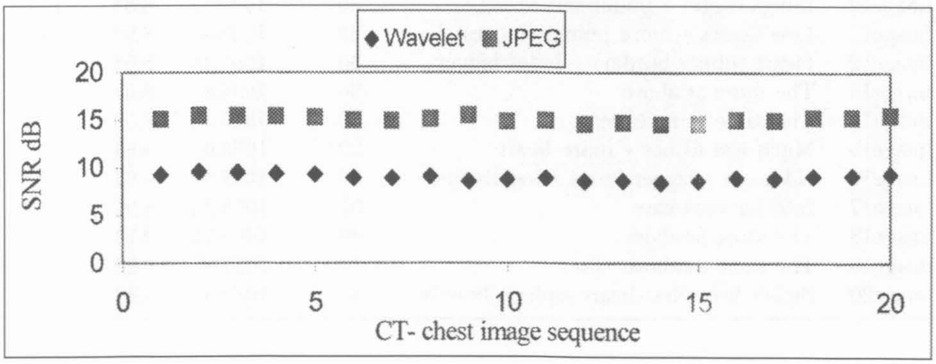

Fig. 7: SNR against CT-chest image sequence for JPEG and Wavelet compression

TABLE 5
Analysis of CT-abdomen images by using JPEG

JPEG					
Image No	Anatomical Structure	Maximum Compression ratio	MSE	SNR dB	PSNR dB
Image01	Liver bigger + spleen bigger + lung diminishing + no heart	27	257.78	15.89	24.02
Image02	Spleen smaller +less tissue + more bowel	27	254.34	15.89	24.07
Image03	Less liver + spleen vessels + bigger stomach	28	249.21	15.80	24.16
Image04	Liver less + spleen vessels more stomach + more bowels	27	253.07	15.56	24.08
Image05	Less liver + stomach + less bowels diminishing + + spleen diminishing	27	255.20	15.28	24.06
Image06	Less liver + no stomach + kidney appears + much more bowels	26	254.73	14.96	24.07
Image07	Spaces between the organs become wider + less bone + kidney appears + less liver	26	255.39	14.89	24.06
Image08	Vessels for right kidney + less liver + less bones + more bowels	27	250.40	14.59	24.14
Image09	More vessels of both kidneys + very small liver	27	247.94	14.45	24.18
Image10	The same as above	27	248.63	14.21	24.17
Image11	Liver diminishing	29	243.73	14.14	24.26
Image12	No liver + more space between the organs + less bone	29	240.83	14.49	24.31
Image13	No kidney vessels + kidney diminishing	29	241.48	13.73	24.30
Image14	Soft tissues of the abdomen seen + less bowel + image become smaller	31	234.56	13.98	24.43
Image15	Less bowel	30	236.13	14.18	24.40
Image16	The same as above	30	236.40	14.99	24.39
Image17	The same as above	31	236.06	13.84	24.40

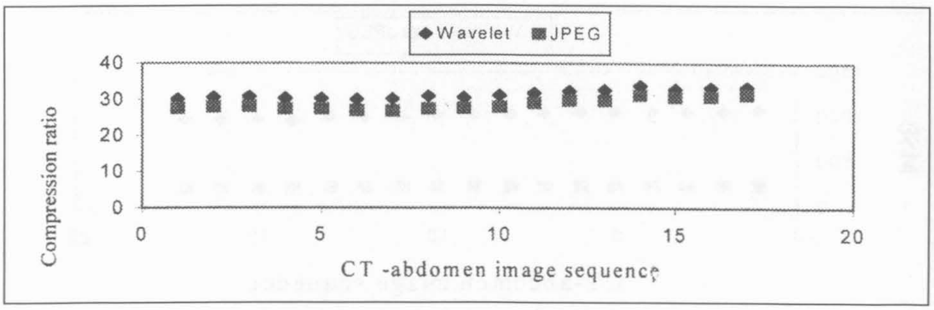

Fig. 8: Compression ratio against CT-abdomen image sequence for JPEG and Wavelet compression

TABLE 6
Analysis of CT-abdomen images by using Wavelet compression

Wavelet compression					
Image No	Anatomical Structure	Maximum Compression ratio	MSE	SNR dB	PSNR dB
Image01	Liver bigger + spleen bigger + lung diminishing + no heart	30	1077.81	9.84	17.81
Image02	Spleen smaller +less tissue + more bowel	30	1064.08	9.84	17.86
Image03	Less liver + spleen vessels + bigger stomach	30	1051.14	9.73	17.91
Image04	Liver less + spleen vessels more stomach + more bowels	30	1056.65	9.52	17.81
Image05	Less liver + stomach + less bowels diminishing + spleen diminishing	30	1065.35	9.07	17.85
Image06	Less liver + no stomach + kidney appears + much more bowels	30	1059.17	8.96	17.81
Image07	Spaces between the organs become wider + less bone + kidney appears + less liver	30	1065.00	8.86	17.86
Image08	Vessels for right kidney + less liver + less bones + more bowels	30	1044.38	8.57	17.94
Image09	More vessels of both kidneys + very small liver	30	1048.07	8.38	17.93
Image10	The same as above	31	1047.92	8.15	17.93
Image11	Liver diminishing	31	1018.98	8.13	18.05
Image12	No liver + more space between the organs + less bone	32	1010.61	8.26	18.05
Image13	No kidney vessels + kidney diminishing	32	1015.28	7.70	18.06
Image14	Soft tissues of the abdomen seen + less bowel + image become smaller	33	990.33	7.73	18.17
Image15	Less bowel	32	1003.72	7.89	18.11
Image16	The same as above	33	991.96	7.77	18.15
Image17	The same as above	33	994.13	7.59	18.15

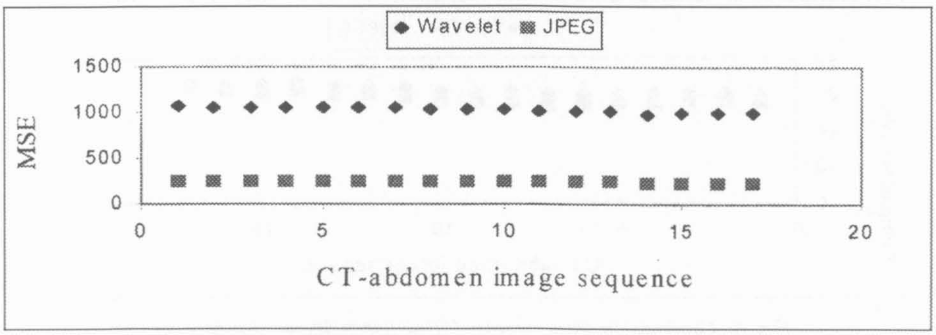

Fig. 9: MSE against CT-abdomen image sequence for JPEG and Wavelet compression

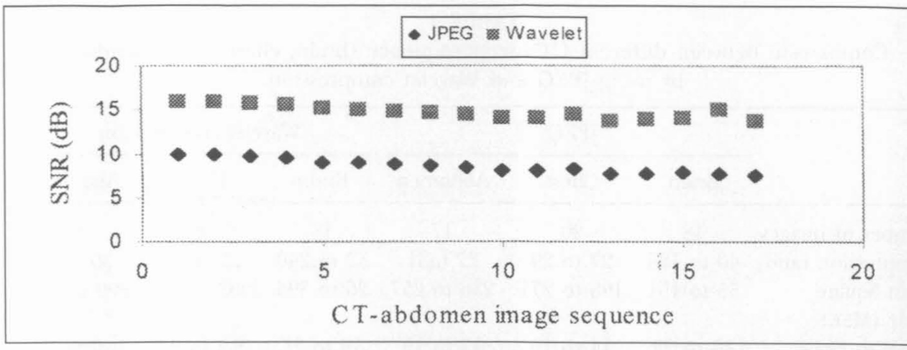

Fig. 10: SNR against CT-abdomen image sequence for JPEG and Wavelet compression

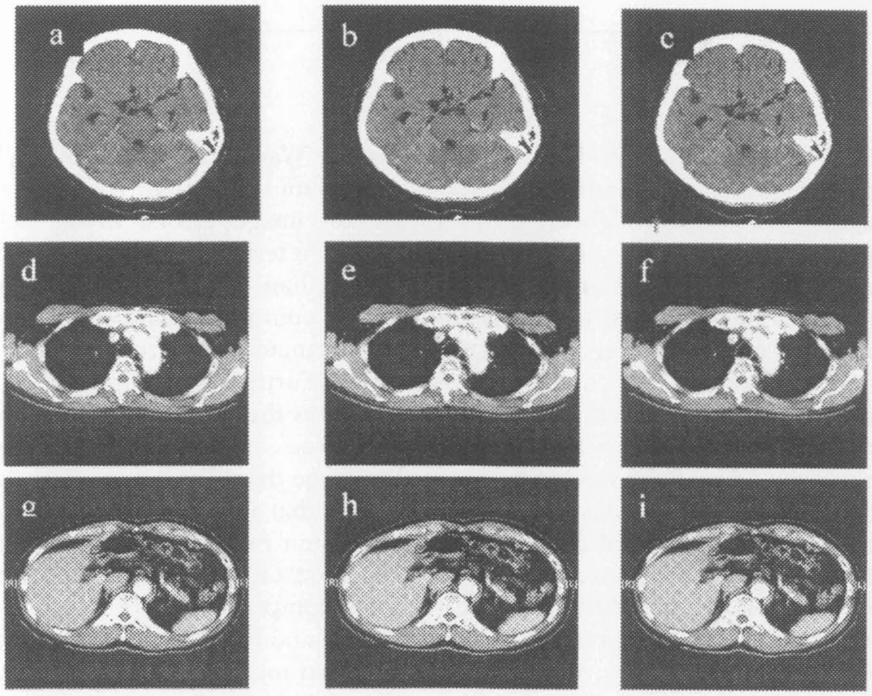

Fig. 11: Subjective comparison between different CT images
a) Original CT- brain image, b) compression ratio 30:1, PSNR =31dB using JPEG,
c) Compression ratio 30:1, PSNR =31dB using wavelet, d) Original CT- chest image,
e) Compression ratio 15:1, PSNR =25.2dB using JPEG, f) Compression ratio 15:1,
PSNR=25.7dB using wavelet, g) Original CT- abdomen image,
h) Compression ratio 15:1, PSNR =33dB using JPEG,
i) Compression ratio 15:1, PSNR =26dB using wavelet

TABLE 7
Comparison between different CT image sequence (brain, chest, and abdomen) by using JPEG and Wavelet compression

	JPEG			Wavelet compression		
	Brain	Chest	Abdomen	Brain	Chest	Abdomen
Number of Images	18	20	17	18	20	17
Compression ratio	40 to 125	27 to 29	27 to31	52 to 240	29 to 31	30 to 33
Mean Square Error (MSE)	55 to 151	198 to 271	236 to 257	26 to 394	1033 to 1099	990 to 1077
Signal to Noise Ratio (SNR) dB	18 to 22	14 to 15	13 to 15	14 to 23	8.5 to 9.6	7 to 9
Peak Signal to Noise Ratio (PSNR) dB	26 to 30	23 to 24	24 to 24	22 to 34	17 to 18	17 to 18

CONCLUSION

From the results of this study we conclude that the Wavelet compression can be used at higher compression ratios before information loss than JPEG for CT images. The Wavelet algorithm introduces less image errors, which yields higher PSNR for low bit rate. We have shown that in terms of image quality, the Wavelet algorithm is either equivalent or better than JPEG for these images. Our results illustrate that we can achieve higher compression ratios for brain than chest and abdomen images and that the anatomical structure and its complexity have an effect on image compression. Furthermore we also observe that by using JPEG, for chest and abdomen images the PSNR values obtained were higher than those achieved by using Wavelet compression. For a lower compression ratio, JPEG yielded higher quality image than Wavelet compression. From the numerical values obtained we observe that for chest and abdomen images the PSNR is equal to 24 dB for compression ratio up to 31:1 by using JPEG, whereas for brain image the PSNR is equal to 22 to 34 dB for compression ratio between 52 to 240:1 by using Wavelet compression. The degree of compression is dependent on anatomic structures and complexity of diagnostic information in the image; so careful consideration must be given to the level of compression ratio before archiving clinical images. Otherwise essential information will be lost.

REFERENCES

BRADLEY, J. and M. D. ERICKSON. 2000. Irreversible compression of medical images Department of Radiology Mayo Foundation, Rochester, M. Accessed on November 2000. http://www.scarnet.org/pdf/SCAR%20White%20Paper.pdf

DAUBECHIES, I. 1988. Orthonormal bases of compactly supported wavelets. *Comm. Pure Appl. Math.* **41:** 909-96.

ERICKSON, B, A. MANDUCA, P. PALISSON, K. R. PERSONS, F. EARNEST, V. SAVCENKO and l. HANGIANDREOU. 1998. Wavelet compression of medical images. *Radiology* **206(3):** 599-607.

IYRIBOZ, T., M. ZUKOSKI, K. HOPPER and P. STAGG. 1999. A comparison of wavelet and JPEG lossy compression methods applied to medical images. *J. Digit Imaging* **12** (2 Suppl 1): 14-17.

LURA TECH GMBL. 2000. Available at http://www.Luratech.com

Pegasus Imaging Corporation (JPEG wizard version 1.3.7). Available at http://www.pegasusimaging.com

PERSONS, K., P. PALLISON, M. PATRICE, A. MANDUCA, J. WILLIAN and E. CHARBONEAU. 2000. Ultrasound grayscale image compression with JPEG and Wavelet techniques. *J. Digit Imaging* **13(1):** 25-32.

SAFFOR, A., R. RAMLI and NG. KWAN. 2001. A comparative study of image compression between JPEG and Wavelet. *Malaysia Journal of Computer Science* **14 (1)**: 39-45.

SAVCENKO, V., B. ERICKSON and K. PERSONS. 2000. An evaluation of JPEG and JPEG 2000 irreversible compression algorithms applied to neurologic computed tomography and magnetic resonance images. *J. Digit Imaging* **13** (suppl 1): 183-185.

SLONE, R. *et al.* 2000. Assessment of visually lossless irreversible image compression: Comparison of three methods by using an image-comparison workstation. *Radiology* **215:** 543-553.

STEPHEN, K. and J. D. THOMPSON. 2000. Performance analysis of a new semi orthogonal spline wavelet compression algorithm for tonal medical images. *Med. Phys.* **27:** 276-288.

Wavelet Compression Engine. 2000. Available at http://www.cengines.com.