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PERFORMANCE EVALUATION OF EMERGING JPEGXR COMPRESSION STANDARD FOR MEDICAL IMAGES

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Medical images require lossless compression as a small error due to lossy compression may be considered as a diagnostic error. JPEG XR is the latest image compression standard designed for variety of applications and has a support for lossy and lossless modes. This paper provides in-depth performance evaluation of latest JPEGXR with existing image coding standards for medical images using lossless compression. Various medical images are used for evaluation and ten images of each organ are tested. Performance of JPEGXR is compared with JPEG2000 and JPEGLS using mean square error, peak signal to noise ratio, mean absolute error and structural similarity index. JPEGXR shows improvement of 20.73 dB and 5.98 dB over JPEGLS and JPEG2000 respectively for various test images used in experimentation.

Keywords : Medical images, Lossless compression, JPEGXR, JPEGLS, JPEG2000

1. Introduction

Telemedicine allow medical doctors at different locations to diagnose and treat patients with the help of medical images transferred via Internet [1]. However, the quality of image is required to be significantly high for proper diagnosis and examination. As a result, transmission of medical images over network requires high bandwidth and large disk storage [2]. Image compression is used to address this problem. There are two types of compression: lossy and lossless. Lossy compression can give large compression ratio but original image cannot be exactly reconstructed from the compressed data and some of the information is permanently lost [3]. Hence, compression error may be considered as diagnostic problem by medical doctors. Alternatively, lossless image compression does not introduce any error in the compressed image and exact recovery of original image is possible. Currently lossless compression is widely accepted in medical imaging industry [4]. The Digital Imaging and Communications in Medicine (DICOM) is an imaging standard used for storage and transmission of medical images [5]. It uses lossless schemes for compression of medical images and current supported compression standards in DICOM are JPEG, JPEGLS [6] and JPEG2000 [7]. JPEGXR is the latest image compression standard supporting both lossy and lossless compression [8]. Braeckman et al. argued that compression performance of lossy compression schemes is highly content dependent. Therefore, they proposed to divide the application view into non-overlapping rectangular patches. These patches are subsequently classified into different content classes and coded using a compression scheme and parameters yielding perceptually optimal performance [9]. On the other hand, our research provides in-depth evaluation of latest JPEGXR with the existing standards using lossless compression. Rest of the paper is organized as follows: Section 2 describes the overview of JPEGXR while simulation results are discussed in section 3. Finally section 4 summarizes the paper.

2. Overview of JPEGXR

JPEGXR (Joint Picture Expert Group Extended Range) is the latest image compression standard designed to meet the current requirements of digital photography using low computational

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resources and storage capacity [10]. It was adopted as an international standards in July 2009 by ISO/IEC and ITU-T as ISO/IEC 29199-2 | ITU-T 832 recommendation. Some important functionalities provided by JPEGXR are: support for lossy and lossless compression, reversible hierarchical lapped biorthogonal transform (LBT), bit stream scalability, optimized quantization, advanced entropy encoding and image tile segmentation [7, 10].

The main steps performed in the encoder are: color conversion, transform (LBT), quantization, coefficient prediction and entropy encoding. Figure 1 describes the workflow of JPEGXR encoder and decoder. After the RGB input is applied JPEGXR converts the color space to luma-chrominance color space and the planes of this space are sometimes sub sampled. LBT transform is used to convert from spatial domain to frequency domain.

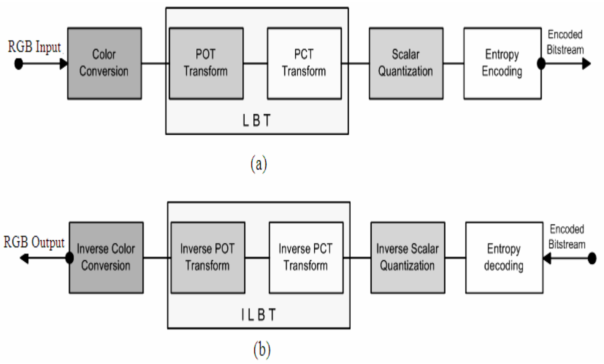

Figure 1. Workflow of JPEGXR in lossless mode (a) Encoder (b) Decoder.

The LBT transform is a combination of photo overlap transform (POT) and photo core transform (PCT) [11]. The POT is an optional transform and its basic purpose is to exploit the correlation across block boundaries to improve efficiency. An additional feature of POT is reduction of blocking artifacts which may occur during low bit rate compression [10]. On the other hand, PCT is a lossless transform and the original image can be build without any loss by taking the inverse PCT transform.

Next step after transformation is scalar quantization. The quantization is applied on transformed frequency coefficients by selecting an optimized quantizer for each macroblock. Then, coefficient scanning is performed on two-dimensional coefficients within a block in a raster order to get one-dimensional vector to be encoded [10]. Finally entropy encoding is done on coefficients using variable length coding. The decoder applies all these steps of encoder in reverse order as shown in Figure 1 (b).

3. Results

Test medical organs of kidney, cardiac, brain, knee and breast were used for analysis [12]. Each test organ was tested using 10 images. Table 1 lists the attributes of the selected image files. Using reference software of JPEGLS [13], JPEG2000 [14] and JPEGXR [15] and by giving uncompressed bitmap medical image as an input, bit streams were generated with different compression ratios. The encoded bit streams were applied to corresponding decoders and reconstructed images were generated. The quality of compression is measured by comparing peak signal to noise ratio (PSNR), mean square error (MSE), mean absolute error (MAE) and structural similarity index (SSIM) metrics [16]. HD Photo Device Porting Kit present in JPEGXR was used for comparison between original and reconstructed bitmap images. Image comparison utility in the Device Porting Kit takes the original and reconstructed bitmap images as inputs and calculates PSNR, MAE, MSE and SSIM values. These values were used to compare the performance of compression schemes.

Table 1. Various attributes of medical images.

Organs	Kidney, Cardiac, Brain, Knee, Breast
Color	Monochrome
Images/organ	10
Bit depth	24 bpp
Image Sizes	769 and 192 KB (Kilo Bytes)
Resolution	512 x 512 and 256 x 256
Source	NEMA, USA

Table 2 shows a comparison between JPEGXR, JPEG2000 and JPEGLS on the basis of time taken to encode and decode an image. Computer having Intel Core 2 Duo 2.8 GHz Processor with 1 GB RAM was used for simulations. It is obvious that JPEGLS is faster than JPEG2000 and JPEGXR, taking less time in encoding and decoding. JPEGXR is slower than JPEGLS but faster than JPEG2000. Encoding and decoding time increases with the increased image size.

Table 2. Comparison of encoding/decoding time.

File Size	JPEGLS		JPEG2000		JPEGXR	
	Encoding (milliseconds)	Decoding (milliseconds)	Encoding (milliseconds)	Decoding (milliseconds)	Encoding (milliseconds)	Decoding (milliseconds)
192 Kbyte	33.4	29.3	145.5	138.9	62	47.2
769 Kbyte	84.2	78.1	482.1	322.2	217.8	148.3

Table 3. PSNR comparison of JPEGLS and JPEG2000 with JPEGXR.

Original Uncompressed Image	Compressed Image Size (KB)	Compression Ratio	Average PSNR (dB)		
			JPEGLS	JPEG2000	JPEGXR
Kidney (769 KB)	50	15.4	23.98560	48.58691	50.02098
	37	20.8	23.51998	46.14780	49.95662
	30	25.6	22.97774	45.07820	48.33951
	25	30.8	22.25621	43.28506	47.89679
	22	35	21.63265	42.53370	46.81854
Cardiac (192 KB)	10	19.2	27.31602	50.95386	51.90105
	7	27.4	27.49553	48.93886	51.264
	6	32.0	26.8333	47.33899	50.44432
	5	38.4	26.78576	46.17008	50.0927
	4	48.0	25.77144	45.43398	49.48585
Brain (192 KB)	11	17.5	24.49499	28.62161	51.89743
	9	21.3	24.01168	28.6084	49.91594
	8	24.0	23.48295	28.59648	48.30366
	6	32.0	23.18075	28.59509	46.8594
	5	38.4	22.79019	28.57620	46.05061
Knee (192 KB)	32	6.0	25.78816	37.67005	49.18345
	27	7.1	25.23642	36.8300	46.11098
	24	8.0	24.69033	35.94695	43.84962
	21	9.1	24.19876	35.09581	41.8885
	19	10.1	23.59536	34.05480	40.52481
Breast (769 KB)	35	22.0	25.78816	37.67005	53.63931
	28	27.5	25.23642	36.83000	50.82338
	23	33.4	24.69033	35.94695	48.76307
	16	48.1	24.19876	35.09581	47.02766
	14	54.9	23.59536	34.05480	45.99647

Table 3 shows a comparison between JPEGXR, JPEG2000 and JPEGLS on the basis PSNR values obtained for 5 different organs. It is clear that for all the organs JPEGXR gives a higher value of PSNR as compared to the other schemes at different compression ratios. Higher value of PSNR indicates good quality.

Table 4. MSE comparison of JPEGLS and JPEG2000 with JPEGXR.

Original Uncompressed Image	Compressed Image (KB)	Compression Ratio	Average MSE		
			JPEGLS	JPEG2000	JPEGXR
Kidney (769 KB)	50	15.4	25.979235	0.90086	0.64714
	37	20.8	28.930308	1.57914	1.04094
	30	25.6	32.766280	2.02024	1.51056
	25	30.8	38.702645	3.05308	2.10584
	22	35	44.670489	3.62990	2.69924
Cardiac (192 KB)	10	19.2	120.68814	0.41987	0.52205
	7	27.4	115.81039	0.48616	0.83024
	6	32.0	134.89776	0.58721	1.20001
	5	38.4	136.3464	0.63655	1.57065
	4	48.0	172.68774	0.73203	1.86073
Brain (192 KB)	11	17.5	240.25648	97.0330	0.42018
	9	21.3	265.51450	100.37767	0.66340
	8	24.0	299.17274	100.99888	0.96219
	6	32.0	319.68995	101.21732	1.34231
	5	38.4	349.26131	101.34406	1.61842
Knee (192 KB)	32	6.0	171.56080	11.120190	0.78477
	27	7.1	194.78374	13.493270	1.59217
	24	8.0	220.87785	16.535500	2.67994
	21	9.1	247.35282	20.115480	4.20952
	19	10.1	284.23570	25.56497	5.76236
Breast (769 KB)	35	22.0	79.77018	0.362500	0.28130
	28	27.5	90.99757	0.611010	0.53796
	23	33.4	104.50938	0.823750	0.86453
	16	48.1	117.03089	1.098190	1.28920
	14	54.9	136.28896	1.364180	1.63477

Table 4 shows the comparison between JPEGXR, JPEG2000 and JPEGLS on the basis of average MSE values obtained for all the images except cardiac image. JPEG2000 gives smaller value of MSE for cardiac image. Smaller values of MSE indicate good quality. It is obvious that overall JPEGXR performs better than other 2 schemes if MSE is considered.

Table 5. MAE comparison of JPEGLS and JPEG2000 with JPEGXR.

Original Uncompressed Image	Compressed Image (KB)	Compression Ratio	Average MAE		
			JPEGLS	JPEG2000	JPEGXR
Kidney (769 KB)	50	15.4	12.77863	0.67109	0.55047
	37	20.8	13.37830	0.93689	0.74158
	30	25.6	14.04079	1.07177	0.91932
	25	30.8	15.13589	1.32402	1.10314
	22	35	16.27569	1.45854	1.25992
Cardiac (192 KB)	10	19.2	7.57460	0.47964	0.45950
	7	27.4	7.20179	0.50821	0.61951
	6	32.0	7.63636	0.55394	0.77520
	5	38.4	7.68280	0.69343	0.90147
	4	48.0	8.59460	0.76394	0.96765
Brain (192 KB)	11	17.5	7.50761	3.80104	0.47662
	9	21.3	7.98921	3.81051	0.47662
	8	24.0	8.46343	3.8136	0.59632
	6	32.0	8.81030	3.81393	0.72673
	5	38.4	9.20562	3.83743	0.74562
Knee (192 KB)	32	6.0	10.0800	2.58000	0.62000
	27	7.1	10.6700	2.85000	0.94000
	24	8.0	11.2700	3.14000	1.25000
	21	9.1	11.8300	3.49000	1.58000
	19	10.1	12.5700	3.92000	1.86000
Breast (769 KB)	35	22.0	4.10124	0.26120	0.23112
	28	27.5	4.32927	0.35889	0.34427
	23	33.4	4.63493	0.42521	0.45525
	16	48.1	4.85593	0.49998	0.57898
	14	54.9	5.21783	0.56069	0.63300

Table 5 shows the comparison on the basis MAE. JPEG2000 and JPEGLS give larger values of MAE as compared to JPEGXR for all the test images. A smaller value of MAE indicates good quality.

Table 6 shows the comparison on the basis of SSIM. A higher value of SSIM indicates good quality. It is obvious that JPEGXR gives higher values of SSIM as compared to JPEG2000 and JPEGLS for all the test images.

Table 6. SSIM comparison of JPEGLS and JPEG2000 with JPEGXR .

Original Uncompressed Image	Compressed Image (KB)	Compression Ratio	Average SSIM		
			JPEGLS	JPEG2000	JPEGXR
Kidney (769 KB)	50	15.4	0.88424	0.99953	0.99966
	37	20.8	0.8744	0.99916	0.99963
	30	25.6	0.86127	0.99892	0.99945
	25	30.8	0.83964	0.99837	0.99934
	22	35	0.81731	0.99806	0.99921
Cardiac (192 KB)	10	19.2	0.81544	0.99902	0.9988
	7	27.4	0.81581	0.99886	0.99807
	6	32.0	0.77842	0.99864	0.99722
	5	38.4	0.79139	0.99853	0.99633
	4	48.0	0.70944	0.99831	0.99567
Brain (192 KB)	11	17.5	0.7794	0.89968	0.99948
	9	21.3	0.75941	0.89941	0.99919
	8	24.0	0.72956	0.89919	0.99883
	6	32.0	0.7045	0.89907	0.99839
	5	38.4	0.67783	0.89871	0.99803
Knee (192KB)	32	6.0	0.96309	0.99759	0.9998
	27	7.1	0.95812	0.99706	0.99967
	24	8.0	0.95230	0.99637	0.9994
	21	9.1	0.94647	0.99562	0.99908
	19	10.1	0.93859	0.99446	0.99875
Breast (769 KB)	35	22.0	0.95509	0.99978	0.99986
	28	27.5	0.94988	0.99965	0.99970
	23	33.4	0.94257	0.99954	0.99950
	16	48.1	0.93531	0.99939	0.99927
	14	54.9	0.92680	0.99924	0.99908

Figure 2 shows the subjective comparison of JPEGXR with JPEG2000 and JPEGLS using 10 medical images/organ on basis of a) PSNR b) MAE c) MSE d) SSIM. It is apparent that JPEGXR achieves better performance in comparison to other used standards.

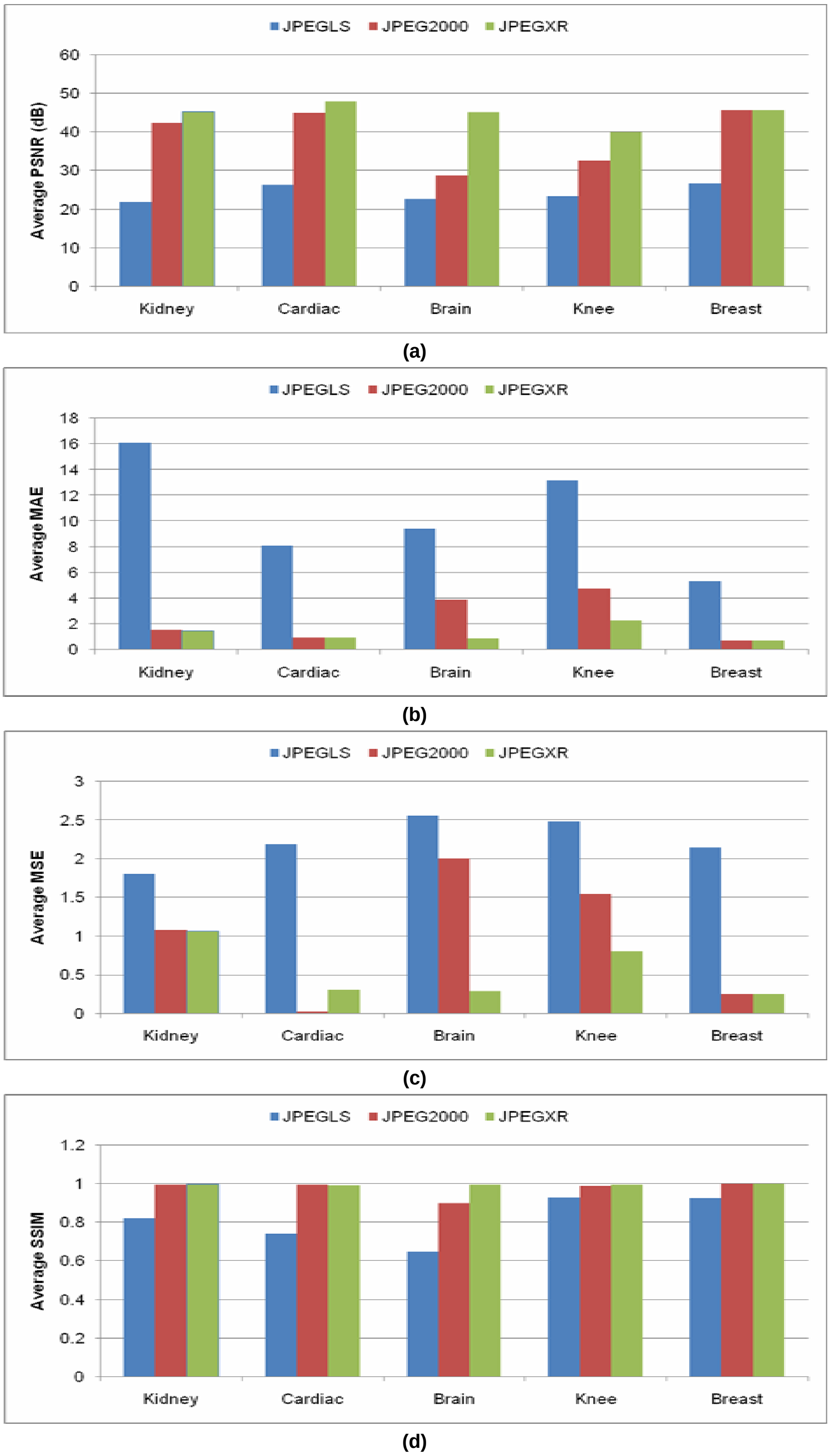

Figure 2. Objective comparison of JPEGXR with JPEG2000 and JPEGLS using 10 medical images/organ on basis of (a) PSNR (b) MAE (c) MSE (d) SSIM.

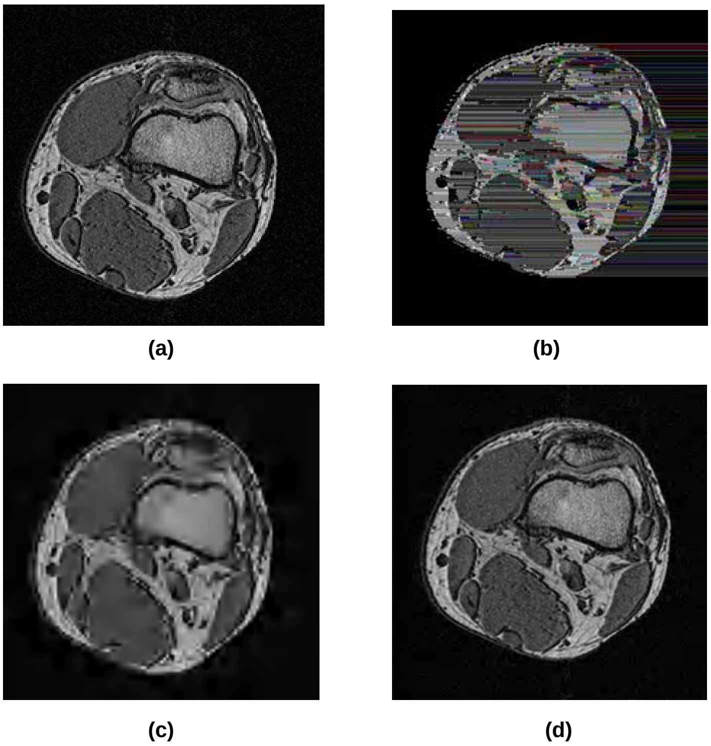

Figure 3. Subjective comparison of Knee Image with compression ratio 27.4 (a) Original (b) JPEGLS (PSNR 21.1685) (c) JPEG2000 (PSNR 24.716) (d) JPEGXR (PSNR 33.1316) .

Figure 3 shows the effect of compression on a Knee image using all the three compression schemes. Figure 3(b) shows that the performance of JPEGLS is degraded at high compression rates. Figure 3(c) indicates that JPEG2000 produces a blurring effect at high compression ratio while this effect is not present in JPEGXR as seen from Figure 3(d). Therefore, we can conclude from subject comparison of Figure 3 that JPEGXR performance is on the higher side in comparison with JPEGLS and JPEG2000.

4. Conclusion

We have presented the performance comparison of JPEGXR over existing image compression standards for medical images using lossless compression. On the basis of comparative analysis, JPEGXR is found to perform better than JPEG2000 and JPEGLS. JPEGXR compression scheme is stable and gives a high PSNR value as compared to JPEGLS and JPEG2000. MAE, MSE and SSIM parameters also show that JPEGXR performs better than JPEGLS and JPEG2000. Therefore, it is concluded that JPEGXR can be used for compression of medical images without losing the subjective and objective quality of images.

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