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Comparative Performance of Non-Linear Transforms for Magnetic Resonance Angiography Image Compression

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ABSTRACT

Magnetic resonance angiography is an MRI exam of the blood vessels. The enhancement in image compression is largely related to require fast and efficient methods for the storage and transmission of information between individuals. This effort examines the comparative performance of Wavelift Transform, Essentially Non-Oscillatory cell average transform, morphological Haar wavelet transform, Maxlift and Medlift transform methods using analysis of variance for MRA image compression. There was no significant effect of different MRA image on peak signal to noise ratio. In each transform, PSNR increases with an increase in bit per pixel. Wavelift Transform performs well among the different transforms in terms of quality and compression of image. Future work needs to done by comparing different transforms by using different techniques for MRA image compression.

Key words: SPHIT algorithm, peak signal to noise ratio, non-linear transform

INTRODUCTION

Magnetic Resonance Angiography (MRA) is used to image blood vessels, a technique based on Magnetic Resonance Imaging (MRI) [1]. Imaging speed is important in many MRA applications. Magnetic Resonance Angiography images take large storage and time to transmission [1]. It is an urgent need to reduce the amount of acquired data without degrading the image quality.

Image compression plays a vital role in several important and diverse applications including remote sensing, medical imaging and ECG imaging. Digital image is mainly set of various pixel values. In most images, a common feature is correlation of neighbouring pixels and therefore contains redundant information. The primary task is to find less correlated representation of the image. By using the compression algorithms redundant bits are removed from the image so that image size is reduced and the image is compressed [2]. Transforms are used to obtain a suitable signal representation for efficient source coding [3]. Image compression can be done by using different transforms. However, image compression results always vary with linear and non-linear transforms due to their individual properties.

Wavelet transform (WT) are linear tool and traditionally implemented by convolution or FIR filter bank structures. However, implementation requires a large number of arithmetic computations and a large storage capacity. But these features are not desirable for high speed or low power image processing application. Sweldens developed the algorithm for nonlinear WT by introducing lifting schemes. Lifting schemes has many advantages over the convolution based approach. These are discussed as follows (i) it requires less computation (up to 50%) compared to the convolution based approach (ii) During lifting implementation, no extra memory buffer is required because of the in-place computation feature of lifting (iii) it offers integer to integer transformation suitable for lossless image compression [4, 5]. Lifting can be used to construct wavelet decompositions for signals that are defined on arbitrary domains, or to construct nonlinear coupled or uncoupled wavelet decompositions [6].

Max-lifting scheme preserves the numbers and shapes of flat regions in a piecewise constant signal. This scheme preserves local maxima and moreover it does not create new ones. It is therefore expected that max-lifting will preserve, over a range of scales, the number and shapes of regions of constant signal value. Max-lifting decomposition produces one scaled image and three detail image (a horizontal, vertical, and diagonal detail image). The detail signals are zero at areas of smooth gray level variations, and that sharp gray level variations are mapped to negative (black) detail signal values [6].

Wavelets are non-adaptive schemes. Hence large coefficients always appear at discontinuities when wavelets are used. In images, edges constitute discontinuity in the data. The edges in an image are vital information and it is necessary to preserve them while efficiently representing the image. Hence essentially non-oscillatory (ENO) interpolation technique avoids the discontinuities and large coefficients are not appearing at edges and provide better compression capabilities. The ENO interpolatory technique is a data dependent, nonlinear technique which can eliminate the Gibbs phenomenon [4].

The Morphological Haar (Mhaar) Wavelet is an uncouple wavelet decomposition scheme. The main dissimilarity with the classical haar wavelet is that the linear signal analysis filter of the latter is replaced by an erosion (or dilation), i.e., by taking the minimum (or maximum) over two samples. The Mhaar wavelet decomposition method can do better work in preserving edges as compare to the linear case. This is expected, since the signal analysis filters in the linear Haar wavelet decomposition method are linear lowpass filters and as such smooth-out edges. The signal analysis filters in the Mhaar case are non-linear, and as such may preserve edge information [7].

In particular, linear transform is well defined for image compression but there are few studies on image compression using non-linear compression. Researchers [3, 5, 7] used Wavelift Transform, Essentially Non-Oscillatory cell average (ENOCA) transform, morphological Haar wavelet (Mhaar) transform, Maxlift and Medlift transform for ECG compression. However, there is not much published data on MRA image compression with different non linear transforms. Therefore, the research work was done by evaluating the performance of Wavelift Transform, ENOCA, Mhaar, Maxlift and Medlift transform for MRA image compression.

PERFORMANCE EVALUATION

The performance of different transforms was measured by calculating the peak signal to noise ratio (PSNR) in dB. It was found that the performance evaluation criteria which best matches the individual visual quality of the image was the PSNR. For this cause, importance was placed on the PSNR. Typical values for the PSNR in Lossy image compression were between 30 and 50 dB, provided the bit depth is 8 bits, where higher was better [4, 6]. For 16-bit data typical values for the PSNR were between 60 and 80 dB. In the absence of noise the PSNR was infinite.

$$PSNR = 10log_{10}\left(\frac{255^2}{MSE}\right)dB$$

where, MSE is mean squared-error between the original and reconstructed images. The bit rates are not entropy estimates, they were calculated from the actual size of the compressed files [8].

METHODOLOGY

In this study, five transforms (Wavelift transform, Essentially Non-Oscillatory cell average (ENOCA) transform, morphological Haar wavelet (Mhaar) transform, Maxlift and Medlift transform) were used for comparison. There was set of 75 samples images available on physiobank database [9]. Out of these, 20 sample images were selected randomly for this study. In Wavelift transform, MRA image was transformed using cdf 9/7 and decomposed to 5 levels. In the ENOCA transform, MRA image was transformed with three stages and five-degree interpolation. Levels used for decomposition was 3 in case of Mhaar transform, Maxlift and Medlift transform. These images were transformed in to above said transforms independently. These transformed coefficients were encoded by using SPHIT algorithm [8]. The compression was done at different ranges varied from 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 and 0.9 bit per pixel.

Compression ratio (CR) was calculated as follows:

CR= maximum bits / Total bits (262144)

Maximum bits were 26214, 52428, 78643, 104857, 131072, 157286, 183500, 209715 and 235929 at 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 and 0.9 bit per pixel, respectively.

The compressed MRA images decoded for reconstruction by using SPHIT algorithm [8] followed by inverse transforms. Then the reconstructed MRA images were compared with original MRA images and peak signal to noise ratio (PSNR) was calculated to check the MRA image quality. The data were analyzed by analysis of variance (ANOVA) to check the significant difference within and between transforms at various ranges of bit per pixel in various images. In ANOVA, there was significant difference only in case of $p< 0.05$.

Visual comparison of linear transforms for MRA image compression was done between original and reconstructed image by selecting E1154S7100 image only. The three different bpp values (0.1, 0.5 and 0.9) were taken to check the image quality.

RESULTS AND DISCUSSION

The average PSNR varied from 27.62 to 31.90 in different MRA images in Wavelift Transform (Table 1). However, PSNR significantly ($p < 0.05$) increases with an increase in bits per pixel (bpp) (Table 6). Average PSNR in different bpp was higher by 5.3, 13.3, 16.7, 18.6, 21.5, 26.6, 31 and 34.4 per cent in bpp of 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 and 0.9, respectively compared to 0.1.

Similar were the findings in ENOCA transform, Mhaar transform, Maxlift and Medlift transform (Table 2-5). However, average PSNR in different images of MRA varied from 19.89 to 23.23, 20.08 to 23.43, 18.64 to 21.88 and 18.91 to 22.24, in ENOCA transform, Mhaar transform, Maxlift and Medlift transform respectively. Likewise in Wavelift Transform, average PSNR in ENOCA transform, Mhaar transform, Maxlift and Medlift increased with an increase in bpp but the magnitude was different. Similar findings were reported earlier [8]. They observed that with an increase in bpp, PSNR increases in WT using SPHIT algorithm. However, they did not report these results on medical images in comparison to present study. There were no significant effects of different MRA images on PSNR (Table 6). Average PSNR of different transforms were compared to check the performance of transform. There were significant difference among the transforms image wise and bpp wise (Table 7). The highest average PSNR was observed in Wavelift transform (30.13) followed by Mhaar transform (21.89), ENOCA transform (21.70), Medlift (20.71) and lowest in Maxlift transform (20.35).

As there was no significant difference between different MRA images on PSNR, only one image (E1154S71000) was selected for visual comparison. With an increase in bpp value, the quality of reconstructed image improved (Fig. 1-5).

Table -1 Performance of MRA Compression with WAVELIFT Transform on Different MRA Images

S No.	MRA Image	bit per pixel									
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	Mean
1	E1154S71000	24.77	25.67	27.72	29.05	29.66	29.92	30.31	31.06	33.22	29.04
2	E1154S71001	25.35	26.16	28.82	29.6	30	30.42	30.71	33.22	34.05	29.81
3	E1154S71002	25.53	26.38	28.99	29.7	29.99	30.42	31.47	33.59	34.28	30.04
4	E1154S71003	25.62	26.45	29.06	29.77	30.04	30.46	31.54	33.7	34.33	30.11
5	E1154S71004	25.55	26.31	28.91	29.64	29.99	30.42	30.66	33.25	34.03	29.86
6	E1154S71005	25.26	26.08	28.36	29.25	29.78	30.05	30.41	31.36	33.44	29.33
7	E1154S71010	23.45	24.94	25.5	27.41	28.64	29.18	29.57	29.77	30.12	27.62
8	E1154S71015	24.97	25.77	27.8	29.01	29.6	29.83	30.22	31.19	33.33	29.08
9	E1154S71020	25.37	26.14	28.72	29.48	29.81	30.22	30.48	33.22	34.04	29.72
10	E1154S71025	25.54	26.22	29.19	29.81	30.17	30.51	32.8	33.87	34.45	30.28
11	E1154S71030	25.69	26.68	29.23	29.84	30.24	30.59	33.15	34.07	34.63	30.46
12	E1154S71035	26.07	28.88	29.94	30.35	30.81	33.19	34.28	34.8	35.20	31.50
13	E1154S71040	25.8	28.3	29.73	30.15	30.62	32.57	33.87	34.55	34.94	31.17
14	E1154S71045	25.71	27.00	29.35	29.94	30.38	30.7	33.41	34.25	34.74	30.61
15	E1154S71050	25.73	27.19	29.43	30.01	30.46	30.73	33.64	34.46	34.88	30.73
16	E1154S71055	25.78	27.68	29.58	30.11	30.61	31.74	33.84	34.49	34.84	30.96
17	E1154S71060	25.78	26.53	29.5	30.08	30.48	30.79	33.51	34.39	34.85	30.66
18	E1154S71065	26.06	28.29	29.79	30.24	30.68	31.78	34.02	34.64	34.99	31.17
19	E1154S71070	26.56	29.23	30.32	30.77	31.16	33.83	34.65	35.09	35.49	31.90
20	E1154S71075	23.55	25.29	25.91	28.89	29.57	29.94	30.58	30.58	33.23	28.62
	Mean	25.41	26.76	28.79	29.66	30.13	30.86	32.16	33.28	34.15	30.13

Table -2 Performance of MRA Compression with ENOCA Transform on Different MRA Images

S No.	MRA Image	bit per pixel									
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	Mean
1	E1154S71000	17.82	19.07	20.11	21.73	22.02	21.95	22.49	23.69	23.88	21.42
2	E1154S71001	18.74	19.65	21.21	22.2	22.38	22.48	23.99	24.43	24.54	22.18
3	E1154S71002	19.12	19.95	21.29	22.27	22.47	23.18	24.57	24.76	24.84	22.49
4	E1154S71003	19.2	19.95	21.65	22.25	22.4	23.28	24.57	24.76	24.81	22.54
5	E1154S71004	18.97	19.77	21.42	22.09	22.25	22.71	24.03	24.42	24.55	22.25
6	E1154S71005	18.63	19.51	20.79	21.77	22.01	21.89	23.06	23.8	23.91	21.71
7	E1154S71010	16.82	17.9	18.19	20.05	20.89	21.07	21.00	20.9	22.19	19.89
8	E1154S71015	17.59	18.54	19.25	20.91	21.54	21.65	21.84	23.21	23.49	20.89
9	E1154S71020	18.11	19.01	20.12	21.56	21.98	21.93	23.01	23.9	24.03	21.52
10	E1154S71025	18.30	19	20.36	21.63	21.89	21.73	23.46	23.87	24.00	21.58
11	E1154S71030	18.05	18.81	20.12	21.36	21.75	21.63	23.43	23.92	23.96	21.45

12	E1154S71035	18.45	19.31	21.08	22.01	22.27	23.44	24.48	24.65	24.6	22.25
13	E1154S71040	17.89	19.02	20.34	21.62	21.9	22.35	23.82	24.16	24.20	21.70
14	E1154S71045	17.72	19.05	20.03	21.42	21.72	21.58	23.01	23.51	23.63	21.30
15	E1154S71050	17.90	19.23	20.3	21.44	21.73	21.59	23.26	23.77	23.92	21.46
16	E1154S71055	17.81	19.5	20.64	21.64	21.81	21.71	23.50	23.94	24.16	21.63
17	E1154S71060	18.37	19.94	21.30	21.93	22.06	22.25	23.73	24.13	24.31	22.00
18	E1154S71065	18.90	20.49	21.87	22.37	22.32	23.39	24.36	24.63	24.16	22.50
19	E1154S71070	19.63	20.56	22.52	23.05	23.01	24.6	25.18	25.29	25.26	23.23
20	E1154S71075	16.41	18.58	18.99	20.42	20.97	21.03	20.99	21.73	22.71	20.20
	Mean	18.22	19.34	20.58	21.69	21.97	22.27	23.39	23.87	24.06	21.70

Table -3 Performance of MRA Compression with MHAAR Transform on Different MRA Images

S No.	MRA Image	bit per pixel									
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	Mean
1	E1154S71000	17.25	18.75	19.57	20.42	21.27	22.11	22.79	23.39	23.95	21.06
2	E1154S71001	18.44	19.79	20.76	21.63	22.5	23.19	23.73	24.45	24.99	22.16
3	E1154S71002	18.8	20.14	21.21	22.11	22.86	23.44	24.24	24.81	25.34	22.55
4	E1154S71003	18.88	20.17	21.21	22.14	22.8	23.36	24.11	24.79	25.24	22.52
5	E1154S71004	18.94	19.92	21.26	22.09	22.79	23.33	24.03	24.59	24.94	22.43
6	E1154S71005	18.79	19.61	20.73	21.54	22.31	22.94	23.48	24.13	24.68	22.02
7	E1154S71010	17.16	17.96	18.51	19.45	20.16	20.92	21.60	22.27	22.71	20.08
8	E1154S71015	17.79	18.81	19.63	20.60	21.41	22.3	22.99	23.61	24.23	21.26
9	E1154S71020	18.13	19.14	20.07	20.90	21.77	22.47	23.04	23.71	24.26	21.50
10	E1154S71025	18.32	19.24	20.37	21.26	22.15	22.93	23.57	24.35	24.96	21.91
11	E1154S71030	17.99	19.02	19.98	20.99	22.1	22.89	23.62	24.44	25.25	21.81
12	E1154S71035	18.32	19.36	20.47	21.42	22.34	23.14	24.00	24.61	25.00	22.07
13	E1154S71040	17.99	19.1	20.23	21.26	22.21	23.02	23.81	24.45	24.92	21.89
14	E1154S71045	17.90	19.09	20.08	21.10	21.97	22.74	23.48	24.18	24.81	21.71
15	E1154S71050	17.84	19.18	20.39	21.37	22.25	22.97	23.72	24.44	24.96	21.90
16	E1154S71055	17.62	19.1	20.38	21.36	22.25	23.04	23.78	24.43	25.02	21.89
17	E1154S71060	17.86	19.44	20.80	21.70	22.65	23.36	24.02	24.74	25.28	22.21
18	E1154S71065	18.65	20.25	21.70	22.61	23.44	24.16	24.93	25.47	26.01	23.02
19	E1154S71070	19.30	20.63	22.10	23.02	23.8	24.51	25.19	25.84	26.47	23.43
20	E1154S71075	15.26	17.51	18.97	19.93	20.81	21.82	22.78	23.56	24.12	20.53
	Mean	18.06	19.31	20.42	21.35	22.19	22.93	23.65	24.31	24.86	21.89

Table -4 Performance of MRA Compression with MAXLIFT Transform on Different MRA Images

S No.	MRA Image	bit per pixel									
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	Mean
1	E1154S71000	16.28	17.25	18.46	19.17	19.91	20.54	21.95	22.66	23.32	19.95
2	E1154S71001	17.07	18.4	18.94	19.54	20.11	21.35	21.85	22.40	22.90	20.28
3	E1154S71002	17.56	18.92	19.55	20.11	20.69	21.96	22.65	23.24	23.75	20.94
4	E1154S71003	17.77	19.01	19.7	20.27	20.89	22.13	22.87	23.47	24.03	21.13
5	E1154S71004	17.88	18.79	19.35	19.82	20.31	21.58	22.14	22.66	23.14	20.63
6	E1154S71005	17.59	18.5	19.14	19.64	20.13	21.49	22.07	22.71	23.34	20.51
7	E1154S71010	16.27	16.57	17.37	18.02	18.56	19.06	19.54	20.90	21.43	18.64
8	E1154S71015	16.85	17.22	18.04	18.67	19.11	19.63	21.04	21.53	22.13	19.36
9	E1154S71020	16.94	17.67	18.66	19.22	19.67	20.78	21.60	22.24	22.83	19.96
10	E1154S71025	17.23	18.40	19.1	19.70	20.30	21.69	22.33	22.92	23.49	20.57
11	E1154S71030	17.33	17.81	18.83	19.49	20.01	21.53	22.09	22.68	23.24	20.33
12	E1154S71035	17.52	18.57	19.28	19.95	20.58	21.95	22.62	23.17	23.63	20.81
13	E1154S71040	17.01	18.02	19.15	19.92	20.6	21.93	22.55	23.13	23.61	20.66
14	E1154S71045	16.83	17.9	19.08	19.83	20.39	21.65	22.39	23.04	23.62	20.53
15	E1154S71050	16.84	17.82	19.06	19.72	20.28	21.66	22.26	22.93	23.53	20.46
16	E1154S71055	16.55	17.44	18.71	19.44	20.1	21.38	22.09	22.75	23.4	20.21
17	E1154S71060	16.78	17.83	19.14	19.83	20.53	21.88	22.55	23.25	23.87	20.63
18	E1154S71065	17.31	19.05	19.49	20.20	20.76	22.04	22.68	23.26	23.75	20.95
19	E1154S71070	18.02	19.43	20.2	20.84	22.36	23.01	23.71	24.41	24.96	21.88
20	E1154S71075	14.67	15.8	17.19	18.41	19.07	19.56	20.20	21.60	22.29	18.75
	Mean	17.02	18.02	18.92	19.59	20.22	21.34	22.06	22.75	23.31	20.35

Table -5 Performance of MRA Compression with MEDLIFT Transform on Different MRA Images

S No.	MRA Image	bit per pixel									
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	Mean
1	E1154S71000	16.75	17.44	18.72	19.42	19.97	20.4	21.1	21.99	22.83	19.85
2	E1154S71001	17.47	18.70	19.70	20.24	20.67	21.36	22.22	23.03	23.67	20.78
3	E1154S71002	17.99	19.19	20.11	20.55	20.91	21.78	22.69	23.32	24.02	21.17
4	E1154S71003	18.20	19.32	20.31	20.68	21.03	21.94	22.81	23.47	24.08	21.32
5	E1154S71004	18.25	19.11	20.02	20.52	20.91	21.62	22.47	23.15	23.73	21.09
6	E1154S71005	18.10	18.85	19.67	20.17	20.52	21.01	21.91	22.67	23.19	20.68
7	E1154S71010	16.67	17.9	17.62	18.39	19.08	19.38	19.74	20.31	21.14	18.91
8	E1154S71015	17.15	18.54	18.67	19.51	19.85	20.26	20.75	21.66	22.54	19.88
9	E1154S71020	17.38	19.01	19.21	19.79	20.22	20.53	21.63	22.53	23.14	20.38
10	E1154S71025	17.59	19.00	19.49	20.06	20.56	21.23	22.15	23.00	23.70	20.75
11	E1154S71030	17.40	18.81	19.18	19.93	20.44	21.09	22.10	22.98	24.08	20.67
12	E1154S71035	17.73	19.31	19.8	20.44	20.83	21.82	22.88	23.55	24.08	21.16
13	E1154S71040	17.43	19.02	19.51	20.21	20.82	21.59	22.61	23.35	24.03	20.95
14	E1154S71045	17.25	19.05	19.37	20.17	20.66	21.14	22.19	23.11	23.77	20.75
15	E1154S71050	17.22	19.23	19.51	20.30	20.83	21.35	22.32	23.16	23.84	20.86
16	E1154S71055	16.93	19.5	19.41	20.22	20.78	21.23	22.31	23.13	23.78	20.81
17	E1154S71060	17.24	19.94	19.71	20.48	20.96	21.74	22.57	23.31	24.01	21.11
18	E1154S71065	17.68	20.49	20.37	21.04	21.43	22.42	23.26	23.89	24.39	21.66
19	E1154S71070	18.34	20.56	20.91	21.49	22.26	23.15	23.87	24.59	24.95	22.24
20	E1154S71075	14.46	18.58	17.3	18.84	19.64	20.02	20.43	21.48	22.44	19.24
	Mean	17.36	19.08	19.43	20.12	20.62	21.25	22.10	22.88	23.57	20.71

Table -6 Comparison within Transform by using ANOVA

ANOVA Test within transform (p<0.05)					
	Wavelift	ENOCA	Mhaar	Maxlift	Medlift
Image wise	0.32	0.16	0.46	0.36	0.16
rate bit per pixel	$4.15x10^{-66}$	$3.30x10^{-64}$	$9.57x10^{-76}$	$7.17x10^{-72}$	$3.48x10^{-64}$

Table -7 Comparison of Difference Transforms by using ANOVA

ANOVA Test on transforms (p<0.05)					
	Wavelift	ENOCA	Mhaar	Maxlift	Medlift
Image wise	$3.52x10^{-11}$				
rate bit per pixel	$9.41x10^{-62}$				

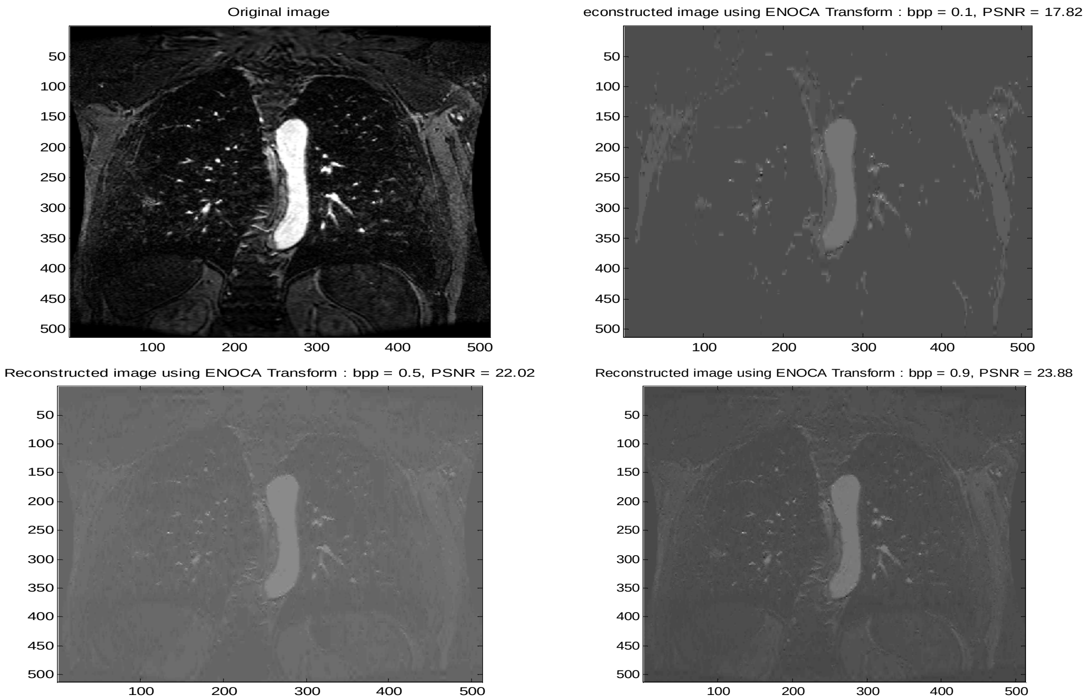

Fig.1 Comparison of original image with reconstructed image at 0.1, 0.5 and 0.9 bpp using ENOCA Transform

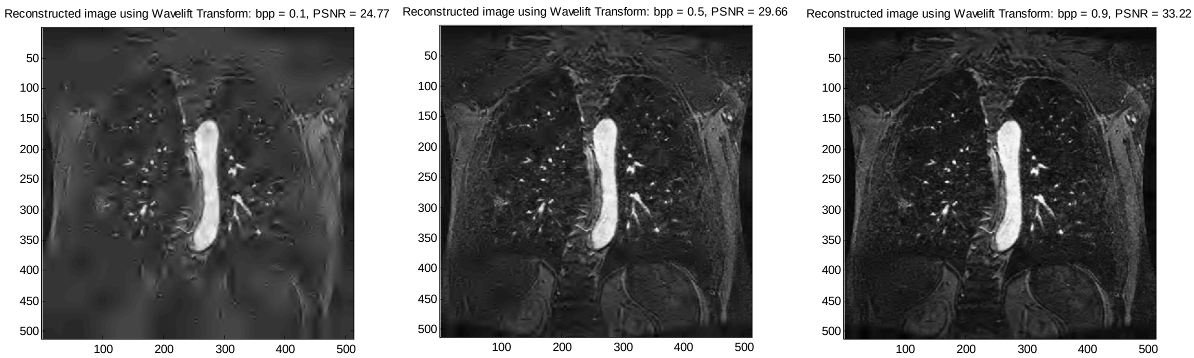

Fig.2 Comparison of original image with reconstructed image at 0.1, 0.5 and 0.9 bpp using WAVELIFT Transform

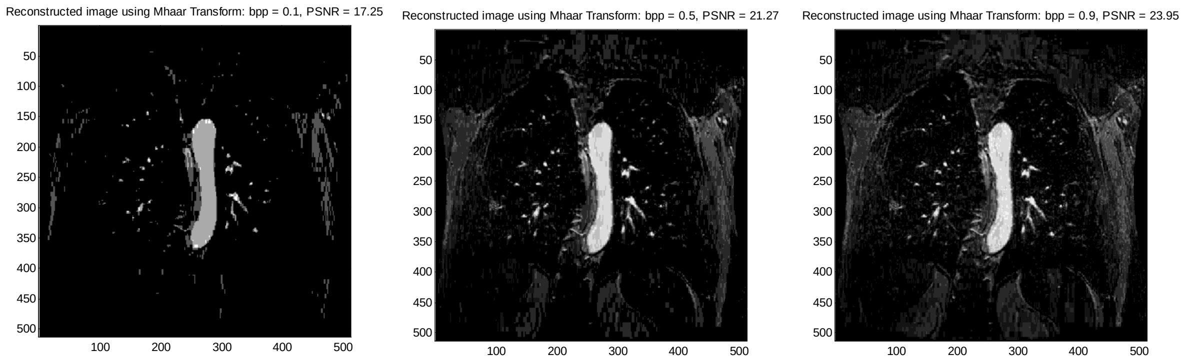

Fig.3 Comparison of original image with reconstructed image at 0.1, 0.5 and 0.9 bpp using MHAAR Transform

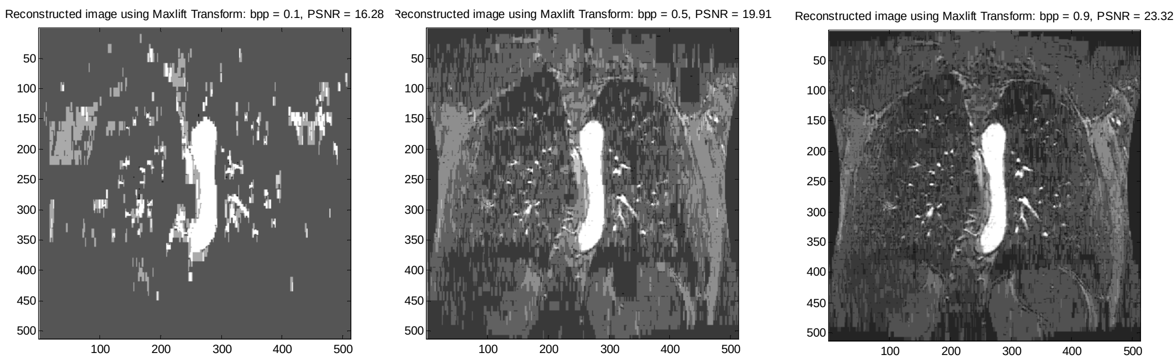

Fig.4 Comparison of original image with reconstructed image at 0.1, 0.5 and 0.9 bpp using MAXLIFT Transform

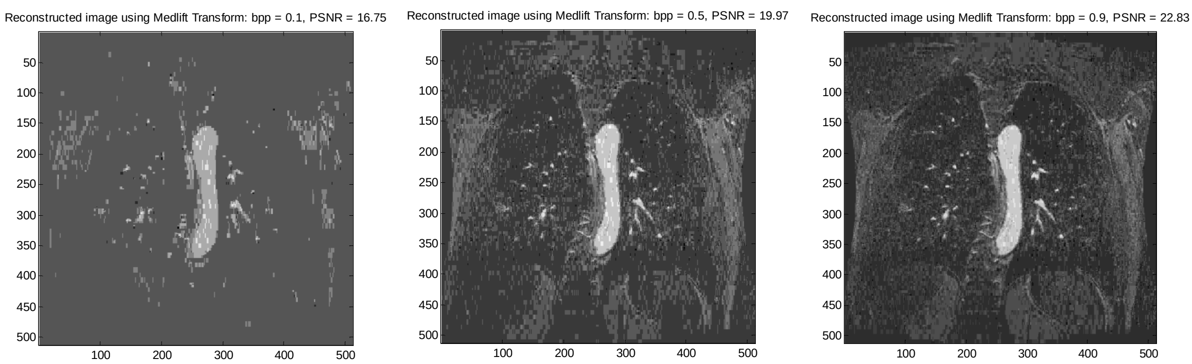

Fig.5 Comparison of original image with reconstructed image at 0.1, 0.5 and 0.9 bpp using MEDLIFT Transform

CONCLUSION

There was no significant effect of different images on PSNR. With an increase in bpp value, quality of image improved. Wavelet transform performed better among all the transforms in terms of quality and compression of image. Future work needs to done by comparing different transforms by using different techniques for MRA image compression.

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