# Wavelet based coding of 2-D and 3-D MR Images

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*Abstract*— This paper presents a lossless wavelet based intraband coding scheme for Magnetic Resonance (MR) images with progressive transmission capability. This work is based on the scheme proposed in [1]. The contribution of this work is in reducing the side information required for the original scheme and in extending the scheme to 3-D images. The overall performance achieved by the modified scheme is better than the original scheme and is comparable to Set Partitioning in Hierarchical Trees (SPIHT) scheme, the state of art wavelet based progressive transmission scheme. The overall progressive transmission performance of the proposed 3-D scheme which exploits both intraframe and interframe correlation between MR sequences, is superior to the 2-D scheme.

## 1. INTRODUCTION

Image compression is necessary for efficient archiving and transmission of images. Image compression schemes can be broadly classified as lossy and lossless schemes. A lossy scheme is irreversible in the sense that it cannot faithfully retrieve the original image, whereas, a lossless scheme is reversible. Lossy compression schemes can achieve high compression ratios of the order 10:1 to 30:1, whereas, lossless schemes achieve modest compression ratios of about 2:1 to 4:1. The high compression ratios of lossy schemes are generally at the expense of image quality. In the medical image scenario, lossy compression schemes are not generally used. This is due to a possible loss of useful clinical information which may influence diagnosis. Image analysis operations like enhancement may result in accentuating the degradation caused by lossy compression. In addition to these technical reasons there are legal issues which prohibit the use of lossy schemes. Hence there is a need for efficient lossless compression schemes for medical data.

A compression scheme with progressive transmission capability is very useful in applications like telemedicine, where data needs to be transmitted at a faster rate. With this capability, image data can be transmitted from a coarse to fine resolution. The user at the receiving end can download the image up to the resolution required and if necessary up to perfect reconstruction. This kind of scheme is useful in not only for effective compression but also for efficient transmission. Several lossless schemes based on linear prediction and interpolation have been proposed in the past. Context-based adaptive lossless image coding (CALIC) [5], prediction based techniques by Rambadran et al., [3], Marius Midtvik et al., [2] and Hierarchical interpolation (HINT) [4] are some of the available lossless schemes. Among them, only HINT has progressive transmission capability. This is a spatial domain technique. Recently, wavelet based compression schemes gained popularity due to their superior performance. Wavelet based schemes naturally render progressive transmission capability. Embedded image coding using zerotrees of wavelet coefficients (EZW) by Shapiro [6] and Set Partitioning in Hierarchical Trees (SPIHT) [7] by A.Said et al., are the most popular techniques. These schemes exploit interband correlation using zerotree data structure.

These schemes cannot be used for lossless coding schemes as wavelet transform maps integer-valued input images to real-valued wavelet images. To circumvent this problem, integer wavelet transform built by lifting scheme [8] can be used. Integer wavelet transform maps integers to integers and hence can be used for lossless coding of images. In this paper, we present an image coder having a progressive transmission capability with lossless reconstruction option. This work is based on the scheme proposed by Adrian Munteanu et al., [1] where correlation within the wavelet band is exploited as against the EZW and SPIHT schemes, where correlation across the wavelet bands is exploited. We improve this scheme by efficiently transmitting the side information. The resulting scheme is found to give performance close to SPIHT. The advantage of this scheme lies in its simple implementation and effective performance.

Medical image sequences like Magnetic Resonance images (MRI) are data sets representing 3-D sampling of some organ. Such sequences contain interframe correlation in addition to intraframe correlation. In principle, schemes which exploit both interframe and intraframe correlation are expected to perform better than those based on only intraframe correlation. However, our experiments in exploiting interframe correlation suggest that, one can get an advantage in trying to exploit interframe correlation only if the the slice thickness is low (1.5 mm and less). With this motivation, we extended the above scheme to 3D MR images with slice thickness of 1mm. We compare the performance of our modified schemes (both 2D and 3D) with the original schemes (both 2D and extension to 3D) and SPIHT (2D and 3D).

## 2. PRE-PROCESSING

A typical MR image consists of two parts:

1. Air part (background)

2. Flesh part (foreground)

The flesh part contains the useful clinical information which needs to be compressed without any loss. On the other hand, the air part does not contain any clinical information. It is only noise and consumes unnecessary bit budget and impairs the performance of a compression scheme. In [2], a scheme is proposed which uses two source models, one for background and the other for foreground, and an improvement in performance is reported. But no justification is given to code the air part as there is no useful information present in it. In this work, we ignore the air part. We generate image masks in such a way that the flesh part is totally included and the pixel values in the air part are made zero. The rest of this section explains an image independent algorithm for mask generation.

Morphological operations can be effectively used to generate image masks, which contain a value of '1' in the foreground and a value of '0' in the background. The original image is then multiplied with these masks to obtain "background noise free" images while keeping the information in the foreground intact. The algorithm for generating the mask is given below:

1. Binarize the image with a threshold decided by the histogram of the image.

2. Holes may be formed within the foreground. Close these holes using morphological 'closing' operation.

3. Background may contain spurious lines. Use morphological 'erode' operation to remove these lines.

4. The above erosion operation also erodes the boundary of the foreground region. To make sure that the mask spans the entire foreground region, use morphological 'thickening' operation to thicken the boundary of the foreground region.

5. Multiply the original image with the resulting binary mask.

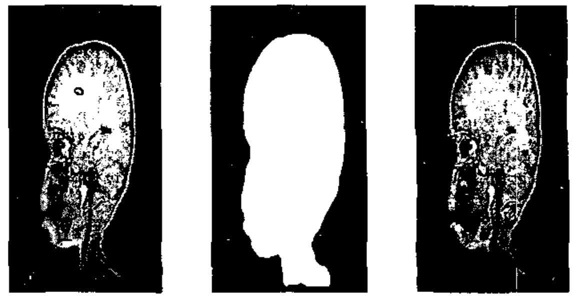
Figure 1 shows an MR image, its mask and the image obtained after multiplication with the mask.

## 3. Integer Wavelet Transform

For lossless image coding, we need a transformation which results in integer coefficients. This can be achieved by integer wavelet transforms. These transforms can be built using lifting schemes as explained in [8]. We employ biorthogonal (2,2) integer wavelet transform for our coding scheme. One dimensional transform is represented by the following equations:

$$\begin{aligned} d_{1,l} &= s_{0,2l+1} - \lfloor 0.5(s_{0,2l} + s_{0,2l+2}) + 0.5 \rfloor \\ s_{1,l} &= s_{0,2l} + \lfloor 0.25(d_{1,l-1} + d_{1,l}) + 0.5 \rfloor \end{aligned}$$

where, $(s_{0,j})_j$ is the original signal, $(s_{1,j})_j$ and $(d_{1,j})_j$ are lowpass and highpass coefficients respectively and $\lfloor x \rfloor$ represents integer part of $x$. Wavelet filter bank tree can be constructed up to any level by applying the above transform on



(a) (b) (c)

**Figure 1.** Suppression of background in an MR image using morphological operations. (a) original image (b) the generated mask (c) background suppressed image.

successive lowpass signals. The signal can be reconstructed faithfully by reversing the above transform. We need 2-D transforms for images which can be easily obtained by applying 1-D transform on rows and columns separately. Such transforms are called separable transforms. Likewise 3-D wavelet transform can be obtained by applying 1-D transform to the three dimensions sequentially. Figure 2 shows sample MR slices to be compressed and figure 3 shows 3-D Separable integer wavelet decomposition of the above MR Images with 2 levels in spatial and 2 levels in temporal (across slices) domain

## 4. Coding Scheme

We use the coding scheme proposed of [1]. This scheme exploits correlation within the band. The schemes proposed by [6] and [7] exploit interband correlation using zerotrees. We improve the scheme by reducing the side information required to be sent to the decoder. The details of the scheme are given below:

1. Apply $n$-level ($n = 4$ or 5) 2-D separable integer wavelet transform to the given image.

2. Tile the wavelet transformed image into $v \times v$ lattices.

3. For each lattice $k$, find the maximum absolute value $w_{max}$. Let $T_k = \lfloor log_2 abs(w_{max}) \rfloor$ be the threshold of the $kth$ lattice. Store these values in the array $th$.

4. Set the maximum of all the thresholds as the global threshold, $T_g$.

5. Scan the wavelet image starting from the lowest frequency band to the highest frequency band in zig zag manner. In each band, the lattices are scanned in a raster order.

6. If $T_k < T_g$, the lattice is insignificant with respect to $T_g$ and a '0' is recorded in the list $lstb$. If $T_k >= T_g$, the lattice is significant which decoder needs to be informed . If this

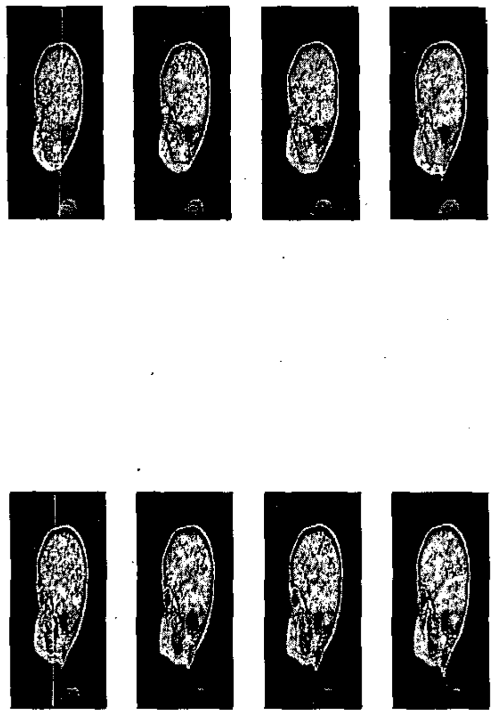


**Figure 2**. Sample 8 consecutive slices of Brain MR Images with 1mm thickness.

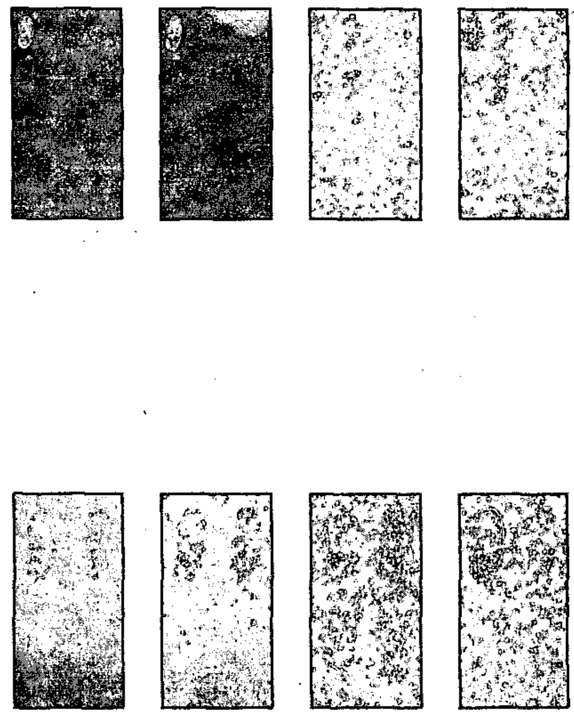


**Figure 3**. 3-D Separable Integer Wavelet Decomposition of the above MR Images with 2 levels in spatial and 2 levels in temporal (across slices) domain.

lattice is first time significant, a '1' is recorded in the list $lstb$. If the lattice is already significant, no information is sent to the decoder, since this lattice will be significant for the future lower global thresholds.

7. If the lattice is significant, check for the significance of each coefficient in raster scan order. If the coefficient is absolute significant, a '1' is appended to the significant list $lis1$ otherwise a '0' is appended. If the coefficient is positive significant, a '0' is appended to the sign list $lis2$ or a '1', if it is negative significant.

8. *Refinement Pass:* The current bit of the significant coeffcients (at the previous threshold) is sent to the decoder.

9. After all lattices are scanned, set $T_g = T_g - 1$. If target bit rate is achieved or $T_g = 0$ stop, otherwise go to step 5.

The lists $lis1$, $lis2$ and $lstb$ can be further losslessly compressed by employing arithmetic coding. Since the most important coefficients (with higher thresholds $T_k$) are coded before the least important ones (with lower thresholds), there will be an ordering of wavelet coefficients resulting in progressively transmittable bit stream. The decoder can stop at any step and reconstruct the image that is best at that level. The image reconstructed at $T_g = 0$ will be identical to the original image and hence results in lossless compression. The main difference between this scheme and that proposed by [1] is in sending the significance map of the lattices. In [1] the array $th$ is entropy coded and sent to the decoder. This impairs the performance of the scheme at higher thresholds. The bit budget that would be spent for resolutions at these thresholds is not worth. In this scheme, the significance information of lattices is sent only when it is required. This greatly increases the performance at higher thresholds (which is desired in a progressive transmission scheme). But the difference in performance at lower thresholds is not very significant. However, the overall performance of progressive transmission, the desired functionality, is improved by this scheme.

## 5. Extension to 3-D Images

The above scheme can easily be extended to volumetric MR images. The idea is to exploit both intraframe and interframe correlation in these images and hence to achieve higher compression ratios. We extended this scheme to 3-D images by employing separable 3-D integer wavelet transform. A 1-D integer wavelet transform is applied across the slices (call it as temporal axis) at each pixel. This results in temporal low frequency and high frequency images. Each of these images are then decomposed by separable 2-D integer wavelet transform as described in section 3. Hence each level of decomposition results in 8 bands (4 temporal lowpass bands and 4 temporal high pass bands). The motivation behind applying 3-D transform is to decorrelate the images in temporal direction in addition to spatial decorrelation so that decorrelated images can be efficiently coded. Tile the wavelet images by cuboids of size $v \times v \times vt$ (typically $v = 2$ and $vt = 2$). Apply the algorithm described in the previous section to obtain a progressive bit stream.

## 6. Experimental Results

We compare the performance of our modified scheme with the original scheme [1] and SPIHT [7]. We apply the above algorithms on 8-bit MR images provided by National Institute of Mental Health and Neuro Sciences (NIMHANS), Bangalore, India. We first compare 2-D algorithms and then 3-D alogorithms. The MR images are first preprocessed to remove background noise as explained in section 2. This simple preprocessing step significantly improves the overall performance of all the above schemes. We take 4-level 2-D integer wavelet decomposition of the preprocessed image. When higher values of $v$ are used, the performance improves for higher thresholds but at lower thresholds more coefficients will be significant and hence more bits need to be spent for significance information. This reduces the performance at the lower thresholds. Since, wavelet coefficients at the highest frequency band are mostly insignificant, we use $v = 4$ for this frequency band and $v = 2$ for the rest of the frequency bands. We arrived at these values after experimenting with various values of $v$. Figure 4 gives compression ratio Vs PSNR (peak signal to noise ratio) of the three schemes. SPIHT and our modified scheme are superior at lower PSNRs than the original scheme. The performance of the modified scheme is improved significantly with respect to the original scheme at lower PSNRs and is slightly better at higher PSNRs. The performance of the modified scheme is comparable to that of SPIHT. The intraband schemes are very easy to implement compared to SPIHT. Hence comparable performances can be achieved with easily implementable intraband schemes.

We implement 3-D algorithm on a group of 8 MR images. The size of images are $256 \times 256 \times 8$, the interframe thickness being 1mm. The interframe correlation of these images motivated us in extending the 2-D algorithms to 3-D. We apply 2-level 3-D integer wavelet transform in both temporal and spatial directions. We use $v = 2$ and $vt = 2$ in both intraband schemes. Figure 5 shows the comparative performance of 3-D modified scheme, 3-D intraband scheme with explicit side information and 3-D SPIHT [9] algorithm. The overall progressive transmission performance of MR images improves by extending the 2-D schemes to 3-D. The performance of the modified scheme is significantly better than the original scheme and comparable to that of SPIHT. The performance of the 3-D schemes improve significantly at lower PSNRs. The performance at higher PSNRs can be improved by employing context based entropy coding of significance and sign information. Table-1 shows compression ratios for different PSNRs of 2-D and 3-D schemes.

## 7. Conclusions

We presented wavelet based lossless image compression scheme for MR images. This scheme exploits intraband correlation as opposed to interframe correlation by EZW and SPIHT schemes. This scheme is simple in implementation as compared to EZW and SPIHT algorithms. The performance of the scheme is comparable to that of SPIHT at a reduced implementation cost. We also extended the scheme to three dimensions to compress 3-D images by exploiting both inter and intraframe correlation. This results in an improved performance in progressive transmission of MR images.

## 8. Acknowledgements

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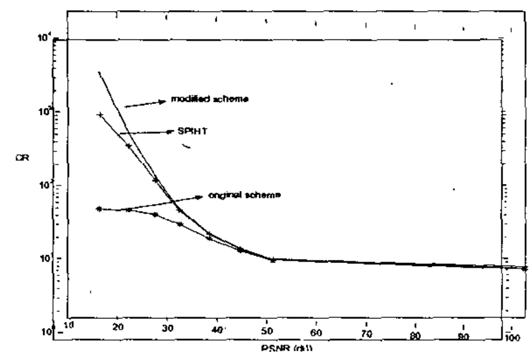


**Figure 4.** PSNR Vs CR (compression ratio) performance curves of 2D schemes Note: Y axis is on log scale.

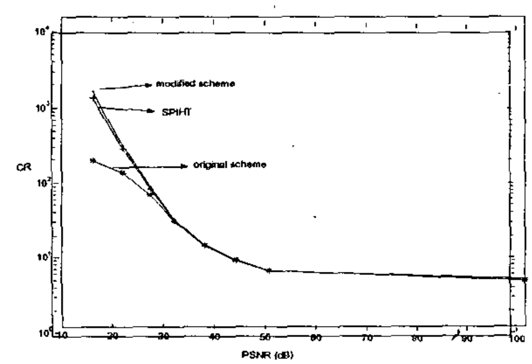


**Figure 5.** PSNR Vs CR (compression ratio) performance curves of 3D MR schemes. Note: Y axis is on log scale.

| PSNR | 16.3 | 22 | 27 | 32 | 38 | 44 | 50 | 100 |
|---|---|---|---|---|---|---|---|---|
| 2DS | 853 | 190 | 59 | 22 | 10.8 | 6.9 | 5.1 | 4.1 |
| 2DOS | 24 | 24 | 21 | 15 | 9.5 | 6.6 | 5 | 3.9 |
| 2DMS | 1207 | 219 | 61 | 22 | 11 | 7 | 5.1 | 3.9 |
| 3DS | 911 | 202 | 62 | 23 | 11 | 7 | 5.2 | 4.2 |
| 3DOS | 132 | 99 | 52 | 23 | 11.5 | 7.2 | 5.3 | 3.9 |
| 3DMS | 1089 | 224 | 67 | 24 | 11.5 | 7.2 | 5.3 | 3.9 |

Table:1 Compression Ratios. PSNR in dB; 2DS : 2D SPIHT; 2DOS : 2D Original scheme; 2DMS : 2D Modified Scheme; 3DS : 3D SPIHT; 3DOS : 3D Original Scheme; 3DMS : 3D Modified Scheme

## References


[1] Adrian Munteanu, Jan Cornelis, "Wavelet-Based Lossless Compression of Coronary Angiographic Images", *IEEE trans. on Medical Imaging*, vol.18, no.3, pp.272-281, 1999.

[2] Marius Midtvik and Ingvil Hovig, "Universal Coding of MR images", *IEEE trans. on Medical Imaging*, vol.18, no.9, pp.795-800, September, 1999.

[3] T.V.Rambadran and Keshi Chen, "The Use of Contextual Information in the Reversible Compression of Medical Images", *IEEE trans. on Medical Imaging*, vol.11, no.2, pp. 185-197, June, 1992.

[4] P.Roos and M.A.Viegever, "Reversible 3-D decorrelation of medical images", *IEEE trans. on Medical Imaging*, vol.12, no.3, 413-420, 1993.

[5] Xiaolin Wu and Nasir Memon, " Context-Based, Adaptive, Lossless Image Coding", *IEEE trans. on Commn.*, vol.45, no.4, pp 437-444, April, 1997.

[6] J.M.Shapiro, "Embedded image coding using zerotrees of wavelet coefficients", *IEEE trans.in Signal Process.*, vol.41, pp 3445-3463, 1993.

[7] A.Said and W.pearlman, "A new fast and efficient image codec based on set partitioning in hierarchical trees", *Circuits Syst. Video Technol.*, vol.6, pp 243-250, 1996.

[8] Wim Sweldens " The Lifting Scheme: A custom-design construction of Biorthogonal Wavelets", *Journal of Applied and computational Harmonic Analysis*, vol.3, pp 186-200, 1996.

[9] B.J.Kim,Z.Xiong and W.pearlman, "Low bit-rate scalable video coding with 3D set partitioning in hierarchical trees (3D sphit)", *IEEE trans Circuits Syst. Video Technol.*, vol.10, pp 1374-1387, Dec.2000.