Wavelet-based Medical Image Compression through Prediction

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(2006-NUST-MS PhD-CemE-11)

Submitted to the Department of Computer Engineering
in partial fulfillment of the requirements for the degree of
Master of Science
in
Computer Engineering

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College of Electrical & Mechanical Engineering
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2008

In the name of The GOD, The Most Gracious, The Most Merciful.

ABSTRACT

As image compression is desirable to minimize storage space and for reduction of transmission cost over the network. There are two types of image compression, lossy and lossless Medical Images are of special type and purpose which require lossless compression as a minor loss can cause very serious consequences.

This thesis work is on medical images compression using Wavelet Transform and Prediction technique. Computed Tomography (CT) and Magnetic Resonance (MRI) Images are used for analysis and experiment. Advanced form of wavelet transform, Lifting Wavelet Transform is used for image decomposition. Correlation that is present between the neighboring, parents and parent neighboring pixels is used for analysis of decomposed image. One prediction equation for each sub-band is developed using linear prediction technique. Using the prediction equation of each sub-band, coefficients of the sub-band are predicted, compared and matched with original coefficients through plotting a graph of coefficients. It has been observed that a equation with all variables can causes multicollinearity problem. Different combinations of variables have been analyzed to over come the multicollinearity and to achieve the accurate prediction. At this stage graph of original coefficients is matched exactly with predicted coefficients graph. After modeling the prediction equation and selecting the variables for each equation, different fine sub-bands are predicted using the coarsest sub-bands while the coarsest sub-bands are processed by Discrete Pulse Code Modulation Transform (DPCM). Arithmetic coding of the combined data vector has been performed to achieve the highest compression.

Reverse Wavelet transform is applied to obtain the original image at receiving end. The results has been compared with recent methods for medical image compression. The proposed method gives the best results in terms of compression and coding/decoding time. It is a simple method which employs useful methodology for variable selection. MATLAB 7.0 has been used for the implementation of proposed approach. Experiments have been conducted on a variety of standard grayscale images.

ACKNOWLEDGEMENTS

I am thankful to God Almighty for giving me the ability to finish this research work and allow me to acquire knowledge from it.

I am thankful to my supervisor Brig Dr Muhammad Younus Javed for his continuous guidance and help and all the committee members for their time and diligence.

Finally, I would like to thank Lieutenant Colonel Javed Akhtar for his guidance during this research work.

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Chapter 1

INTRODUCTION

1.1 Introduction

Today the use of computers in the department of health care is increasing. The vast amount of data generated by Computed Tomography (CT) and Magnetic Resonance Image (MRI), creates storage and bandwidth problems when sent over a network. Various data compression techniques are used in these applications to handle the data.

Medical images are of specific purpose and characteristics where a minor loss of information cannot be afforded, lossless compression is required for these types of images. This work includes a lossless image compression technique based on the prediction of current data through previously known data. The efficiency of this scheme depends on the accuracy of prediction, more the prediction value close to the original value more effective will be the compression scheme.

Different advanced image compression techniques are developed for medical images. These techniques include Embedded Block Coding with Optimized Truncation technique (EBCOT), Context Based Adaptive Codec (CALIC), Embedded Predictive Wavelet Image Coder (EPWIC) and Wavelet based Compression of medical images with Adaptive Prediction (WCAP). EBCOT, CALIC and WCAP are lossless techniques while EPWIC is a lossy technique.

The proposed method is based on inter-band and intra-band correlation between coefficients. Lifting Wavelet Transform is used to decompose the image and Coefficient Graphic Method is used for selection of predictor variables. Finally Arithmetic coding is used to code the data. Technique used is a contribution to the area of lossless image compression.

1.2 Fundamental of Data Compression

Data compression is a process which reduces the amount of data required to represent any information. Digital image compression identify and exploit one or more of the three basic redundancies i.e coding, inter pixel and psycho visual .to reduce the data.[1].

There is difference between data and information. Data is that which represents the image and information is what, represented by an image.

Redundant data is that which provides no relevant information or which provides information which is already known.

1.2.1 Coding Redundancy

Digital images are represented by constant number of bits for each pixel without keeping in view the value of or frequency of occurrence of that value in the image .The most common method for coding redundancy reduction is variable length coding which reduces the average number of bits per pixel.

1.2.2 Inter pixel Redundancy

The inter pixel redundancy is defined as the common information in two pixels.

1.2.3 Psycho visual Redundancy

Some information in a image is less important for human eye. This information is psycho visual redundant and can be eliminated trough the process of quantization.[2]

1.3 Types of Image Compression

There are two basic types of image compression

1.3.1 **Lossless Image Compression**

This image compression technique is reversible and image can be reconstructed after compression without loss of information or minimum loss of information. It is used in medical and space images where loss of small information may be of serious consequences. The lossless image compression techniques like, Huffman Coding, Arithmetic Coding and, and Predictive coding are commonly used.

1.3.1.1 **Huffman Coding**

Devid Huffman has developed this technique the codes generated are called Huffman codes. In this type of coding the symbols having higher probability of occurrence have shorter code than the symbols having lower probability of occurrence. It is most commonly used coding approach.

1.3.1.2 **Arithmetic Coding**

This technique is recommended by the Joint Bi-level Imaging processing Group (JBIG). It is part of the standard for coding binary images. It is a method for generating variable length coding. It is useful for sources with highly skewed probabilities. Arithmetic coding is used in various applications of lossless and lossy compression.

1.3.1.3 **Predictive Coding**

Predictive coding schemes are best for encoding text and for lossless encoding images. In this technique the past values of the data sequence are used to predict the actual value of the source. A predictive model is defined to predict the actual value and than prediction error is encoded. As the method is based on the history of the sequence in a predictive manner for encoding, this scheme named predictive coding scheme.

1.3.2 **Lossy Compression**

In lossy compression, reconstructed image does not have the same pixel values as the original image. Loss of redundant bits or extra information effects the image quality. More compression is achieved as compared to the lossless image which is at the cost of image quality. Commonly used image compression techniques are Scalar Quantization, Vector Quantization, Differential Encoding, Transform Coding, Sub-band Coding and Wavelet based compression.

1.3.2.1 **Scalar Quantization**

When quantization is performed on each data coefficient, it is known as scalar quantization. The encoder mapping is reversible and large infinite set of values can be represented.

1.3.2.2 **Vector Quantization**

In this technique source outputs are grouped together and encoded as a single block. Efficient lossy as well as lossless compression algorithms can be obtained.

1.3.2.3 **Differential Encoding**

Some samples have sample to sample correlation. Each sample is predicted through its past value and the difference between prediction and sample value is encoded and transmitted. It does not provide high compression as vector quantization but easy to implement.

1.3.2.4 **Transform Coding**

In this technique source output is decomposed and than encoded. Discrete Cosine Transform (DCT) and Discrete Walsh-Hadamard Transform are forms of this technique. In this technique source is divided into blocks, take the transform of these blocks, quantize the coefficients and than encode these quantized values.

1.3.2.5 **Sub band Coding**

In this technique source output is separated into different bands of frequencies using digital filters. First a set of filters is selected for decomposing the source, sub-band signal is obtained, output of filter is decimated and than encoded the decimated output.

1.3.2.6 **Wavelet based compression**

One of the most common applications of wavelet is image compression. It is used in JPEG 2000 standard to perform decomposition of the image. Wavelets got the idea of compression from transform and sub band coding. Today, it is an area of extensive research and also applied in this work, will be discussed in detail in sub subsequent chapters.

1.4 **Merits and Demerits of Image Compression**

Every development comes with some merits and demerits, Image compression advantages include decrease of storage requirements and reduction in transmission cost.

It enhances the quality of multimedia presentation and reduces the backup and recovery cost. However its disadvantage is less reliability of compressed data as a single bit error can cause misinterpretation of succeeding bits by decoder. Another disadvantage is that extra overheads involve in encoding and decoding process which make identification of compressed data complex.

1.5 **Scope of Thesis**

This work proposes a lossless compression approach for medical images based on the wavelet compression. This technique incorporates the prediction model to predict the fine sub band coefficients through coarse sub bands. Predictive error of fine sub-band coefficients are quantized and encoded with differential pulse code modulated output of coarse bands. A bit/pixel is obtained which indicates high compression.

1.6 **Thesis Outline**

Chapter-2 describes the theoretical and practical basis of Wavelet transform, Lifting wavelet transform is discussed in chapter-3 and chapter-4 contain Implementation mythology. Chapter 6 shows experimental results and comparisons of results with previous techniques and then conclusion in last chapter.

Summary

An overview of compression fundamentals and its types is illustrated in this chapter. Many lossy and lossless compression techniques are discussed and finally scope of thesis and structure of thesis outlined.

Chapter 2

COMPRESSION THROUGH WAVELETS

2.1 Background

Signals are often represented in time domain or in frequency domain using Fourier Transform. When we wish to multiply or add two images we want transformation of images in number system to do the calculation and than transform the result back into image form. Wavelet Transform provides us this facility, which is is a new and fast developing method for analyzing images/signals. Image compression is among variety of fields where wavelets is applied. In this chapter we discuss wavelet compression technique in detail.

2.2 Fourier Transform

Fourier Transform breaks down a signal into its constituent frequencies, when we want the signal to be in frequency domain. It is useful especially for stationary signals. In this method time information of the signal is lost which is also desirable in non-stationary signals, which contain various transitory characteristics. These characteristics are very important part of a non stationary signal which can not be analyzed through Fourier Transform.[3]

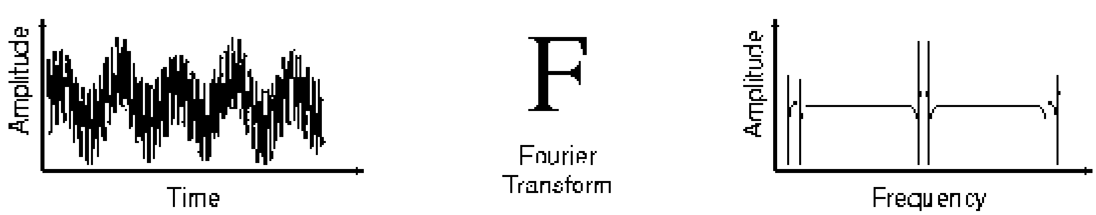


Figure. 2.1 Fourier transform

In 1946 an effort is made to correct this deficiency by Dennis Gabor. This technique is called Short-Time Fourier Transform and it maps the signal into a two dimensional function of time and frequency. The limitation of this technique is limited precision which is determined by the size of the window. Once a particular size of the time window is chosen, the window will be unchanged for all frequencies. Often signals require flexible approach and a variable window is required to determine more accurate information of time and frequency.[4].

Figure2.2 Short Time Fourier Transform

2.3 Why Wavelet used for Image Compression

Wavelet transform provides the Time-frequency representation of the signal which provides us time and frequency representation simultaneously.

Time-domain signal is passed from various high pass and low pass filters, the process is repeated until required decomposition is achieved. Real time signal is divided into its constituent frequency components to know that which frequency band correspond to which signal. Putting all of them together and plotting them on a 3-D graph (time, frequency and amplitude) to show which frequencies exist at which time.

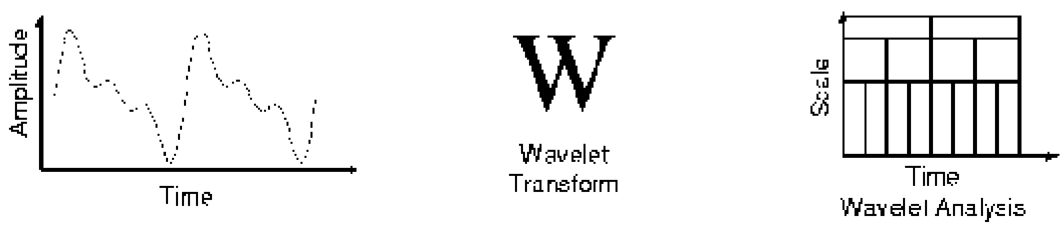


Figure2.3 Wavelet Transform

2.4 **Wavelet Properties**

A wavelet is a waveform of limited duration. It has an average value of zero. Sinusoids do not have limited duration but, it extends from minus infinity to plus infinity. That is why the sinusoid functions are smooth and predictable while the wavelet is asymmetric and irregular. As compared to Fourier transform which break up the signal into waves of various frequencies, wavelet transform breaks up the signal into shifted and scaled version of regional wavelet. Original wavelet is also called mother wavelet. Signal with sharp variations can be better analyzed with an irregular wavelet than with a smooth sinusoid.

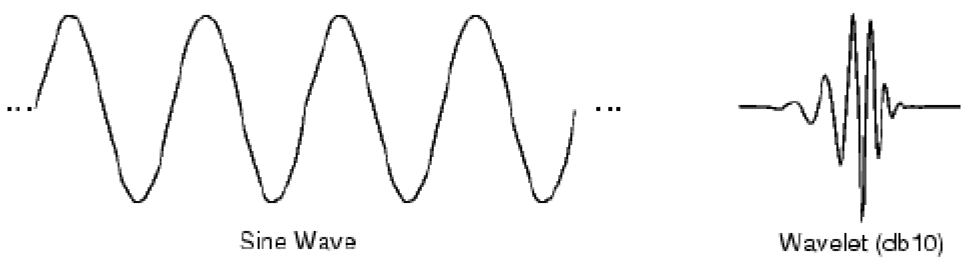


Figure 2.4 Wavelet analysis

2.4.1 **Admissibility**

The admissibility and regularity are the basic wavelet properties. The square integral functions ψ (t) satisfying ψ the admissibility condition as following equation.

$$|\Psi(w)|^2 = \int \frac{|\Psi(w)|}{\Psi} d w < +\infty \qquad (2.1)$$

The signal can first analyzed and than reconstructed without loss of information

$\Psi(w)$ is the Fourier transform of $\Psi(t)$.The admissibility condition implies that the Fourier transform vanishes at the zero frequency. Which indicates that wavelet have a band pass like spectrum. A zero at the zero frequency means that the average value of the wavelet in the time domain is zero.

$$\int \Psi(t) = 0 \qquad (2.2)$$

Which indicates that Ψ (t) must be wave Ψ .

2.5 The Continuous Wavelet Transform

The process of Fourier analysis can be represented as following

$$F(w) = \int_{-\infty}^{\infty} f(t)e^{-jwt}dt$$ $$F(w) = \int_{-\infty}^{\infty} f(t)e^{-jwt}dt$$ (2.3)

This is the sum over of all time signals multiplied by a complex exponential. Complex exponential can be divided into real and imaginary components. The result of the Fourier transform is the Fourier coefficients, which when multiplied by a sinusoid of appropriate frequency, gives the constituent sinusoidal components of the original signal. Graphically the process looks like the figure below.

Similarly the continuous wavelet transform is defined as the overall time of the signal multiplied by scaled and shifted version of the wavelet function Ψ .

$$CWT_X^{\Psi}(\tau,s) = \Psi_x^{\Psi}(\tau,s) = \frac{1}{\sqrt{s}}\int x(t)\Psi^*(\frac{t-\tau}{s})dt \qquad (2.4)$$

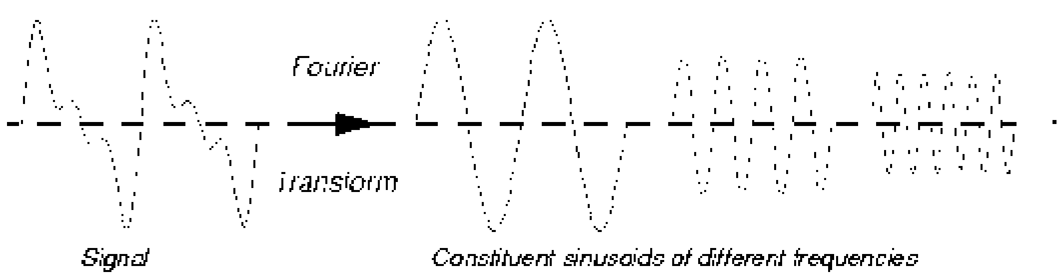


Figure2.5 Fourier Decomposition

The output of the CWT are many wavelet coefficients C, These coefficients are functions of scale and position. $\Psi(t)$ is the transforming function, and it is called the mother wavelet, the term wavelet means small wave. The smallness refers to the condition that, this (window) function is of finite length.

2.6 **Scaling**

Scaling means to dilate or compress a signal, larger scales stretched out the signals and small scales compress the signals. In terms of frequency, low frequencies and high scales correspond to global information of the signal that mostly spans the entire signal. While the high frequencies (low scales) corresponds to detailed information of a hidden pattern in the signal that lasts for relatively short time. Scale factor normally denoted by the letter "a" and effects of scaling can easily be observed.

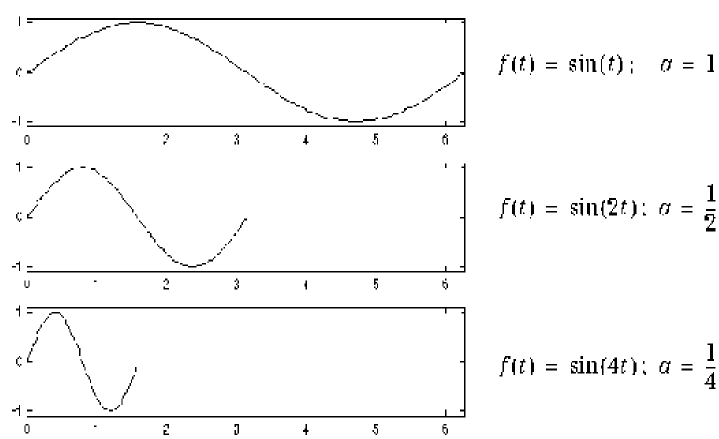


Figure 2.6 Scaling of sinusoid

The scale factor works similarly in the wavelets. The smaller the scale factor, the more compressed the wavelet

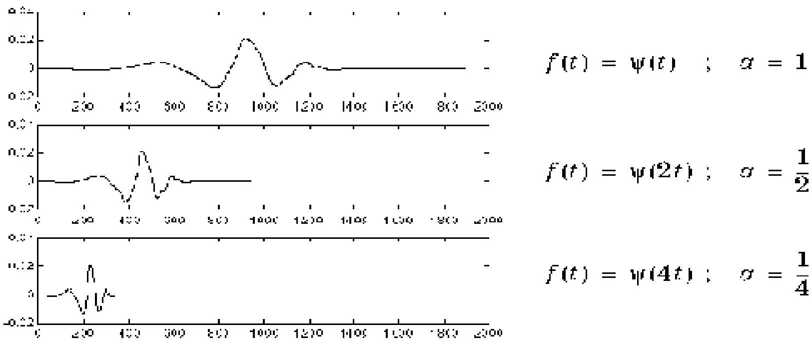


Figure 2.7 Scaling of wavelet

The figure show that for a sinusoid, sin(wt) scale factor is inversely related to the radian frequency. So in the wavelet scale is related to the frequency of the signal.

2.7 Shifting

Shifting a wavelet simply means delaying it or hastening it. It can be shown mathematically, delaying a function f(t) by k is f(t-k).

Wavelet function, Ψ (t) Shifted Wavelet function, Ψ (t-k)

Figure 2.8 Shifting

2.8 The Discrete Wavelet Transform

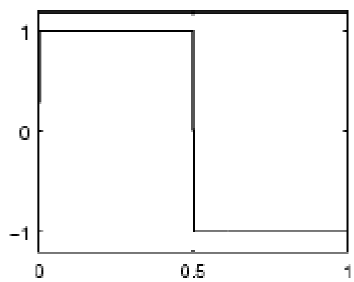
The discrete wavelet transform provides sufficient information both for analysis and synthesis of the original signal. It results in significant reduction in the computation time. The DWT is considerably easier to implement as compared to CWT.

An easier way to implement this scheme using filters was developed in 1988 by Mallat. The Mallat algorithm is in fact a classical scheme known in the signal processing as two channel sub-band coder. This filtering algorithm yields a fast wavelet function.

2.9 **Wavelet Families**

2.9.1 **Haar**

Wavelet starts from Haar, which is similar to a step function. It is discontinuous.



Wavelet function

Figure 2.9 Haar Wavelet

2.10 **Daubechies**

Daubechies Wavelet was a great success in the field of wavelet research .It is also called compactly supported ortho-normal wavelet. It makes the discrete wavelet analysis practicable. The names of the Daubechies family wavelets are written dbN, where N is the order and db is the name of the wavelet. The db1 wavelet is similar to the Haar wavelet. The other members of the family are as following.

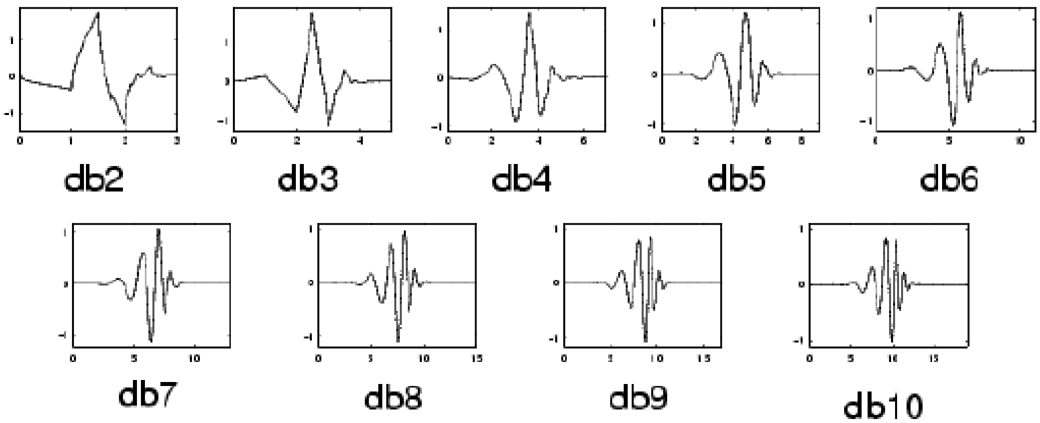


Figure 2.10 Daubechies Wavelet

2.11 **Bi-orthogonal Wavelet**

The wavelet family has linear phase property which is essential for image reconstruction. In the figure below left side wavelet is for image decomposition and the right side of it is for image reconstruction, instead of using single wavelet.

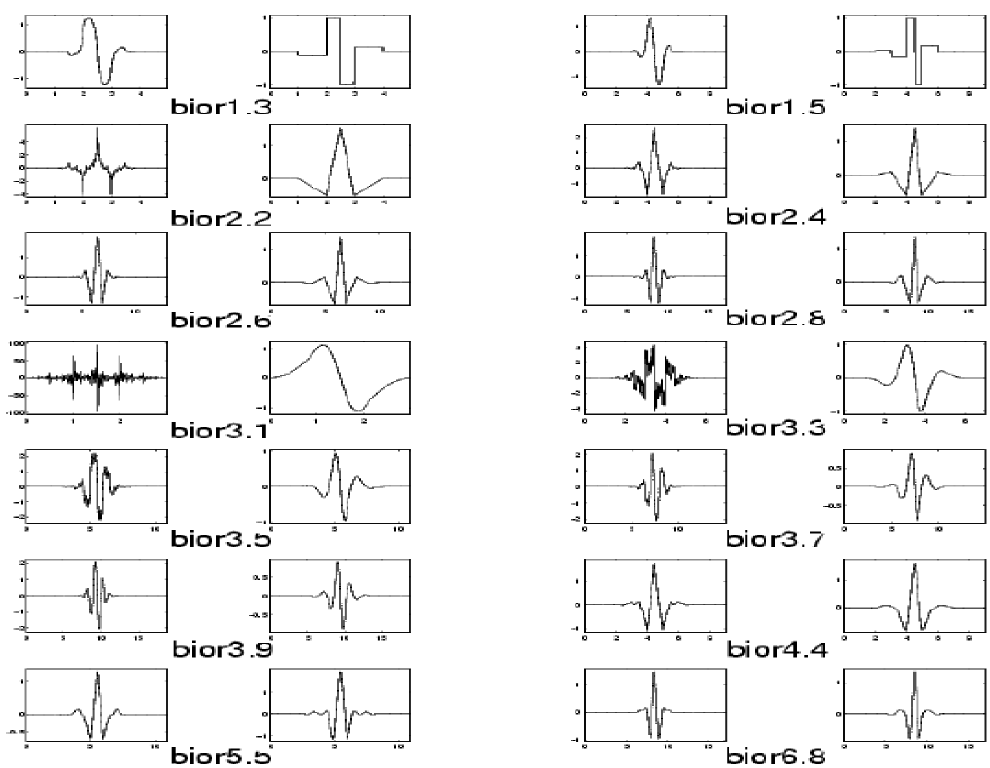


Figure 2.11 Bior Wavelet

2.12 **Coiflets**

This wavelet is built by the I.Daubechies on the request of R.Coifman. The wavelet function has 2N moments equal to 0 and the scaling function has 2N-1 moments equal to o. The two functions have a support of length 6N-1. Coiflets wavelets of different lengths are shown in figure below

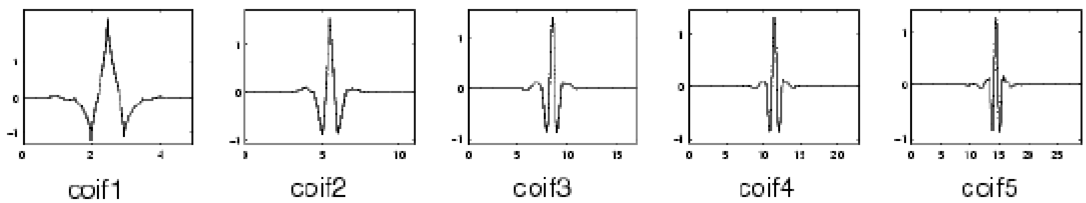


Figure 2.12 Coiflets Wavelet

Chapter3

Lifting Wavelet Transform

3.1 Background

Lifting method generates an infinite number of discrete bi-orthogonal wavelets. Forward lifting wavelet transform divides the data set in two halves, even and odd. This algorithm is recursive, in which one step output becomes the input for next step.1st step is called split phase. Here the even elements move to the lower half where the odd elements are replaced by the differences and even elements are replaced by averages. When again split phase starts, even elements become the input. The first element of the array contains data averages. The order of coefficients is based on increasing frequency. One of the important properties of the lifting wavelet transform is that, its inverse transform is the mirror of forward transform.

3.2 Split Phase

The predict wavelet transform first step is split phase, which divides the data set into odd and even coefficients. Predict step approximates the data set. The difference of the approximation and the actual data replaces the odd elements, where the even elements are remained unchanged and become the input for next step of the transform. In predict step odd values are being predicted from the even values and can be shown by following equation.

$$K_{m+1,n} = odd_{m,n} - (even_{m,n})$$

Opposite to it is inverse predict transform shown in figure 3.5, prediction value is added in the odd element. In inverse transform Merger step comes after the predict step. Here odd and even elements combine back into a single data stream. In many wavelet applications the simple predict wavelets can not be used. Odd elements are predicted from the even elements. The even elements are obtained by sampling the original data set by power of two. Wavelets are used in construction of filters. The process of down sampling in the predict wavelets unable to provide an approximation of data at each step, which is a requirement of filter design [5].

3.3 Update Phase

Even elements are replaced by an average in up date step. Due to averaging a smoother input for the next stage of the wavelet transform is provided. The odd elements represent an approximation of the original data set, which is being used for filter construction. A lifting scheme diagram is shown in figure 3.1.

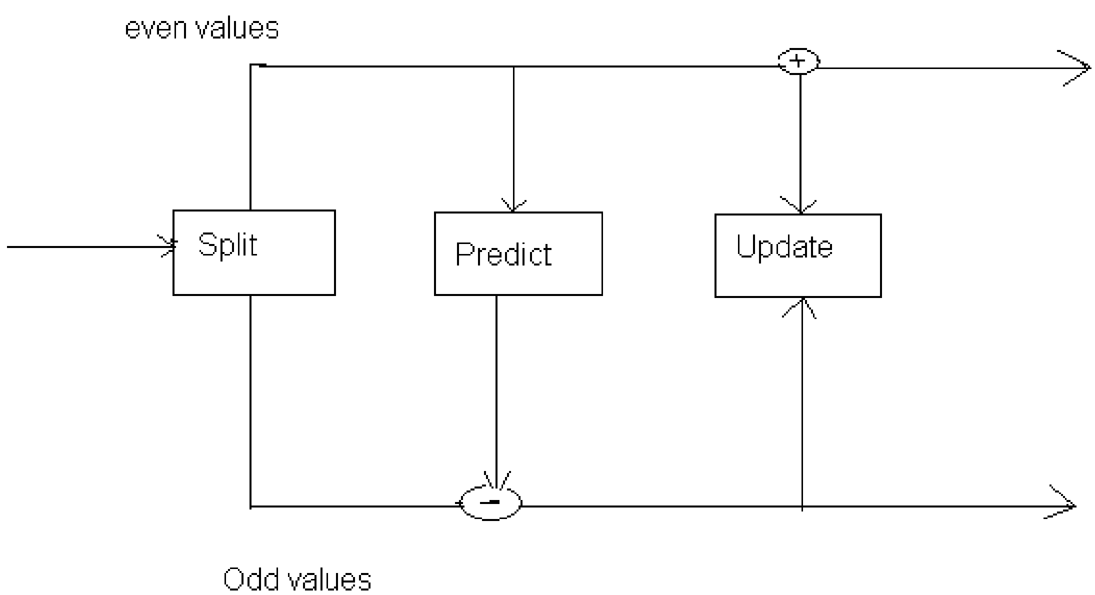


Figure 3.1 Lifting Wavelet forward Transform [6]

It is next step after prediction phase. The values of odd elements are replaced by the difference between the odd elements and their even predictors. In calculation of average, update phase must operate on the differences stored in the odd elements [5].

3.4 **Lifting with Hear Transform**

In Haar transform in lifting scheme version, prediction step have to predict that the odd elements are equal to the even elements. The difference of the odd value and predicted value will replace the odd element.

In lifting wavelet using Haar transform average of the even/odd pair replace the even element. The original value of the odd element is replaced by the difference between it and its even predecessor.

The averages which are actually even elements become the input for next step in the forward transform due to recursive nature of algorithm. This is shown in figure 3.2, below.

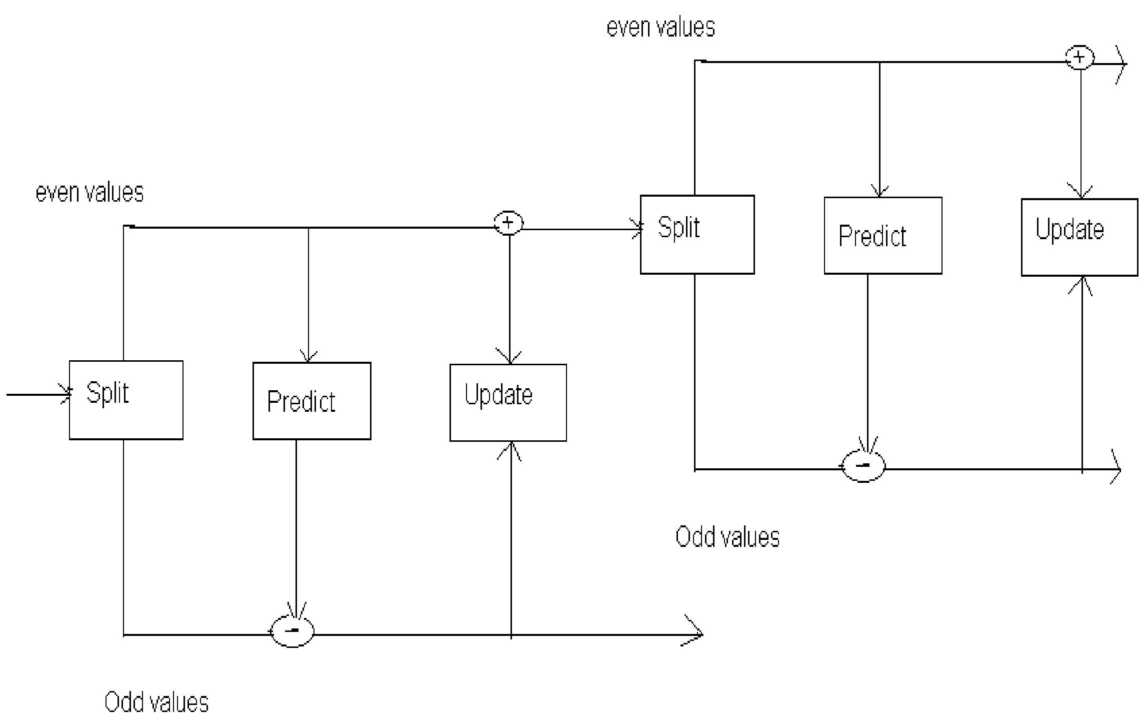


Figure 3.2 Four steps lifting wavelet forward transform [6]

The number of total data elements processed by the wavelet transform should be a power of two. If data elements are 2^n, then the first step of the forward transform will generate 2^{n-1} total averages and same number of differences. These differences in other words called wavelet coefficients. A 4-steps forward wavelet transform on a 16-elements data set is shown in figure 3.3

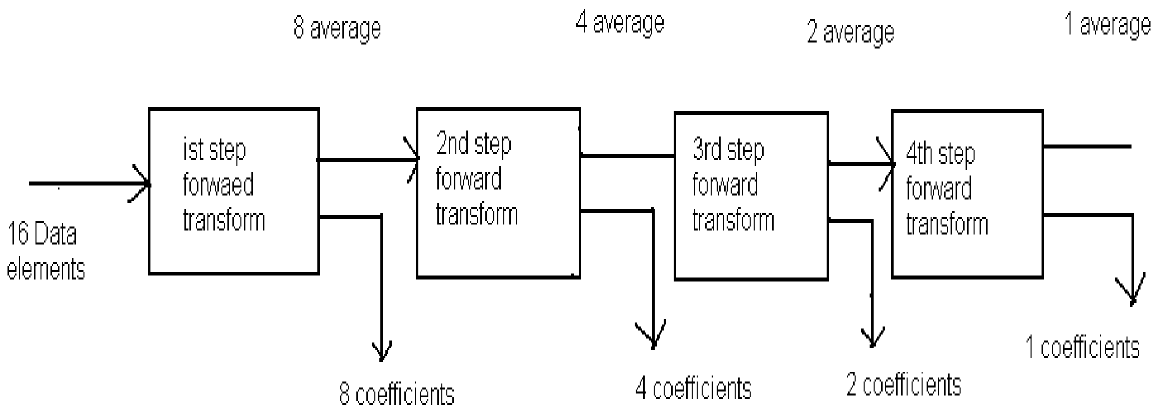


Figure 3.3 Four steps of 15 element wavelet transform [6]

In split phase odd elements move to the second half o f the array, where the even elements come to the lower half. Odd elements are replaced by differences and the even elements are replaced by averages at the end of transform. For next step even elements become the input. Split phase starts again. The result of the forward transform is shown in figure 3.4. The first element in the array contains the data average. The coefficients are ordered by increasing frequency. An important feature of the lifting scheme is that the inverse transform is a mirror image of the forward transform. In haar transform case, additions are substituted for subtractions and subtractions for additions. Split step is replaced by merge [7].

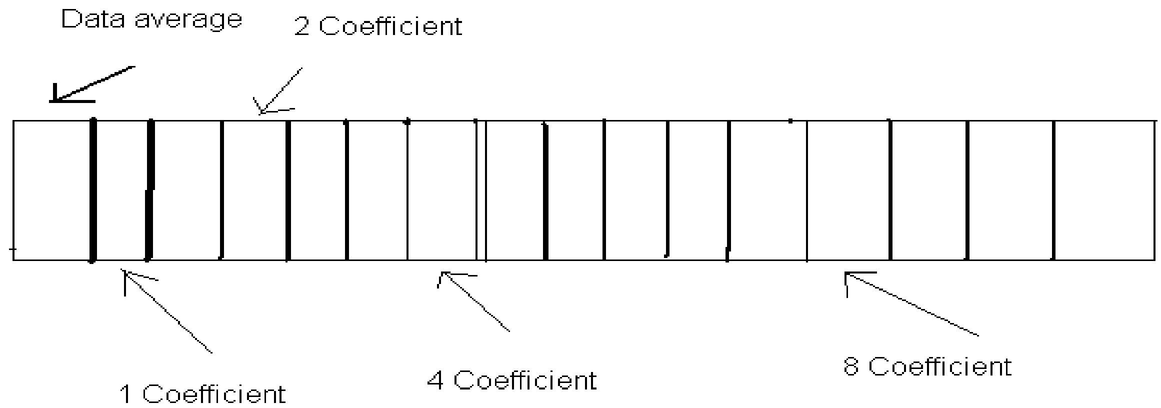


Figure 3.4 Result of wavelet transform with coefficients ordered in increasing frequency

3.5 Filters in Predict and Update Step

Digital signal processing deals with filters. Filters select some part of any signal to pass through while suppress and filter the other part. From a high pass filter, high frequency components pass through while low frequency components are suppressed. The function of low pass filter is opposite to it, which allow the low frequency components to pass through and stop high frequency components.

The odd elements are replaced with the difference between the odd elements and the predict function in the predict step. The differences that replace the odd elements will represent the high frequency components of the signal. That can be viewed as high pass filter.

The even elements are replaced with a local average in the update step, the resultant signal is an approximation of the signal that is smoother than the previous level signal. It is like a low pass filter, since the smoother signals have very few high frequency components [6].

3.6 Other name for Predict and Update Step

Every area of specialty has its own language. Fifteen years back when wavelet mathematics became a recognized area of applied mathematic, lifting scheme has been designed. So there is a small body of wavelet terminology used in the lifting scheme.

There is a wavelet function used in the predict phase. This function is used to calculate the difference or wavelet coefficients and behaves as the high pass filter for the odd half of the data set.

Scaling function is equivalent to the wavelet function in wavelet literature. This scaling function results in a smoother representation of the even half of the input data set. This function behaves as low pass filter [6].

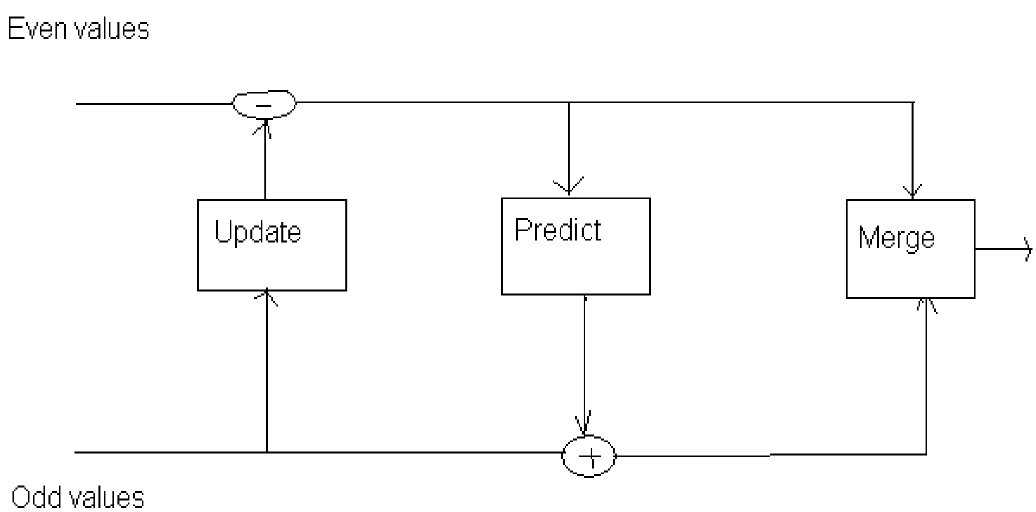


Figure 3.5 Lifting Scheme Inverse Transform [6]

3.7 Lifting Integer Wavelet Transform

The final stage of a wavelet transform is the stage where it ensures that the wavelet coefficients are integers. The wavelet coefficients are assumed as floating point numbers in the classical transform including non-lifting wavelet transform. This is because of filter coefficients that used in the transform filters which are usually floating point numbers. In the lifting scheme it is not difficult to maintain the integer data, although the dynamic range can be increased. Lifting scheme had made it possible due to

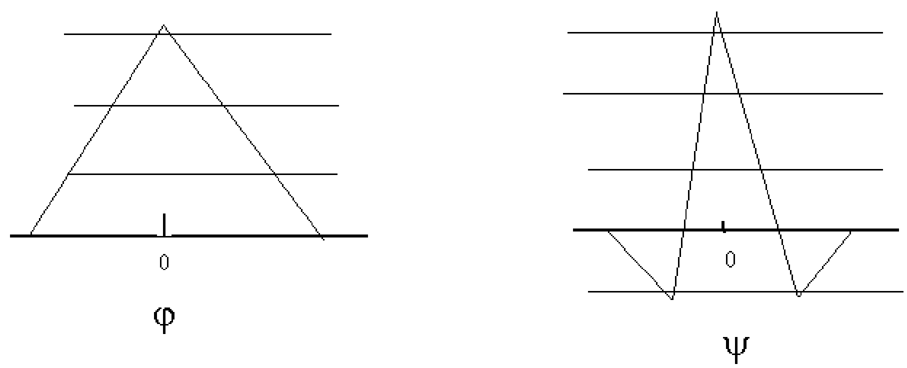


Figure 3.6   Lifting Scheme transformation of signal [8]

It's easy inevitability property of lifting. Whatever be the round operation, lifting operation will be reversible.

Scaling normally does not give integer results but it is part of the lifting transform. The solution of the problem is to forget the scaling and just concentrate on the fact that the transform coefficients have to be scaled. This is important for applications like de-noising. If there is no scaling than it is desirable to let the scaling factor to be close to one. This can be achieved by using the non-uniqueness of the lifting factorization. Second and effective solution is to factor the scaling into lifting step [9].

The integer lifting transform is unable to guarantee the preservation of the dynamic range of the input signal. Normally the dynamic range is multiplied by two, but there are schemes that can maintain the dynamic range [10].

3.8 **Properties of Lifting Wavelet Transform**

There are some properties of lifting scheme which never be found in other transforms. Some of most important properties of lifting scheme are as following [8]:-

a. The inverse transform of lifting is very clear in which sign of all the scaling factors are changed and “split” is replaced by “merge” and data flow is reversed. It provides an easy variability.

b. We need only the samples of previous lifting step and therefore old stream can be replaced by new stream at every summation point. When a filter bank is iterated by using in place lifted filters we get interlaced coefficients. Splitting of input into odd and even numbered samples takes place and perform “in place lifting” steps. After complete one step the high pass filtered samples, the wavelet coefficients come to the odd number places and the low pass filtered samples come to the even numbered places. Again we perform transform step but by using low pass filtered samples and this sequence again divided into odd and even numbered samples. The odd numbered samples are again transformed into wavelet coefficients and even numbered sample has been processed further. At the end all wavelet coefficients has been interled.

c. The third important property that shown in figure 3.6 is that lifting is not causal. It is not a serious problem, because we can delay the signal to make it causal, but it will not real time signal. It is possible to design a causal lifting transform.

d. For long filters the lifting scheme decreases the computational complexity to half.

Chapter 4

Implementation Methodology

This chapter deals with the design and implementation of proposed approach. Matlab has been chosen as a development tool because of the availability of required toolboxes and functions.

4.1 Design of System

The block diagram of proposed scheme is shown in Figure 4.1, it actually consists of two major phases. First is the transform phase and second is encoding phase.

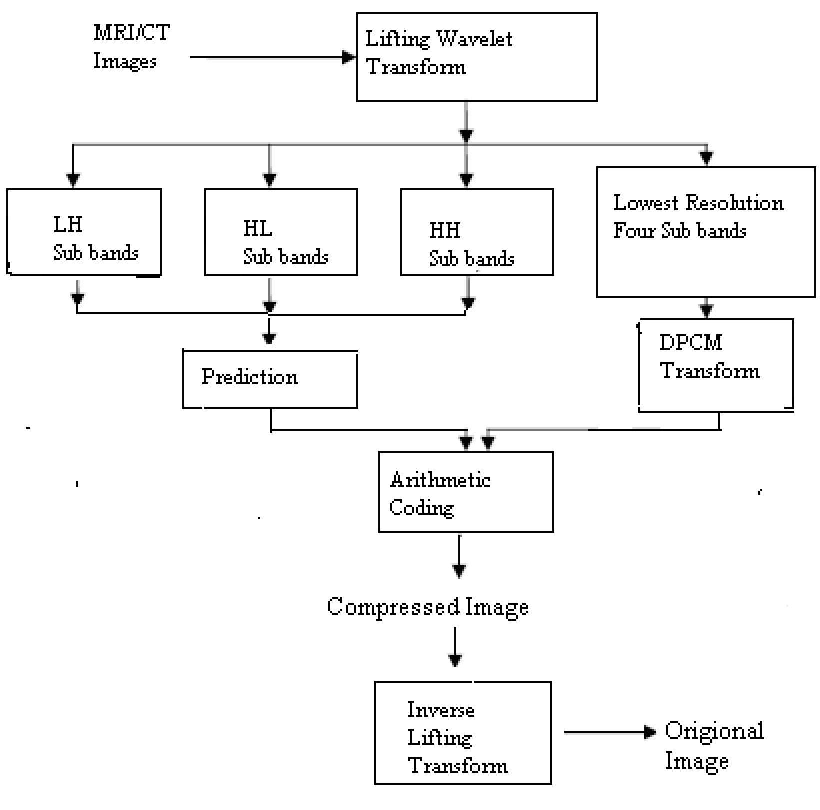


Figure 4.1 Block diagram of proposed scheme

Block diagram of proposed approach includes multiple steps such as image acquiring, decomposing and applying lifting wavelet transform, development of prediction equations and application of arithmetic coding.

4.2 **Pseudo code of proposed approach**

Step 1: Acquire a group of grayscale CT/MRI images

Step 2: Apply lifting wavelet transform to get the coefficients

Step 3: Get the correlation coefficient of different sub-band coefficients (except coarse bands)

Step 4: Develop the prediction equation for each sub-band using linear prediction equation and get the predictor variables.

Step 5: Select the appropriate predictor variables for each sub-band by coefficient graphic method.

Step 6: Apply DPCM transform to coarse bands.

Step 7: Apply arithmetic coding to get the compressed image.

Step 8: Decode the encoded bit stream.

Step 9: Get reconstructed image.

4.2.1 **Pseudo code of step 1 and 2**

```
begin
For (group of images (no)
        Read the images
        Convert the images into gray scale
        Convert the images in power of 2 sizes
        Apply the lifting wave transform from highest band to lowest band separately
        Combine the coefficients in a single vector
        Show the decomposed images
pause
End
```

Through this code we get the decomposed images. Every image will be decomposed into separate bands as selected decomposition level (1, 2, 3…). Separate sub-bands represent horizontal, vertical and diagonal components of the image.

4.2.2 **Pseudo code of step 3 and 4**

Correlation coefficient (for one coefficient in a sub-band) = correlate (sub band to be predicted, parent sub-band, aunt 1 sub-band, aunt2 sub-band)

Response variable = Linear prediction equation (addition of product of predictor variables and model parameters)

Compare response variable with original variable

Reduce the predictor variables

Select the best combination of variables which match with original variable by plotting the coefficients of both

Finalize the prediction equation with best combination of predictor variables

Apply the prediction equation for whole sub-band to predict all the coefficients in the sub band

Predict all the finer sub bands using this method

4.2.3 **Pseudo code of step 5 and 6**

Define the training set

Convert the training set into a single vector

Select the order

Select the length

Find the predictor, codebook and partition by applying “dpcmopt”, on training set, order and length

Apply the “dpcmenco” to find the index and quants

Make a single vector of all the coefficients of sub-bands

Apply arithmetic coding (arithenco) on single vector

4.2.4 **Pseudo code of step 7 and 8**

Apply “arithdeco” on the vector to decode

Apply “dpcmdeco” on the vector to decode

Reconvert the single vector into different sub-bands

Apply the inverse lifting wavelet transform to get the original image

4.2.5 **<u>Pseudo code for compression rate in Bits Per Pixel (bpp)</u>**

Calculate the total bits in original image

Calculate the total bits in compressed image

Calculate the Bits Per Pixel (bpp) by dividing the total bits of original image by total bits in compressed image

The detailed description of different steps of compression system with the depiction of each step has been given below.

4.3 Detail Description of steps in block diagram

4.3.1 Acquiring Image

Acquire a group of grayscale CT/MRI standard test images of size 128*128 from World Wide Web for compression process. Figure 4.3 shows the Eight MRI images used for analysis. In further processing the correlation coefficients of different pixel values of same and different sub-bands are required to be calculated. To calculate the correlation coefficient of two coefficients of different sub-bands few possible values of coefficients at these points are required. To fulfill this requirement a group of MRI and CT images acquired. The size of these images should be any power of 2^n. Any other size of the image can be adjusted using Matlab command. The image is loaded using the “imread” command, whose syntax is

Imread (‘filename’)

Here the filename is a string containing the name of the image file with any extension. The extensions can be jpeg, tiff, gif, bmp, png, xwd. The overall command can be written as

f = imread (“filename.jpg”)

Before loading, the image size should be known. Size of image can be confirmed using the function “size”, which gives the row and column dimensions of an image. The command syntax is “Size (f)”, the output of command gives the size of the image in row and column. There are other functions in the Matlab like.

[M, N] = size (f):

Here M returns the number of rows and N returns the number of columns in the image. There is another function “whos” in the Matlab which gives the additional information about an array. For example “whosf” command will give name, size, number of bytes and class of an array. We can adjust the size of an image (any power of 2) through matrix indexing. For example if the size of the image is 131x131 we can adjust its dimensions 128 x 128 by following Matlab command.

p = f (1 : 28, 1 : 28);

Similarly if the size of the image is 125x125 we can change its dimension by following command.

f (128, 128) = 0

By using Matlab commands we can change the image class and type. For example a unit 8 type image can be converted to double type by using “im2double” command as following.

m = im2 double (k)

Conversion command converts the unit 8 class to double by dividing each value of the array by 255.

4.3.2 **Displaying the Original Image**

After loading the image and adjusting its size the image can be displayed using the “imshow” command. The syntax of command is

imshow (k)

Because a group of images are loaded, another image “g” can be displayed using “imshow”, command, Matlab replaces the first image by second image. To retain the first image and output a second image, Matlab function “figure” can be used. The syntax of command is as following.

Figure, imshow (k)

by using the command syntax “imshow (f), figure, imshow (l)” both images(f and l) can be displayed. In Matlab different commands can be written in one line separated by commas. Image is reprocessed by Matlab before decomposition. If the input image is colored it should be converted to black and white image by “rgb2gray” command. Colored image is three dimensional and it must be converted into two dimensions before decomposition of the image. The syntax of the Matlab command through which an image can be converted to black and white form is as following [11].

n= rgb2gray (m),

An image in group of images can be displayed one by one

4.3.3 Application of lifting wavelet transform on group of images.

Three scales lifting wave decomposition is used to decompose the image to get the coefficients. Figure 4.4 shows the decomposed form of each MRI image. Lifting wavelet transform is an advance form of wavelet transform which provides easy processing of the image. In simple wavelet transform coefficients of the transform are arranged before applying the inverse wavelet transform but rearrangement of coefficients is not required before using inverse lifting wavelet transform. Inverse feature of the lifting transform is a mirror of the forward transform. The number of data elements which can be processed by the lifting transform should be any power of two. If there are 212 data elements, the first step of the forward transform will produce 211 averages and 211 differences by splitting the data into even and odd halves. At the end the odd elements are replaced by difference between values of two halves and even elements are replaced by average value of two halves. In this way lifting transform containing three steps split, predict and update at the end let the even elements unchanged which becomes the input for the next step in the transform. The predict step, predict the odd values from the even values. Update step comes after the predict step, where the even elements are replaced by averages. In the inverse transform merge step comes after predict step. In merge step odd and even elements combine to form a single data stream.

The even elements in transform have been used to predict the odd elements. The even elements are sampled values of original data [5] [6] [7].

4.3.4 **Correlation analysis of different wavelet coefficients**

All coefficients in parent, aunt and current sub-bands of processing coefficients have been used to find the correlation coefficient. Correlation coefficients are further used to find the predictor variables. Figure 4.2 shows the map used for correlation between coefficient C and coefficients in its parent, aunt and current sub-bands. Coefficient in each sub-band is correlation with coefficients of current, parent and neighboring sub-bands. The correlation coefficient of processing coefficient is calculated in the process of predicting the processing coefficient. The basic correlation analysis requires variable values to calculate the correlation between two coefficients. The correlation between fixed values cannot be calculated. To fulfill this requirement a group of CT and MRI images are loaded. When correlation between processing coefficient and other coefficients are calculated, it is not correlation between two fixed values but between two variables. There are four coefficients in current sub-band, five in parent sub-band and two in neighboring sub-bands having valuable correlation coefficient values. The correlation coefficients of these eleven coefficients are used to predict the processing sub-band coefficients. These correlation coefficients are put in linear prediction model equation with original value of processing coefficient to find the twelve prediction model parameters. These model parameters are then put in the prediction equation to predict the current processing coefficient. This prediction equation can be used for prediction of all coefficients of that sub-band. Separate equation is developed for each sub-band. The prediction equation output is compared to the original value of the coefficient to evaluate the accuracy of prediction equation. The predicted value close to the original value indicates the accuracy of prediction equation [12].

4.3.5 **Development of prediction equations and Selection of prediction variables**

The linear prediction model containing k independent variables can be expressed as:

$$y = \beta_O + \beta_1 x_1 + \beta_2 x_2 + \ldots\ldots + \beta_K x_K + \varepsilon \qquad (6.1)$$

Here y is the response variable, $x_1 + x_2, \ldots\ldots x_k$ are the predictor variables and $\beta_o, \beta_1, \ldots\ldots \beta_k$ are the model parameters and ε is the random error.

The prediction equations for HL, LH, and HH sub-band coefficients of CT/MRI images are separately derived as in following equation [13]:

$$y = \beta_o + \beta_1 x_{parent} + \beta_2 x_{parentnorth} + \beta_3 x_{parenteast} + \beta_4 x_{prentwest} + \beta_5 x_{north} + ... \quad (6.2)$$

Eleven locations with respect to predicted coefficient are shown in Figure 4.2.

4.3.6 **Selection of prediction variable**

To reduce the storage size and to avoid extraneous results the number of prediction variables should be reduced within an acceptable error. To achieve more accurate prediction, the number of prediction variables should be adaptively adjusted based on the image properties.

To achieve more accurate prediction, different prediction equations have been used for each sub-band. Here coefficient graphic method is used for selection of variables. In this method predicted coefficient graph (shown in figure 4.6) is compared to the original graph. By analyzing all the variable combinations, the sub-band equation is selected. This method is more simple and accurate as compared to the backward elimination method.

The order of prediction is from coarse sub- band to the fine sub-band and from left-up to right-down coefficient in a sub-band. The original and predicted coefficients graph is shown in Figure 6.5.

4.3.7 **Application of DPCM on coarse sub-band**

The coefficients in the coarsest sub-bands are not predicted $LL_{3,}$ $LH_{3,}$ HL_3 and HH_3 coefficients are directly processed by DPCM transform. Differential Pulse Code Modulation (DPCM) is a process of converting an analog signal into a digital signal. The sampling of analog signal is performed and the difference between the original sample value and the predicted value, which is based on pervious samples, is quantized. After quantization the values are encoded to form digital value.

Concept of DPCM is based on the fact that most of the signals have correlation between neighboring samples. Encoding exploit redundancy in sample values to achieve lower bit rate. Difference between the original value and sampled value is called Prediction error. Compression of data achieved in DPCM depends on the technique used for prediction. In predicting a signal value, the receiver only knows the reconstructed pixel values. Quantization is a lossy process which introduces error and the reconstructed value always differ from the original value. Identical prediction process should be performed at transmitter and receiver, so that the transmitter prediction base on the reconstructed values. In design of a DPCM system, predictor and the quantizer are optimized separately to avoid the complexity.

Application of DPCM on signals having correlation between alternate signals, gives good compression ratio. Images are one of the examples of signals which have this type of correlation between pixels. In images there is a correlation between pixels of same frame and consecutive frames. DPCM compression method can be conducted both for inter-frame and intra-frame coding. Inter-frame coding exploits special and inter-frame coding exploits temporal redundancy.

In inter-frame coding, pixels in which correlation is found are of the same frame while in inter-frame it is between the values of consecutive frames. In both the cases prediction of target pixel is carried out using the previously coded neighboring pixels [10] [13].

The DPCM is used with compression methods like quantization of coarser-band differences. The output is a smarter code word [10].

4.3.8 **Arithmetic Coding**

Combination of coarse and fine sub-band coefficients is arithmetically coded. Arithmetic coding is popular method of generating variable length coding. This scheme is also recommended by the Joint Bi-level Imaging Processing Group (JBIG) as part of the standard for coding binary images. JBIG is a joint expert group of the International Standard Organization (ISO). International Electro technical Communication (IEC), and the Consultative Committee on International Telephone and Telegraph (CCITT). A very low resolution representation of the image is sent first in progressive transmission of an image, which requires few bits to encode. The image is further refined by transmitting more information. The JBIG standard is combination of "Progressive Transmission" and lossless compression algorithms.

The output from an arithmetic coding process is a single number less than but greater then or equal to zero. This single number can be decoded to generate the exact stream of symbols that went into its construction. In order to construct the output number the symbols being encoded should have set probabilities assigned o them.

Once the character probabilities are known, the individual symbols are assigned a range along a probability line from 0 to 1. Each character can be assigned any segment of the range. In the encoder and decoder it should be done in the same manners. One character is assigned the portion of range from 0 to 1 related to probability of its appearance [15].

Encoding and decoding a stream of symbols by using arithmetic coding is not difficult. Arithmetic coding is best for standard 10 bit and 32 bit numbers. Floating point is not required.

4.2.6.9 **Reconstruction of image**

Reconstruction of image is achieved by arithmetic decoding, DPCM decoding and lifting reverse wavelet transform. This is the function which gives the actual required output. It gets the output of the arithmetic coding as input. The following actions take place here.

- The output of arithmetic decoding is given as input to this function.
- Other inputs given to this function are the reconstruction filters and level of decomposition used in the transformation stage.
- In simple inverse wavelet transform output of the decoder is used to arrange the data into the approximation and detail components but lifting wavelet transform does need this.
- The components are used to perform inverse lifting wavelet transform.

The reconstruction of image using lifting wavelet transform is a mirror image of the forward lifting wavelet transform.

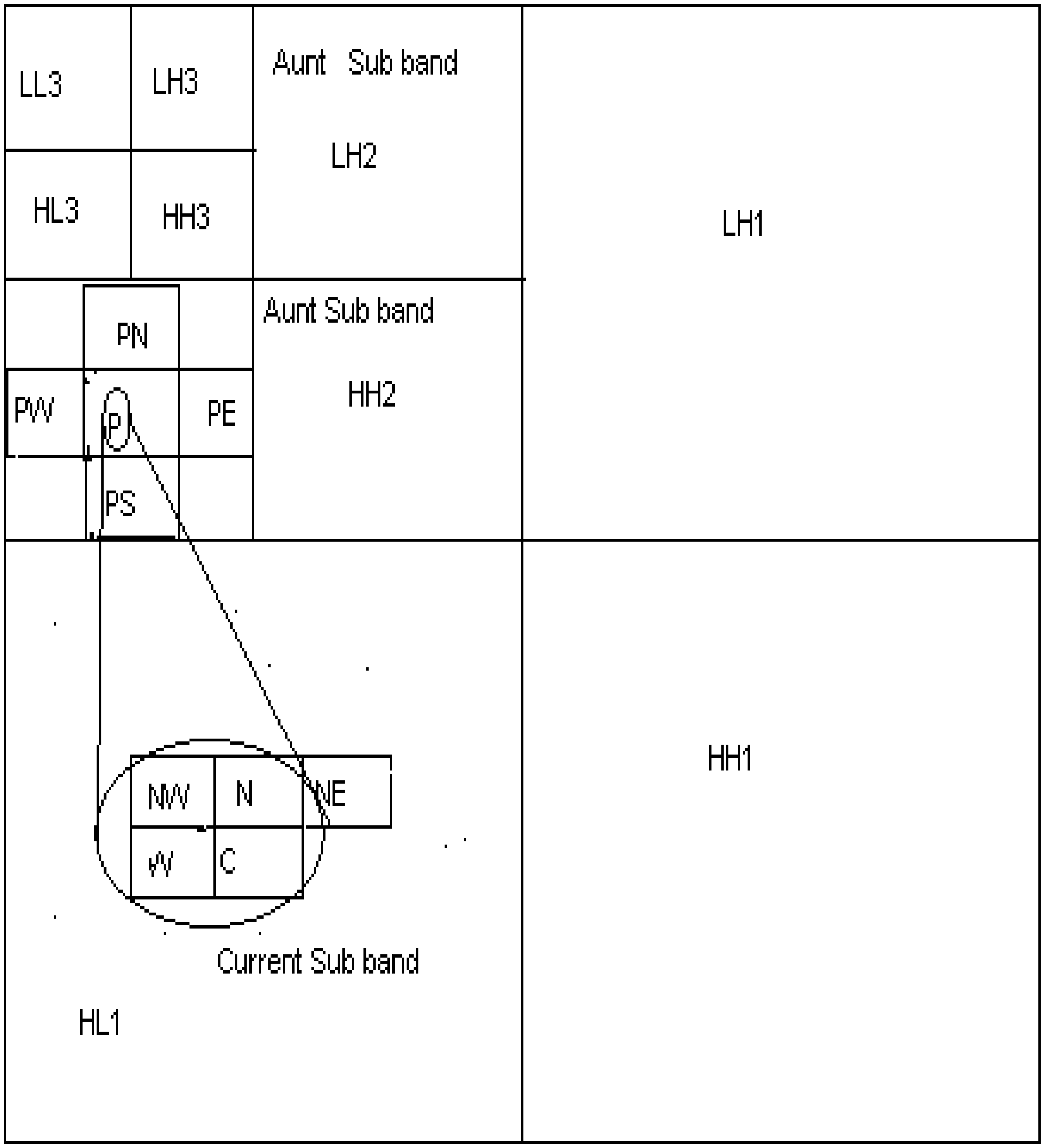
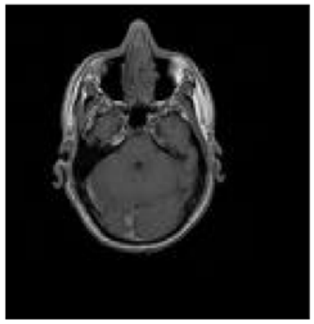
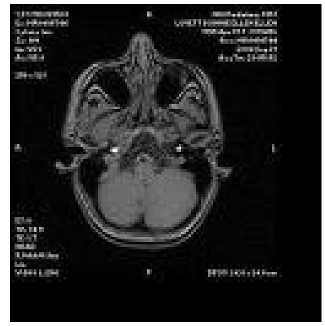


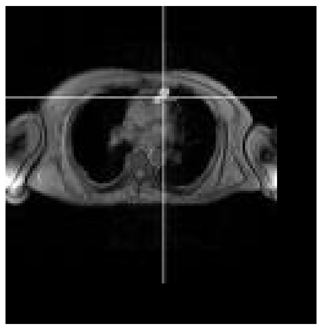
Figure 4.2 The relationship map for computing correlation [12]



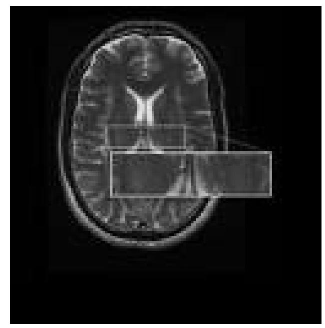
MR1-1



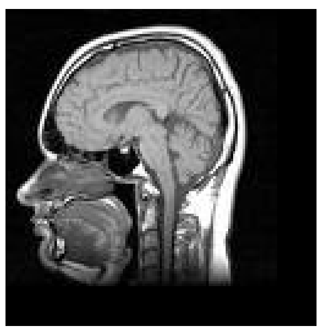
MRI-2



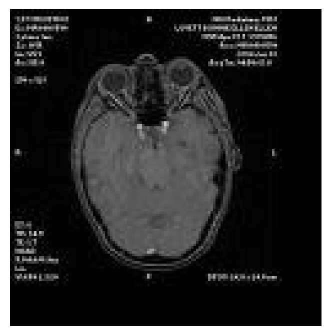
MRI-3



MR1-4



MRI-5

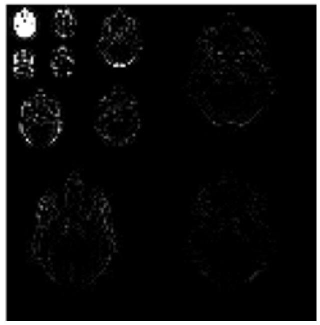


MRI-6

MRI-7

MRI-8

Figure 4.3 Group of Eight MRI images

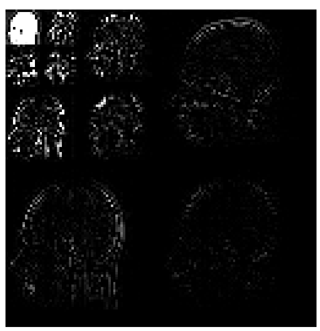


DMRI-1

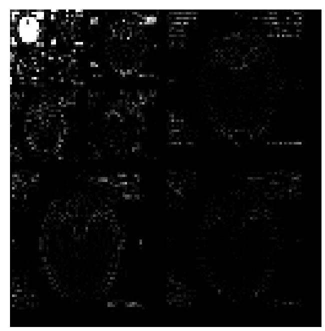
DMRI-2

DMRI-3

DMRI-4



DMRI-5

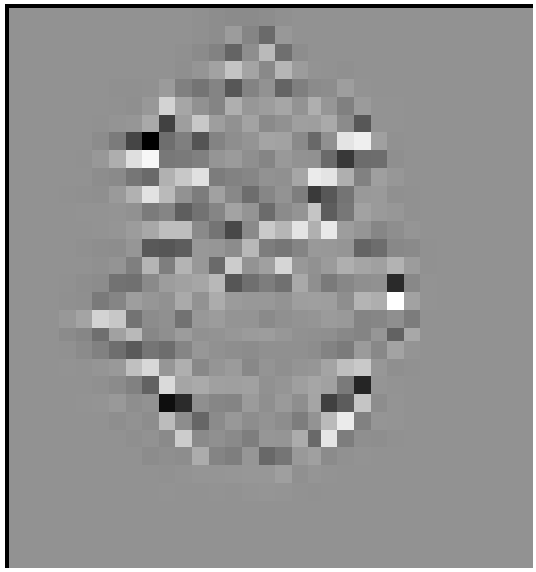


DMRI-6

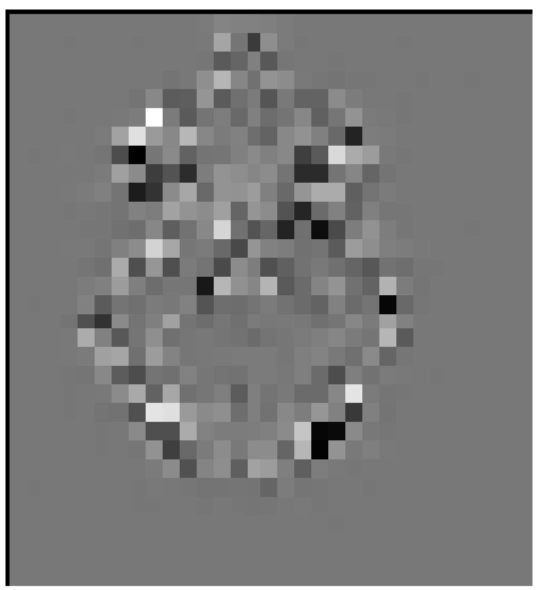
DMRI-7

DMRI-8

Figure 4.4 Decomposed MRI images using lifting wavelet scheme with 3*scale

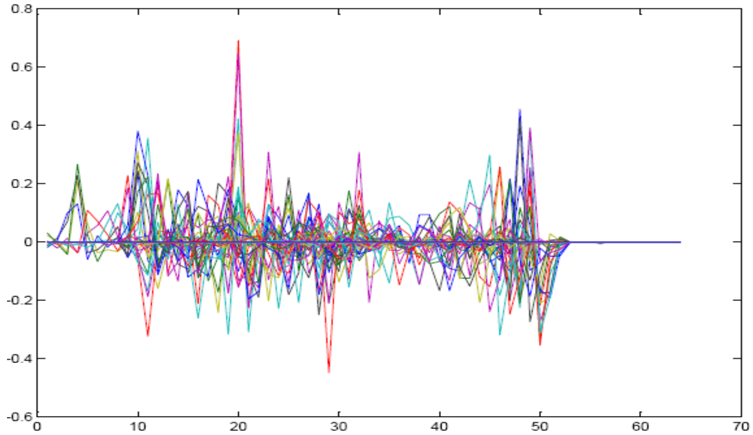


Original

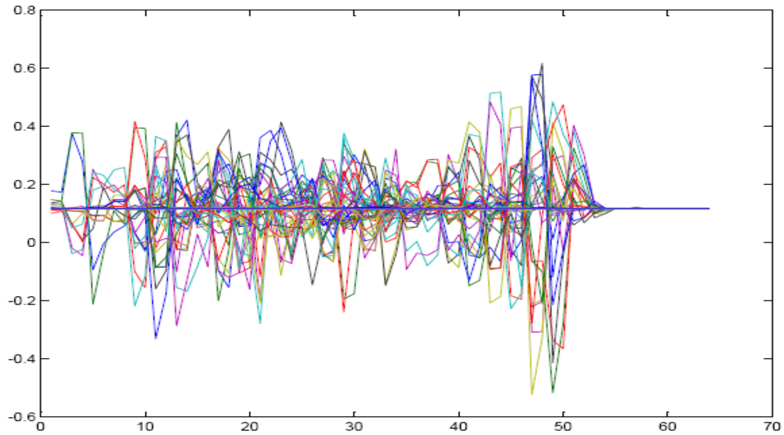


Predicted

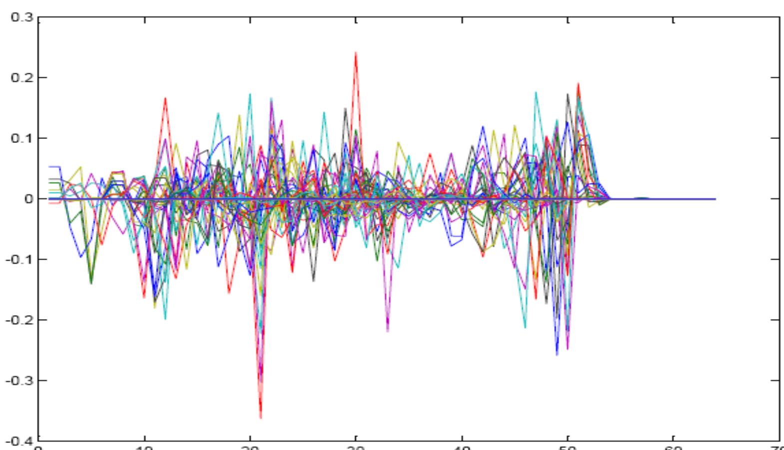
Figure 4.5 Sub-band Coefficient plot



a. Coefficients of Sub-band (original)

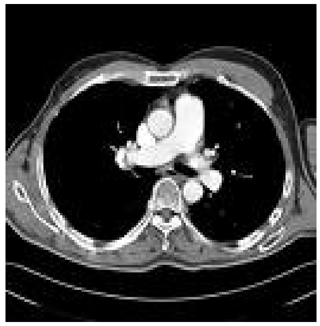


b. All Coefficients of sub-band

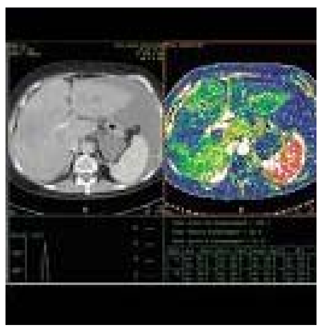


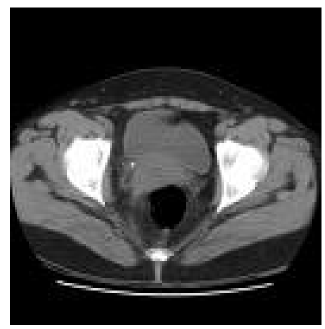
c. Selected coefficients of sub band

Figure 4.6 Graph of Coefficients

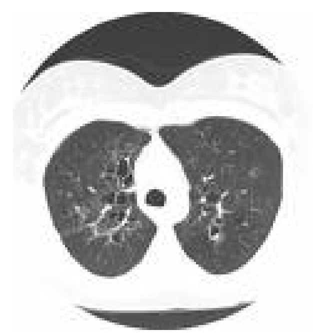


CT-1 CT-2





CT-3 CT-4



CT-5 CT-6

Figure 4.7 Group of Six CT images

Chapter 5

RESULTS AND COMPARISONS

5.1 Background

Two groups of gray scale standard test images (CT and MRI) of size 128×128 have been taken from web for experiments and comparisons. MATLAB 7.0 has been used for the implementation of the proposed approach and results have been conducted on Pentium-IV, 3.20 GHz processor with a memory of 512 MB. Different quality metrics i.e Compression Ratio (CR), Compression Percentage (CP), Mean Square Error (MSE), and Peak Signal to Noise Ratio (PSNR) are evaluated for analysis and comparisons. The compression ratio, Bits Per Pixel (bpp) is the best method for the purpose. In previous work on medical images bpp has been used.

5.2 Compression Rate

The compression rates for the 14 medical images using the proposed method are listed in Table 5.1. Figure .1 shows the compression rate obtained by using proposed method for medical images like MRI and CT in graphic form. The comparison of proposed method with five famous lossless compression methods like SPHIT, JPEG2000, CALIC, SSM and WCAP are given in Table 5.2 and comparisons are shown in graphic form separately for CT and MRI images in figure 5.2 and figure 5.3. The proposed method almost achieves the highest compression rates for MRI and CT images. The compression rate for 14 medical images is calculated as shown in the Table 5.1 using proposed method. The compression rate is calculated in bits per pixel. The bit per pixel is calculated by following formula:-

$$\frac{\text{Total no of bits in original image}}{\text{Total no of bits in compressed image}}$$

In all the previous techniques used for medical image compression "Bits Per Pixel " has been used to measure the compression rate. So it is convenient to measure the compression by this method to further compare the proposed method with state of art methods. Table 5.1 show the compression of Eight MRI and six CT images in bits per pixel. Compression in MRI images ranges from 1.47 bpp to 1.50 bpp. The average compression of MRI images is 1.49 bpp.

The compression of CT images ranges form 1.42 to 1.44. Average compression rate of six CT images is 1.43 bpp.

Figure 7.1 shows the compression of MRI and CT images in graphical form to analyze the compression of different medical images at a glance. It can be observed from data in table 5.1 and graph in figure 5.1 that CT and MRI image have different compression rates. The compression rate of CT images ranges from 1.42 to 1.44 bpp, while the compression rate of MRI images ranges from 1.47 to 1.50 bpp. These ranges do not show very high variance in compression between different images. It indicates that although correlation coefficients of different images for same coefficients are different but difference is not more them a certain limit. Due to these characteristics of medical images same equation for each sub-band is used for all the images for prediction of coefficients.

5.3 **Comparisons**

Comparison of different state of art methods for medical image compression with proposed method is made in table 4.2. Average compression for each method is obtained to get the comparative results. For CT images the SPHIT shows the highest bits per pixel while the JPEG, CALIC and SSM are 2nd, 3rd and fourth respectively. The average of WCAP and proposed method is almost equal. But comparison of WCAP and proposed method has large difference in behavior. This difference can not be shown by averaging the compression rates. The compression of WCAP for different CT images ranges for 1.18 to 1.61, while the compression rate for different CT images in proposed method ranges from 1.42 to 1.44.

This compression and limitation of averaging criteria raises an important question. If a student takes seven marks out of ten in three consecutive tests and second student takes nine in two tests and three in third test, which student is more reliable for his teacher to take him to competition. It is obvious that teacher will not take risk and will send the first student to competition, which is more reliable then the second student in spite of highest marks obtained by second in two tests. It means proposed method is a better compression technique than WCAP method. Figure 5.2 displays the comparison in graphical form for CT images. All other techniques show ripples in their behavior while the proposed method appears the best method as shown in the graph. Figure 4.3 shows the comparison of different compression methods for MRI images. The performance of proposed method is significant with WCAP at second place and SSM, CALIC, JPEG2000 and SPHIT following respectively.

5.3.1 **Comparison with Set Partitioning In Hierarchical Trees encoding scheme (SPIHT)**

SPHIT method is an encoding and decoding scheme that has been used for partitioning of trees in a way to keep together insignificant coefficients together in larger subsets. SPHIT partitioning provide binary decisions that provides a significant map encoding, which is much efficient than its predecessor methods. Refinement steps take the significance map encoding and refine the representation of these significant coefficients. Decoder uses the received encoded bit stream with header data to reconstruct the transform coefficient values [16].

Comparison of proposed method with SPHIT scheme is shown in Figure 5.2 and 5.3. Graphs drawn are based on the data shown in Table 5.2. Figure 5.2 shows the comparison of both schemes for CT images in terms of compression rate (bpp). SPHIT shows the highest compression rate among all the schemes while the proposed scheme shows the lowest compression rate. However for two CT images SPHIT curve overlap the proposed curve. For other three images the SPHIT compression rate ranges from 1.8 to 2.1 bpp, while the proposed scheme curve values move between 1.4 and 1.5 bpp. For MRI images as shown in Figure 5.3, SPHIT curve compression rate for five images ranges from 2.4 to 3.6 bpp, while proposed scheme compression rate ranges from 1.49 to 1.5 bpp. Clearly the proposed scheme compression rate is far better than SPHIT for both types of medical images.

5.3.2 **Comparison with Improved JPEG 2000**

This improved JPEG2000 combines Embedded Block coding with optimized Truncation (EBCOT) technique. In this technique “lifting integer wavelet transform” is used which offers plenty of advanced features. It provides high performance lossless compression which is much better than JPEG standard. The limitation of this scheme is that it only works at low bit rates. Figures 5.2 and 5.3 clearly show the difference between proposed scheme and advanced JPEG2000. For two CT images the bpp obtained from advanced JPEG2000 are better than the proposed scheme but for three pixels the performance of proposed scheme is far better than advanced JPEG2000. The performance of advanced JPEG2000 is better only for some images dues to advance features like “Lifting Integer Wavelet Transform” combined with it. For most of the images performance of proposed scheme is better.

5.3.3 Comparison with Context based Adaptive Lossless Images Code (CALIC)

CALIC scheme is based on the context based adaptive lossless image code approach. It uses enclosing 360^0 modeling contexts to achieve the distribution of the encoded symbols and the prediction scheme. Table 5.2 and Figure 5.2 show that the scheme achieves more compression for only few CT Images. For MRI images proposed scheme is superior then CALIC, average performance of proposed scheme is for better then the CALIC. There is another version of CALIC called inter-band version, which incorporates inter-band prediction technique to the original CALIC. This version is only for multi-spectral and remotely sensed images.

5.3.4 Comparison with Scanning Statistical Modeling (SSM)

SSM scheme uses 5/11 filter with quincunx decomposition for medical images compression. It is only efficient for lower-quality ultrasound images. Figure 5.2 and 5.3 indicate that the performance of proposed scheme is better than SSM for most of the images and far better then SSM for all MRI images. For CT images SSM curve is like a saw-tooth waveform. For MRI images its compression curve values range from 2.7 to 3.9 bpp for five medical images.

Proposed scheme is better than SSM for most of the CT images and for all MRI images.

5.3.5 **Comparison with Wavelet-based Medical Images Compression with Adaptive Prediction (WCAP)**

WCAP and proposed scheme has been based on the correlation method. Figure 5.2 and 5.3 show performances of WCAP scheme curve more close to proposed scheme curve as compared to other schemes. For CT images average performances of both schemes are almost equal but proposed scheme shows far less variance for different images, while the WCAP shows the saw-tooth waveform, which is not desired.

For MRI images proposed scheme curve compression values are near to 1.5 bpp for different images, while the WCAP range varies from 2.1 to 3.6 bpp, which is undesirable. It clearly indicates the superiority of proposed scheme on WCAP.

Type	**Compression Rate(bpp)**
MRI1	1.47
MRI2	1.49
MRI3	1.47
MRI4	1.48
MRI5	1.49
MRI6	1.49
MRI7	1.50
MRI8	1.50
MR Average	**1.49**
CT1	1.43
CT2	1.44
CT3	1.43
CT4	1.42
CT5	1.44
CT6	1.43
CT Average	**1.43**

Table 5.1 Compression rates of proposed scheme on different MRI and CT images.

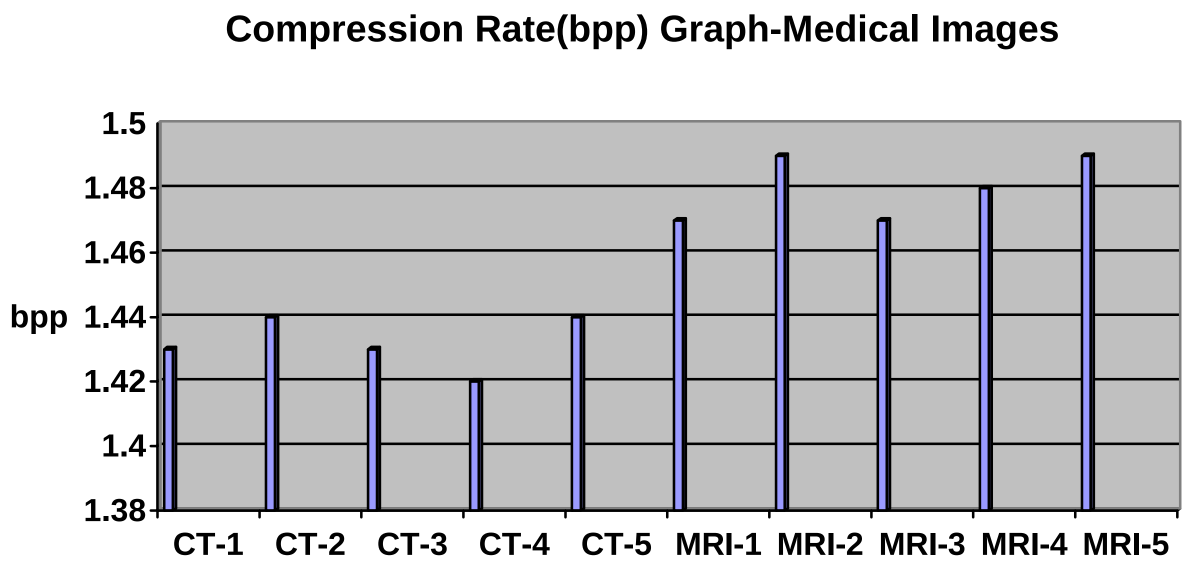


Figure 5.1 Compression rate achieved for medical images using proposed method

Type	**Method**					
	SPHIT	**JPEG 2000**	**CALIC**	**SSM**	**WCAP**	**Proposed**
CT1	1.45	1.32	1.21	1.20	1.18	1.43
CT2	2.07	1.95	1.74	1.71	1.71	1.44
CT3	1.88	1.73	1.57	1.48	1.39	1.43
CT4	1.89	1.77	1.60	1.63	1.61	1.42
CT5	1.46	1.37	1.34	1.24	1.23	1.44
CT Average	**1.75**	**1.63**	**1.50**	**1.45**	**1.42**	**1.43**
MRI1	2.51	2.44	2.42	2.37	2.38	1.47
MRI2	3.33	3.27	3.25	3.17	3.00	1.49
MRI3	3.61	3.53	3.50	3.45	3.31	1.47
MRI4	3.06	3.00	2.99	2.93	2.72	1.48
MRI5	2.4	2.33	2.31	2.27	2.08	1.49
MRI Average	**2.98**	**2.91**	**2.89**	**2.84**	**2.70**	**1.48**

Table 5.2 Comparison of proposed method with different methods of medical image compression on the basis of compression rate (bpp)

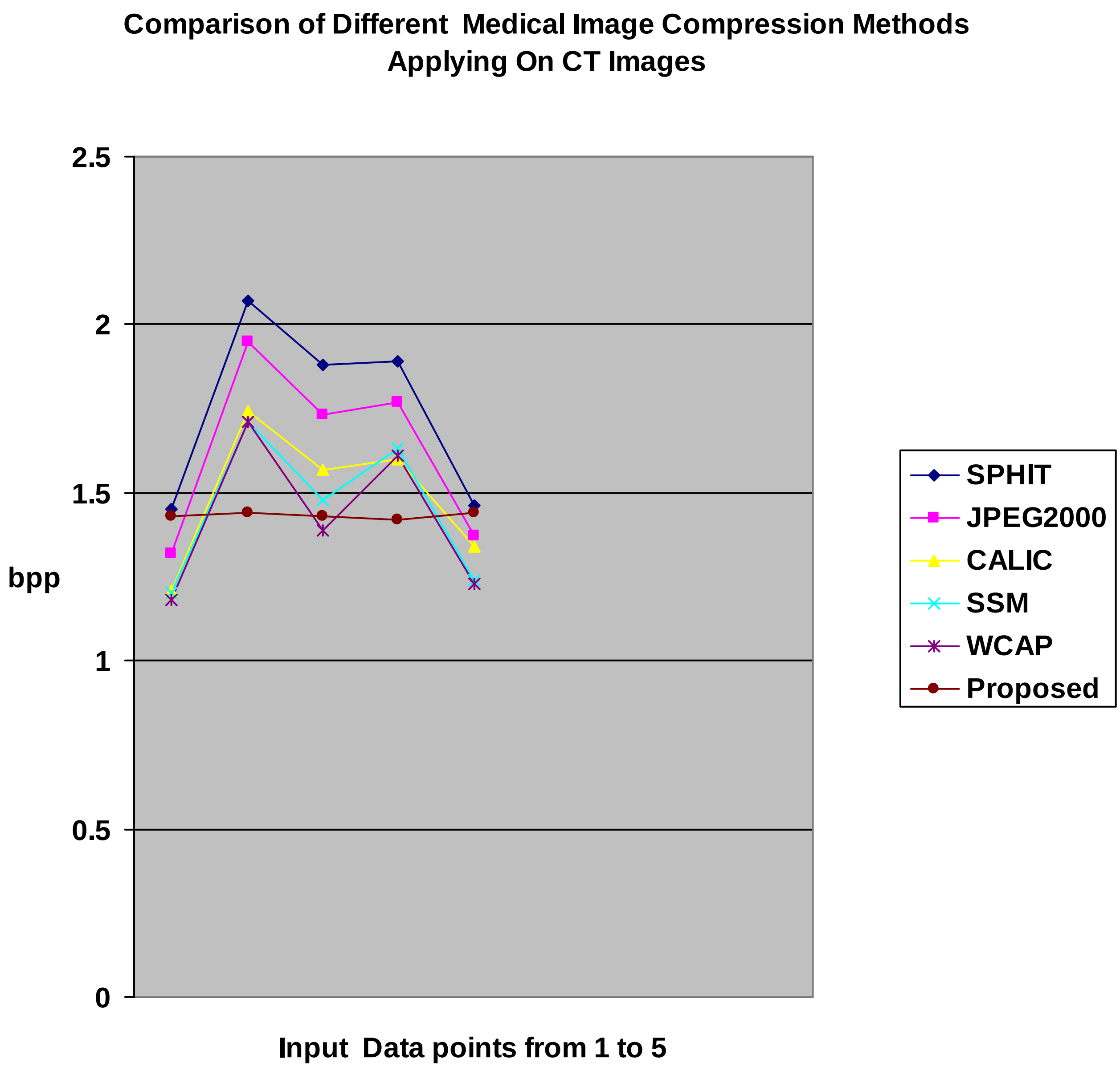


Figure 5.2 Comparison of different medical image compression methods using CT images

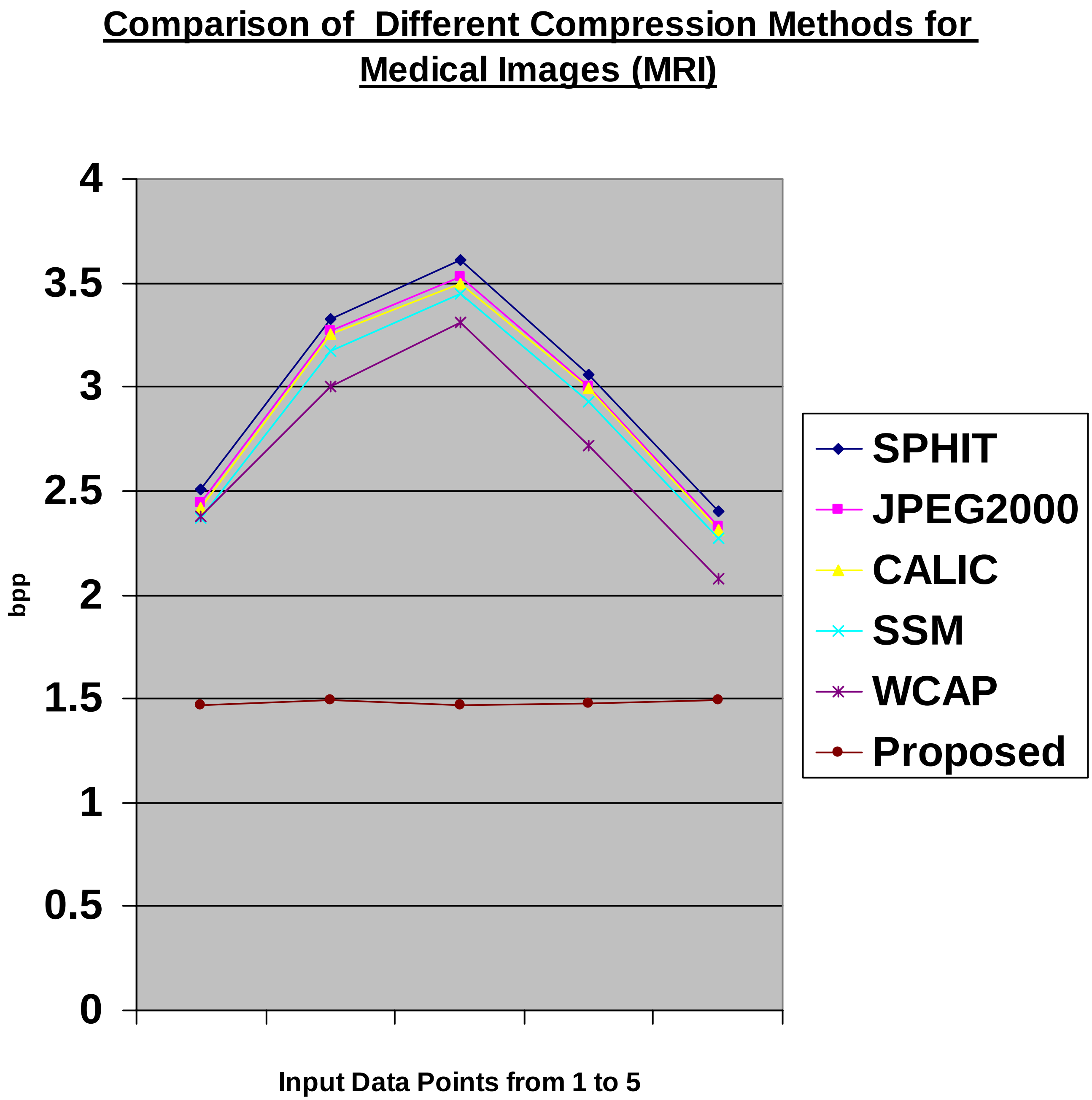


Figure 5.3 Comparison of different medical image compression methods using MRI images

5.4 **Time Taken**

Time taken criteria is also used for analysis. Time taken for encoding and decoding for proposed scheme is shown in table 5.3, 5.3 and 5.4 in graphical form separately for MRI and CT images. The average encoding and decoding time for MRI and CT images are also calculated for comparison. Comparison of different methods is shown in table 5.4 and its graphic shape in figure 5.4 and 5.5 for CT and MRI images respectively. Figure 5.5 shows the encoding/decoding time graph of CT images. It is almost showing the same results as shown by the MRI graph.

Average encoding and decoding time of all the CT and MRI images are calculated and shown in table 5.4. Then average of both type of images calculated for encoding/decoding time and shown in the last row of the table. To facilitate the comparison average encoding/decoding time for both the images are shown in figure 5.6, by using five state of art methods and proposed method. We can analyze that giving so much compression, average encoding/decoding time of proposed scheme is not much less than the other state of art methods. It lays almost in middle of the graph for both CT and MRI images.

In table 5.3 Encoding and Decoding time of 8x MRI and 6x CT images are recorded. The encoding time of MRI images ranges from 2.43 seconds to 2.60 seconds. The decoding time of MRI images is more than encoding time as it ranges from 3.01 to 3.23 seconds. The average encoding time for MRI images is 2.50 seconds and average decoding time for CT images is 3.12 seconds. Encoding time for CT images ranges from 3.07 to 3.21 seconds. The average encoding time for CT images is 2.62 seconds and average decoding time is 3.13 seconds.

MRI images Encoding/Decoding time is shown in figure 5.4. Graph clearly indicates more time for decoding part of image processing.

5.5 **<u>Comparison of Encoding/Decoding Time of Different Schemes</u>**

Figure 5.6 and 5.7 show the comparison of encoding/decoding time for different schemes. Figure 5.6 shows that encoding/decoding time value of proposed scheme for CT images lies at middle of all schemes. JPEG2000 shows the lowest encoding/decoding time with SSM highest. This average performance of proposed scheme in terms of encoding/decoding time is acceptable due to its performance in terms of compression rate, which is far better than all the schemes.

For MRI images, shown in figure 5.7, encoding/decoding time is almost similar to CT images graph of figure 5.6. Proposed scheme lies in middle of other schemes. By giving ideal compression rate for MRI images, proposed scheme encoding/decoding time lies within acceptable range.

Type	**Encoding Time(Sec)**	**Decoding Time(Sec)**
MRI1	2.46	3.03
MRI2	2.43	3.01
MRI3	2.46	3.12
MRI4	2.48	3.21
MRI5	2.60	3.23
MRI6	2.50	3.11
MRI7	2.54	3.17
MRI8	2.59	3.07
MR Average	**2.50**	**3.12**
CT1	2.62	3.14
CT2	2.62	3.06
CT3	2.61	3.14
CT4	2.62	3.07
CT5	2.61	3.21
CT6	2.64	3.17
CT Average	**2.62**	**3.13**

Table 5.3 Encoding and Decoding time taken by proposed scheme

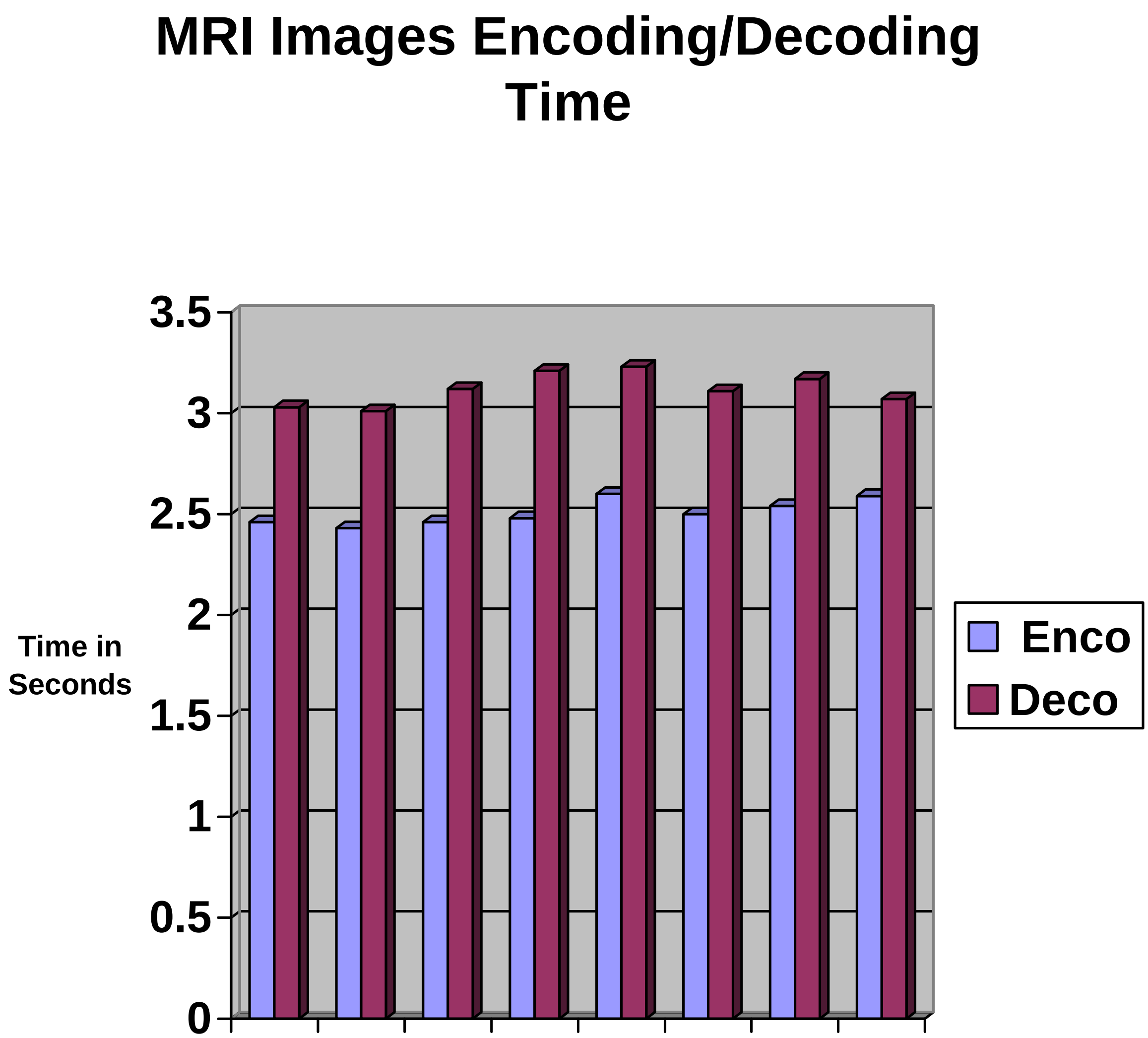


Figure 5.4 Encoding and Decoding time taken by proposed scheme for MRI images

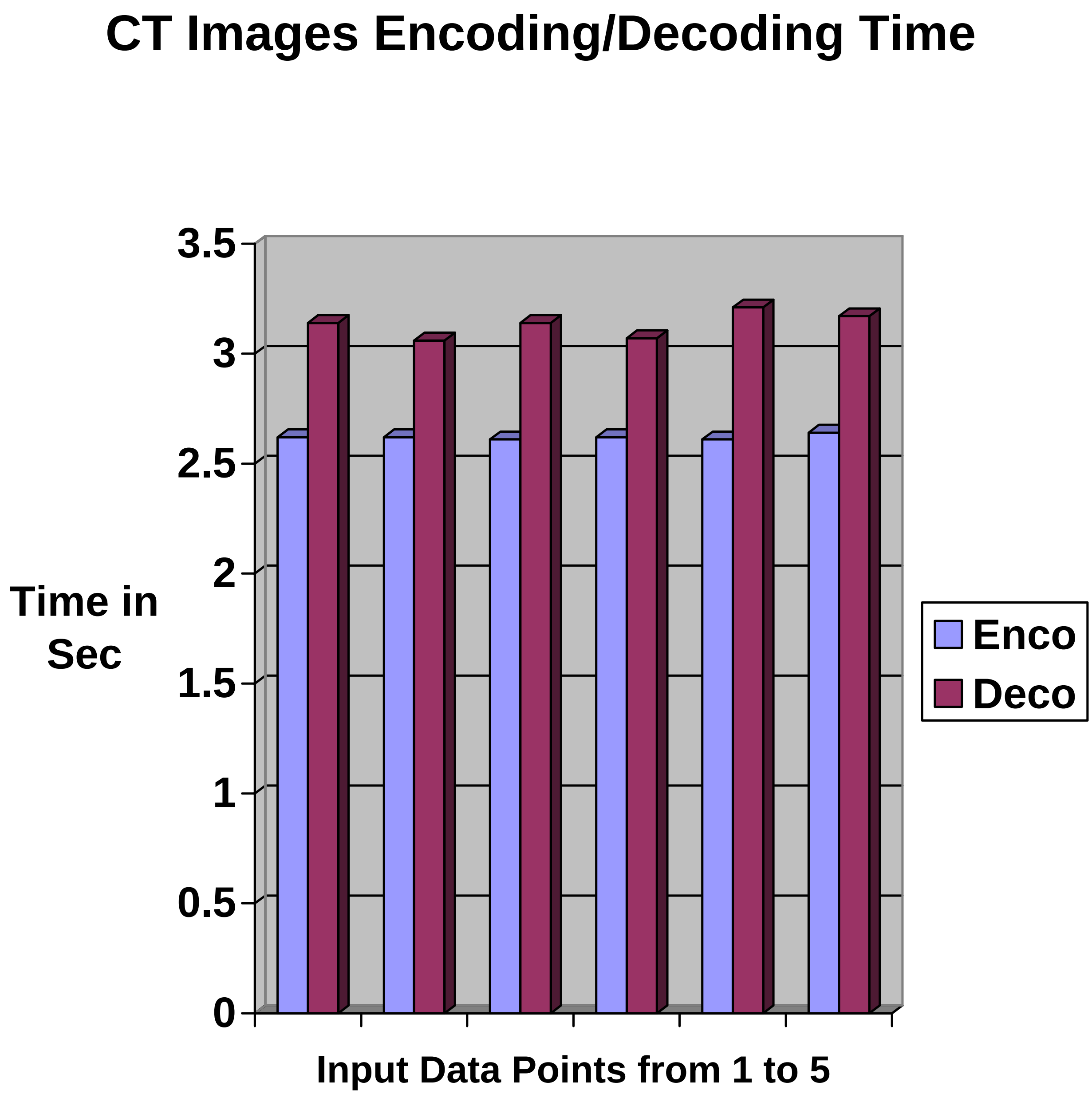


Figure 5.5 Encoding and Decoding time taken by proposed scheme for CT images

Type	Method					
	SPIHT	JPEG2000	CALIC	SSM	WCAP	Proposed
CT Average	2.3/2.7	1.1/1.0	5.5/3.5	6.8/5.2	5.4/2.9	2.62/3.13
MRI Average	1.8/1.8	0.8/0.8	3.2/2.4	4.8/3.3	3.4/2.1	2.50/3.12
Average	**2.05/2.25**	**0.95/0.9**	**4.35/2.95**	**5.8/4.25**	**4.4/2.5**	**2.56/3.12**

Table 5.4 Comparison of Average Encoding and Decoding time taken by different compression methods

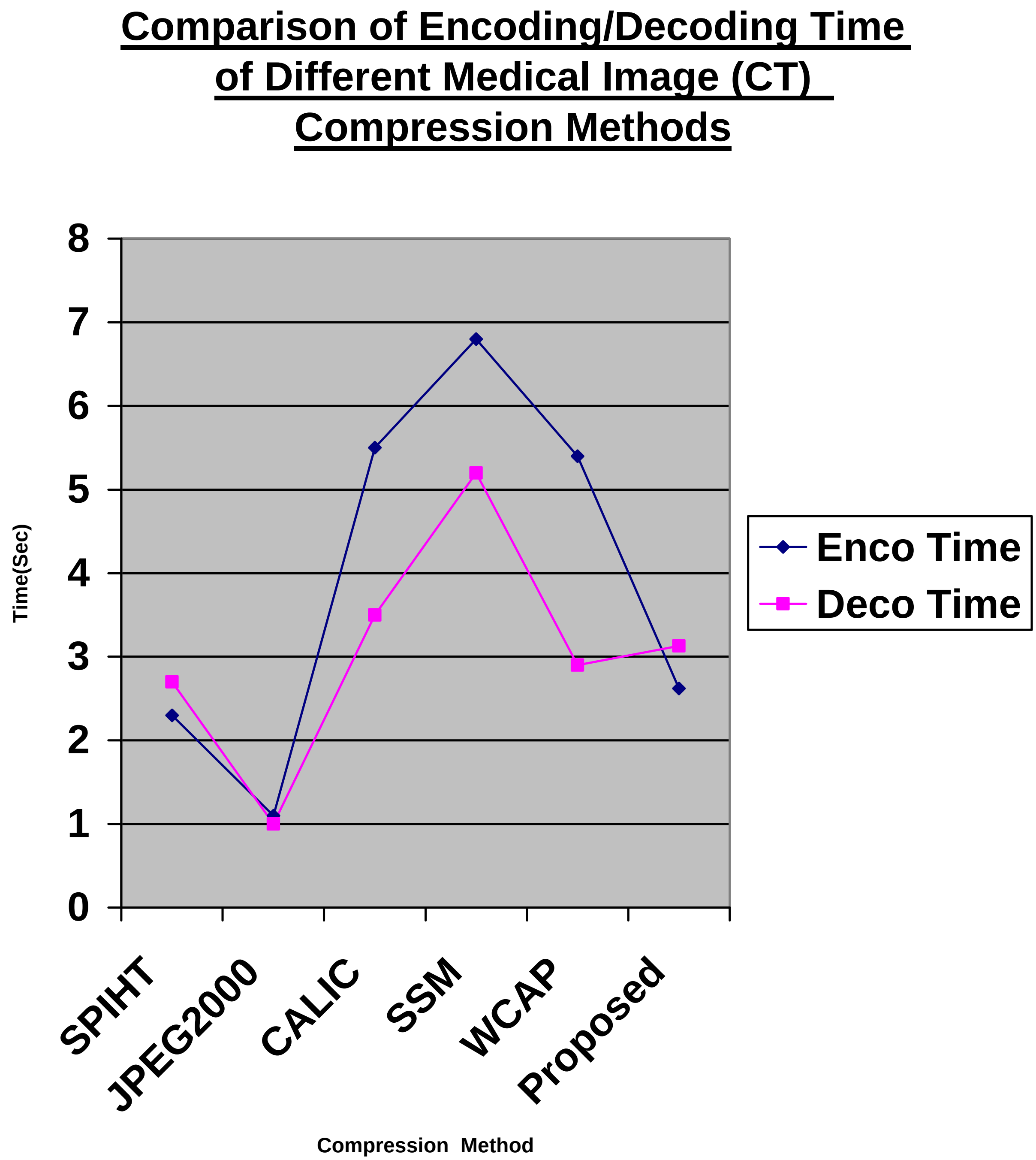


Figure 5.6 Comparison of average Encoding and Decoding time taken by different compression methods for CT images in graphic form.

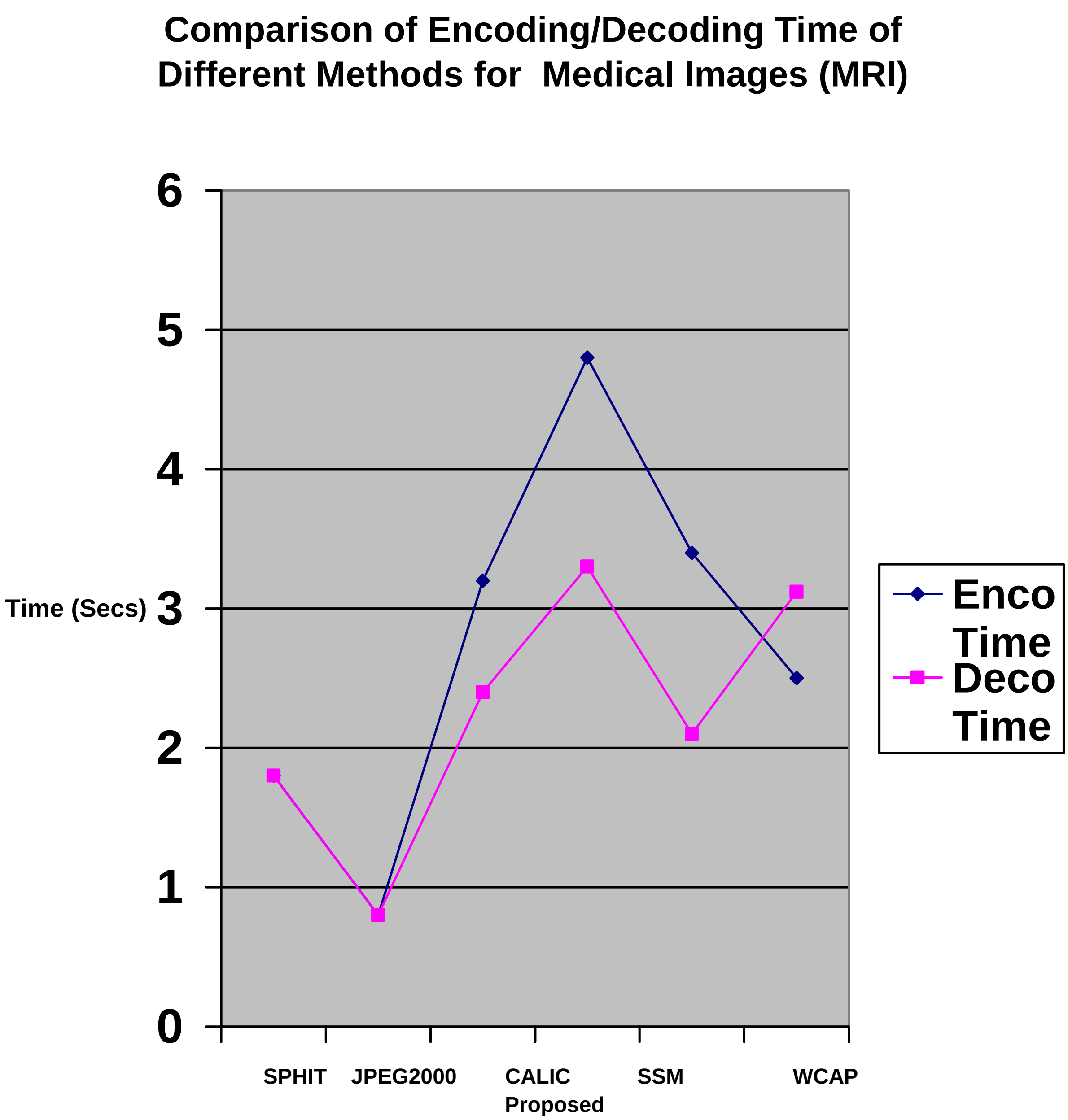


Figure 5.7 Comparison of Average Encoding and Decoding time taken by different compression methods for MRI image in graphic form

5.5 Concluding Remarks

Every development comes with some merits and demerits, Image compression advantages include decrease of storage requirements and reduction in transmission cost. It enhances the quality of multimedia presentation and reduces the backup and recovery cost. However its disadvantage is less reliability of compressed data as a single bit error can cause misinterpretation of succeeding bits by decoder. Another disadvantage is that extra overheads involve in encoding and decoding process which make identification of compressed data complex.

This work proposes a lossless compression approach for medical images based on the wavelet compression. The technique incorporates the prediction model to predict the fine sub-band coefficients through coarse sub-bands. Predictive error of fine sub-band coefficients are quantized and encoded with differential Pulse Code Modulated output of coarse-bands. A bit/pixel is obtained which indicates high compression.

In the proposed WBMICP approach, compression rate has been improved by exploiting dependencies among wavelet coefficients [1]. A new method, coefficient Graphic Method is used to avoid multicollinearity problem which is the main contribution of this method. Comparing with the SPHIT, JPEG2000, CALIC, SSM and WCAP, proposed method achieves the highest compression rate.

Chapter 6

Conclusion and Future Work

6.1 Conclusion

An image is basically a 2-D light intensity function can be presented in matrix form. After discretizing of analog image along the coordinates and brightness it can be converted into a digital image. All the images are different depending on number of bits used for the pixels and format. In compression of an image, data representing the image is reduced. Compression exploits the redundancy of different types inherent in the image. Compression is used to reduce the storage size of the data and compression rate. Lossy and lossless are two types of image compression. Image is perfectly recovered in lossless compression. This type of compression is used in medical images like, CT, MRI, ECG and X-rays. The technique like arithmetic coding, dictionary techniques and predictive coding are utilized with modifications. The second type of compression is lossy. It is widely used for different applications. Basically the compression is a lossy process. There are many techniques used for lossy compression with day by day advancement in the techniques with ongoing research in the area. Scalar/vector quantization, differential encoding, transform coding, sub-band coding, wavelet compression and its modified versions like lifting wavelet transform and lifting integer wavelet transform are the techniques used in lossy compression, wavelet transform is an advance method for analyzing the images. Image compression is one of its applications. It developed from Fourier transform and windows transform. The idea is also being taken from sub-band and pyramid coding. Fourier transform has limitations like, can only be represented in the frequency or time domain and can not be represented simultaneously in time and frequency domain. It possesses poor local characteristics of the signal. We mostly deal with non-stationary signals but Fourier transform is only suitable for stationary signals. This limitation of the Fourier transform is overcome by designing short Fourier transform, which further resulted into wavelet transform. Although it has limitations of limited size and fixed nature due to which all the signals can not be presented in it. This arise the desire of flexible window which causes the development of wavelet transform. Wavelet means small wave. It is the basis of wavelet transform. Wavelet has the characteristics of shifting and scaling which make it a flexible window. Many applications of wavelet are developed for different uses.

In wavelet analysis a wavelet prototype function called mother wavelet is used. The original signal is than presented through wavelet coefficients. These coefficients than processed as per task required to achieve the desired results. Wavelet transform is presently used in many fields, a development in the wavelet transform is made called "Fast wavelet transform", to get immediate processing through computer. Wavelet transformation decomposes a signal into low and high frequency components. Low frequency components are called approximation coefficients and high frequency components are called detail coefficients. The image can be further decomposed using higher scale to get further approximation and detail coefficients. The detail components are further divided into horizontal, vertical and diagonal components. There is one approximation and three detail components.

At every stage the decomposition components have different representation. The required level is coded using different coding techniques or combination of techniques. Detail component is used to reconstruct in applications like, pattern recognition. The horizontal components give the horizontal detail of image and vertical and diagonal give vertical and diagonal details of image respectively. High frequency components are contained in the horizontal, vertical and diagonal coefficients, while the low frequency components are contained in the approximation coefficients. The total number of sub-bands depends on the scale of decomposition used for image compression. Scale of the decomposition depends on the required compression of the image and size of the image. Larger image size requires huge scale of decomposition.

Lifting wavelet transform is an advance form of wavelet transform. Forward lifting scheme divides the data into even and odd halves. This algorithm is recursive in nature in which output is input for next step. In lifting wavelet transform there are three steps in the process. Split, predict and update phase. In the split step odd elements move to the second half and even elements move to the lower half of the array. At last, even elements are replaced by averages and odd elements are replaced by differences of the two halves. In split phase of the next round even elements become the input. The inverse transform of the lifting wavelets are not useful for most wavelet applications. Here the even elements are used to "Predict" the odd elements, which result from sampling the data set by powers of two, the number of data element processed by the wavelet transform must be a power of two, 2^n data elements produce 2^{n-1} differences. The differences are called wavelet coefficients.

The lifting scheme developed twenty years back is now a recognized area of the applied mathematics. The last stage of wavelet transform is the "Integer Lifting Wavelet Transform". Integer wavelets make sure that wavelet coefficients are integers. In general transform the coefficients are assumed to be floating point numbers. This is due to the type of filters used. The rounding operation is most amazing feature of lifting wavelet transform. The lifting operation is reversible, whatever the rounding operation is used, scaling normally does not yield integer results but it is part of the lifting transform. After ignoring the scaling, the scaling factor be close to one. Other solution of the problem is to factor the scaling into lifting steps. The integer lifting transform does not guarantee the prescription of the dynamic range of input signal.

Correlation analysis of the wavelet coefficients is the basis of prediction. Prediction is an efficient method of compression. Prediction means inferring the current data on basis of previous data. There is strong correlation between neighboring pixels. This redundancy of neighboring pixels is exploited to predict the current data from previously processed data. After decomposing the image using lifting wavelet transform, different sub-bands of approximation and detail coefficients are formed. A coefficient in a sub-band can be predicted through the equation formed by correlation coefficients of its neighbors, parents and aunt-band coefficients. Practically there are eleven coefficients in an image which have significant correlation with the processing coefficient. These correlation coefficients are found to develop an equation for prediction of coefficients of each sub-band. The correctness of equation depends upon the difference between original value and predicted value. After development of prediction equation the major work is selection of predictor variables. More variables in an equation can cause multi co-linearity problem. Some variables from the prediction equation are selected while others are discarded. There are many methods for selection of variables. A method used in WCAP is "Back Ward Elimination". This is a statistical method in which statistical test of different variables have been carried out. A "F" value is calculated, the variable whose F value fall below a threshold is discarded. All the variables with "F" value above a threshold value is included in the prediction equation. Once the prediction equation is finalized, it can be used for prediction of coefficients in that specific sub-band. Back ward elimination method is a complicated method which is replaced in the proposed method by coefficient graphic method. The coefficient graphic method is a simple method in which graph of original coefficients is drawn. The graph is compared with selected coefficients graph. Different graphs for different combinations of variable are drawn to compare the graph with original coefficient graph. The combination of variables whose graph matches with the original coefficient graph is selected for prediction equation. This method is not statistical and only hit and trial method but give good results. The requirement is to give this process a statistical method to select the variables. At the receiving end only the information of course-band coefficients, with difference of error between original and predicted equation is received. The fine sub-band coefficients are predicted using equation for each sub-band. The error is subtracted from the predicted value to get the correct value of each coefficient.

Reconstruction of original image is carried out by combining the course-band coefficients and predicting fine-band coefficients in a single vector and applying inverse lifting wavelet transform on the vector.

After successful reconstruction of the original image, compression rate is calculated. In the process of calculating the compression rate first the numbers of bits in reconstructed image are divided by the number of bits in original image. Compression rate criteria, bits per pixel (bpp) have been used.

6.2 Future Work

Existing techniques to compress the medical images have been based on some steps used in the lossy compression. For example in prediction step quantization is an important step. Quantization is a lossy process in which we cannot recover the original values. In WCAP, which is claimed to be a lossless method, but quantization has been used in prediction step. The difference between the original and prediction value is quantized into only three steps (- 1, 0, 1). When more than hundred steps converted into three steps compression is achieved. Consequently while implementation of WCAP, it has been observed that reconstruction of original image is not possible. The problem is removed in the proposed scheme by “coefficient graphic method” but there is a requirement of compression without lossy step of quantization in lossless compression.

Other area which needs improvement in lossless compression is the coding technique. Presently the arithmetic coding is used, but there should be improvement in the existing coding techniques to develop image compression.

The selection of variable criteria in prediction equation needs further research and improvement. The method used in WCAP “Back Ward Elimination”, is a statistical method, but it is very complex and time consuming. Other disadvantage of the method is that the threshold value below which the variable is required to be discarded is an estimated value. There should be a statistical method to select the threshold to discard the predictor variable.

The whole processes should be streamlined to get a compact transform for lossless image compression based on prediction technique.

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