REVERSIBLE WATERMARKING IN HEALTH DATA MANAGEMENT

by

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B.Tech, Jawaharlal Nehru Technological University, India, 2007

A REPORT

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Electrical and Computer Engineering
College of Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2010

Approved by:

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Abstract

The area of healthcare delivery and medical data management has undergone a huge transformation in the recent years. This is directly related to the significant advancements in information and communication technologies. Vast amounts of medical data is to be efficiently stored, retrieved and distributed. The above mentioned reasons collectively have created new challenges, especially regarding the security of this highly sensitive information.

Digital watermarking is a recently established area of research with many applications. The potential of medical image watermarking has only recently been realized by the research community. Medical image watermarking can be exploited to simultaneously address the issues of data security, archiving, retrieval and most importantly data authentication.

This report discusses the perspectives of digital watermarking in the area of medical data management. Integer wavelet transform has been used to achieve reversible watermarking as every detail is important, especially in the case of medical images. Multiple watermarks which convey patient's personal and examination data, keywords for information retrieval and the physician's digital signature for authentication are embedded in an imperceptible manner. Different types of medical images have been acquired and tested using the proposed method.

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Acknowledgements

I would like to thank Dr. Satish Chandra for guiding me throughout this project. I also like to express my gratitude to Dr. John J. Devore and Dr. Don Gruenbacher for being part of my graduate committee. I would also like to thank each and every personnel in the department of electrical and computer engineering.

Most Importantly, I thank my parents Mr. B. Koteswara Rao and Mrs.B.Anjamma for their love and support.

CHAPTER 1 - Introduction

 "Digital watermarking" means embedding information into digital material that can be detected or extracted later to make an assertion about the data [1]. This digital material may include images, audio, video and other multimedia documents. Digital watermarks can be classified on the basis of certain characteristics and properties that depend on the type of application. These include imperceptibility, resistance to distortions and malicious attacks, the capacity of information, the coexistence with other watermarks, and the degree of complexity of the watermarking method [1].

They can also be classified into reversible and irreversible watermarking. In some applications bit-by-bit exactness in comparison to the original content is desired for the restored media after the embedded watermark is extracted successfully. Watermarking schemes that satisfy this reversibility requirement are called reversible watermarking schemes. Reversible watermarking is drawing more interest in the recent years, especially for some crucial applications such as medical, military imaging, and remote sensing.

This report discusses perspectives of reversible digital watermarking in a range of medical data management and distribution issues and implements a scheme which addresses the issues of medical data protection, archiving, and data authentication.

1.1 Motivation

Medical image watermarking demands a range of watermarks depending on the application and the degree to which it meets the properties of imperceptibility, robustness and capacity. Robust watermarks are identical for authentication applications and the capacity or payload is not an important factor in these applications. On the other hand, if the watermark has to enrich the original data with additional useful information it should meet the capacity requirements.

In order to accommodate all the above mentioned range of applications, multiple watermarks should be jointly embedded, each designed to meet its corresponding needs and restrictions, and being independently retrieved [2].

Medical images have special properties and requirements. Since any damage to the original content of the image can increase the possibility of a misdiagnosis, reversible watermarking is very highly desired in medical image watermarking. Another alternative is to select region of interest (ROI) having diagnostic importance, which is left untouched during the embedding procedure. The rest of the image can be used for embedding the watermark as there is no limitation that applies to diagnostically significant regions [2].

A brief description of watermarking perspectives involved in medical data management follows [2].

1. Data Access: Medical watermarking provides patient confidentiality by embedding patient's data into the image. This prevents the process of storage and transmission of patient's information separately. This would provide a reduction in storage and bandwidth requirements. This also combines patient's information permanently with the image and can only be accessed through a key. In this manner we can control the patient's data access by unauthorized persons.

2. Titles: Watermarks can act as captions or annotations which provide valuable information about the patient's health history. Also, regions of diagnostic significance can be stored using descriptive watermarks.

3. Authentication: Watermarks can serve as identification tools for the physician. It can have a digital signature or an identification code of the physician. This can also be in an encrypted form which will provide an additional layer of security.

4. Data Integrity: Data integrity is of high importance in medical images. It can be achieved by embedding what are called fragile watermarks. These provide tamper protection and any change to the original data will affect the watermark and hence is easily detected. Comparison of original watermark with the retrieved one will provide an idea about extent of damage and can be used to determine if the image has the ability to provide accurate diagnosis.

5. Markers: Watermarks can act as keywords for data archiving, retrieval from large image databases through querying mechanisms. These markers may include diagnostic codes (e.g., ICD9), image acquisition characteristics, etc. Watermarking methods using wavelet transforms can derive image characteristics which can be used for image retrieval.
The above mentioned digital watermarking perspectives indicate the importance of it in data management of medical information systems.

1.2 Methods

There have been different methods of reversible watermarking developed over the years. Here are a few of them:

In the scheme proposed by Fridrich et al. [3], block based DCT is utilized. In the embedding stage, the 128-bit authentication payload h (hash function) of all the DCT coefficients is calculated. A certain number of middle-frequency coefficients are selected from each DCT block. These are selected in a pre-determined fashion. The least significant bits of the selected coefficients are compressed in a lossless fashion. The original bit stream B is compressed to B1. The difference in bits created (B-B1) is used for embedding the authentication payload h. The compressed bit stream and the payload are then concatenated and replace the LSBs of the selected coefficients. To verify the authenticity at the decoding end, the same protocol is followed to select the same middle-frequency coefficients. The compressed bit stream including

the authentication code h is extracted from the LSBs. The extracted bit stream is then decompressed and used to replace LSBs of those selected middle-frequency coefficients. The same hash function is used to obtain h1. If h1 is equal to h, the received image is considered authentic and LSBs of the received image are replaced with the decompressed bit stream to obtain the original image. The hash output gives only global information about the image, the signature of the image, with no local information. When a local attack is done on the coefficients, this algorithm can only give information about the authenticity without being able to locate the position where the tampering actually occurred.

A common method used by Alattar, Tian et al. is to look for two unequally represented sets of pixel groups such that changing of the elements belonging to one set affects its association. A binary location map is created, with each bit corresponding to one pixel group and value (0 0r 1) representing the membership of that pixel group. The location map subsequently undergoes some form of lossless compression. The watermark is combined with the compressed version to form a bit stream for embedding. The embedding is carried out by changing the intensity of pixel groups in order to make their membership consistent with the binary value of their corresponding bit in the bit stream. The watermark extraction consists of verifying the membership of each pixel group in the watermarked image. The original image can be recovered by uncompressing the location map and then changing the intensity of each pixel group so that its intensity becomes compatible to its actual membership recorded in the location map. One major drawback in this scheme is that the ratio of number of elements in two sets is highly dependent on the original image and images with more details tend to have lower ratio. This drastically lowers the embedding capacity.

Van Leest et al. [4] proposed another reversible watermarking scheme based on a transformation function that introduces gaps in the image histogram of image blocks. The transformation function maps the gray level of the input pixel to a unique output value so that one or two values in the range are not used, thus leaving those gaps. These gaps are then used to embed the watermark. By creating more gaps in the mapped domain the embedding capacity can be increased. But this in turn decreases the visual quality of the embedded image. With the help of the embedded overhead information the watermark can be extracted and the original image can be restored. There is one big security concern involved with this scheme, it being

computationally not complex; an attacker can try all the possible 256 gray levels assuming that gray level being tried is the gap.

The report is organized as follows; Chapter 2 introduces the concept of discrete wavelet transform (DWT) and integer wavelet transform. Chapter 3 describes the method used in this report. Chapter 4 and 5 presents the results of the tests performed and conclusion respectively.

CHAPTER 2 - Discrete Wavelet Transform

Multiresolution representations are useful in analyzing the information content of a signal. It helps to analyze the different frequencies present in the signal at different resolutions. The wavelet transform of a signal provides the time frequency representation of the signal without changing the information content of the signal.

Wave is an infinite length continuous function in time or space, whereas the wavelet is a localized which has its energy concentrated in time or space. The basic idea behind wavelet transform is to represent the signal to be analyzed as a superposition of wavelets. Thus wavelet analysis is similar to Short Time Fourier Transform (STFT) analysis. The wavelet function changes its width with each spectral component; the wavelet transform overcomes the inability of the STFT to give good time resolution at higher frequencies and good frequency resolution at lower frequencies.

2.1 Convolution Based DWT

Given a sequence x[n], we can obtain the 1D-DWT by filtering and sub-sampling as depicted in figure 2.1. The input data is initially filtered using an analysis filter bank consisting of a high pass filter, h[n] and low pass filter, g[n]. The filtered signals are then subsampled by a factor of 2 to give s0 [n] and d0 [n]. The low pass and high pass subband sequences respectively.

2. 1

$$s0[n] = \sum_{k=-\infty}^{\infty} x[k]g[2n-k]$$

$$d0[n] = \sum_{k=-\infty}^{\infty} x[k]h[2n-k] \quad \text{2. 2}$$

The forward discrete wavelet transform (DWT) decomposes a 1D sequence to give two sequences with half the number of the samples in the original sequence.
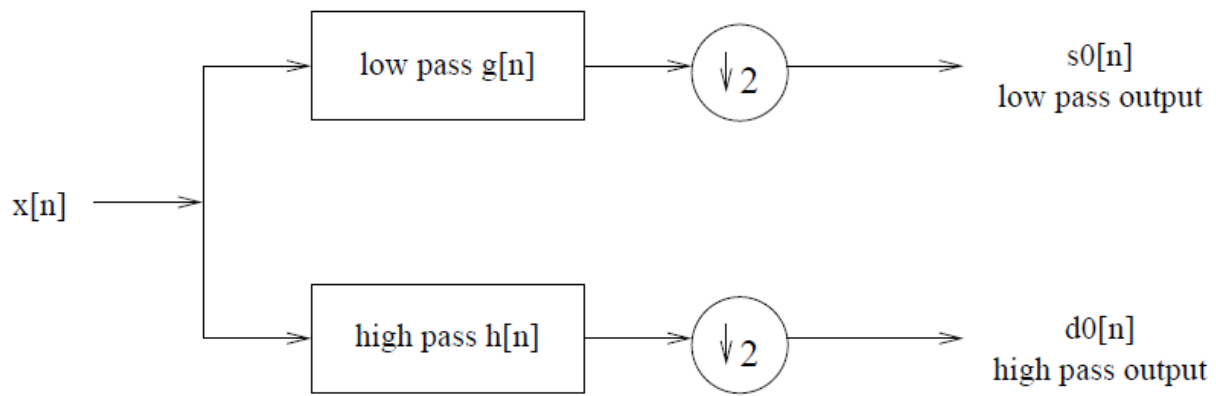
Figure 2.1 1D-DWT Structure

In case of 2D-DWT we get four subbands from one level. The LL subband contains the low level details of the image. In the next level, the 2D-DWT of the LL subband is obtained and this is repeated in each succeeding level.
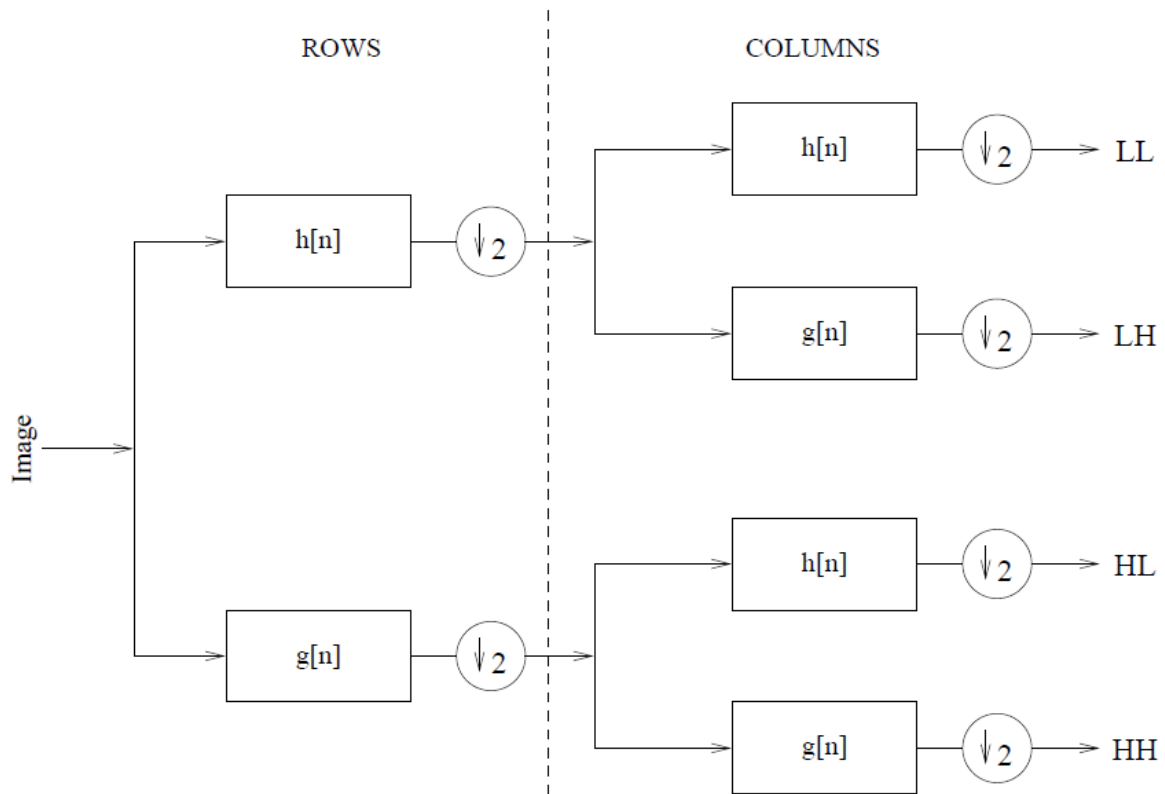

Figure 2.2 Filter bank structure used in wavelet decomposition of an image

2.2 Lifting Based DWT

The lifting scheme is a better method to obtain the wavelet transform than the classical convolution method. The original motivation for the development of the lifting scheme was the implementation of second generation wavelets. Second generation wavelets unlike the first generation wavelets do not use the translation and dilation of the same wavelet prototype in different levels. Any classical wavelet filter bank can be decomposed into lifting steps through use of the Euclidean algorithm.

The number of computations in the lifting scheme is half that of the standard convolution scheme for long FIR filters [5]. The lifting technique also offers several advantages integer to integer wavelet transform, symmetric inverse and forward transform etc. The lifting scheme simplifies the computation of DWT by concentrating on the basic principles behind use of wavelets. The wavelet transform of one dimensional signal gives a multiresolution representation of the signal. At each resolution level, the wavelet basis functions decorrelate the information in the signal and we get a high pass and a low pass component. So, the basic plot of the wavelet transform is to build a sparse approximation exploiting the correlation present in the input signal. The lifting scheme helps to achieve this smaller approximation using fewer computations.

2.2.1 Predict and Update

The lifting scheme consists of three stages: split, predict and update. Consider a one dimensional sequence x[n] whose elements have some correlation between them. We can represent the signal in a compact manner by exploiting the correlation structure present in it [5].

Initially the input signal x[n] is split into two subsets, the even sample set s0 [n] and odd sample set d0 [n]. This is also called lazy wavelet transform. In the predict step the linear combination of elements in one subset are used to predict the values of the other subset using the assumption that the two subsets produced in the splitting step are correlated. If the correlation is high in the original sequence, the predicted values would be close to the actual values. The predict step is shown in equation 2.3, where p[k] is the prediction coefficient. The linear combination of the even subsequence values is used to predict the odd subsequence values.

2.3

$$d1[n] = d0[n] - \sum_k p[k]s0[n-k]$$

The detail variable d1   records the difference between the actual and predicted value. After the predict step, the input sequence is represented in terms of even samples, s0 [n] and detail values, d1 [n].

The predict step causes the loss of some basic properties of the signal like mean value, which needs to be preserved. The update step lifts the even sequence values using the linear combination of the predicted odd sequence values so that the basic properties of the original sequence is preserved [5]. The even sequence values s1 obtained as the result of equation 2.4 is equivalent to the subsampled low pass version of the original sequence.

$$s1[n] = s0[n] - \sum_k u[k]d1[n-k] \quad \text{2.4}$$

The DWT of a one dimensional signal using lifting technique with one pair of lifting steps can be summarized as follows:

1. Split Step: The input sequence x[n] is split into odd and even subsequences, d[n] and s[n] respectively
2. Predict Step: This step predicts data in the subsequence d[n] using the samples in s[n] and replaces the samples in d[n] using the prediction error
   d[n] ←d[n] – P(s[n])
3. Update Step: This step updates s[n] using d[n].
   s[n] ←s[n] + U(d[n])

2.3 Integer to Integer transform

Wavelet transform usually produces floating point coefficients even when performed on integer sequences. The original integer data can be reconstructed perfectly by using these coefficients. It was shown by Calderbank et al., [6], that we can build wavelet transforms that map integers to integers using lifting structure. This is achieved by rounding off the predict filter or update filter output before adding or subtracting in each lifting step. The lifting steps at level I decomposition can be given as,

$$d_{i,1}[n] = d_{i,0}[n] - \left\lfloor \sum_k p_i[k]\, s_{i,0}[n-k] + 1/2 \right\rfloor \qquad \textbf{2.5}$$

2.6

$$s_{i,1}[n] = s_{i,0}[n] - \left\lfloor \sum_k u_i[k]\, d_{i,1}[n-k] + 1/2 \right\rfloor$$

These lifting steps are invertible and inverse lifting steps can be obtained by reversing the operations and flipping the signs.

CHAPTER 3 - Method

3.1 Description

Wavelet analysis has recently received considerable attention from the research community due to its ability to provide time and frequency information simultaneously, hence giving a time-frequency representation of the signal. Research into human perception indicates that the retina of the eye splits an image into several frequency channels each spanning a bandwidth of approximately one octave. The signals in these channels are processed independently. Similarly, in a multiresolution decomposition, the image is separated into bands of approximately equal bandwidth on a logarithmic scale. There is a lot or resemblance between the dyadic scaling decomposition of the wavelet transform and the signal processing of the human visual system (HVS), which allows adapting the introduced by either quantization or watermark embedding to the masking properties of the human eye [7]. It is therefore expected that use of the discrete wavelet transform will allow independent processing of the resulting components without significant perceptible interaction between them.

The watermarking scheme used here addresses different concerns involved in healthcare management systems, namely ability to recover original image without any distortion, medical confidentiality protection, data integrity and access control, efficient data management and also satisfying the strict imperceptibility requirement applicable to medical images. The method embeds four different watermarks,

1) A signature watermark containing doctor's identification code is used for source authentication by the recipient.
2) An index watermark, which is comprised of keywords like diagnostic codes, etc., can be used for image retrieval by database querying mechanisms.
3) A reference watermark, which refers to patient's personal identification like demographics, health history and etc...
4) A caption watermark is also embedded which contains the patient's diagnosis and treatment details.

The watermarks are embedded in different decomposition levels and subbands depending on their type. They can be independently embedded and retrieved, without any interaction among them. By integrating this idea into different medical acquisition systems like CT, MRI, ultrasound, PET and etc...Wide range of applications like e-diagnosis or medical image sharing through PACS (Picture Archiving and Communication) can be achieved. During the process of image acquisition, the physician embeds information like, his/her identification code, patients personal and examination data, keywords for image indexing, and any other information that may be useful for other physician's guidance. The image is watermarked with this info and stored in the hospital database. Image can be retrieved through querying mechanisms.

3.2 Algorithm

The multiple watermarks embedding procedure depends on proper quantization of selected coefficients. This helps in preventing unacceptable modifications of watermark bits by providing integer changes in the spatial domain. This is achieved by selecting the haar wavelet for the image decomposition. It produces coefficients which are dyadic rational numbers, their denominators are powers of 2; addition or subtraction from them of a multiple of 2^l, where l is the decomposition level, assures that the inverse discrete wavelet transform gives integer pixel values. This property is exploited in the embedding procedure.

Wavelet transform normally gives detail coefficients which are real numbers. Through a certain quantization function we assign a binary number to every coefficient.

3.1

$$Q(f) = \begin{cases} 0, & \text{if } 2k.\Delta + s \le f < (2k+1).\Delta + s \\ 1, & \text{if } (2k+1).\Delta + s \le f < (2k+2).\Delta + s \end{cases}$$

where k is an integer, s is a user-defined offset for increased security, and Δ, the quantization parameter, is a positive real number.

The above quantization function Equation 3.1 can also be written as

$$Q(f) = \begin{cases} 0, & \text{if } \lfloor (f-s)/\Delta \rfloor \text{ is even} \\ 1, & \text{if } \lfloor (f-s)/\Delta \rfloor \text{ is odd} \end{cases}$$
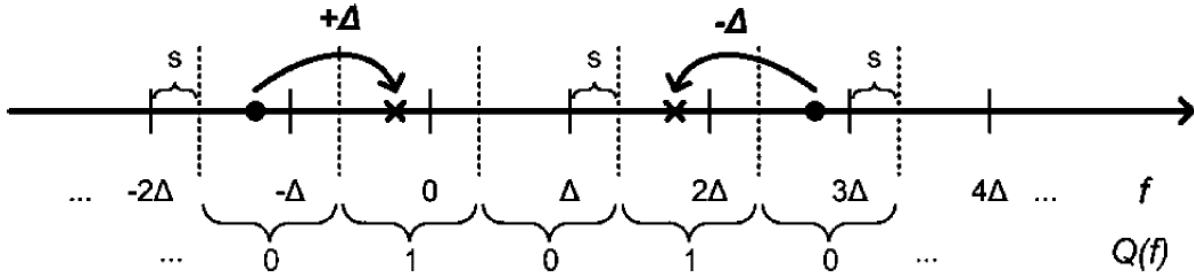
13

Figure 3.1 Quantization Procedure [2]

As discussed previously, subtraction or addition of a multiple of 2^l to the haar coefficients results in integer pixel values through discrete wavelet transform. The embedding procedure consists of adding or subtracting an appropriate constant from the coefficients chosen to be used in the process. We use the quantization parameter Δ, defined as $\Delta = 2^l$, where l is the decomposition level.

The watermark embedding procedure is explained below.

1) The watermark to be embedded is obtained by reading the patient's information from a text file and converting it to binary.

2) The four level lifting wavelet decomposition is performed to obtain a image approximation at level four and sequence of images corresponding to the horizontal, vertical, and diagonal details at each of the four decomposition levels.

3) At each decomposition level, a watermark bit w_i is embedded into the key-determined coefficient f according to the following conditions:

a) If Q (f) $= w_i$, the coefficient is not modified.

b) Otherwise, the coefficient is modified so that Q (f) $= w_i$, using the following equation:

$$f = \begin{cases} f + \Delta, & if\ f \leq 0 \\ f - \Delta, & if\ f > 0 \end{cases} \qquad \textbf{3.3}$$

4) The watermarked image is obtained by performing the four level inverse wavelet transform.
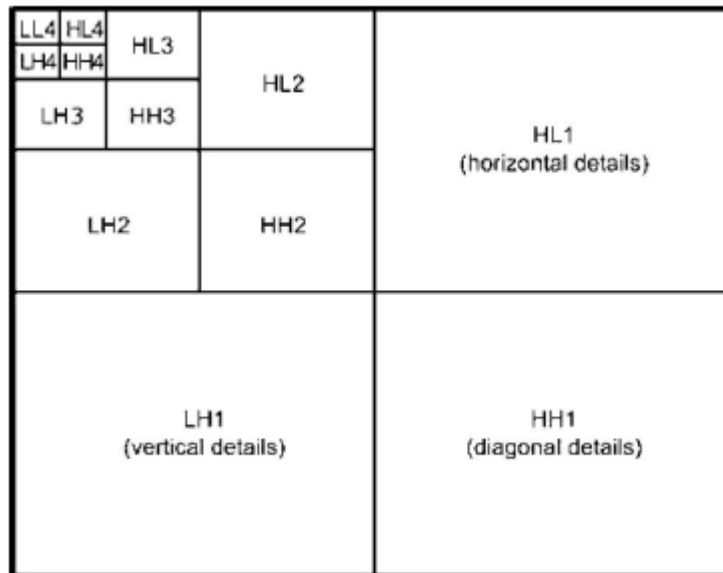

Figure 3.2 Structure of Four level DWT [2]

The above figure 3.2 shows the subband structure of a four-level wavelet decomposition of an image, consisting a coarse scale image approximation at the highest decomposition level LL4, and twelve detail images corresponding to the horizontal HL, vertical LH and diagonal HH details at each of the four levels.

The method of modifying the coefficient to embed the watermark shown in equation 3.3 has shown to cause the least visual degradation to the image [8].

 The watermark extraction process is similar to that of the embedding one except that the extractor requires the knowledge of location of the watermark. This can be implemented through key-based embedding and detection. This prevents unauthorized personnel to access the watermark and tamper with it. The extraction process and restoring the original image is explained below.

1) The four level lifting wavelet decomposition is performed to obtain a image approximation at level four and sequence of images corresponding to the horizontal, vertical, and diagonal details at each of the four decomposition levels for the watermarked image.

2) The watermarked coefficients are identified by key-based detection.

3) Watermark bits are extracted by applying the quantization function shown in equation 3.2 and the original coefficients are also recovered.

4) The lossless image can be obtained by applying the four-level inverse wavelet transform.

The watermark containing the doctor's signature is the most important of the watermarks and requires more robustness to preserve the signature which helps in proper authentication. The capacity is not very important in this case as digital signatures are of limited length. These two points are taken into consideration and signature watermark is embedded in the fourth level. The more the decomposition level the more robust the watermark is. The higher decomposition levels correspond to the perceptually significant, high resolution low frequency components of the image. The common image processing techniques, compression, or attacks effect the high frequency components which are at lower decomposition levels and hence higher the decomposition level more robust the watermark is .

The need for robustness for index, reference and caption watermarks is not as important as for the signature watermark. The size of these above mentioned watermarks is also more than that of the signature watermark. Considering the above points and also the trade-off between the capacity and robustness, index watermark is embedded in the third decomposition level, reference and caption watermarks are embedded in the second and first level respectively.

The horizontal and vertical subbands have more or less the same characteristics and behavior.

The energy of the approximation and detail images obtained by four-level DWT can be calculated,

$$e_k = \frac{1}{N_k \cdot M_k} \sum_i \sum_j |I_{k(i,j)}|$$ **3.4**

Where k denotes the approximation and detail images at each of the decomposition levels, I_k are the coefficients of the subband images, N_k and M_k are their corresponding dimensions.

Subband	Level 1	Level 2	Level 3	Level 4
Approximation	-	-	-	94.79
Horizontal Detail	6.03	9.56	13.34	20.09
Vertical Detail	4.87	8.05	12.74	18.73
Diagonal Detail	3.17	7.47	11.67	19.23

Table 3-1 Energy of Approximation and Detail Images of Four Level DWT

Table 3-1 above gives the energy of the approximation and detail images for a four-level wavelet decomposition of a sample ultrasound image. We can observe that subbands at higher decomposition levels corresponding to perceptually significant low frequency coefficients have more energy than those of lower decomposition levels. We can also observe that horizontal detail subbands have more energy than vertical and diagonal subbands in this case. This can be explained due to the elongation of ultrasound image speckle spots in the horizontal direction [10]. We embed watermarks in the horizontal subbands to ensure greater robustness when compared to other detail subbands. The approximation subband LL4 has most energy of the original image and has a huge impact on image quality. Thus, this it is not used for embedding to retain imperceptibility.

CHAPTER 4 - Results

The algorithm was implemented on different types of images like ultrasound, CT, MRI and regular lena image. Multiple watermarks were read from a patient text file and embedded at various locations in the image. All the images used are of size 256,320.

The multiple watermarks are converted into 7 bit ASCII. The watermark used in this report has a total length of 146 characters which is equivalent to 1022 bits.

Here is a sample watermark with random data,

```
1    DocID F562654
2    IIdx 460-519.9
3    PatRef abcde.180.5'10.030486.asdfgtas
4    Diag Diabet.ype2as.dfghj.klqqwe.asdqwert.sdfge.asdfgert
5    Trtmt abcde.fghij.klqwer.tyuitu.qwerqw.asdcvbgw.qwerasdf
```

As mentioned in the previous chapter, wavelet transform has been used in the watermarking process which in turn results in several subbands. These are known as horizontal, vertical and diagonal coefficients of the transformed image. They can be observed in figure 4.0.
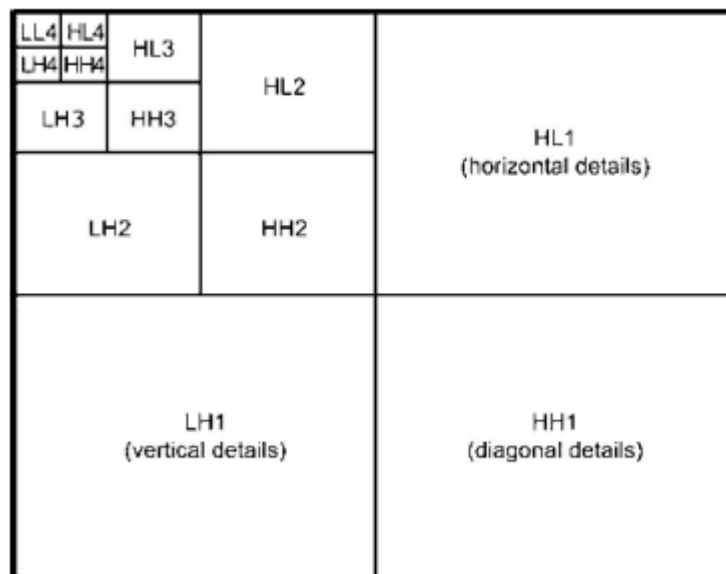

Figure 4.1 Four Level DWT [2]

The algorithm for embedding the watermarks in the image has been explained in chapter 3. The watermarks have been embedded in all the above mentioned subbands and the corresponding peak signal to noise ratio (PSNR) and Mean square error (MSE) have been calculated.

Mean square error (MSE) and peak signal to noise ratio (PSNR) can be calculated as,

$$MSE = \frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} [I(i,j) - I'(i,j)]^2 \qquad \textbf{4.1}$$

Where I is the original image, I' is the watermark embedded image and M, N are the dimensions of the image.

$$PSNR = 20 \cdot log10 \left(\frac{255}{\sqrt[2]{MSE}}\right) \qquad \textbf{4.2}$$

Peak signal to noise ratio (PSNR) is inversely proportional to the mean square error (MSE). Higher the PSNR better the quality of the embedded image.

Some of the original, wavelet transformed and embedded images are displayed below.
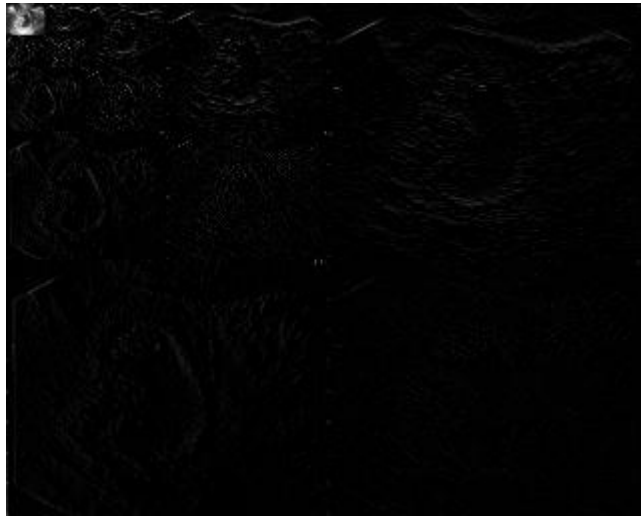

Figure 4.2 Original Ultrasound Image

Figure 4.3 Four Level DWT of Ultrasound Image
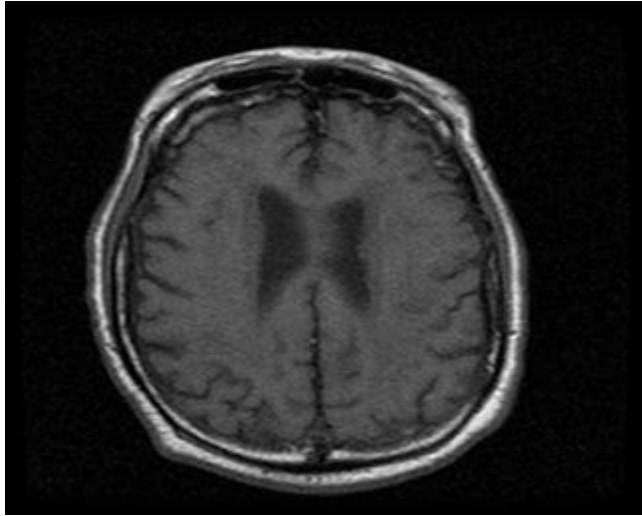

Figure 4.4 Embedded Ultrasound Image
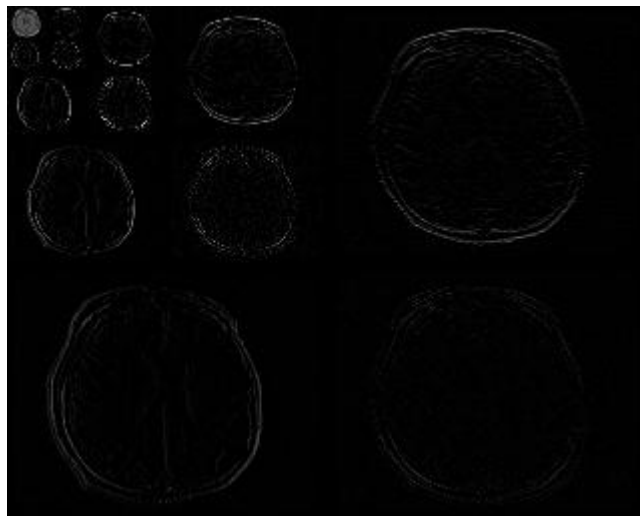
Figure 4.5 Original MRI Image

Figure 4.6 Four level DWT of MRI Image
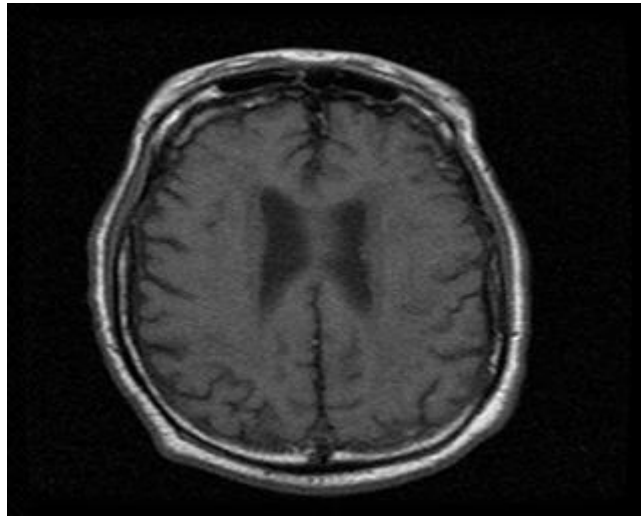
Figure 4.7 Embedded MRI Image

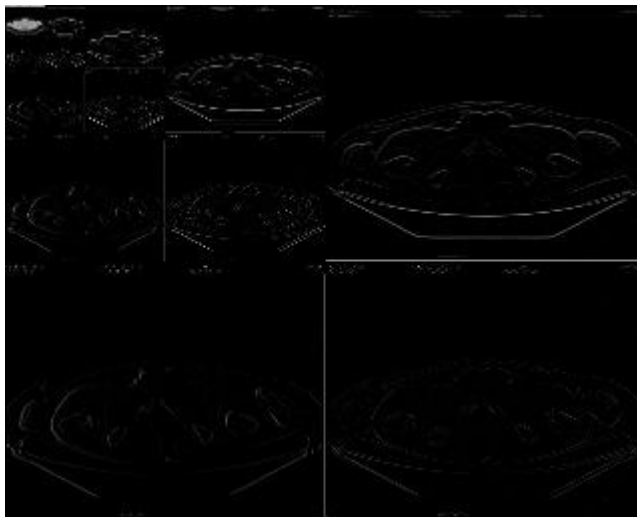**Figure 4.8 Original CT Image**

Figure 4.9 Four level DWT of CT Image

Figure 4.10 Embedded CT Image

Figure 4.11 Original Lena Image
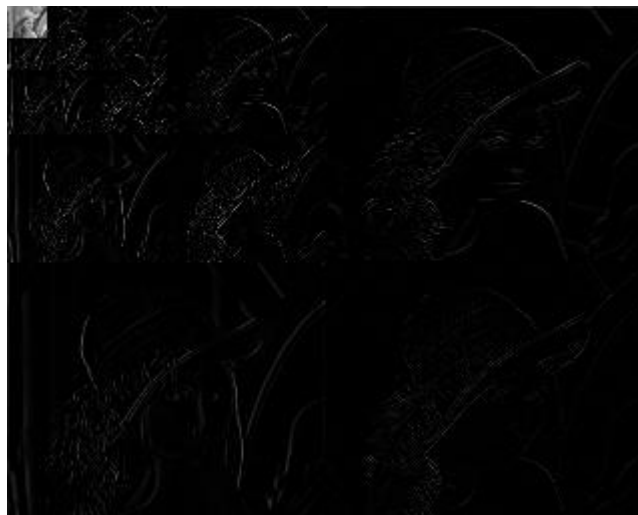
Figure 4.12 Four level DWT of Lena Image

Figure 4.13 Embedded Lena Image

Type of Image	Embedding in Horizontal Coefficients (PSNR)	Embedding in Vertical Coefficients (PSNR)	Embedding in Diagonal Coefficients (PSNR)
Ultrasound	62.173	61.229	82.691
CT Scan	61.639	61.133	84.061
MRI	62.098	61.875	83.914
Lena	61.836	61.044	83.054

Table 4-1 PSNR Values of Images Corresponding to the Embedding Location

Figure 4.14 Comparisons of PSNR for different embedding locations

The results from the above table 4-1 demonstrate that embedding in the diagonal subband of wavelet transform results in a better image quality than compared to embedding in the ho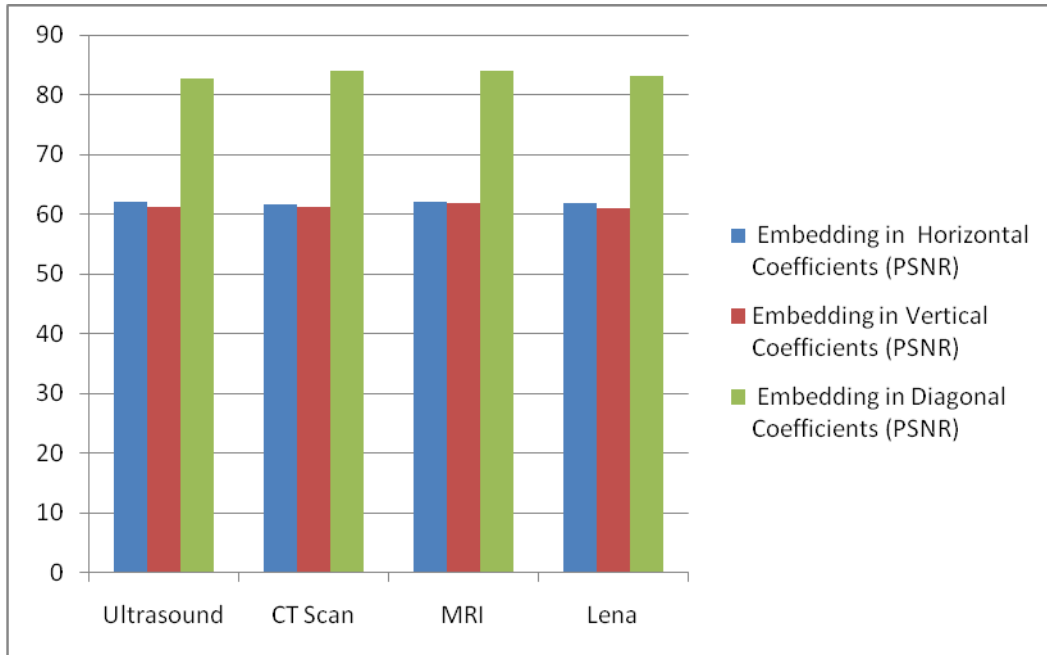rizontal and vertical subbands. The reason for this is that the diagonal subbands have a very little effect on image quality. Embedding the watermark in the diagonal subbands will give us a better PSNR than compared to other subbands. The downside for embedding in the diagonal subbands is that they are very susceptible to common image processing methods, compression and attacks. The tradeoff between robustness and image quality needs to be taken into consideration when designing the watermarking scheme.

We can also observe that there is not much difference in PSNR values between horizontal and vertical coefficients except in the case of ultrasound images. This can be attributed to the

elongation of ultrasound image speckle spots in horizontal direction [9]. Ultrasound images have speckle texture and this is a consequence of physics underlying the data acquisition. Depending on the application, speckle in medical images can be viewed as signal or noise.

In general, both horizontal and vertical subbands have similar characteristics and behavior, in contrast to diagonal ones [9]. Any modification of the image is very likely to affect both horizontal and vertical detail coefficients.

The above presented experimental results of the performed tests illustrate the efficiency of this watermarking scheme. It is also noteworthy that different medical imaging modalities like MRI, CT, and Ultrasound were used in the testing process and the results are very satisfactory. For all the imaging modalities tested, the watermarking scheme caused no distortion that could affect the perceptual quality and diagnostic value of the images. Both subjective perceptual quality and PSNR values indicate the efficiency of the scheme in a range of imaging modalities and also can be a wonderful asset in health data management.

CHAPTER 5 - Conclusion

Medical image watermarking can be used to tackle a range of issues of great importance in health data management. Health informatics including origin, data authentication, efficient data management, storage and retrieval has become more challenging and medical image watermarking provides complementary solutions to these issues.

The watermarking scheme addresses the above issues by imperceptibly embedding different types of watermarks into the wavelet coefficients of medical images and also in a reversible manner. The original image and watermark can be extracted without any loss of information. The experimental results demonstrate the efficiency of the scheme.

Even though the original image can be recovered without any loss, there might still exist a fear of misdiagnosis. Due to which strict limitations apply to alterations of diagnostically significant parts. These diagnostically significant regions are known as Region of Interests (ROI). It is very much possible to add the feature of defining Region of Interests (ROI) and not embed any data in these areas. This can completely alleviate any fears of misdiagnosis. These ROI's are usually defined when images are acquired or archived

This method can be integrated into healthcare information systems to provide greater security and also help in accurate diagnosis thus leading to best practice treatment. This scheme can serve as a great tool to make the complex process of health data management into an easier, secure and reliable system.

Error correction coding like BCH coding can be used to increase the robustness of the embedded data.

The use of integer wavelet transform and wavelet decomposition ensures reversible data hiding. Wavelet subband decomposition is also the basic technique used in JPEG2000 compression. JPEG2000 is a very important part in Digital Imaging and Communications in Medicine (DICOM), a standard for handling, storing, printing, and transmitting information in medical

imaging. It includes a file format definition and a network communications protocol. Future work will be to integrate this watermarking scheme with JPEG2000 compression to provide a better tool in storage and transmission of medical images.

References

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Appendix A - Matlab Code

Main Program

```matlab
% i   -> always for loops
% u,v -> for indexing
clear all;
close all;
%% initalize the variable
fig = 1;
%% read the patient data
fid = fopen('record.txt');
p_data = textscan(fid, '%s %s');
p_data;
fclose(fid);
%% read the image
img     = imread('185.tif');

  size_rgb = size(img,3);
  if ~isempty(size_rgb)
     img     = rgb2gray(img) ;
  end
figure(fig);fig = fig + 1;
imshow(img);%title('Original image');
%% do the wavelet transform on the image

%%-- Haar wavelet
full_coeffs = fourlevelhaardwt(img,0);

ca1=full_coeffs{1};ch1=full_coeffs{5};cv1=full_coeffs{9} ;cd1=full_coeffs{13};% level 1
ca2=full_coeffs{2};ch2=full_coeffs{6};cv2=full_coeffs{10};cd2=full_coeffs{14};% level 2
ca3=full_coeffs{3};ch3=full_coeffs{7};cv3=full_coeffs{11};cd3=full_coeffs{15};% level 3
ca4=full_coeffs{4};ch4=full_coeffs{8};cv4=full_coeffs{12};cd4=full_coeffs{16};% level 4

%%-- Display
```

```
l4=[ca4 ch4; cv4 cd4];
l3=[l4  ch3; cv3 cd3];
l2=[l3  ch2; cv2 cd2];
l1=[l2  ch1; cv1 cd1];
figure(fig); fig = fig + 1;
imshow(uint8(l1));title('4 level Wavelet Transformed image');
%% energy of the images produced by 4 level dwt
% level 1
[M,N]=size(ch1);
energyd1=0;
energyh1=0;
energyv1=0;
for i=1:M
   for j=1:N
      energyd1=energyd1+abs(cd1(i,j));
      energyh1=energyh1+abs(ch1(i,j));
      energyv1=energyv1+abs(cv1(i,j));
   end
end
energyd1=energyd1./(M*N)
energyh1=energyh1./(M*N)
energyv1=energyv1./(M*N)

% level 2
[M,N]=size(ch2);
energyd2=0;
energyh2=0;
energyv2=0;
for i=1:M
   for j=1:N
      energyd2=energyd2+abs(cd2(i,j));
      energyh2=energyh2+abs(ch2(i,j));
      energyv2=energyv2+abs(cv2(i,j));
   end
```

```
end
energyd2=energyd2./(M*N)
energyh2=energyh2./(M*N)
energyv2=energyv2./(M*N)


% level 3
[M,N]=size(ch3);
energyd3=0;
energyh3=0;
energyv3=0;
for i=1:M
    for j=1:N
        energyd3=energyd3+abs(cd3(i,j));
        energyh3=energyh3+abs(ch3(i,j));
        energyv3=energyv3+abs(cv3(i,j));
    end
end
energyd3=energyd3./(M*N)
energyh3=energyh3./(M*N)
energyv3=energyv3./(M*N)

% level 4
[M,N]=size(ch4);
energyd4=0;
energyh4=0;
energyv4=0;
energya4=0;
for i=1:M
    for j=1:N
        energyd4=energyd4+abs(cd4(i,j));
        energyh4=energyh4+abs(ch4(i,j));
        energyv4=energyv4+abs(cv4(i,j));
        energya4=energya4+abs(ca4(i,j));
```

```
    end
end
energyd4=energyd4/(M*N)
energyh4=energyh4/(M*N)
energyv4=energyv4/(M*N)
energya4=energya4/(M*N)

%% embed the water marks
end_index_4 = 0;
end_index_3 = 0;
end_index_2 = 0;
end_index_1 = 0;
roi = [];
%% wm mask
ch1_wm_mask = zeros(size(ch1));
ch2_wm_mask = zeros(size(ch2));
ch3_wm_mask = zeros(size(ch3));
ch4_wm_mask = zeros(size(ch4));
%% embed doctor's Signature
d_ref  = char(p_data{2}{1});
[e_ch4, end_index_4, ch4_wm_mask] = embedwm(d_ref,    ch4, 1, end_index_4+1,
ch4_wm_mask);
%% embed image idex
i_ind  = char(p_data{2}{2});
[e_ch3, end_index_3, ch3_wm_mask] = embedwm(i_ind,    ch3, 2, end_index_3+1,
ch3_wm_mask);
%% embed patient's ref id
p_id   = char(p_data{2}{3});
[e_ch2, end_index_2, ch2_wm_mask] = embedwm(p_id ,    ch2, 4, end_index_2+1,
ch2_wm_mask);
%% embed diagnosis
diag   = char(p_data{2}{4});
[e_ch1, end_index_1, ch1_wm_mask] = embedwm(diag ,    ch1, 5, end_index_1+1,
ch1_wm_mask);
```

```
%% embed treatment
treat  = char(p_data{2}{5});
[e_ch1,   end_index_1,   ch1_wm_mask]   =   embedwm(treat,e_ch1,   5,   end_index_1+1,
ch1_wm_mask);

%% inverse DWT to get water marked image

full_coeffs  = {ca1,e_ch1,cv1,cd1;
          ca2,e_ch2,cv2,cd2;
          ca3,e_ch3,cv3,cd3;
          ca4,e_ch4,cv4,cd4};
embedded_img =  fourlevelhaardwt(full_coeffs,1);

% max(max(embedded_img))
% min(min(embedded_img))

%%-- display
figure(fig); fig = fig + 1;
imshow(uint8(embedded_img));%title('Embedded image');

%% retrieve the water mark
end_index_4 = 0;
end_index_3 = 0;
end_index_2 = 0;
end_index_1 = 0;

%%-- Haar wavelet
full_coeffs = fourlevelhaardwt(embedded_img,0);

e_ca1=full_coeffs{1};e_ch1=full_coeffs{5};e_cv1=full_coeffs{9}      ;e_cd1=full_coeffs{13};%
level 1
e_ca2=full_coeffs{2};e_ch2=full_coeffs{6};e_cv2=full_coeffs{10};e_cd2=full_coeffs{14};%
level 2
```

```
e_ca3=full_coeffs{3};e_ch3=full_coeffs{7};e_cv3=full_coeffs{11};e_cd3=full_coeffs{15};%
level 3
e_ca4=full_coeffs{4};e_ch4=full_coeffs{8};e_cv4=full_coeffs{12};e_cd4=full_coeffs{16};%
level 4

%%-- Display
e_l4=[e_ca4 e_ch4; e_cv4 e_cd4];
e_l3=[e_l4  e_ch3; e_cv3 e_cd3];
e_l2=[e_l3  e_ch2; e_cv2 e_cd2];
e_l1=[e_l2  e_ch1; e_cv1 e_cd1];
figure(fig); fig = fig + 1;
imshow(uint8(e_l1));title('water marked wavelet');
%% get doctor's signature
[d_ref end_index_4 r_ch4] = retrievewm(e_ch4, 1, end_index_4+1, 7, ch4_wm_mask);
disp(sprintf('DocID %s',d_ref))
%% get image index
[i_ind end_index_3 r_ch3] = retrievewm(e_ch3, 2, end_index_3+1, 9, ch3_wm_mask);
disp(sprintf('IIdx %s',i_ind))
%% get patient's id
[p_id  end_index_2 r_ch2] = retrievewm(e_ch2, 4, end_index_2+1, 30, ch2_wm_mask);
disp(sprintf('PatRef %s',p_id))
%% get diagnosis
[diag  end_index_1 r_ch1] = retrievewm(e_ch1, 5, end_index_1+1, 50, ch1_wm_mask);
disp(sprintf('Diag %s',diag))
%% get treatment
[treat end_index_1 r_ch1] = retrievewm(r_ch1, 5, end_index_1+1, 50, ch1_wm_mask);
disp(sprintf('Trtmt %s',treat))

ms=mse(double(img)-double(embedded_img))
psnr=20*log10((255*255)/(ms*ms))

%% inverse transform to get original
r_l4=[ca4  r_ch4; cv4 cd4];
r_l3=[r_l4 r_ch3; cv3 cd3];
```

r_l2=[r_l3 r_ch2; cv2 cd2];

r_l1=[r_l2 r_ch1; cv1 cd1];

figure(fig); fig = fig + 1;

imshow(uint8(r_l1));title('Recovered wavelet image');

full_coeffs = {ca1,r_ch1,cv1,cd1;

ca2,r_ch2,cv2,cd2;

ca3,r_ch3,cv3,cd3;

ca4,r_ch4,cv4,cd4};

recovered_img = fourlevelhaardwt(full_coeffs,1);

% max(max(embedded_img))

% min(min(embedded_img))

%%-- display

figure(fig); fig = fig + 1;

imshow(uint8(recovered_img));%title('Recovered image');

max(max(double(r_l1) - double(l1)))

max(max(double(recovered_img) - double(img)))

Functions with in the program

function ret_val = fourlevelhaardwt(ip,i)

els = {'p',[-0.125 0.125],0};
lshaarint = liftwave('haar','int2int');
lsnewint = addlift(lshaarint,els);

if i == 0 % forward DWT

   img=double(ip);

  [ca1,ch1,cv1,cd1] = lwt2(img,lsnewint);% level 1

```matlab
    [ca2,ch2,cv2,cd2] = lwt2(ca1,lsnewint);% level 2
    [ca3,ch3,cv3,cd3] = lwt2(ca2,lsnewint);% level 3
    [ca4,ch4,cv4,cd4] = lwt2(ca3,lsnewint);% level 4

    ret_val = {ca1,ch1,cv1,cd1;
            ca2,ch2,cv2,cd2;
            ca3,ch3,cv3,cd3;
            ca4,ch4,cv4,cd4};

else % inverse DWT

    ca1=ip{1};ch1=ip{5};cv1=ip{9} ;cd1=ip{13};% level 1
    ca2=ip{2};ch2=ip{6};cv2=ip{10};cd2=ip{14};% level 2
    ca3=ip{3};ch3=ip{7};cv3=ip{11};cd3=ip{15};% level 3
    ca4=ip{4};ch4=ip{8};cv4=ip{12};cd4=ip{16};% level 4

    il4    =ilwt2(ca4,ch4,cv4,cd4,lsnewint);
    il3    =ilwt2(il4,ch3,cv3,cd3,lsnewint);
    il2    =ilwt2(il3,ch2,cv2,cd2,lsnewint);
    ret_val=ilwt2(il2,ch1,cv1,cd1,lsnewint);

    %ret_val = uint8(ret_val);
    ret_val = ret_val;
end

function [embedded_coeff, end_index, mask] = embedwm(data, coeff, level, start_index, mask)


%% initialize
delta = 2^level;
step  = 5;
embedded_coeff = coeff;
start_index    = start_index-1;
wtr_mrk = [];
%% get data to be embedded
emb_data   = char(data);
emb_data_b = st2bi(emb_data);
%% embed the data
m    = length(emb_data);
for i = 1:m
   u    = start_index + (i-1)*8+1;
   v    = start_index + i*8;

   %%-- get the quantized coeff
   emb_coef = embedded_coeff(u:v);
   q_coef   = floor((emb_coef - step)/delta);
   q_coef   = mod(q_coef,2);

   %%-- get the mask
   coeffs_mask = mask(u:v);
```

```matlab
    %%-- get the 8 bit watermark
    wtr_mrk  = emb_data_b(u-start_index:v-start_index)';

    %%-- compare the q coeffs with the water mark
    cmp     = xor(wtr_mrk, q_coef);
    indx    = find(cmp==1);

    %%-- change the coeff based on the comparison
    zero_mask        = xor(emb_coef(indx),ones(1,length(indx)));
    coeffs_mask(indx)  = coeffs_mask(indx) - sign(emb_coef(indx))      + zero_mask;
    emb_coef(indx)     = emb_coef(indx)    - sign(emb_coef(indx))*delta + zero_mask*delta;


    embedded_coeff(u:v) = emb_coef;
    mask(u:v)          = coeffs_mask;
 end

end_index = v;

return;

function [wm, end_index, r_coeffs] = retrievewm(coeffs, level, start_index, length, mask)

%% initialize
wm = [];
delta = 2^level;
step  = 5;
zigma = 2;
start_index =  start_index - 1;
r_coeffs    = coeffs;
for i = 1:length
   u    = start_index + (i-1)*8+1;
   v    = start_index + i*8;

   %%-- get the embedded coeffs
   embedded_coeff  = coeffs(u:v);

   %%-- get the quantized coeffs
   q_coef       = floor((embedded_coeff - step)/delta);
   q_coef       = mod(q_coef,2); %%-- for verification end

   %%-- water mark
   wm = [wm, q_coef];

   %%-- get the original coeffs
   r_coeffs(u:v)  = coeffs(u:v) - delta*mask(u:v);
end

wm = bi2st(wm);  %%-- for verification end
end_index = v;
```

```matlab
function biVect = st2bi(textStr)


   Ascii = uint8(textStr);

   biSt = transpose(dec2bin(Ascii,8));
   biSt = biSt(:);

   N = length(biSt);
   biVect = zeros(N,1);

   for i = 1:N
      biVect(i) = str2double(biSt(i));
   end

   biVect = logical(biVect);

end


function x = bi2st(biVect)


   biVals = [ 128 64 32 16 8 4 2 1 ];

   biVect = biVect(:);

   if mod(length(biVect),8) ~= 0
      error('Length of binary vector is not a multiple of 8.');
   end

   biMatx = reshape(biVect,8,[]);

   x = char(biVals*biMatx);


end
```