SOCIETY FOR SCIENCE AND EDUCATION UNITED KINGDOM

JBEMi JOURNAL OF BIOMEDICAL ENGINEERING AND MEDICAL IMAGING

ISSN: 2055-1266
VOLUME 4 ISSUE 2

Comparative Study of Medical Image Contrast Enhancement using Discrete Wavelet Transform and Dual Tree Complex Wavelet Transform

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ABSTRACT

Image Enhancement is one of the most important preprocessing technique in image processing technology that leads to improvement of contrast and visual appearance of an image to make the original image more appropriate for specific application. Medical image enhancement is the area of active research. Many techniques have already been proposed and implemented for enhancement of digital images for their specific application domain, wavelet transform is found as one of them that has been proved very simple and effective, which is a multiresolution analysis of an image using a set of analyzing functions that are dilations and translations of a few functions. Discrete Wavelet Transform (DWT) and Dual Tree Complex Wavelet Transform (DTCWT) are most popular techniques for medical image enhancement. DTCWT has been found better than DWT due to its properties like shift invariance, less aliasing and better directionality than DWT. These properties play an important role in biomedical image enhancement. For these reasons, to obtain some improvements in clinical diagnosis and pathological applications, DWT is replaced by Dual tree complex wavelet transform. Experimental results are presented to illustrate the comparison of DWT and DTCWT to a set of medical images.

Keywords: Medical Image Enhancement, DWT, DTCWT, MSE, PSNR, MAE.

1 Introduction

The goal of medical image enhancement is to upgrade the interpretability or perception of information contained in image for human or computer based diagnosis. Image enhancement plays an important role in various areas like medical image processing, speech recognition, microscopic imaging, industrial X-ray image processing etc.

Recently a lot of work regarding image enhancement algorithms has been done to improve visual quality of image such as medical images, satellite imaging and real life photographs from digital cameras etc which require color contrast enhancement to provide better picture details of an image for specific applications. Considerable attention has to be paid towards the use of medical image enhancement with the use of advanced medical equipments as the surgeons need enhanced images for better interpretation and diagnosis e.g. for reviewing atomic region in MRI and ultrasound images. Medical image enhancement is concerned to the devise and implementation of problem-specific approaches to the enhancement to

DOI: 10.14738/jbemi.42.3109
Publication Date: 29th April 2017
URL: http://dx.doi.org/10.14738/jbemi. 42.3109

improve visual quality of image as well as further analysis. There has been a lot of research mainly on frequency domain methods. Wavelet transform, a new time –frequency analysis tool was developed and which accomplished desired results in image processing field after Mallat[14] presented the fast decomposition algorithm. There are many image enhancement techniques based on wavelet transform such as Lu et al[13], Yang and Hansell [27], Fang and Qi [5], Zhou et al [29] etc.

Experimental results of medical images have proved that DTCWT has better performance of enhancement, details preservation and low computation complexity than DWT.

The rest of paper is organized as follows: Section 2 describes the Existing methods for Image Enhancement. Section 3 gives the basic concepts of Wavele¬¬¬t transform and its types. In Section 4, methodology adopted for medical image enhancement using DWT and DTCWT is explained in detail. Section 5 presents the results of contrast experiments on medical ultrasound images and finally, Section 6 draws the conclusion.

2 The Existing Ranking Methods

In 2005 a method was proposed in which wavelet transform had been applied with filters and making use of zero padding of high frequency subbands, high resolution images were generated. Low resolution images are improved in visual quality by wavelet domain resolution enhancement using zero padding method i.e WZP [2].

In 2007 interpolation filters were designed by using correlation between lower level subband and higher level subband. First wavelet transform is applied to low resolution images and filters are estimated accordingly , these estimated filters are now used to estimate bands in higher level. After that inverse wavelet transform is applied to enhance the resolution of input image [24].

In 2011 used Stationary wavelet transform to enhance high frequency components of images. Comparatively better results were produced using this technique [8].

Another method was based on decomposition of original image into different subbands with the help of DTCWT. Then interpolation is applied to both high frequency subband images and original images. Finally IDTCWT is applied on interpolated images to get high resolution images. Super resolved images produced by this method have better PSNR and visual quality than other methods [10].

Main challenge for the scientists and researchers was to preserve details of image along with required enhancement as there are some problems with Discrete wavelet transform like it produces artifacts and lack of directional sensitivity due to which image enhancement is done at the cost of complications in preservation of features of image like edges, ridges and boundaries. Complex wavelet transform was thought of as a solution of such problems but CWT uses complex filtering approach to decompose a signal into real and imaginary parts in wavelet domain and complex filters were not that much easy to design. Hence CWT could not find much useful in image processing domain. In wavelet domain approach, Dual tree complex wavelet transform has been devised and observed to provide shift invariance and still produces perfect reconstructed signal.

3 Wavelet Transform

Wavelet transform is a technique by which a signal can be decomposed into set of basis functions called wavelets. Prior to wavelet transform, Fourier transform were used. But Fourier transform can only retrieve the frequency content of a signal and consequently time information of the same gets lost. Wavelet transform retrieves both time domain and frequency domain information of the signal.

The wavelet transform can be described mathematically as follows:

$$w_k^j = \int f(x)\Psi\left(\frac{x}{2^j} - k\right)dx \quad (1)$$

where ψ is called the mother wavelet which is a transforming function and the signal which is to be transformed is given by f(x), j is scale of decomposition and k is the translation parameter. Wavelet transform can be broadly classified as:

a) Continuous wavelet transform (CWT)
b) Discrete Wavelet Transform (DWT)
c) Complex Wavelet Transform (ℂWT)

Continuous wavelet transform (CWT): It is similar to Fourier transform, in which convolution between signal and analyzing function is done to find the similarity between them. The difference between both lies in different analyzing function for them. In Fourier transform the analyzing function are complex exponential e^{jwt},whereas in CWT the analyzing function is wavelet Ψ.

Discrete Wavelet Transform (DWT): Discrete wavelet transform is multiresolution in nature which has made it popular in many applications where scalability and tolerable degradation are important. DWT transforms a

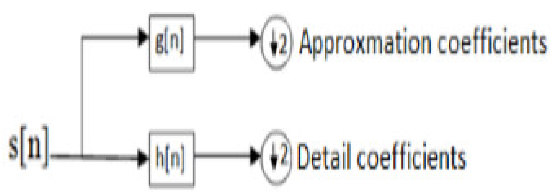


Figure 1: Single stage decomposition in DWT

discrete time signal to a discrete wavelet representation by using filter banks. To calculate DWT of the signal, the

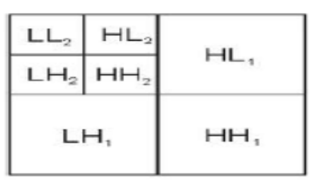


Figure 2: Two dimensional decomposition in DWT

signal is passed through a chain of two complementary filters known as quadrature mirror filter as they are essential to be related with each other. First the signal s(n) is passed through low pass filter with impulse response g(n) leading to emergence of approximation coefficients The convolution can be expressed mathematically as:

$$y(n) = (s * g)[n] = \sum_{k=-\infty}^{\infty} s(k)g(n-k) \quad (2)$$

where y(n) is the output signal after the application of g(n) filter coefficients on the input signal s(n). The above mentioned mechanism has been shown in fig. 1 where the same signal s[n] is simultaneously fed to low pass filter g(n) and high pass filter h(n) whose output are approximation coefficients $\mathrm{y}_{\mathrm{low}}$ detail coefficients and $\mathrm{y}_{\mathrm{high}}$ respectively.

$$y_{low} = \sum_{k=-\infty}^{\infty} s(k)g(2n-k)$$

$$y_{high} = \sum_{k=-\infty}^{\infty} s(k)h(2n+1-k) \quad (3)$$

After the decomposition and down sampling approximation and detail coefficients are obtained, All the components are assembled back to reconstruct original signal such that no loss of information must take place.

DWT for an Image: Image is a two dimensional signal the high frequency and low frequency sub images frm an image can be obtained by therefore DWT by applying 1D DWT along the rows of an image signal first followed by applying on the columns of the image, the high frequency sub images comprise image's edge features information and detail information which can be further decomposed into N levels to get 3N+1 different frequency bands i.e. LL,LH,HL and HH bands, which is shown in fig. 2.

1,2 Decomposition levels
H- High frequency bands
L- Low frequency bands
These all subbands contain different features of an image such as LL Band provides approximation coefficients, LH contains horizontal details, HL band provides vertical details and HH band contains the diagonal details of an image at a specific level of decomposition.

1) Complex Wavelet Transform: There are some disadvantages of ordinary wavelet transform like down sampling operation at each level in wavelet transform leads to Lack of shift invariance due to which a high variation in amplitude of wavelet coefficients occurs because of a slight change in input signal
2) Lack of directional selectivity, which occurs due to incapability of DWT to distinguish between the opposing diagonal directions
3) Absence of phase information, which is the incapability of DWT to provide the local phase information when there is complex valued signal whose phase can be found from its real and imaginary projections and DWT uses separable filtering with real coefficient filters that gives real valued detail and approximation coefficients.

If complex wavelet filters are used then good directionality approximate up to six directions and improved shift variance can be achieved. Such improved form of DWT is called Complex wavelet transform ($\mathbb{C}$WT) which is used to generate complex wavelet coefficients but complex wavelet transform has not been used much in image processing because complex filters were not easy to design.

Kingsbury [16] put forward a new implementation of complex wavelets known as Dual tree complex wavelet transform (DTCWT) which has been proved more efficient than DWT and also overcome the difficulty of designing complex filters. DTCWT is found to produce all the effects of complex coefficients without the use of complex filters. Two separate DWT decompositions are used in DTCWT using two filter banks to calculate the complex transform of a signal. If care is taken while designing the filters such that the filters that are used in one decomposition stage are related with those in other one then it is possible to produce both real and complex coefficients. For an N point signal this transform produces 2N DWT coefficients which make it two times expansive. DTCWT has proven better than DWT in preserving details of an image and giving phase information which plays important role in clinical diagnosis applications.

4 Methodology

4.1 DWT based bio – medical image contrast enhancement

The input biomedical image is decomposed into high and low frequency sub bands using Wavelet Transform followed by Haar Transform. There is plenty of information present in High frequency sub bands, hence it becomes necessary to further decompose the high frequency sub images But these sub-images contain a lot of noise as well, therefore even after applying Haar transform noise is still left in these sub- images. Before applying enhancement method it is very much necessary to reduce noise of high frequency which can be done by using threshold method. Different soft threshold values are used for thresholding high as noise properties vary in these sub images.

By considering characteristics of these sub-images threshold values can be set using following formula:

$$X_{jil} = \sigma_{jil}\sqrt{2\log N_{jil}} \tag{4}$$

where

$$\sigma_{jil} = \sum_{k=1}^{N_{jil}} \frac{1}{N_{jil}}\left(x_{jil}^{k} - \bar{x}_{jil}\right)^2$$

In the given formula variable j gives the scale levels, i(i=1,2,3) indicates HL, LH, HH high frequency sub-bands resp.and l(l=00,01,10,11) signifies high frequency sub- images of frequency i and $\bar{x}_{jil}$ is the mean value of jil sub-image. Noise in these sub-images can be reduced by using following formula:

$$S(x,y) = \begin{cases} H(x,y) - X_{jil,} & H(x,y) \geq X_{jil} \\ 0, & -X_{jil} \leq H(x,y) \leq X_{jil} \\ H(x,y) + X_{jil,} & H(x,y) \leq X_{jil} \end{cases} \tag{5}$$

where X_{jil} are soft threshold values of the jil sub-image, values, H(x, y) represents the high-frequency coefficient of the position (x, y) in the jil sub-image, and S(x, y) gives the coefficient of the position (x, y) denoised. After thresholding the wavelet coefficients are multiplied with the enhancement weight values which are different for different sub-images and these weight values are calculated by using $S(x,y)$ values for particular position values.

4.2 DTCWT based bio – medical image contrast enhancement

First, Complex Wavelet Transform of level 1 is applied to input bio medical image. The weight coefficient based on histogram equalized input image and input image is calculated using the following formula

$$w = \frac{\max(S_1) + \max(S_2)}{2\times\max(S_1)} \tag{6}$$

where Singular Value Decomposition of the histogram equalized image is given by S2 that of the input image is given by S1.

Then the calculated weight coefficient is applied to get SVD Equalized image

$$L_e = U_1 \times S_w \times V_1^T \tag{7}$$

where U_1 and V_1 are orthogonal square matrices, L_e is enhanced low frequency sub-image Sw is given as follows

$$S_w = w \times S_1 \tag{8}$$

The above SVD Equalized image is used along with the low frequency coefficients for inverse complex wavelet transform to get the image with contrast enhancement.

Fig. 3 and 4 shows the process flow of Image enhancement using DWT and DTCWT respectively where block labeled as D represents Down sampling operation, block U indicates up sampling operation, block L stands for sub images of low frquency and bock H shows high frequency respectively.

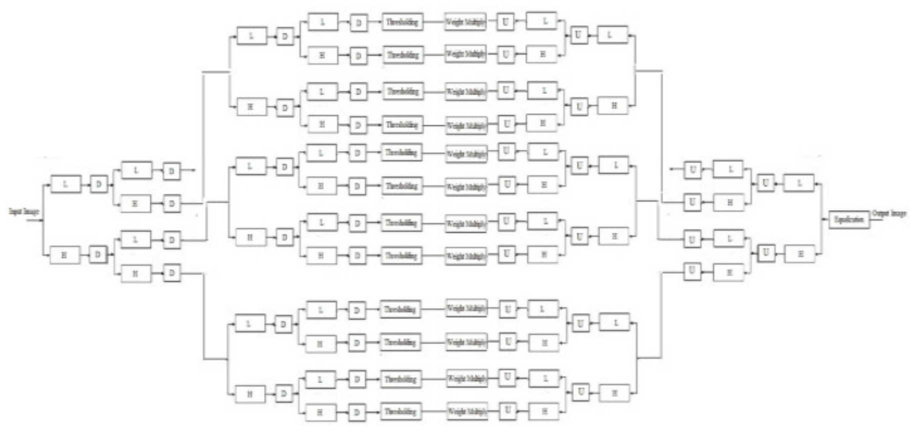


Figure 3: Mechanism of image enhancement using DWT

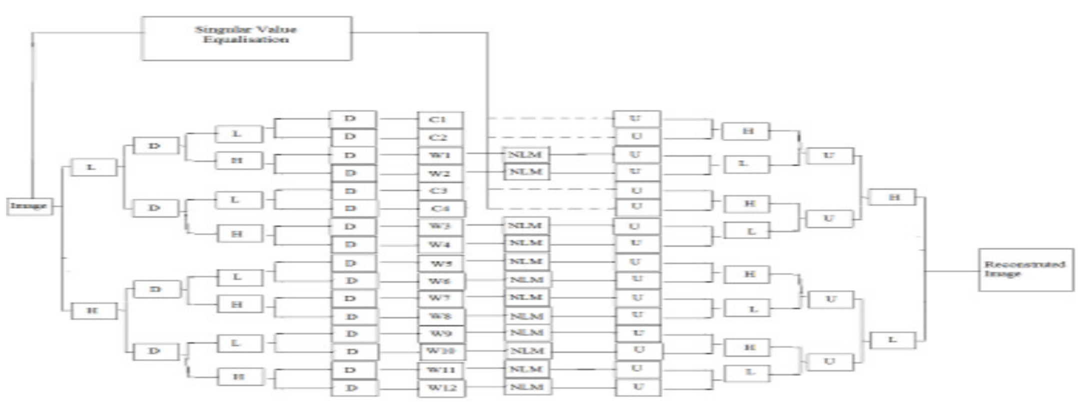
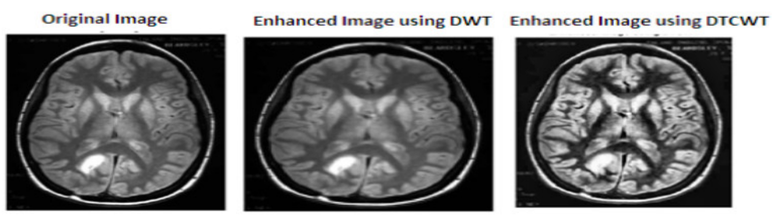


Figure 4: Mechanism of image enhancement using DTCWT

C1, C2, C3 and C4 are those image coefficients which have been produced by low pass filtering and W1, W2,W3……W12 are the wavelet coefficients that are produced by high pass filtering. NLM

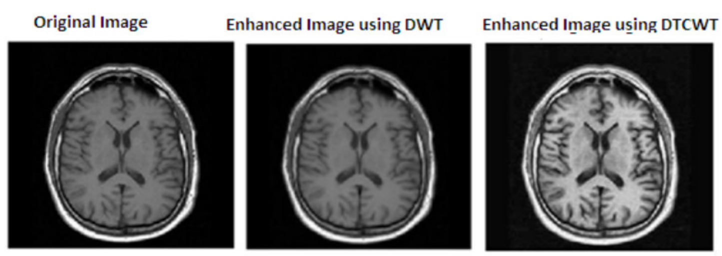
5 Results and Discussions

Biomedical Image Contrast Enhancement techniques have been implemented on some medical images to show the superiority of these techniques with the help of some quality metrics like MAE (mean absolute error), MSE (mean square error) and PSNR (Peak Signal to Noise Ratio). MSE gives the squared error between the enhanced and the original image, Mean Absolute Error between two digital images gives the absolute similarity measurement of these images to each other whereas PSNR measures the ratio between the power of a signal and the power of distorting noise. The required values of these parameters mostly dependent on type of application, however the quantitative and qualitative parameters are tools to compare the effectiveness of a particular algorithm on image quality.. Fig. 5(a, b,c) and 6(a, b,c) are shown below in that fig. (a) is input image, (b) is high contrast image obtain from contrast enhancement using DWT technique and (c) is high contrast image obtain from contrast enhancement using DTCWT. Also Table 1 shows the quantitative results i.e., MAE, MSE and PSNR for both the techniques respectively. The visual and quantitative results ascertain the effectiveness of DTCWT over DWT for contrast enhancement of medical images.



(a) (b) (c)

Figure 5 First medical image and respective processing on it to enhance the same



(a) (b) (c)

Figure 6 Second medical image and respective processing on it to enhance the same

Table 1 Calculated performance parameters of Enhanced Medical Images

S.No.	PSNR		MSE		MAE	
	DWT	DTCWT	DWT	DTCWT	DWT	DTCWT
1	25.81	40.51	0.0026	0.0010	2.5940	1.5586
2	25.22	32.95	0.0030	0.0011	3.0134	2.1046

5 Conclusion

Improved MSE, MAE and PSNR have been found with the use of DTCWT when compared to that of ordinary DWT. This improvement is due to near shift invariance and good directionality of wavelet coefficient using DTCWT which can be thought as an efficient method and will be very useful in medical imaging for pathological and clinical applications in diagnosis purpose.

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