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Image Denoising using different Wavelet Transforms with Hard and Soft Thresholding

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Abstract— Image denoising is very important application in the field of image processing. Wavelet transform can be used for image denoising to achieve more accurate results. Different wavelet transform exists in literature and can be classified as continuous and discrete wavelet transforms. In this paper discrete wavelet transforms like Haar, Bior, Symlet, Daubechie and Coiflet have been used with hard and soft thresholding techniques and with different levels of decompositions. The image denoising capability of each transform has been measured in term of peak signal to noise ratio. Simulation results have been presented.

Keywords— Denoising, Hard Threshold, Peak Signal to Noise Ratio, Soft Threshold, Wavelet Transform.

I. INTRODUCTION

An image is a two-dimensional function f(x,y), where x and y are the spatial coordinates, and the amplitude of at any pair of coordinates (x,y) is called the intensity or gray level of the image at that point[1]. Images are often corrupted with noise during image acquisition and transmission. For example during the image acquisition, the performance of imaging sensors is affected by a variety of factors, such as environmental conditions and by the quality of the sensing elements themselves. The noise degrades the quality of an image and loss the useful information details. The noisy image is visually unpleasant and it is difficult to perform various further analyses like segmentation, recognition and compression. Therefore, it is very important to reconstruct an original image from the corrupted observations. Noise is unwanted signal that interferes with the original signal and degrades the visual quality of digital image. Image denoising techniques are necessary to remove such noise while retaining as much as possible the important signal feature. The main objective of noise removal is to suppress the noise while preserving the original image details. Image denoising is required before the image data are analyzed. Conventional analysis methods can be classified into: time domain and the frequency domain. The frequency domain analysis is more attractive one because it can give more detailed information about the signal and its component frequencies whereas; the time domain analysis can give overall qualitative information. This paper presents comparison of different wavelet transforms for hard and soft threshold with different levels of denoising. The paper is organized as follows: section I is introduction, section II present the comparison between Fourier transform and wavelet transform, basics of wavelet transform and denoising algorithm is presented in section III, simulation results have been presented in section IV, section V is conclusion and section VI is future work.

II. FOURIER TRANSFORM VS. WAVELET TRANSFORM FOR DENOISING

Traditionally, Fourier transform (FT) was used to perform such analysis. It is well known from Fourier theory that a signal can be expressed as the sum of a possibly infinite, series of sines and cosines referred as a Fourier expansion. The main disadvantage of a Fourier expansion, is that it has only frequency resolution and no time resolution. To overcome this problem from many years, many solutions have been developed which are more or less able to represent signal in the time and frequency domain at the same time. The purpose of time-frequency joint representation is to cut the signal of interest into many parts and then analyze the parts separately. It is clear that analyzing a signal this way will give more information. However the Fourier analysis has some inherent limitations in the analysis of the non-linear phenomena and it is impossible to know the exact frequency and the exact time of occurrence of the frequency in a signal. Over the past 10 years, the wavelet theory has become one of the emerging and fast-evolving mathematical and signal processing tools for its many distinct merits. The wavelet transform can be used for multi –scale analysis of the signal through dilation and translation, so it can extract the time-frequency features of the signals effectively.

In wavelet analysis the use of fully scalable modulated windows solve the signal-cutting problems. The window, shifted along the signal and for every position the spectrum is calculated. Then this process is repeated many times with a slightly shorter (or longer) window for every new cycle. In the end, the results will be a collection of time-frequency representations of the signal, all with different resolutions. Because of this collection of representations we can speak of a multiresolution analysis [2]. Wavelets are mathematical functions that cut up data into different frequency components, and then study each component with a resolution matched to its scale. They have advantages over traditional Fourier methods in analyzing physical situations where the signal contains discontinuities and sharp spikes. Wavelet functions are distinguished from other transformations in that they not only dissect signals into their component frequencies, they also vary the scale at which the component frequencies are analyzed. Therefore wavelets, as component pieces used to analyze a signal, are limited in space. In other words, they have definite stopping points along the axis of a graph--they do not repeat to infinity like a sine or cosine wave does. The ability to vary the scale of the function as it addresses different frequencies also makes wavelets better suited to signals with spikes or discontinuities than traditional transformations such as the FT. Wavelet transforms, due to its excellenlocalization property, has rapidly become an essential signal and image processing tool for a variety of applications, including compression and denoising [3, 4, 5]. Wavelet denoising attempts to remove the noise present in the signal while protecting the signal's characteristics, nevertheless of its frequency content. It involves three steps: a linear forward wavelet transform, nonlinear thresholding step and a linear inverse wavelet transform. Wavelet thresholding [3 - 5] is a signal estimation technique that utilizes the capabilities of wavelet transform for signal denoising. It removes noise by killing coefficients that are inconsiderable relative to some threshold, and turns out to be simple and effective, depends heavily on the choice of a thresholding parameter and the choice of this threshold determines, to a great extent the effectiveness of denoising.

III. WAVELET TRANSFORM AND DENOISING ALGORITHM

Wavelet transform in its integral form can be defined as

$$[W_\psi f](a,b) = \frac{1}{\sqrt{|a|}} \int_{-\infty}^{\infty} \overline{\psi\left(\frac{x-b}{a}\right)} f(x)dx \tag{1}$$

The wavelet coefficients c_{jk} are then given by

$$c_{jk} = [W_\psi f]\left(2^{-j}, k2^{-j}\right) \tag{2}$$

Here **a= 2^{-j}** is called the binary dilation or dyadic dilation, and **b= k2^{-j}** is the binary or dyadic position.
The fundamental idea of wavelet transform is that the transformation should allow only changes in time extension, but not shape. This is affected by choosing suitable basis functions that allow for this. Changes in the time extension is expected to conform to the corresponding analysis frequency of the basis function. Based on the uncertainty principle of signal processing,

$$\Delta t \Delta \omega \geqq \frac{1}{2} \tag{3}$$

where t represents time and ω angular frequency (ω = 2πf, where f is temporal frequency). The higher the required resolution in time, the lower the resolution in frequency has to be. The larger the extension of the analysis windows is chosen, the larger is the value of Δt.

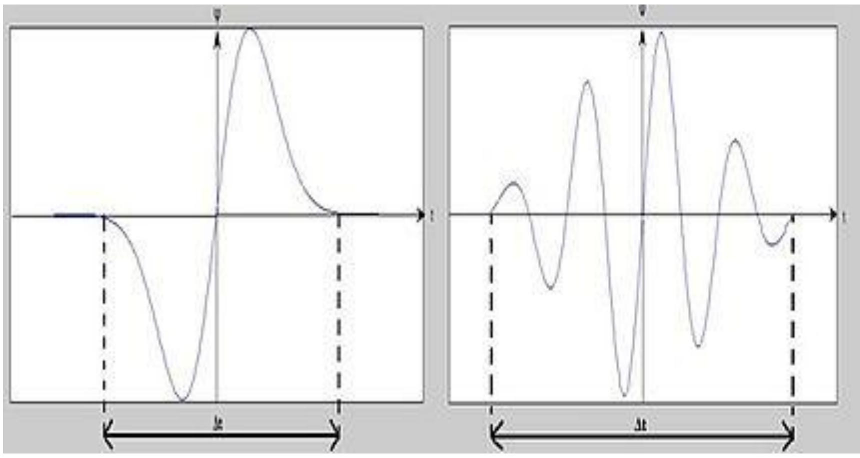

Fig 1: Wavelet Waveform

In other words, the basis function Ψ can be regarded as an impulse response of a system with which the function x(t) has been filtered. The transformed signal provides information about the time and the frequency. Therefore, wavelet-transformation contains information similar to the short-time-Fourier-transformation, but with additional special properties of the wavelets, which show up at the resolution in time at higher analysis frequencies of the basis function.
To denoise the image by using wavelet transform, the following procedure is adopted:
a) Take the Original image and add the Guassian noise at the variance of 0.01. The Wavelet Toolbox is used to fetch the noisy image.
b) Select the Transform and the image will be decomposed according to the selected level.
c) The wavelet decomposition of an image is carried out as follows: In the first level of decomposition, the image is split into 4 subbands, namely the HH, HL, LH and LL subbands. The HH subband gives the diagonal details of the image; the HL and LH subbands give the horizontal and vertical features respectively [6].

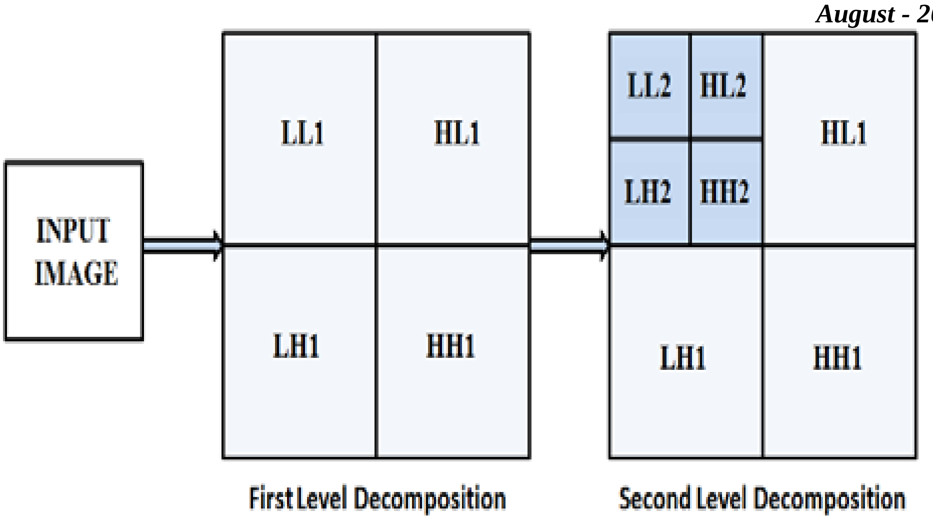

Fig 2: Two levels Image decomposition

d) The LL subband is the low resolution residual consists of low frequency components and its subbands are further split at higher levels of decomposition. In Wavelet Subbands as the level increases the coefficients of subband becomes smoother.HL2 is smoother than HL1 and so threshold value should be smaller than for HL1[9].
e) At each level different threshold value is calculated with the help of Wavelet Toolbox. The threshold value can keep or kill the coefficients. We have performed Soft and Hard Thresholding at each decomposition level of an image for different wavelet transforms. At each level the value of threshold is different.
f) At the end the inverse of the wavelet transform has been performed to get the denoised image.
g) The performance of various wavelet transforms has been compared with the help of various parameters.

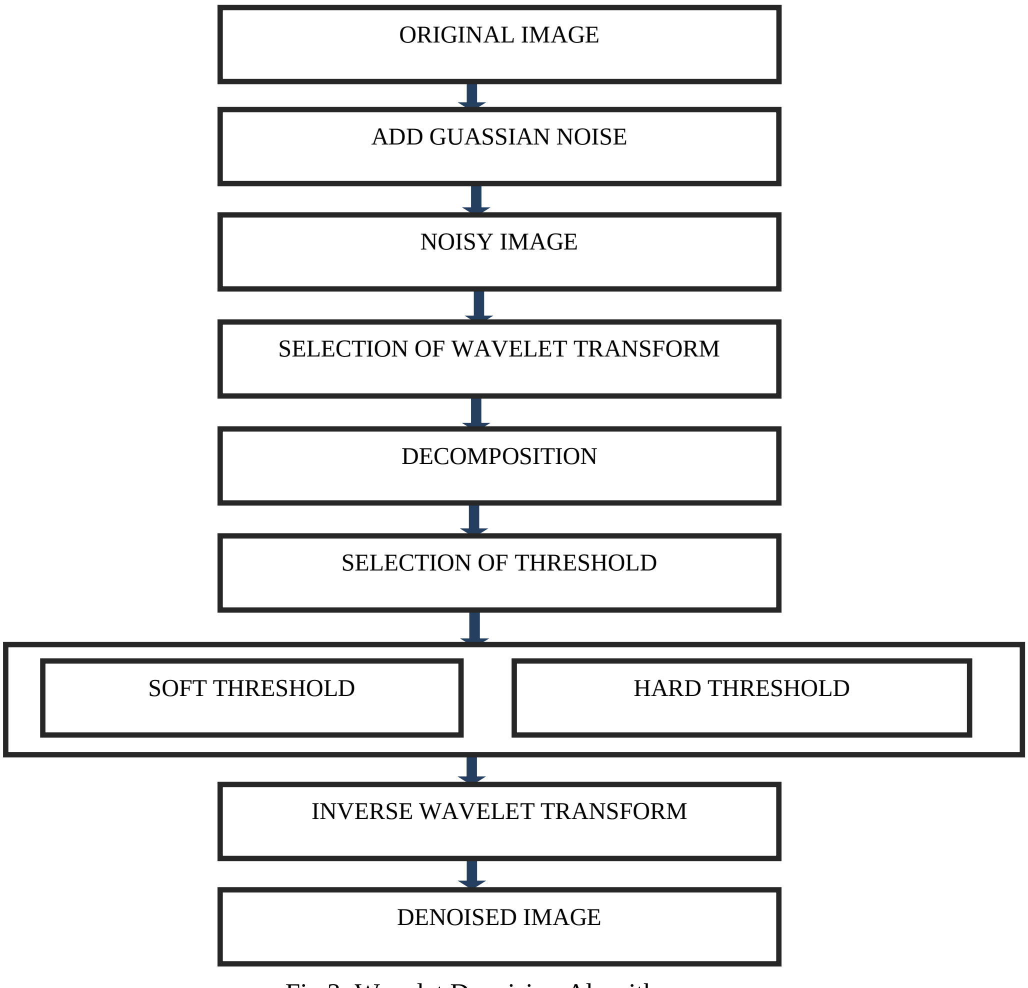

Fig 3: Wavelet Denoising Algorithm

IV. SIMULATION RESULTS

The noisy image is denoised by using different wavelet transforms like Haar and Daubechie, Bior, Coiflet and Symlet transforms with hard and soft thresholding techniques. The PSNR of the noisy image has been calculated as 16 dB.

Fig 4: Original Image

Fig 5: Noisy Image

Fig 6: Denoised Image

Table 1: Value of PSNR for different Levels of Wavelet Transforms and Different Thresholds

Level	Type of Wavelet Transform and Type of Threshold									
	Bior		Coif		dB		Haar		Sym	
	Hard	Soft	Hard	Soft	Hard	Soft	Hard	Soft	Hard	Soft
1	+50.97257	+50.15502	+50.98803	+50.02093	+50.02552	+50.91970	+50.91970	+50.02552	+50.98981	+50.01508
2	+48.98412	+45.55692	+49.90402	+46.53799	+49.64530	+46.72800	+49.64530	+46.72800	+49.91371	+46.48690
3	+48.26503	+43.91169	+49.52834	+45.03740	+49.33172	+44.99521	+49.33172	+44.99521	+49.47225	+44.97906
4	+48.21849	+43.88945	+49.54517	+45.30373	+49.40080	+45.44610	+49.40080	+45.44610	+49.48636	+49.48636

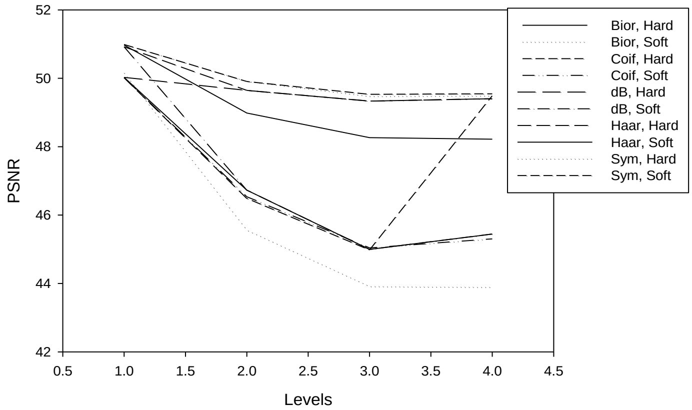

Fig 7: Variation of PSNR for Different Transforms and Different levels with Hard and Soft Threshold

Table 1 and Figure 7 show the variation of PSNR of the denoised image after application of different wavelet transforms at different levels with hard and soft threshold. From table 1 and Figure 6, it has been concluded that symlet wavelet transform results in best performance with PSNR of 50.98981 dB with hard threshold while Bior transform with soft threshold has performed worst. It has also been concluded that for all the transforms, hard threshold has performed better as compared to soft threshold. Results also shows that as the level of transform increases, the value of PSNR decreases for each transform for both hard and soft thresholds.

V. CONCLUSIONS

Wavelet Transform can be used for image denoising to achieve more accurate results. In this paper for denoising standard Lena image, corrupted with Additive White Gaussian noise, different wavelet transforms like Haar, Bior, Symlet, Daubichies and Coiflet have been used with hard and soft thresholding techniques and with different levels of decompositions. Results show that symlet wavelet transform results in best performance with PSNR of 50.98981 dB with hard threshold while Bior transform with soft threshold has performed worst. It has also been concluded that for all the transforms, hard threshold has performed better as compared to soft threshold. Results also shows that as the level of transform increases, the value of PSNR decreases for each transform for both hard and soft thresholds.

VI. FUTURE WORK

The present work is focused on the performance evaluation in different wavelet transforms in image denoising, the Images corrupted by Gaussian noise. The future work can be focused on the use of evolutionary algorithms like SOMA algorithm and conjunction with wavelet transforms. The use of Neural network and Fuzzy logic can be explored for denoising an image. The combination of Neural network and Fuzzy logic called Neuro/Fuzzy system can be a future area of concern.

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