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An Efficient Method for Denoising Medical Images using 3D DWT and Bilateral Filter

Indulekha N.R[1], Dr. Sasikumar M[2]

M.Tech (Signal Processing), Dept. of Electronics and Communication, Marian Engineering College, Trivandrum, Kerala, India[1]

Professor, Dept. of Electronics and Communication, Marian Engineering College, Trivandrum, Kerala, India[2]

ABSTRACT: Medical imaging emerges as one of the most important sub-fileds in the world of science and technology. There is no compromise in the quality of medical images as it is used to diagnose a variety of illness. Developing a significant denoising method, plays a major role in image processing.In this paper, image is first decomposed into eight subbands using 3D DWT and bilateral filter and Thresholding methods are incorporated. The approximation coefficient obtained from DWT is filtered using Bilteral filter and the detail coefficients are subjected to Wavelet Thresholding. Hard thresholding and Soft threshold are the commonly used thresholding techniques. For better results, Bayes shrink, Visushrink etc were used to estimate the threshold value. Image is reconstructed by the inverse wavelet transform of the resultant coefficients and then it is filtered using Bilateral filter. MRI images and Ultrasound images are taken as datasets for quantitative validation. The Peak Signal to Noise Ratio (PSNR), Root mean square error (RMSE), Structural Similarity Index (SSIM) are employed to quantify the performance of denoising.

KEYWORDS: Image denoising, Multi resolution analysis, 3D DWT, Bilateral Filter, Wavelet Thresholding

I. INTRODUCTION

The field of medical imaging advances so fastly that it can be used for diagnotic and treatment purposes. X-rays, Computed Tomography, Ultrasound, Positron Emission Tomography(PET), Single Positron Emitted computed Tomography(SPECT), and Magnetic Resonance imaging etc are some of the available imaging modalities for various applications. Quality of medical images is an important factor which helps to achieve best possible diagnosis. The presence of noise occured during acquisition or transmission could suppress and blur important features in the images.It is important to remove noise from these images as it could limit the effectiveness of diagnosis. Depending on the equipment used for image acquisition, noise may be additive or multiplicative. There are various methods to restore image from noisy disturbances. Conventional denoising methods are noise dependent and application oriented. Significant feature preservation is an important factor to be considered while denoising. Filter plays an important role in the image restoration process which can be categorised into Linear filters and Non-Linear filters. High frequency noise is removed using simple spatial filtering technique but the convolution process involved increases the computational complexity. Frequency domain methods are used inorder to overcome this but it results in an overly smoothed images. Non-linear filtering techniques are employed due to the unsatisfactory outcomes of linear filtering techniques. These include Bilateral filtering, Anisotropic diffusion filter, Non-local filter etc.

II. RELATED WORK

All image denoising algorithms share the same property of keeping the meaningful edges and removing the less meaningful ones. Image denoising is an open problem and has received considerable attention in the literature for many years. Rather than spatial domain filtering techniques, wavelet domain techniques showed superiority in image denoising.

In the beginning, linear smoothing filters were used for reducing noise from images[1][2]. Though the process is simple, it leads to certain artifacts like blurness. Inorder to overcome these drawbacks, non-linar techniques are employed. Median filter is a commonly used non-linear filter whose response is based on the ranking of pixel values included in the filter region [3]. Image denoising based on statistical model of wavelet coefficients have been

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developed by many researchers. Hidden Markov Model(HMM), Gaussian Scale Mixture(GSM) model are some of the examples which are quite popular in image denoising but fails to remove ringing artifacts which leads to the formation of additional edges in the image [4][5].

Barbua et al [6] developed Anisotropic filter which follows an iterative smooting procedure for denoising. Better denoising effect can be obtained but it tends to overblur the image leads to boundary sharpening with many texture details lost.It provides a smoothening effect to the images while preserving the edges.Buades et al [7] introduced Non-Local means filter which estimates each and every pixel intensity based on the presence of similar patterns and features in the image. Visual quality and objective quality gives poor results compared to other denoising methods.

Bilateral filter proposed by Tomasi and Manduchi [8] has been widely used for image denoising which combines both range filtering and domain filtering. Eventhough edge preservation is maintained, it cannot handle speckle noise and tends to oversmoothness and edge sharpening. Transform based methods which include DFT or wavelet extracts the image coefficients. Pizurica and Philips [9] developed wavelet domain denoising in which information containing coefficients are thrown away by the process of Thresholding. Wavelet thresholding is one of the most popular approach for image denoising. Selection of threshold is an important factor for which variety of strategies like Visushrink [10], Bayesshrink[11], Sureshrink[12] etc were used.Hard thresholding and soft thresholding are the widely used thrsholding techniques.

Ming Zhang et al. (2008) proposed multi-resolution bilateral filter [13], where bilateral filtering is applied to the approximation (low-frequency) sub-bands of a signal decomposed using a wavelet filter bank. The multi-resolution bilateral filter is combined with wavelet thresholding [14].

III. Scope of the Work

Literature survey on bilateral filtering reveals that it is not applicable for handling speckle noise, despite presrving edges very well. This paper focuses on utilizing 3D-DWT in combination with bilateral filtering to denoise images contaminated with any types of noise. Suitable thresholding technique is chosen to remove insignificant coefficients in the 3D-DWT domain.

IV. Proposed Algorithm

The input medical image is corrupted with different types of noise and the noisy input image is transformed into wavelet domain using 3D DWT. . After a one-level of 3D discrete wavelet transform, the volume of image data is decomposed into HHH, HHL, HLH, HLL, LHH, LHL, LLH and LLL. The approximate signal, resulting from scaling operations only, goes to the next octave of the 3-D transform. It has roughly 90% of the total energy. Meanwhile, the other seven subbands contain the detail signals. The approximate signal band is filtered using Bilateral filter which removes the unwanted distortions from it while preserving the fine details and edges. Meanwhile, wavelet thresholding is performed for the remaining 7 detail subbands. Inverse wavelet transform is applied to the filtered subbands and image is reconstructed. Finally, the reconstructed image so obtained is passed through bilateral filter obtaining the denoised image. The functional block diagram is illustrated in the figure shown below:

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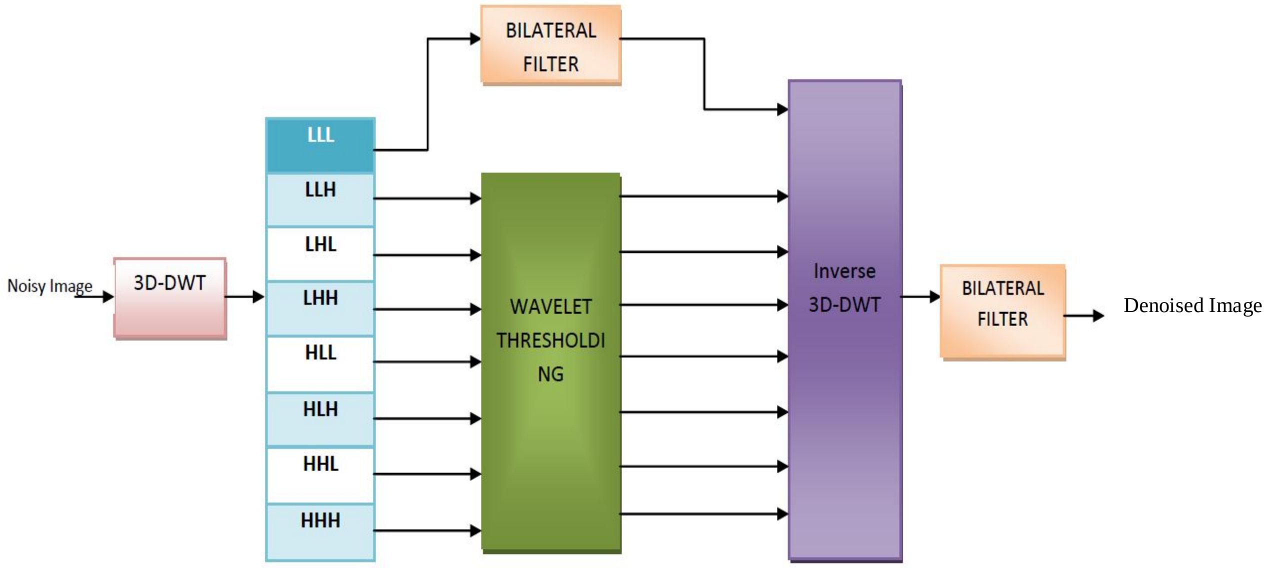

Fig.1. Functional block diagram of the proposed method

The detail coefficients obtained from 3D-DWT is subjected to wavelet thresholding. Hard thresholding, Soft thresholding, Thresholding based on Bayes shrink and Visu shrink are the methods employed in this framework. Inverse transform is taken with the thresholded coefficients along with the filtered approximation coefficient. Resultant image is filtered using Bilateral filter inorder to obtain smooth texture while preserving edges.

A. *Three- dimensional Discrete Wavelet Ttransform(3D-DWT)*

3D DWT is the combination of three 1D DWT in the x,y,z direction which is the image decomposition in the row, column, and depth direction. First level decomposition of image using 3D DWT results in eight subbands viz HHH, HHL, HLH, HLL, LHH, LHL, LLH & LLL as shown in Fig 1.

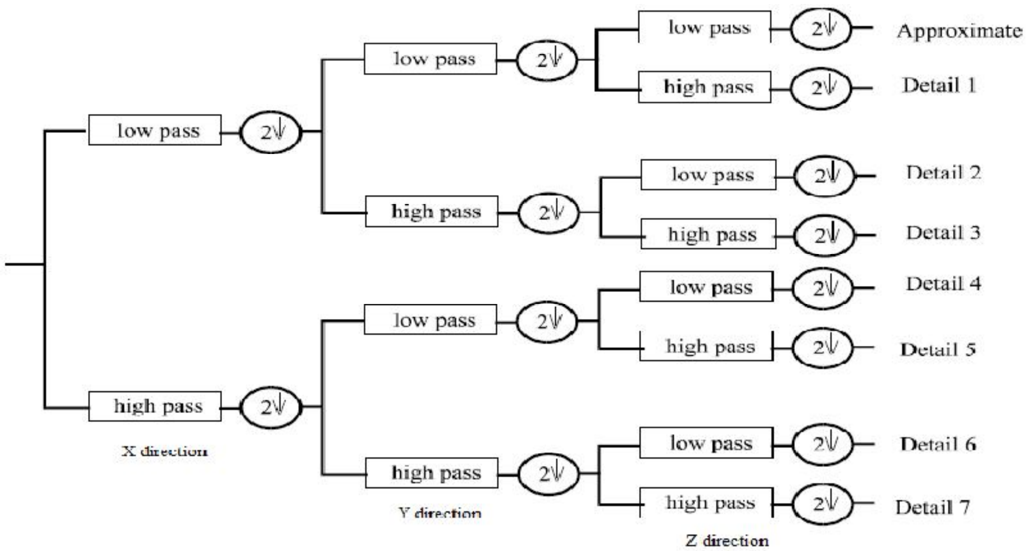

Fig. 2. Three dimensional discrete wavelet transform

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The x component of the image is convoluted with lowpass and high pass filter followed by downsampling. The resulting coefficients is then convoluted with low pass and high pass filetr in the y-direction followed by downsampling.Final eight subbands are obtained by convoluting the resultant coefficients with low pass and high pass filter in the z- direction followed by subsampling. The interslice distances gets smaller due to better medical input devices which improves the correlation between images resulting in even better results for 3D transform. Excellent representation of decomposed image may be useful for quantization and coding techniques.

B. *Bilateral Filter*

A bilateral filter is a non- linear filter developed by Tomasi and Manduchi [8] which attempts to smooth an image while preserving edges. It takes the weighted sum of the pixels in the local neighbourhood in which the weights depend on both the spatial distance and intensity distance. In this way the edges are preserved while noise are averaged out. Mathematically,

$$\hat{I}(X) = \frac{1}{C}\sum_{y\in N(X)} e^{-\frac{\|y-x\|^2}{2\sigma_d^2}} e^{\frac{-|I(y)-I(x)|^2}{2\sigma_r^2}} I(y) \qquad \text{eq. (1)}$$

where, I is the original image to be filtered, x is the coordinateof the current pixel to be filtered, and are the spatial and intensity parameters. N(X) is the spatial neighbourhood of x and C is the normalization constant given by,

$$C = \sum_{y\in N(X)} e^{-\frac{\|y-x\|^2}{2\sigma_d^2}} e^{\frac{-|I(y)-I(x)|^2}{2\sigma_r^2}} \qquad \text{eq. (2)}$$

One of the main disadvantage of the bilateral filter is that it smoothes the areas where pixels are similar. This allows us to leave relatively unaffected edges in the images.

C. *Wavelet Thresholding*

Wavelet thresholding is an image denoising technique which removes coefficients that are insignificant to the image rspective to some threshold value. The efficiency of thresholding lies in the choice of threshold parameter. Hard thresholding and Soft thresholding are the generally used thresholding techniques. There are a variety of thresholding techniques based on the threshold paramaters. Some of them are Bayes shrink, Visu shrink,Sure shrink etc.

1. Hard Thresholding

If the absolute value of the image coefficients is less the threshold *t*, then it is set to zero, otherwise it remains the same. Mathematically,

$$T_H = \begin{cases} x & for\ |x| > t \\ 0 & for\ all\ other\ regions \end{cases} \qquad \text{eq. (3)}$$

2. Soft Thresholding

Occurence of ringing/Gibbs effect in the denoised image due to hard thresholding leads to discontinuities. To overcome this Donoho [15] introduced Soft thresholding which assumes the value to be zero if the coeffecient is less than the thrshold value otherwise the value is replaced by the threshold. Mathematically,

$$T_S = \begin{cases} sign(x)\ \ |x| - t & for\ |x| > t \\ 0 & for\ all\ other\ regions \end{cases} \qquad \text{eq. (4)}$$

Eventhough it removes dicontinuities, it degrades the image coefficients and results in bluring.

3. Bayes Shrink

Bayes shrink method is used to minimize the Bayesian risk which is proposed by Chang et al [12] . It uses soft thresholding and performs on each subband obtained from wavelet decompostion. Bayes threshold, t is defined as

$$t = \frac{\sigma^2}{\sigma_s} \qquad \text{eq. (5)}$$

where σ^2 is the noise variance and σ is the signal variance.

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Additive noise is defined as:

$$\sigma_w^2 = \sigma_s^2 + \sigma^2 \qquad \text{eq. (6)}$$

σ_w^2 can be evaluated as :

$$\sigma_w^2 = \frac{1}{n^2}\sum_{x,y-1}^{n} w^2(x,y) \qquad \text{eq. (7)}$$

Signal variance , σ_s^2 canbe computed as:

$$\sigma_s = \sqrt{max(\sigma_w^2 - \sigma^2, 0} \qquad \text{eq. (8)}$$

1. Visu Shrink

Visu shrink method uses a threshold value,t which is proportional to the noise standard deviation. This method which was developed by Donoho Donoho [16] follows the hard thresholding rule. It is defined as :

$$\mathrm{T} = \sigma\sqrt{2log(M)} \qquad \text{eq. (9)}$$

It follows global thresholding scheme which fails to remove speckle noise.

V. Simulation Results

The proposed method was simulated for standard medical images such as MRI and Ultrasound image. The types of noise considered in this work were Gaussian, Poisson and Speckle noise. This method resulted in good observations. The standard Peak Signal to Noise Ratio (PSNR), Root mean square error(RMSE) and Structural Similarity index (SSIM) are employed to quantify the performance of denoising.

Fig. 3 to Fig 5 shows the denoising results of MRI image in the presence of Gaussian noise with σ = 20, Poisson noise and Spckle noise subjected to thresholding based on Bayes shrink method. Thresholding based on Bayes shrink method shows better results compared with other thresholding methods.

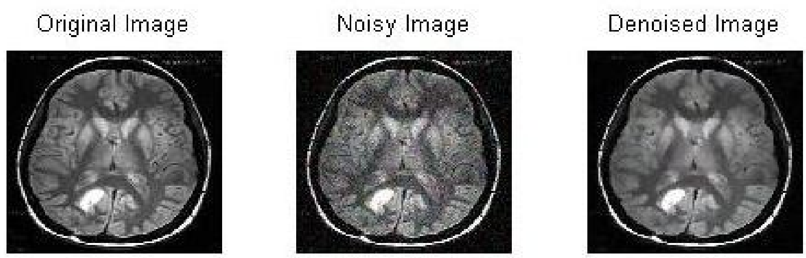

Fig. 3. Denoising results for MRI image in the presence of random noise with =20

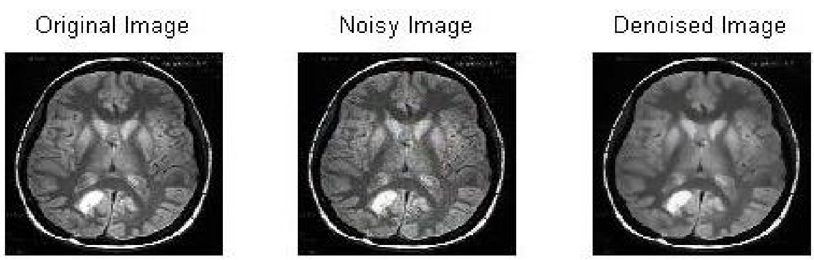

Fig.4. Denoising results based on Bayes shrink thresholding

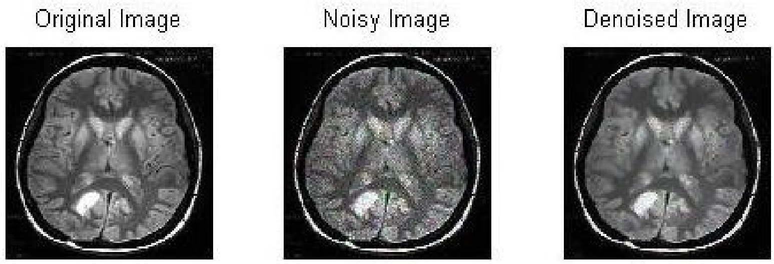

Fig. 5. Denoising results based on Bayes shrink thresholding

Fig. 6 – Fig 7 shows the denoising results of US image in the presence of Gaussian noise with σ = 20, Poisson noise and Spckle noise. Thresholding based on Bayes shrink method shows better results compared with other thresholding methods.

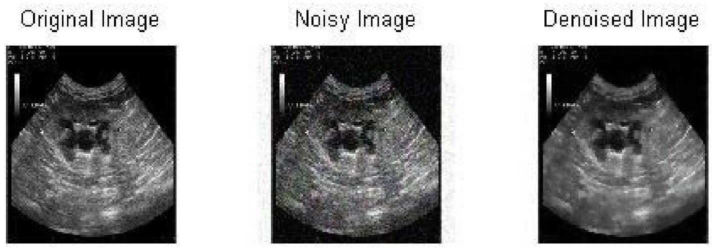

Fig. 6. Denoising results based on Bayes shrink thresholding

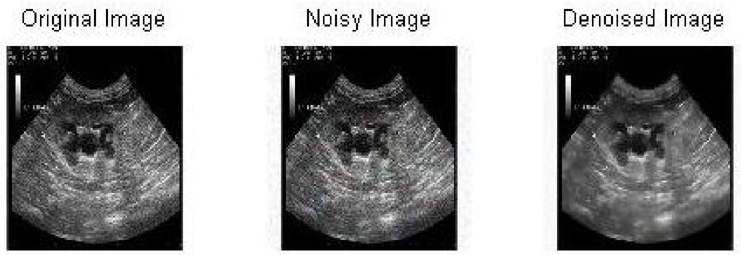

Fig. 7. Denoising results based on Bayes shrink thresholding

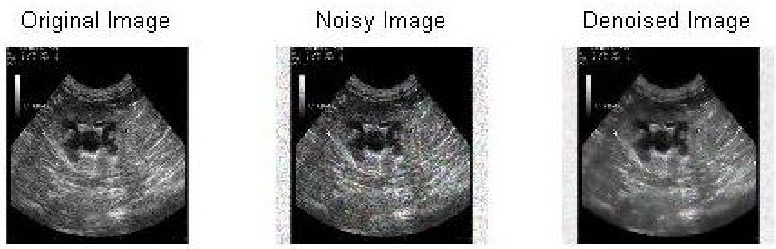

Fig. 8. Denoising results based on Bayes shrink thresholding

The visual quality of the image obtained using the proposed method found to be better compared to other denoising methods..The denoised image found to have minimum artifacts and PSNR,RMSE and SSIM were computed for the

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denoised image. Table 1 summarizes the quality metrics obtained when the input images were contaminated with different types of noises.

Image	Thresholding Methods	Gaussian			Poisson			Speckle		
		PSNR	RMSE	SSIM	PSNR	RMSE	SSIM	PSNR	RMSE	SSIM
MRI imgae	**Soft**	33.534	5.368	0.994	33.674	5.282	0.991	32.5118	6.038	0.991
	Hard	33.6599	5.2913	0.994	34.130	5.012	0.992	32.6277	5.958	0.992
	Bayes	**33.7343**	5.2459	0.99	**34.1597**	4.995	0.992	**32.6668**	5.9319	0.993
	Visushrink	33.518	5.3808	0.994	33.6874	5.274	0.997	32.4624	6.073	0.991
Ultrasound Image	**Soft**	32.9265	5.7512	0.9893	32.230	6.237	0.997	29.9098	8.148	0.997
	Hard	33.2400	5.553	.9894	32.715	5.881	0.998	30.1699	7.8808	0.998
	Bayes	**33.2499**	5.5468	0.9893	**32.7342**	5.886	0.998	**30.1745**	7.903	0.998
	Visushrink	32.9415	5.7473	0.9895	32.2400	6.230	0.997	29.8985	8.1585	0.997

Table 1 Quality metrics for various colour images affected by Gaussian (σ=20), Poisson noise and Speckle noise

The proposed method not only has better visual quality but also performs exceptionally well in terms of objective evaluation parameters, when compared with other conventional denoising techniques. The PSNR values obtained by the proposed method were plotted along with other denoising methods under the same noise conditions. Table 2 gives the PSNR values of conventional denoising methods along with the proposed method inorder to measure the quality of filters. The comparison plot is as shown in Fig. 9.

Filter type	PSNR				
	σ = 10	σ = 20	σ = 30	σ = 40	σ = 50
MRBF	32.2	30.1	29.8	28.6	27.9
BLS-GSM	29.7	27.1	26.8	25.8	24
Non Local means	28.1	27.7	29.8	28.6	27.9
Proposed method	**34.4**	**33.7**	**32**	**30.7**	**30.1**

Table 2 Image quality evaluation metrics for different types of filter

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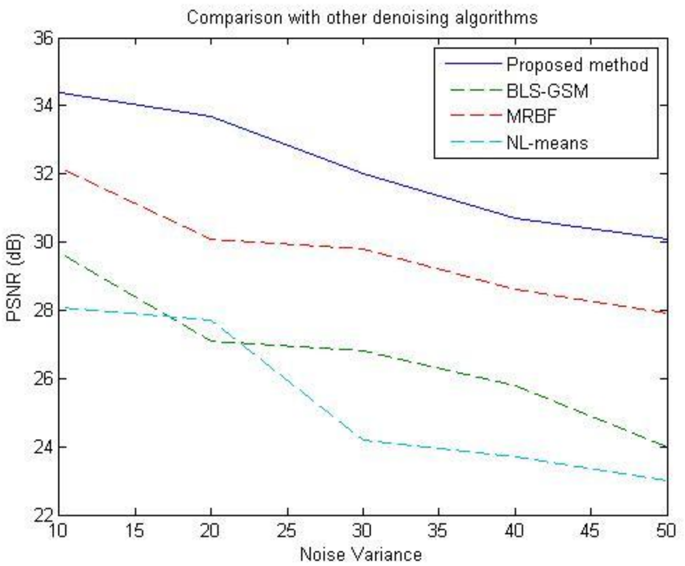

Fig. 9. Plot of output PSNR for increasing noise variance of Gaussian noise

The proposed method preforms well in the presence of Gaussian, Poisson and Speckle noise. Noise has been reduced to great extent with reduced computation and processing time. The combination of the three conventional methods viz Discrete wavelet transform, Bilateral filter and Wavelet thresholding builds a strong and efficient method for medical image denoising.

VI. CONCLUSION AND FUTURE WORK

A novel method for the noise removal of medical images using 3D-DWT has been proposed. In this framework, Bilateral filtering and wavelet thresholding is performed on the subbands obtained from 3D DWT. The method utilizes the properties of 3D DWT and bilateral filter to preserve the information containing pixels & edges and thresholding is performed inorder to to segment an image by setting all pixels whose intensity values are above a threshold . The method uses different thresholding methods and a comparitive study of those is done.The proposed method achieves better visual quality with minimum disturbing artifacts.. The Peak Signal to Noise Ratio (PSNR), Root mean square error (RMSE), Structural Similarity Index (SSIM) are employed to quantify the performance of denoising and obtained good results for the framework. This work can be extended to work on to the 2^{nd} level of 3D-DWT. Medical images other than MRI and Ultrasound image can be taken for processing.

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BIOGRAPHY

Indulekha N.R. is a research scholar, pursuading her Masters in Technology(M. Tech), under the university of Kerala, India. She did her Bachelor of Technology (B.Tech) in LBS Institute of Technology for women, Trivandrum, Kerala, India. Her research interests include Image denoising & Computer vision.

Dr. M. Sasikumar obtained his B.Sc.(Engg.) from Kerala University (1968); M.E from Indian Institute of Science, Bangalore(1974); Ph.D from IIT,Madras (1985). He retired as the principal of College of Engineering, Trivandrum in 2001. He has about 40 years of teaching experience as Lecturer/ Assistant Professor, Professor in various Engineering Colleges in Kerala. His research area of interest includes Image Signal Processing. He has published about 150 papers in International/ National journals.