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Efficient Denoising of Multi-modal Medical Image using Wavelet Transform and Singular Value Decomposition

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***Abstract*: Medical image denoising is a key step for reconstructing a high-quality image in image processing. Noises like Gaussian, Speckle etc. usually degrades the medical images while acquiring, transferring, and recovering from storing devices. So, research for an effective denoising techniques having high Peak Signal-Noise Ratio (PSNR) and low Mean Square Error (MSE) values is still going on. Wavelet Transform (WT) and Singular Value Decomposition (SVD) are powerful methods for removal of noise. In this paper, medical images like X-ray, CT and ultrasound images are used for experimentation. Noises like Gaussian and Speckle are applied on multi-modal images and denoised by SVD or wavelet transform. Denoising results of WT and SVD are compared on the basis of MSE and PSNR.**

Keywords: Multimodal Medical Image Denoising, Wavelet Transform (WT), Gaussian noise, Speckle Noise, Singular Value Decomposition (SVD)

I. INTRODUCTION:

Scans of medical images are widely used to find the deformities in the various organs of the body. With the development of economical imaging techniques and computational equipment, medical images are regularly used by the radiologists for detection, presentation and cure of several ailments. X-Ray, CT (Computed Tomography) image, MRI (Magnetic Resonance Imaging), Ultrasound image, PET (Positron Emission Tomography) and SPECT (Single Photon Emission Computed Tomography) etc. are mostly used for medical diagnosis. These medical images are not same as the natural photographic pictures as they reproduce the interior composition of the body organs.

For exact finding, medical images have to be sharp, flawless, without any noise and artefacts. As imaging technologies are being widely used, the conservation of the quality of the images becomes important. But, during acquiring, transmitting, and recovering medical images from storing devices, it gets degraded. The presence of noise not only mask but also distort main subtle structures and presence of artefacts can cause wrong findings. Therefore the denoising of medical images is important to ensure accurate and timely identification of ailments for treatment. [1]

A. Noises affecting Medical Images

Medical image denoising method can be designed by understanding, noise types and its origin. Mostly medical images are obtained from MRI, CT, and X-ray equipment. Noise is always present in images to some extent. Although the nature of noise is random, but it reflects some particular distribution. Depending upon their characteristics and source, they are classified into different types. [2] [3] In this paper, effect of Gaussian and Speckle noise on X-ray Image are studied.

Gaussian Noise: Nearly all types of medical images contain Gaussian noise. It spreads over the whole image. So, the summation of the actual pixel value and Gaussian distribution forms the pixel value of the noisy pictures. Gaussian noise distribution is similar to a bell. [2]

Speckle (Multiplicative) Noise: In an image, due to different practices Gaussian noise and speckle noise appear superficially. As their cause of origin is different they need different approaches for their removal. When an image, f (x, y), is tainted by speckle noise then

$$g(x,y) = f(x,y)*n(x,y) \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

It is also called as multiplicative noise. [2]

II. DISCRETE WAVELET TRANSFORM (DWT)

Fourier transform (FT) and Wavelet Transform (WT) are transform-domain filtering which transform the spatial realm information to the frequency realm. And filtering processes are implemented in frequency domain. Discrete Wavelet Transform (DWT) was first developed by the Hungarian mathematician Alfre´d Haar. DWT includes the process of analysis and synthesis. Using DWT, a scan is decomposed into an order of different spatial resolution scans. It splits the scan into LL, HL, LH, and HH bands. The sub-band LL is a having lower resolution and carry lower frequency portion of the scan. While other three sub-bands have higher frequency portion where HL carry vertical, LH carry horizontal, and HH carry diagonal directions, information. The Haar transform method is the least complex wavelet transformation method. In this method, the average of two neighbouring pixel values give low pass filter values. And the difference between the two neighbouring pixel values give high filter values. [4]

A. Wavelets:

These are various wavelets like Harr, db 2 and 4, sym2 and 4, bior 1.1 and 6.8, coif, dmey etc. Here for experimentation Harr wavelet is used.

Harr wavelet: Harr wavelet is a square-shaped function which can be rescaled. Its mother wavelet function x(t) can be described as: [5]

$$x(t) = 1,\ 0 \leq t < 0.5$$
$$= -1,\ 0.5 \leq t < 1$$
$$= 0,\ \text{otherwise}$$

B. Singular Value Decomposition (SVD):

In Singular value decomposition (SVD), it is possible to change the order (of diagonal matrix) along which data points show the most deviation. By reducing the dimensions, one can find the optimum approximation of the original data points. So, it is used as a technique for reduction of data or noise. It is established on a Linear Algebra's theorem. Here, rectangular matrix A can be divided into the product of three matrices – an orthogonal matrix U, a diagonal matrix S, and the transpose of an orthogonal matrix V . Mathematically, it is shown as:

$A_{mn} = U_{mm} S_{mn} V^T_{nn}$

where $U^T U = I$, $V^T V = I$; the columns of U are orthonormal eigenvectors of $A A^T$, the columns of V are orthonormal eigenvectors of $A^T A$, and S is a diagonal matrix and contain the square roots of Eigen values from U or V in decreasing order. Here, one can efficiently denoise by deleting elements which do not give significant deviation, So, the vectors are smaller, and comprise only the elements that are responsible for the most important relations with the original data. [20]

III. Performance Evaluation in Image Denoising:

Subjective method and objective method are two types of techniques for image quality assessment (IQA). In subjective method, image quality is decided by the human beings which is considered as the most correct and reliable method. But, this method is very slow, costly and challenging. So, the second method i.e. objective method is favoured. Objective methods are grouped according to their strategies: Mathematical metrics and Human Visual System (HVS) based metrics. In mathematical metrics, the image is considered as a 2-Dimensional signal, and for measuring image quality, the similarity between original image and distorted image are measured. In HVS based metrics, the dissimilarity between the original and the distorted images is normalized as per the visibility which is determined by human perception's psychophysics. [6] Under objective method, Root Mean Square Error (RMSE) is normally used. For image quality measurement, it is regarded as very reliable. Mathematically: let the actual image, noisy image and the denoised image be denoted by i(x,y), n(x,y) and i'(x,y) respectively. And, the discrete spatial coordinates of the images are represented by x and y. Assume the size of image be MxN pixels i.e., x = 1, 2 …, M and y = 1, 2 …., N. Then, the MSE and RMSE can be defined as

$$\text{MSE} = \sum_{x=1}^{M} \sum_{y=1}^{N} \frac{[i'(x,y) - i(x,y)]^2}{MN} \quad (1)$$

$$\text{RMSE} = \sqrt{MSE} \quad (2)$$

Second image quality measuring parameter is PSNR. PSNR is inversely proportional to RMSE and its unit is in db (decibels). It is defined as the ratio of Peak Signal Power to Noise Power. It is mathematically defined by

$$\text{PSNR} = 20\log10[255/\text{RMSE}] \text{ db} \quad (3)$$

here 255 is the Maximum Pixel Value for an 8 bits/gray-scale image. It compares the quality of reconstructed image and the original image. It gives a single number which indicates the class of new image. Denoised images having lesser MSE and greater PSNR are considered superior. [8][9][10][11]

IV. Literature Review:

To get fast results, a good denoising method needs a low computational complications. Main requirements of medical image noise reduction approaches can be summarised as (i) protection of edges and other finer parts, (ii) conservation of similarity in structure, (iii) absence of artifacts and (iv) reduced operation complications. [7] While developing an effective image noise reduction method, the prior info about noise type is essential to the effectiveness and elementary mathematical design of the algorithm. The noises which corrupt multi modal medical images are Gaussian Noise, Poisson Noise, Impulse Noise and Speckle noise**.** The appearance of any type of noise in medical images is a totally unpredictable. [1] Due to Optical deficiencies and instrumentation noise (e.g. semiconductor devices' thermal noise) more noise get added. Aliasing of high-frequency signal parts causes noise, and also quantization error is occurred because of digitization process. Because of communication errors and compression other noise can contaminate the images. [2]

Wavelets based denoising techniques

Various wavelets for medical image denoising are proposed by researchers. Nadir Mustafa *et al*. [12] proposed bi-orthogonal wavelet which is found to be more effective method than other wavelet families such as Haar, Daubechies, and Symlets. For soft and hard thresholding, better denoising results were obtained for mean square error (MSE). Here, for creating a de-noising image, un-scaled white noise and the original image was mixed. On the basis of the statistical measurements and visual quality of MRI image, Sugandha Agarwal et al. [13] proposed Symlet based Wavelet Transform. This method had shown better denoising results than other wavelet transforms. In this paper, the efficiency of various wavelet family i.e. Haar, Morlet, Symlet, Daubechies in denoising MRI of brain image for speckle noise was compared. According to R. Sujitha *et al*. [14] proppposed the haar wavelet (db1) which outperformed other wavelets for both Simulated & MRI image respectively for any random noise. S. Kother Mohideen et al. [15] mentioned wavelet coiflet for better image denoising. Gaussian noise with different variance was applied on natural image for experimentation. L. Gabrella et. al. [16] found Harr wavelet more suitable for low Gaussian noise and Coif wavelet for high noise as compare to db4, sym4 wavelets. CT image was used for the experimentation. As per Ajeet Singh [17], the best PSNR is attained at the decomposition level of two. N. E. Benhassine et. al. [18] performed denoising by choosing the optimum decomposition level and mother wavelet. Walid El-Shafai et. al. [19] proposed denoising model centred on CNN to remove Gaussian and Speckle noises in various medical images. From literature review of wavelet based denoising work, it is clear that researcher have proposed wavelets for specific type noise like Gaussian, speckle etc. But, the wavelet which can be the best suitable for specific type of noise is yet to be explored. And this experimentation work on medical image denoising search for the best suitable wavelet for four major types of noise.

V. Methodology:

Simple de-noising algorithms based on WT have three steps.

- To find WT of the noisy image.

- Change the noisy wavelet coefficients as per the requirement.
- Find the inverse WT from changed coefficients.

In this study, Wavelet Transform (WT) is used for denoising the medical image corrupted by Gaussian noise and Speckle noise. Here, medical images are taken as an input and noise is added to it. Then, WT using Harr wavelet is applied. The decomposition level used in this study is 2.

Steps used in the study:

Step 1 - Take a medical image (X-ray, CT or Ultrasound image).

Step 2 - Add Gaussian or Speckle noise.

Step 3 - Perform the wavelet transforms.

Step 4 - Take inverse wavelet transform

Step 5 - Find the PSNR and MSE of noisy and denoised output image.

Step 6: Repeat step 1, 2 and denoise the image using SVD. Then repeat step 5.

Step 7 – Compare the results of denoised image by WT with the denoise results of SVD for X-ray, CT and Ultrasound images.

VI. Experimental Setup:

Programs were written in MATLAB 2020B. Multi-modal medical images like chest X-ray, Chest CT and Ovary Ultrasound are used for study of denoising medical images as shown in Fig. 1-6. Gaussian and Speckle noises which mostly affect medical images are introduced in the images at a time with noise variance of 0.02, 0.05 and 0.09. Wavelet transform based on Harr wavelet was performed on noisy images. Wavelet transform operation are performed having level two. The WT denoising process is repeated with different noise variances and each time PSNR and MSE are calculated. Same Process is used to denoise by SVD. Optimized order of SVD is used to denoise the image.

VII. Results and Discussion:

Gaussian noise, Noise Variance = 0.09

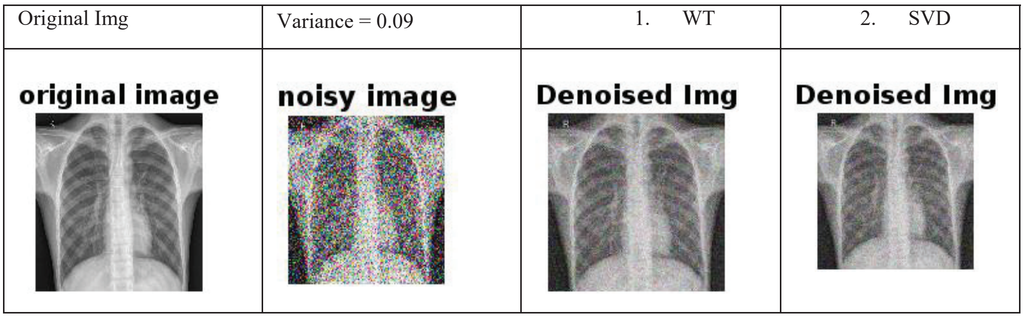

Fig. 1. X-ray chest image denoised by WT and SVD for Gaussian Noise

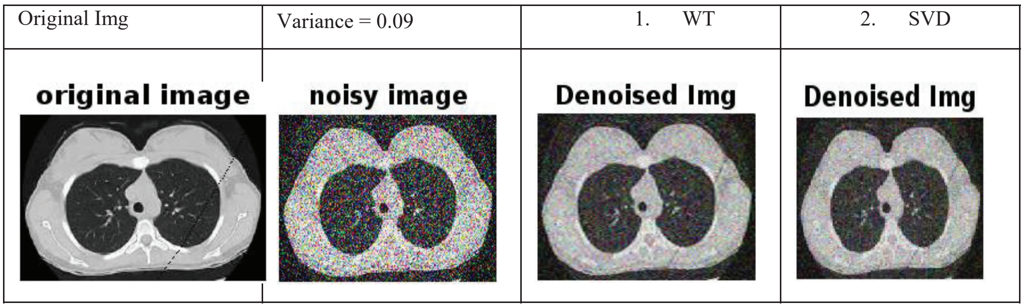

Fig. 2. CT chest image denoised by WT and SVD for Gaussian Noise

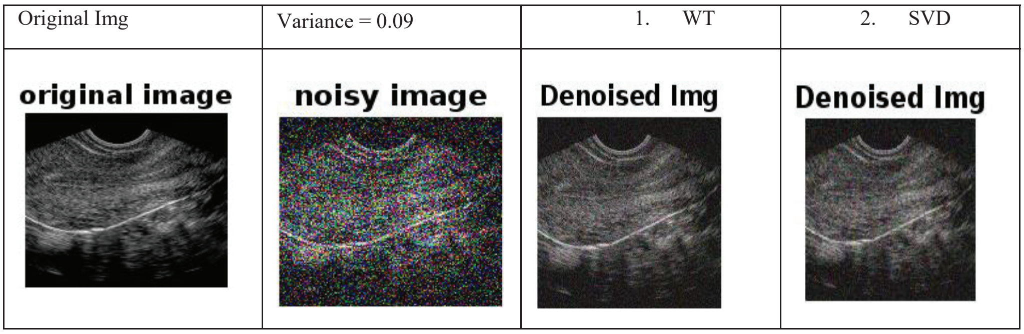

Fig. 3. Ultrasound Ovary image denoised by WT and SVD for Gaussian Noise

TABLE I. (A-C): DENOISING PARAMETERS OF GAUSSIAN NOISE FROM MULTI-MODAL MEDICAL IMAGES

Img	Noise variance	0.02		0.05		0.09	
	Parameters	PSNR	MSE	PSNR	MSE	PSNR	MSE
X-ray	Noisy Img	17.3264	0.0185	13.7875	0.0418	11.7936	0.0666
	WT	**26.8461**	**0.0021**	**24.1505**	**0.0039**	**22.0207**	**0.0062**
	SVD	25.7387	0.0027	23.3510	0.0046	21.5086	0.0071

(a)

Img	Noise variance	0.02		0.05		0.09	
	Parameters	PSNR	MSE	PSNR	MSE	PSNR	MSE
CT	Noisy Img	17.9200	0.0161	14.5124	0.0354	12.4155	0.0573
	WT	**23.9347**	**0.0040**	**21.3067**	**0.0074**	**19.3672**	**0.0116**
	SVD	21.8484	0.0065	19.6214	0.0109	17.9297	0.0161

(b)

Img	Noise variance	0.02		0.05		0.09	
	Parameters	PSNR	MSE	PSNR	MSE	PSNR	MSE
US	Noisy Img	18.2476	0.0150	14.6681	0.0341	12.5173	0.0560
	WT	**25.6269**	**0.0027**	**22.3087**	**0.0059**	**20.1315**	**0.0097**
	SVD	24.1062	0.0039	21.2712	0.0075	19.3907	0.0115

(c)

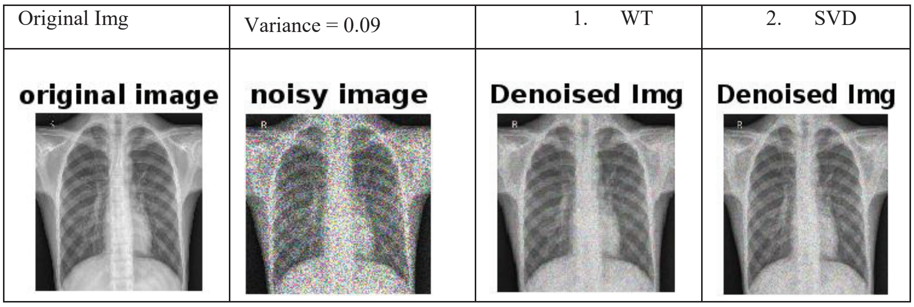

Fig. 4. X-ray chest image denoised by WT and SVD for Speckle Noise

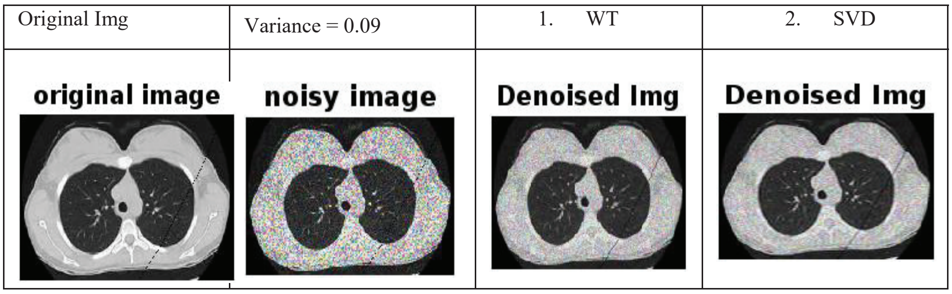

Fig. 5. CT chest image denoised by WT and SVD for Speckle Noise

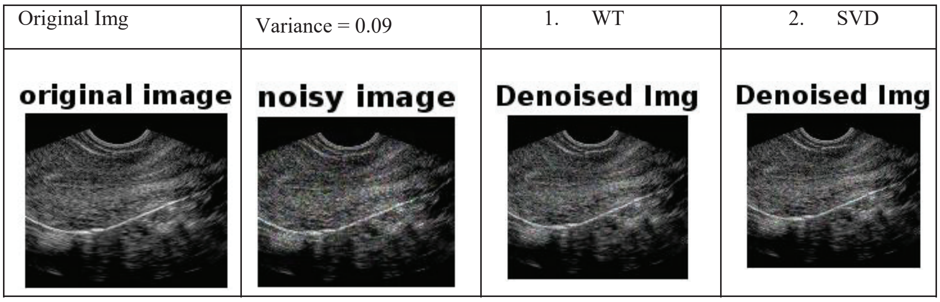

Fig. 6. Ultrasound ovary image denoised by WT and SVD for Speckle Noise

TABLE II. (A-C): DENOISING OF SPECKLE NOISE FROM MULTI-MODAL MEDICAL IMAGES

Img	Noise variance	0.02		0.05		0.09	
	Parameters	PSNR	MSE	PSNR	MSE	PSNR	MSE
X-ray	Noisy Img	21.9187	0.0064	18.1590	0.0153	15.8356	0.0261
	WT	27.9745	0.0016	25.4823	0.0028	23.9934	0.0040
	SVD	**28.1330**	**0.0015**	**26.1465**	**0.0024**	**24.7941**	**0.0033**

(a)

Img	Noise variance	0.02		0.05		0.09	
	Parameters	PSNR	MSE	PSNR	MSE	PSNR	MSE
CT	Noisy Img	22.9224	0.0051	19.1515	0.0122	16.9948	0.0200
	WT	24.9553	0.0032	21.7441	0.0067	19.9475	0.0101
	SVD	**25.0121**	**0.0032**	**22.4255**	**0.0057**	**21.1233**	**0.0077**

(b)

Img	Noise variance	0.02		0.05		0.09	
	Parameters	PSNR	MSE	PSNR	MSE	PSNR	MSE
US	Noisy Img	29.2509	0.0012	25.2696	0.0030	22.7628	0.0053
	WT	30.2730	0.0009	26.3551	0.0023	23.8881	0.0041
	SVD	**32.2268**	**0.0006**	**29.7015**	**0.0011**	**27.7231**	**0.0017**

(c)

The proposed technique is executed in MATLAB 2020B platform. Investigation is applied on 3 X-ray, CT and ultrasound images. Table 1 (a-c) and 2(a-c) show the comparison of the denoising results of WT and SVD applied on multimodal medical images. Performance are evaluated on the values of PSNR and MSE. For Gaussian noise, WT is better than SVD for multimodal medical images. While for speckle noise, SVD is better than WT.

VIII. CONCLUSION AND FUTURE SCOPE:

Many diseases are detected by using medical images CT scan, X-ray, ultrasound, MRI, etc. But, due to noise quality of images degraded and it becomes difficult to diagnose the disease. From above experimental results it is clearly visible that the WT for Gaussian noise gives better PSNR, and MSE than SVD. But, for Speckle noise SVD is better than WT. From denoising results of multi-modal images, it is clear that a WT is not suitable to reduce all type of noise. One has to apply different approach like SVD to reduce of noise depending upon the source of the noise.

For optimization of medical image denoising, other wavelet should be tested along with other denoising techniques like SVD. Here, the tested images are in jpg format and the effect of wavelets and SVD on other types of formats medical images also needs to be tested.

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