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Comparison of Speckle Noise Removal Techniques for Magnetic Resonance Images

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Abstract- The need for good image quality for an accurate and efficient diagnosis has become a necessity. To ensure good image quality, denoising has become a mandatory step. Magnetic Resonance (MR) images are corrupted by noise due to inhomogenuity of magnetic field, excursion of temperature, motion of the tissue, etc. Speckle noise is a type of granular noise which degrades the quality of the image with the appearance of backscattered wave. This paper aims at providing a performance comparison of different denoising techniques for the removal of speckle noise in MR images. The performance comparison was done by using parameters such as Mean Square Error (MSE), Peak Signal to Noise Ratio (PSNR), Mean Structural Similarity (MSSIM), etc. The variation of MSE with respect to increase in noise variance for different noise removal techniques is also covered in this paper.

Keywords—Magnetic Resonance (MR) images, Speckle noise, Denoising.

I. Introduction

Along with the advances in the field of medical imaging, the need for substantial quality of digital images for accurate and efficient diagnosis has become a necessity. Magnetic Resonance (MR) images are corrupted by noise due to inhomogenuity of magnetic field, excursion of temperature, motion of the tissue, etc [1]. Hence to obtain a high quality MR image, denoising process is mandatory. The aim of denoising is to remove the noise and retain the edge information. But, it is difficult to remove the noise and retain the edge information simultaneously in the case of brain MR images, when compared to ordinary image, because the boundaries of the encephalic tissues are highly complicated [2]. The denoising process can be implemented in two ways: first method is by reducing or removing the noise directly in the spatial domain. This method is implemented by using masks or filters. The second method is by transforming the original image to another domain and then applying thresholding techniques to reduce or remove the noise [3]. This method is easy to implement because after transformation, noise is represented by the smallest coefficients in the high frequencies and setting these coefficients to zero removes more noise in the image. The challenge in this method lies in the selection of the optimal value of threshold for efficient denoising of the image. This paper aims at providing a performance comparison of different denoising techniques for the removal of speckle noise in MR images and is organized as follows: Section-II describes some of the spatial denoising techniques used for removing speckle noise. Section-III provides insight on the different performance parameters used for the comparison analysis. Finally, results, discussions and future discussions are drawn in Section-IV.

A. *Speckle Noise*

Speckle noise is a type of granular noise which degrades the quality of the image with the appearance of backscattered wave. This wave originates from many microscopic diffused
reflections. As a result, it becomes more difficult for the user to discriminate fine details of the image during diagnostic examinations [4]. One of the characteristic of speckle noise is that it is deterministic in nature, i.e. two images which have been acquired under the same circumstances will suffer same level of corruption [5]. Speckle noise is multiplicative in nature and can be mathematically modeled as [6]

$$g = f + n * f \qquad (1)$$

Where 'f' is the original image, 'n' is a uniformly distributed random noise with zero mean and non zero variance, and 'g' is the image corrupted by speckle noise. Default value of variance used in the case of random noise 'n' is 0.04.

II. DENOISING TECHNIQUES

A. *Averaging filter(AF)*

In this filter we take a m ∗ m neighbourhood of the image and calculate the maximum and minimum intensity values present in the neighbourhood. Once they are evaluated the modified pixel value is given by

$$f(i,j) = 0.5 * abs(\max + \min) \quad (2)$$

where f(i, j) is the new pixel intensity value of the image at ith row and jth column. max and min denote the maximum and minimum pixel intensity value in the m ∗ m neighbourhood of the image respectively. abs denotes modulus operation.

B. *First order linear filter (FOLF)*

If g(u, v) is the noisy image, then the filtered image output from the first order linear filter (FOLF) is given by

$$f(u,v) = \mu + k * (g(u,v) - \mu) \quad (3)$$

where µ represents the mean pixel intensity value obtained from a neighbourhood of m∗m pixels and k is the coefficient of variation given by

$$k = \sigma^2 / (\mu^2 * \sigma'^2 + \sigma^2 + 0.001) \quad (4)$$

where σ^2 represents the variance in pixel intensity value obtained from a neighbourhood of m ∗ m pixels and σ'^2 represents the variance of the noise.

C. *Median filter (MF)*

Median filter (MF) [7] is a nonlinear filter in which each pixel is assigned median value of its neighbourhood of m∗m pixels. The median is calculated by sorting all the pixel intensity values in the neighbourhood in either ascending or descending order and then finding out the middle pixel intensity value. The new pixel intensity value is equal to the middle intensity value.

D. *Anisotropic diffusion (AD) and Speckle Reducing Anisotropic Diffusion (SRAD)*

Anisotropic diffusion (AD) [8] is a nonlinear smoothing filter which provides piecewise smoothing with the help of a variable called conduction coefficient which controls the contrast of the edge. Speckle Reducing Anisotropic Diffusion (SRAD) [9] is a Partial Differential Equation (PDE) based anisotropic diffusion approach given by [4]

$$f_t = g_t + \frac{\Delta t(div(u(ICOV(g'))X \bigtriangledown f'))}{4} \quad (5)$$

where t is diffusion time index, Δ t denotes time step responsible for convergence rate of diffusion process, u(.) denotes the diffusion function.

E. *Wiener Filter (WF)*

Wiener filter (WF) [6] is a linear adaptive filter that adapts the filter weights with respect to the local image variance. This filter has the ability to produce a better result when compared to linear filter in terms of preserving edges and other high frequency parts of the image.

F. *Homomorphic Filter (HF)*

It is a nonlinear filter in which each pixel is passed through a median filter of 5*5 mask. The output of the median filter is then placed as argument for the exponential function and then normalized to obtain the filtered image pixel intensity value.

G. *Wavelet Thresholding (WT)*

In this method, denoising is performed by applying a two level wavelet transform using the symlets4 (sym4) wavelet. After performing the wavelet transform of the input image, an optimal value of threshold is applied for efficient removal of noise without affecting information present in the high frequency part of the image.

H. *Geometric Filter (GF)*

The output of this filter is obtained by performing a single iteration of the complementary hull algorithm alternatively on the image and its complement [10]. On applying this filter, the valleys and towers present in the image is gradually and iteratively removed and tends to preserve spatial information [11].

III. PERFORMANCE EVALUATION PARAMETERS

The different performance evaluation parameters considered in this paper along with their mathematical expression are :

A. *Mean Square Error (MSE)*

Mean Square Error (MSE) is given by

$$MSE = \frac{\sum(\sum(f(u,v) - f'(u,v))^2)}{m * n} \quad (6)$$

where f(u, v) is the original image of dimensions m ∗ n and
f'(u, v) represents filtered image. MSE should be as low as possible in the case of a good speckle noise removal technique.

B. *Peak Signal to Noise Ratio (PSNR)*
Peak Signal to Noise Ratio (PSNR)is given by

$$PSNR = 10log(\frac{255 * 255}{MSE}) \quad (7)$$

PSNR should be as high as possible in the case of a good speckle noise removal technique.

C. *Average Difference (AD)*
Average Difference (AD) is given by

$$AD = \frac{abs(\sum\sum(f(u,v) - f'(u,v)))}{m * n} \quad (8)$$

where abs denotes modulus operation.

D. *Structural Content (SC)*
Structural Content (SC) is given by

$$SC = \frac{\sum\sum(f(u,v))^2}{\sum\sum(f'(u,v))^2} \quad (9)$$

E. *Normalized Cross correlation (NK)*
Normalized Cross correlation (NK) is given by

$$NK = \frac{\sum\sum(f(u,v)f'(u,v))}{\sum\sum(f(u,v))^2} \quad (10)$$

The value of normalized cross correlation lies between 0 and 1.

F. *Maximum Difference (MD)*
Maximum Difference (MD) is given by

$$MD = max(max((f(u,v) - f'(u,v)))) \quad (11)$$

G. *Laplacian Mean Square Error (LMSE)*
Laplacian Mean Square Error (LMSE) is given by

$$LMSE = \frac{\sum\sum(OP - 4\bigtriangledown^2(f'(u,v)))^2}{\sum\sum OP^2} \quad (12)$$

where OP is given by

$$OP = 4\bigtriangledown^2(f(u,v)) \quad (13)$$

H. *Normalized Absolute Error (NAE)*
Normalized Absolute Error (NAE) is given by

$$NAE = \frac{\sum\sum abs(f(u,v) - f'(u,v))}{\sum\sum abs(f(u,v))} \quad (14)$$

I. *Mean Structural Similarity Index (MSSIM)*
Mean Structural Similarity Index (MSSIM) is given by

$$MeanSSIM = E(\frac{(2\mu_f\mu'_f + c_1)(2\sigma_d + c_2)}{((\mu_f)^2 + (\mu'_f)^2 + c_1)((\sigma_f)^2 + (\sigma'_f)^2 + c2)}) \quad (15)$$

where c1 and c2 are constants. E() represents expectation operator. μ_f represents the mean pixel intensity value in f and μ'_f represents the mean pixel intensity value in f'. σ_f and σ'_f represents the standard deviation in f and f' respectively. σ_d is the covariance of f and f'.

IV. SIMULATION RESULTS AND CONCLUSIONS

For simulation purposes a database of 25 brain MR images were taken. One of the test images used for the performance comparison of different speckle noise removal techniques is shown in Fig.1. Table 1 provides a comparison analysis of different speckle noise removing techniques using the performance parameters. The value of speckle noise variance used for the performance comparison is 0.04. The value of the neighbourhood size used for the performance comparison was 3*3. If we consider MSE, PSNR, and NAE then it can be noticed that the top 3 speckle noise removing techniques are Median filter, Wiener filter and First order linear filter and the worst 3 speckle noise removing techniques are Wavelet thresholding, SRAD and Homomorphic filtering techniques.

The Averaging filter has a high MSSIM value which is surpassed only by Wiener filter and First order linear filter. The Geometric filter has the highest normalized cross correlation value among all the filters considered.

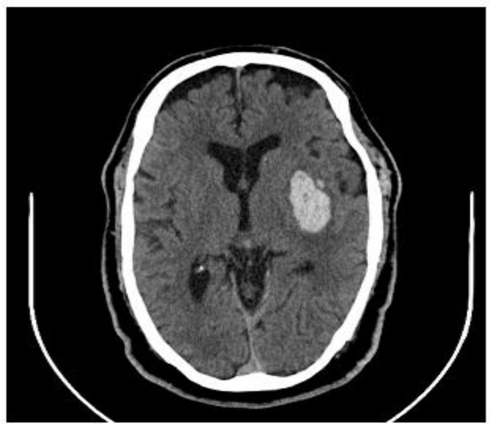

Fig. 1. Test Image

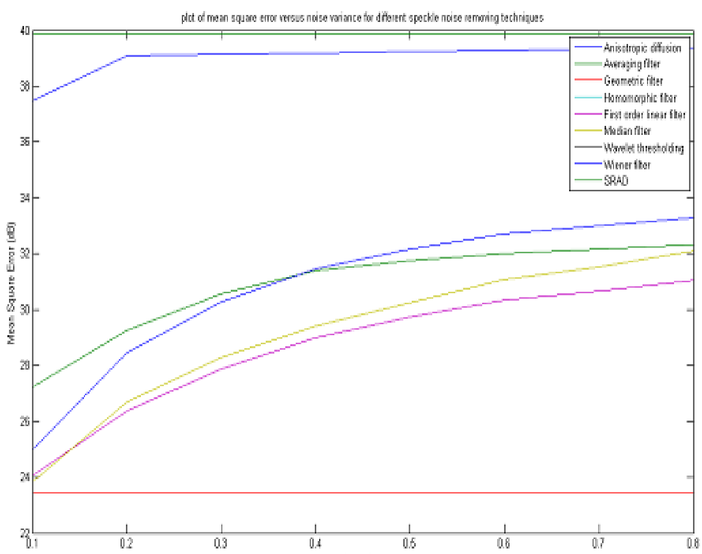

Fig. 2. Mean Square Error versus noise variance for different speckle noise removing techniques

Fig.2 provides an analysis of MSE in dB of various speckle noise removing techniques with respect to noise variance. It can be seen that the MSE of most of the speckle noise removing techniques increases with increase in noise variance. Though it was observed in the previous paragraph that Median filter, Wiener filter and First order linear filter provided good performance in terms of MSE at low values of noise variance, it can be observed from Fig.2 that at high values of noise variance the best performance in terms of MSE is provided by Geometric filter followed by First order linear filter.

V. Conclusion

In this paper, a performance comparison of different techniques for removing speckle noise has been presented. It was bserved that for low values of noise variance, Median filter,Wiener filter and First order linear filter provided good performance in terms of mean square error and peak signal to noise ratio. For higher values of noise variance, Geometric filter and First order linear filter provided better performance in terms of mean square error. Future work in this area could be using a combination of 2 or more speckle noise removal techniques in cascade and obtaining a result which is more acceptable when compared to using these techniques independently.

TABLE I
COMPARISON ANALYSIS OF SPECKLE NOISE REMOVING TECHNIQUES

Parameter	Anisotropic Diffusion	AF	GF	HF	FOLF	MF	WT	WF	SRAD
MSE (Mean Squared Error)	3808.60	247.95	346.16	7319.65	105.22	87.36	7319.80	89.35	7319.73
PSNR (Peak Signal / Noise Ratio)	12.32	24.19	22.74	9.49	27.91	28.72	9.49	28.62	9.49
AD (Average Difference)	1.55	1.41	6.73	47.77	1.83	1.25	47.77	1.41	47.77
SC (Structural Content)	1.09	1.20	0.83	70863.46	1.15	1.07	70042.49	1.11	70328.65
NK (Normalised Cross-Correlation)	0.70	0.90	1.08	0.01	0.93	0.96	0.01	0.94	0.01
MD (Maximum Difference)	255	133	255	255	119	183	254.35	89.46	254.34
LMSE (Laplacian Mean Squared Error)	3.29	0.57	1.69	1.00	0.43	1.06	0.99	0.79	0.99
NAE (Normalised Absolute Error)	0.55	0.13	0.16	1.00	0.09	0.09	1.00	0.09	1.00
MSSIM(Mean SSIM index)	0.52	0.87	0.81	0.55	0.91	0.84	0.55	0.87	0.55

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