Two Stage MRI De-noising using NLM with Bitonic Filtering

Abhishek Sharma, Vijayshri Chaurasia

Abstract*: *Medical image processing is very wide and most interesting area of research now days. It covers wide application in diagnosis of diseases and analysis of inner body structure. Medical image processing include the study of internal body structure like organs, tissues, etc., which produce better information and help to detect disease using the digitalized data of human organs. In last few decades, so many denoising techniques were proposed like DWT techniques, Maximum likelihood (ML) etc. But all these algorithms have some limitations to preserve edges and fine details. So there is need of compromise between de-noising quality and edge preservation to use images for real time application. The proposed advancement in Non-Local Means filtering with different distant function and analyze them for best results. NLM filter reduce noise without degrading important features like edges and fine details. The analysis is based on the quality and quantity base like MSE, PSNR and SSIM.

Keywords* : *NLM filter, Rician Noise, PSNR, SSIM

I. INTRODUCTION

Image denoising methods are most important part of medical imaging, especially Magnetic Resonance Imaging [1][2]. Medical images have wide variety of modalities. Mostly used technique is X-ray, which shows the inner parts of body. Computed tomography (CT) is 3D representation of X-ray. Ultrasound is another technique based on high frequency signals to see inner structure of body. Magnetic Resonance Imaging (MRI) is most effective and safe method to show tissues and bone structure of body. During the acquisition and processing, these images are generally affected by the noise. The noise can be of different characteristics like Gaussian, Rician and Speckle etc. [3] therefore noise detection and noise removal becomes very important part of biomedical imaging. Different denoising algorithms have been proposed continuously for better noise removal and much advancement have been done in last few decades. Noise detection is very crucial part of denoising technique which provides prior information for noise removal. MRI is most suitable technique which provides clearer information of inner body structure. Many different noise removal algorithms have been introduced for magnetic resonance images. These can classified [9][10] based of their working domain as transform domain, statistical domain and filtering domain. These domains can be further classified in sub-categories transform domain includes wavelet based denoising and advancement of wavelet (curvelet and counterlet transform). Statistical domain consists of methods based on maximum likelihood or error based estimations and Linear Minimum Mean Square Error (LMMSE). Filtering domain can be subcategorizing based of their operational strategies as linear and nonlinear filters. Linear filters are temporal and spatial filters like Mean filter and nonlinear filter are bilateral filter [4] [5] and Non local Means filter [9]. The main drawbacks of linear filter are that it introduce blur into images. In further sections, section 2 includes different denoising algorithms. Proposed method is introduced in section 3. Result comparison with previous methods is done in section 4. Finally the conclusion is done in section 5.

Revised Manuscript Received on October 30, 2019.
* Correspondence Author
Abhishek Sharma, Electronics and Communication Department, MANIT, Bhopal, India. Email: vchaurasia@manit.ac.in
Dr. Vijayshri Chaurasia, Electronics and Communication Department, MANIT, Bhopal, India. Email: abhishektit09@gmail.com

II. METHODS AND MATERIAL

The denoising methods designed for medical are very popular and effective because medical images specially MRI are complex images and during denoising it has to be take care that image details like edges and other fine information should not be effected by these processing. Here, we have discussed few advance denoising algorithms which effectively removes the Gaussian and Rician noise.

A. Linear Minimum Mean Square Error (LMMSE)

Some statistical methods [15,16] uses LMMSE estimator to estimate the SNR and other parameter of Rician noise. These parameters like local variance and mean values help to make denoising algorithm effective and make the analysis easy. But this algorithm is not able to preserve the edges sharpness effectively. Therefore denoised images affect homogeneous region and boundary values.

B. Non-Local Means Filter (NLM)

Non local means filter is proposed by Manjon et al [12], which is enhancement of the Yaroslavsky filter (Yaroslavsky, 1985) [13]. previous filters like bilateral filters based on pixels comparison, but NLM works on the concept of region comparison based on their distance of intensity and then average the same image pixels.The denoised image can be restored using weighted average and represents as

$$(A_x) = \sum_{\forall_q \in Y} W_{x,y}\, A_y \qquad (3)$$

Where$W_{x,y}$weight of pixels

$$W_{x,y} = \frac{1}{Z(x)} e^{-\frac{d(x,y)}{h^2}}$$

$$Z(x) = \sum_{\forall_y} e^{-\frac{d(x,y)}{h^2}}$$

$Z(x)$ = normalization factor,
h = decay parameter
d = Euclidian distance
And weight must satisfy following condition

$$0 \le W_{x,y} \le 1$$

$$\sum_{\forall y \in A} W_{x,y} = 1$$

x = point being filtered and
y = all neighbourhood pixels of image

C. Bitonic Filter

Bitonic filter [14] is the combination of linear filter like Gaussian and morphological filter (morphological opening and closing). Mask of the filter is fixed and selected diameter circle. It removes noise with preservation of smooth and discontinuity of signal and without adding any artifacts in signal.

$$B_{w,c} = \frac{\varepsilon_0(x)C_{w,c}(x) + \varepsilon_c(x)O_{w,c}(x)}{\varepsilon_0(x) + \varepsilon_c(x)}$$

Where error of opening is represented as

$$\varepsilon_0(x) = \left|G_\sigma\{x - O_{w,c}(x)\}\right|$$

And error of closing as $\varepsilon_c(x) = \left|G_\sigma\{x - C_{w,c}(x)\}\right|$
and $G_\sigma\ (x)$ represents the Gaussian linear filter

$$r_{w,c}(x) = C^{th}centile\ \{x\}$$

$$O_{w,c}(x) = r_{w,100-c}\left(r_{w,c}(x)\right)$$

$$C_{w,c}(x) = r_{w,c}\left(r_{w,100-c}(x)\right)$$

Here rank filter is represented by $r_{w,c}(x)$, Where w = structuring element, c = centile

III. PROPOSED METHODOLOGY

To overcome the drawbacks of previous algorithms and to improve the performance of filters, a new Advance NLM filter is proposed. The advancement in standard NLM is used that it does not compare pixels but compare regions of neighbours. Therefore, it is known as non-local filtering process. For NLM filtered image, slice splitting and Bitonic filtering is used, which preserve the edges and fine details of image and improve noise removal. The complete process of applied algorithm is explained as follows:

A. Read input noisy image A.

B. Noisy image applied to NLM filter as denoised value

$$(A_x) = \sum_{\forall y \in A} W_{x,y}\, A_y \qquad (3)$$

Where $W_{x,y}$ weight of pixels and A_y is neighbourhood pixels. Following points has been set for this experiment as :

- Window selected of size 3*3 for search area of 9*9 for less complexity.
- Decaying parameter h is set standard deviation σ of noisy image.

C. NLM filtered image Y_p is passes through bit plane slicing process, which divided in 8 planes from lower bit plane to higher bit plan.

D. Each plane is passes through bitonic filter as separate input image. The NLM filtered image Y_p passes through bitonic filter. And the output of bitonic filter for each bit plane will be

$$B(p)_{w,c} = \frac{\varepsilon_0(Y_p)C_{w,c}(Y_p) + \varepsilon_c(Y_p)O_{w,c}(Y_p)}{\varepsilon_0(Y_p) + \varepsilon_c(Y_p)}$$

This filter removes noise further as maxima's and minima's. It preserved edges and fine details but least effecting lower bit plan. The mask radius of circular disc operator used in bitonic filter is set to 2.

E. These bitonic filtered images of different planes are combined to reconstruct denoised image.

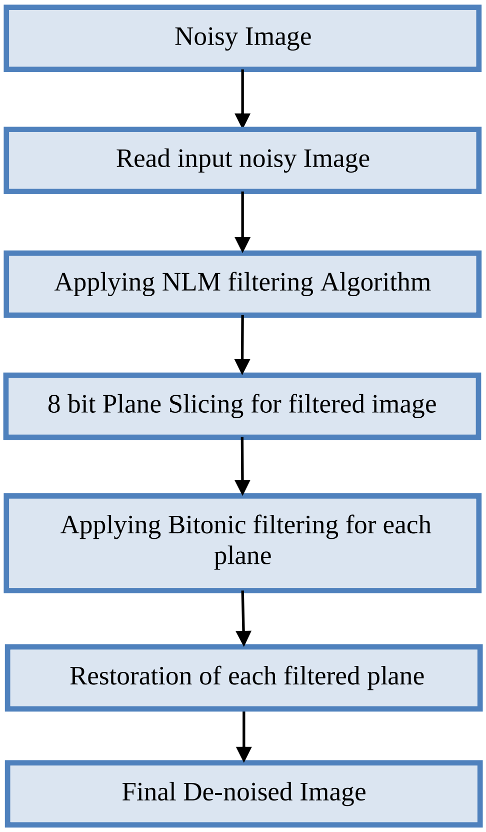

Fig 1. Flow diagram of proposed algorithm

IV. RESULT AND DISCUSSION

The subjective analysis is based on different parameters [11]. First is Peak Signal to Noise Ratio (PSNR) of denoised images. It shows recovered image strength. Second, Mean Squared Error (MSE), which defines error of restored pixel values and another, is Structural Similarity Index Measure (SSIM), which defines intensity difference between Real Test image and Denoised image.

PSNR is represents mathematically as

$$PSNR = 10\ \log\left[\frac{255^2}{\frac{1}{MN}\sum_{i=0}^{M-1}\sum_{j=0}^{N-1}\left(I(i,j) - \hat{I}(i,j)\right)^2}\right] \quad (5)$$

And Mean Square error (MSE) define as

$$MSE = \frac{1}{MN}\sum_{i=0}^{M-1}\sum_{j=0}^{N-1}\left(I(i,j) - \hat{I}(i,j)\right)^2 \quad (6)$$

Where M xN are the no. of Rows and No. of column of image respectively. Real image is denoted by $I(i,j)$ and $\hat{I}(i,j)$ denotes Denoised image.

Another assessment parameter is SSIM [6] can be represented as

$$SSIM(x,y) = \frac{(2\mu_x\mu_y + c_1)(2\sigma_{xy} + c_2)}{(\mu_x^2 + \mu_y^2 + c_1)(\sigma_x^2 + \sigma_y^2 + c_2)} \quad (7)$$

The Simulation was done on T1 phantom image and noise with different densities has been introduced manually. The Original test image with noise at different levels and Denoised images by various methods are shown in following figures. Figure 2 shows the noisy and denoised images for $\sigma = 10$, Figure 3 shows the noisy and denoised images for $\sigma = 20$, and Figure 4 shows the noisy and denoised images for $\sigma = 30$.

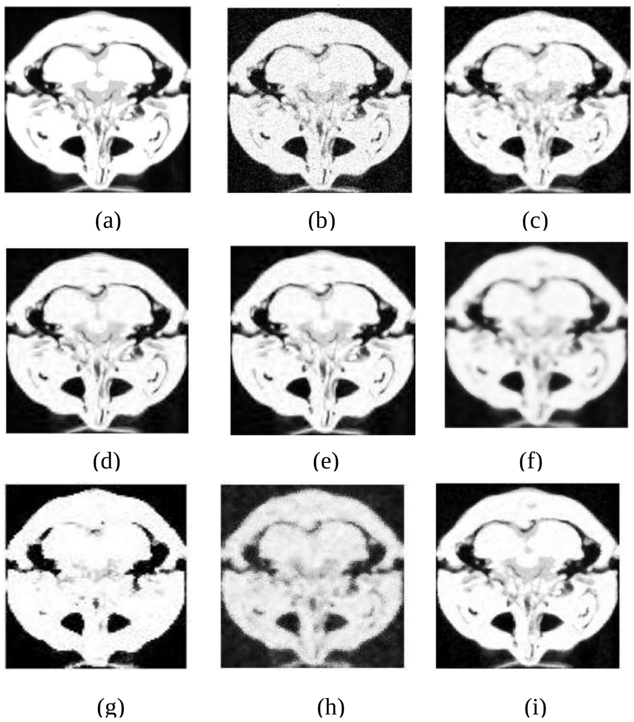

Figure 2: (a) Original T1 MRI Image (Slice 20), (b) Noisy image $\sigma = 10$ (c) De-noised by Median (d De-noised by VS-Hard (e) De-noised by VS-Soft (f) De-noised by Bilateral, (g) De-noised by Bitonic, (g) De-noised by NLM, (g) De-noised by Proposed Method

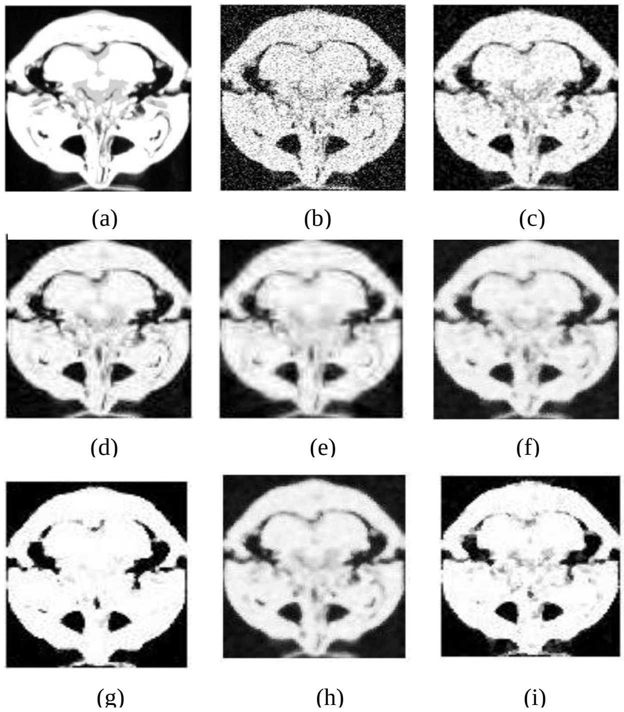

Figure 3: (a) Original T1 MRI Image (Slice 20), (b) Noisy image $\sigma = 20$ (c) De-noised by Median (d De-noised by VS-Hard (e) De-noised by VS-Soft (f) De-noised by Bilateral, (g) De-noised by Bitonic, (g) De-noised by NLM, (g) De-noised by Proposed Method

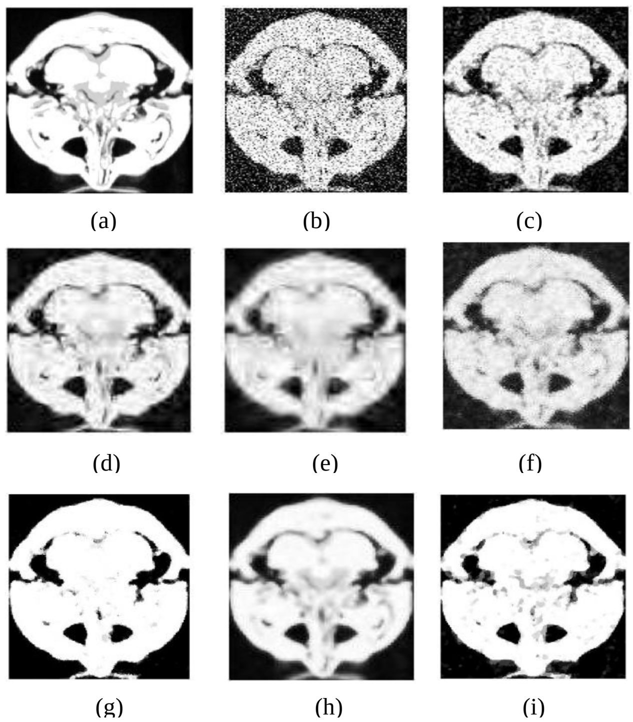

Figure 4: (a) Original T1 MRI Image (Slice 20), (b) Noisy image $\sigma = 30$ (c) De-noised by Median (d De-noised by VS-Hard (e) De-noised by VS-Soft (f) De-noised by Bilateral, (g) De-noised by Bitonic, (g) De-noised by NLM,

Figure 5 shows the graphical representation of MSE of different algorithms. The graph shows that while increasing the noise density, error of previous methods are very high as compare to proposed method. The proposed algorithm produces lowest mean square error, even for high noise density. Table 1 represent the comparative analysis of PSNR of different Denoising techniques (Bilateral Filter [4], Median Filter [8], Visu Shrink with hard thresholding (VS-Hard), Visu Shrink with soft thresholding (VS-Soft), Bitonic Filter [14], NLM Filter [12] and Proposed Filter). The results shows that PSNR of proposed method does not fall much with increment in noise density. Table 2 shows SSIM comparison of those techniques and it is clearly visible that proposed algorithm has maximum similarity between denoised and original image. The observation makes it very clear that the proposed algorithm perform better in details preservation and visual representation.

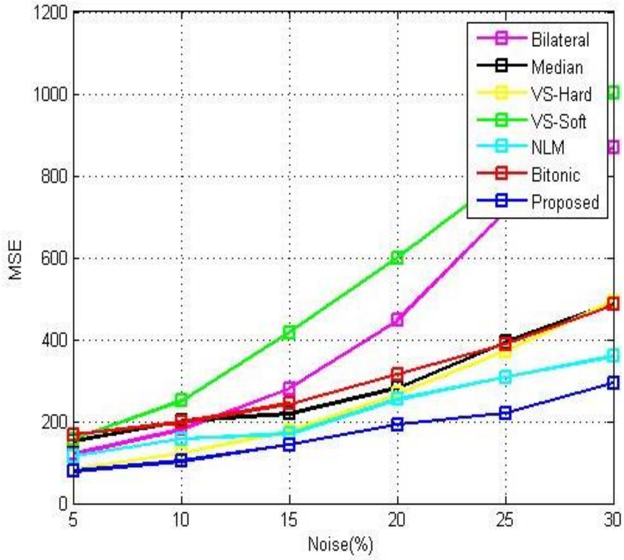

Figure 5. Graph representation of MSE (Mean Square error) of different denoising algorithms

Table- I: PSNR in dB of different algorithms

Sr. no.	Techniques	Noise Density (σ)					
		5	**10**	**15**	**20**	**25**	**30**
1.	Noisy	24.59	23.47	21.18	19.56	17.76	14.6
2.	Bilateral	27.33	25.59	23.67	21.63	19.6	18.74
3.	Median	26.31	25.12	24.74	23.64	22.18	21.24
4.	VS-Hard	28.95	27.29	25.67	23.87	22.44	21.19
5.	VS-Soft	26.16	24.16	21.93	20.35	19.10	18.13
6.	NLM	27.55	26.16	25.86	24.08	23.24	22.58
7.	Bitonic	25.88	25.19	24.29	23.14	22.24	21.28
8.	Proposed Algorithm	**29.83**	**28.72**	**27.56**	**26.29**	**24.72**	**23.46**

Table- II: SSIM comparison of different algorithms

Sr. no.	Techniques	Noise Density (σ)					
		5	**10**	**15**	**20**	**25**	**30**
1.	Noisy	0.7066	0.6687	0.6282	0.5895	0.5418	0.5031
2.	Bilateral	0.7800	0.7370	0.6943	0.6500	0.5798	0.5259
3.	Median	0.8615	0.7986	0.7163	0.6509	0.6423	0.6113
4.	VS-Hard	0.8872	0.8495	0.775	0.7159	0.6619	0.6208
5.	VS-Soft	0.8295	0.7827	0.7041	0.6431	0.5901	0.5485
6.	NLM	0.8515	0.8115	0.7662	0.7150	0.6818	0.6315
7.	Bitonic	0.8273	0.8010	0.7582	0.7018	0.6554	0.5939
8.	Proposed Algorithm	**0.8910**	**0.8526**	**0.7912**	**0.7405**	**0.7140**	**0.6602**

V. CONCLUSION

It is observed from study of previous techniques that denoised algorithm must be capable of preserving the edges and fine details of images. Existing filters are not able to suppress the noise at high noise density. This algorithm is simple and very effective to reduce the noise. It proposed two stage filtering method, which include both NLM and Bitonic filtering approach. Proposed algorithm produces better PSNR and also improve the visual quality as compare to other stat of art methods like Bilateral Filter, Median Filter, VS-Hard VS-Soft, NLM Filter and Bitonic Filter. NLM filter use as primary stage in proposed algorithm and then bit plane slicing is used to separate low and high frequency components and bitonic filtering is used to preserve the image fine details.

The highlighted values in table 1 and 2 shows the effectiveness of proposed algorithm. The visual quality of proposed work is also better than previous methods. The method can improve further with parameter enhancement.

REFERENCES

1. G. A. Wright, "Magnetic Resonance Imaging," IEEE Signal Processing, Magazine, vol. 1, 1997, pp. 56-66.
2. R.C. Gonzalez, R.E. Woods, Processing, 2002.
3. Hakon Gudbjartsson and Samuel Patz, "The Rician Distribution of Noisy MRI Data", Magnetic Resonance in Medicine, Vol. 34, 1995, pp. 910–914.
4. C. Tomasi and R. Manduchi, "Bilateral filtering for gray and color images," Proc. IEEE International Conference on Computer Vision, 1998, pp. 839-846.
5. J. Xiao, H. Cheng, H. Sawhney, C. Rao, and M. Isnardi, "Bilateral filtering-based optical flow estimation with occlusion detection," Proc. European Conference on Computer Vision, 2006, pp. 211-224.
6. Z. Wang, A. C. Bovik, H. R. Sheikh, and E. P. Simoncelli, "Image Quality Assessment: From Error Visibility to Structural Similarity," IEEE Transactions on Image Processing, Vol. 13, 2004, pp. 600- 612.
7. Ayush Dogra, Parvinder Bhalla, Image sharpening by gaussian and butterworth high pass filter, Biomed. Pharmacol. J. 7 (2) (2014) 707–713.
8. T. Sun, Y. Neuvo, "Detail-preserving median based filters in image processing", Pattern Recognition Letter, Vol. 15, 1994, pp. 341–347.
9. Hemalata V. Bhujle, Basavaraj H. Vadavadagi, "NLM based magnetic resonance image denoising – A review", Biomedical Signal Processing and Control, Vol. 47, 2019, pp. 252–261.
10. J. Mohana, V. Krishnavenib, Yanhui Guoca, "A survey on the magnetic resonance image denoising methods", Biomedical Signal Processing and Control Vol. 9, 2014, pp. 56– 69.
11. Dong Wook Kim, Chansoo Kim, Dong Hee Kim and Dong Hoon Lim, "Rician nonlocal means denoising for MR images using nonparametric principal component analysis", EURASIP Journal on Image and Video Processing, 2011.
12. Jose V. Manjon, Jose Carbonell-Caballero, Juan J. Lull, Gracian Garcıa-Martıa, Luıs Mart-Bonmat, Montserrat Robles, "MRI denoising using Non-Local Means", Medical Image Analysis, 12, 2008, pp. 514–523.
13. Yaroslavsky, L. P., "Digital Picture Processing. An Introduction", Berlin-Heidelberg-New York, Springer Verlag 1985.
14. G. Treece, The bitonic filter: linear filtering in an edge-preserving morphological framework, IEEE Transaction on Image Processing. Vol. 25, 2016, pp. 5199–5211.
15. Aja-Fernandez, C. Alberola-Lopez, C.F. Westin, "Noise and signal estimation in magnitude MRI and Rician distributed images: a LMMSE approach", IEEE Transaction on Image Processing. Vol. 17, 2008, pp. 1383–1398.
16. H.M. Golshan, R.P.R. Hasanzedeh, S.C. Yousefzadeh, "An MRI denoising method using data redundancy and local SNR estimation", Magnetic Resonance Imaging, Vol. 31, 2013, pp. 1206–1217

AUTHORS PROFILE

Abhishek Sharma pursuing PhD. From MANIT Bhopal. He did B.E. in Electronics and Communication from Technocrtas Institute of Technology, Bhopal (M.P.) India. He did M.Tech in Microelectronics & VLSI Design from Technocrtas Institute of Technology, Bhopal (M.P.) India. Presently He is pursuing PhD in Electronics and Communication department of Maulana Azad National Institute of Technology, Bhopal (M.P.) india. He has published 06 Research publications of international repute. His area of interest is Image Processing.

Dr. Vijayshri Chaurasia did B.E. in Electronics and Communication from Pt. Ravi Shanker University Raipur (C.G.) India. She did M.Tech in Digital Communication from Maulana Azad National Institute of Technology Bhopal (M.P.) India. She did Ph.D.in Electronics and Communication from MANIT Bhopal. Presently she is working as Assistant Professor in Electronics and Communication department of MANIT Bhopal. She has published around more than 60 Research publication of International repute. Her area of interest is Image Processing and Image Analysis and pattern recognition. She is a member of professional bodies IEEE, ISTE and IETE.