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Modified Non-Local Means Filter for Removing Salt and Pepper Noise from Images of Magnetic Resonance Imaging*

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***Abstract*— Magnetic Resonance Imaging MRI is widely used in medical studies. It is a non-invasive technique. There are several noises which affect the performance of MRI. Salt and pepper noise is a kind of pulsing noise which is produced in images of MRI due to their sensors. Modified Non-Local Means MNLM filter is applied to remove this noise. Noise of salt and pepper of colored images of MRI are removed using 2-stages Modified Non-Local Means filter or 1-stage Modified Non-Local Means filter. These filters are compared to remove salt and pepper noise from these noisy colored images. Peak signal-to-noise ratio PSNR and structure similarity SSIM are used to evaluate quality of denoised images. The parameters of 2-stages Modified Non-Local Means are over performed of parameters of 1-stage Modified Non-Local Means filters. In 2-stages Modified Non-Local Means, when variance of salt and pepper noise is 0.01, PSNR of noisy image is 24.09dB. PSNR of denoised image is 35.19dB. SSIM of noisy image is 0.842. SSIM of denoised image is 0.9896. . In 1-stages Modified Non-Local Means, when variance of noise is 0.01, PSNR of noisy image is 24.19dB. PSNR of denoised image is 32.31dB. SSIM of noisy image is 0.844. SSIM of denoised image is 0.958.**

Keywords—MRI, NLM, PSNR, SSIM

I. INTRODUCTION

MRI is a widely used in medical and research studies. It is a non-invasive technique. It is used to know the anatomy and the function of different parts of the body. It is used without needing to damage radiation. It is used for detecting, diagnosing, treating and monitoring diseases. Many researches are conducted for removing noise from MRI images. H. K. Kwan used intelligent digital filter to reduce salt and pepper noise of images of MRI [1]. S. N. Sulaiman and his colleagues used switching based clustering method to reduce noises from noisy images of MRI [2]. Bruni et al. denoise non-local means image based on noise adaptive SSIM [3]. B. Deepa and M. G. Sumithra used comparative analysis to remove noise of MRI brain images [4]. I. S. Isa et al. denoise MRI images using fundamental filters [5]. F. Mohanty et al. removed salt and pepper noise from MRI images using B-Spline Interpolation [6]. H. M. Ali used median filter to remove salt & pepper noise of images of MRI [7]. X. Wang et al. used iterative NLM filter to remove salt and pepper noise [8]. S. Gupta and R. K. Sunkaria removed salt and pepper noise from medical images by a modified weighted average filter [9]. D. Chowdhury et al. removed salt and pepper noise by using SNPRB Filter [10]. J.V. Manjón and P. Coupe removed noises MRI images by applying deep learning and non-local averaging [11].

II. METHODS OF NOISE REMOVAL

A. NLM Filter

Non-Local Means (NLM) filter is widely used for removing noise from images [12]. Pixels of image are averaged in NLM filter. In this paper, we will use it for removing noise from images of MRI. Pixels of images are averaged in NLM filter. If there is signal with salt and pepper noise.

$$v = u + n \tag{1}$$

Where n is additive noise, u is original signal, and v is noisy signal. The average estimated $\overline{u(s)}$ of a sample s is a weighted aggregate of values at different points t that are within "search neighborhood" N(s) and can be calculated as (2)

$$\overline{u(s)} = \frac{1}{Z(s)} \sum_{t \in N(s)} w(s,t) v(t) \tag{2}$$

Where

$$Z(s) = \sum_{t} w(s,t) \tag{3}$$

The weights can be calculated from (4)

$$w(s,t) = \exp\left(-\frac{\sum_{\delta \in \Delta}[v(s+\delta) - v(t+\delta)]^2}{2L_\Delta \lambda^2}\right)$$
$$= \exp(-\frac{d^2(s,t)}{2L_\Delta \lambda^2}) \tag{4}$$

Where λ is bandwidth parameter ,Δ is local path of samples enclosing s, consisting L_Δ sample; a patch of similar shape also encloses t. Samples of patches are selected at the center of interested points d2 is the squared , summed point to point difference between samples of patches. The patches are centered on s and t points. Each patch is presented to self averaging with weight w(s,s)=1. Smoother results are achieved by central patch corrector as shown in (5)

$$w(s,s) = max_{t \in N(s), t \neq s}^{w(s,t)} \tag{5}$$

The main idea of NLM filter is that the weight w(s,t) depends on patch correlation not on the distance between t and s points. The identical patches retain edges. The self similarity expands along the signal, N(s) is considered to be the whole signal, so averaging operation is exactly non-local.

In the MNLM filter equation (4) will be

$$w(s,t) = \exp\left(-\frac{d^2(s,t)}{(\sqrt{L_\Delta}\lambda^2)^4}\right) \quad (6)$$

$$\sigma = \sqrt{L_\Delta}\lambda^2 \quad (7)$$

In this paper σ=0.35, half patch size=2 and half window size=1

B. Performance of Noise Removal

Two parameters are introduced to evaluate performance of modified NLM filter such as PSNR and SSIM.

$$PSNR(v)db = 10.\log_{10}\frac{[\max(v)]^2}{MSE} \quad (8)$$

$$MSE(u,v) = \frac{1}{N}\sum_i (u-v)^2 \quad (9)$$

The SSIM index is based on the calculation of three values, the luminance value, the contrast value and the structural value. The overall index is a multiplicative combination of the three values [13].

$$SSIM(u,v) = [l(u,v)]^\alpha.[c(u,v)]^\beta.[s(u,v)]^\gamma \quad (10)$$

Where

$$l(u,v) = \frac{2\mu_u\mu_v + C_1}{\mu_u{}^2 + \mu_v{}^2 + C_1} \quad (11)$$

$$c(u,v) = \frac{2\sigma_u\sigma_v + C_2}{\sigma_u{}^2 + \sigma_v{}^2 + C_2} \quad (12)$$

$$s(u,v) = \frac{\sigma_{uv} + C_3}{\sigma_u\sigma_v + C_3} \quad (13)$$

Where μ_u, μ_v, σ_u,σ_v, and σ_{uv} are the local means, standard deviations, and cross-covariance for images *x, y*. If $\alpha = \beta = \gamma = 1$ (the default for Exponents), and $C_3 = C_2/2$ (default selection of C_3) the index simplifies to:

$$SSIM(u,v) = \frac{(2\mu_u\mu_v + C_1)(2\sigma_{uv} + C_2)}{(\mu_u{}^2 + \mu_v{}^2 + C_1)(\sigma_u{}^2 + \sigma_v{}^2 + C_2)} \quad (14)$$

III. Analysis and Results

Three Colored images of MRI are presented for brain. 1st sagittal view image of MRI brain is represented. Transverse view image of MRI brain is represented. 2nd sagittal view of MRI brain is represented. Salt and pepper noises are added to the three colored images of MRI.

As shown in Table 1, variance of salt and pepper noise is changed from 0.01 to 0.1. 2-stages MNLM are used to remove this added noise from noisy image of Figure1. When variance of noise is 0.01, PSNR of noisy image is 24.09dB. PSNR of denoised image is 35.19dB. SSIM of noisy image is 0.842. SSIM of denoised image is 0.9896. As shown in Figure 1, noisy and denoised image of 1st sagittal view image of MRI brain using 2-Stage MNLM Filter when variance of noise is 0.01.

As shown in Table 2, variance of salt and pepper noise is changed from 0.01 to 0.1. 1-stages MNLM are used to remove this added noise from noisy image of 1st sagittal view image of MRI brain. When variance of noise is 0.01, PSNR of noisy image is 24.19dB. PSNR of denoised image is 32.31dB. SSIM of noisy image is 0.844. SSIM of denoised image is 0.958.

As shown in Table 3, variance of salt and pepper noise is changed from 0.01 to 0.1. 2-stages MNLM are used to remove this added noise from noisy image of transverse view image of MRI brain image. When variance of noise is 0.01, PSNR of noisy image is 23.4dB. PSNR of denoised image is 32.74dB. SSIM of noisy image is 0.683. SSIM of denoised image is 0.965. As shown in Figure 2, noisy and denoised image of transverse view image of MRI brain using 2-Stage MNLM Filter when variance of noise is 0.01.

As shown in Table 4, variance of salt and pepper noise is changed from 0.01 to 0.1. 1-stages MNLM are used to remove this added noise from noisy image of transverse view image of MRI brain. When variance of noise is 0.01, PSNR of noisy image is 23.61dB. PSNR of denoised image is 31.79dB. SSIM of noisy image is 0.688. SSIM of denoised image is 0.9.

As shown in Table 5, variance of salt and pepper noise is changed from 0.01 to 0.1. 2-stages MNLM are used to remove this added noise from noisy image of 2nd sagittal view of MRI brain image. When variance of noise is 0.01, PSNR of noisy image is 24.26dB. PSNR of denoised image is 31.89dB. SSIM of noisy image is 0.83. SSIM of denoised image is 0.95. As shown in Figure 3, noisy and denoised image of 2nd sagittal view of MRI brain image using 2-Stage MNLM Filter when variance of noise is 0.01.

As shown in Table 6, variance of salt and pepper noise is changed from 0.01 to 0.1. 1-stages MNLM are used to remove this added noise from noisy image of 2nd sagittal view of MRI brain. When variance of noise is 0.01, PSNR of noisy image is 24.24dB. PSNR of denoised image is 30.05dB. SSIM of noisy image is 0. 83. SSIM of denoised image is 0.91. 1-stage MNLM is shown in figure4. 2-stage MNLM is shown in figure 5.

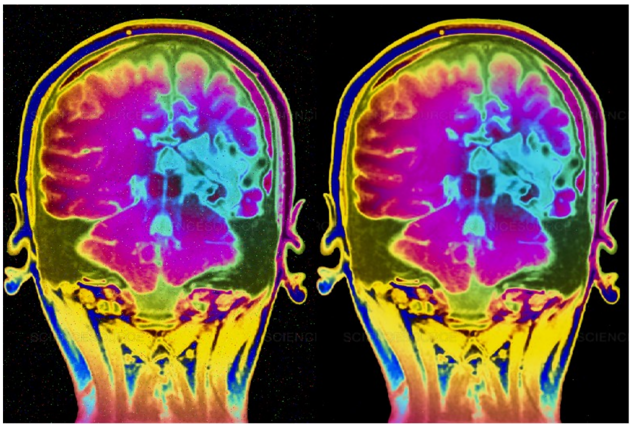

Fig. 1. Before and After Removing Salt and Pepper Niose From Fig.1 using 2-Stage MNLM Filter When Variance of Noise is0.01

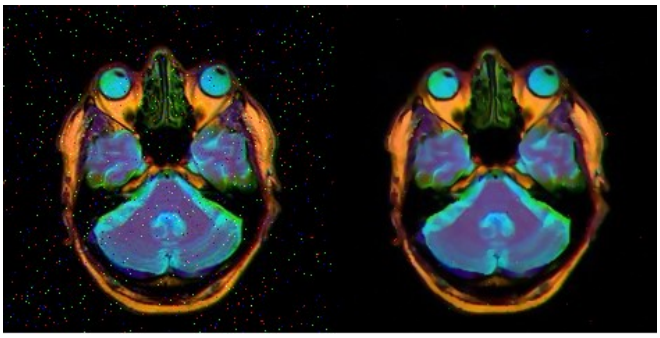

Fig. 2. Before and After Removing Salt and Pepper Niose From Fig.2 using 2-Stage MNLM Filter When Variance of Noise is0.01

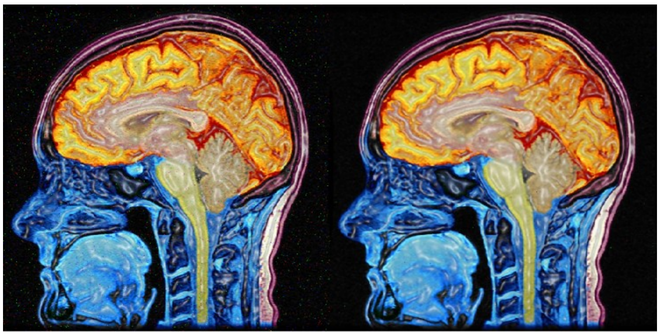

Fig. 3. Before and After Removing Salt and Pepper Niose From Fig.3 using 2-Stage MNLM Filter When Variance of Noise is0.01

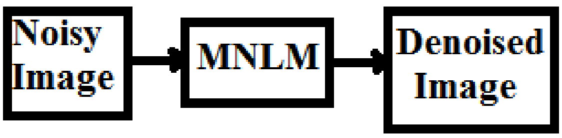

Fig. 4. 1-stage MNLM

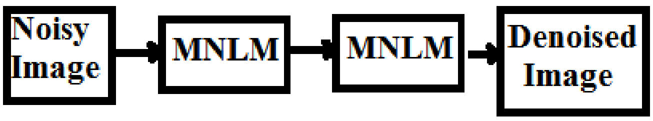

Fig. 5. 2-stages MNLM

TABLE I. 2-STAGES MNLM FILTER PERFORMANCE FOR REMOVING SALT AND PEPPER NOISE OF FIG.1

Noise variance	PSNR noisy dB	PSNR Denoised dB	SSIM noisy	SSIM denoised
0.01	**24.09**	**35.19**	**0.842**	**0.9896**
0.02	21.13	32.56	0.753	0.977
0.03	19.369	30.39	0.697	0.96
0.04	18.11	28.5	0.66	0.94
0.05	17.17	26.95	0.625	0.912
0.1	14.13	21.97	0.52	0.78

TABLE II. 1-STAGE MNLM FILTER PERFORMANCE FOR REMOVING SALT AND PEPPER NOISE OF FIG.1

Noise variance	PSNR noisy dB	PSNR denoised dB	SSIM noisy	SSIM denoised
0.01	24.19	32.31	0.844	0.958
0.02	21.14	29.096	0.754	0.92
0.03	19.398	26.98	0.696	0.881
0.04	18.14	25.42	0.655	0.846
0.05	17.14	24.07	0.62	0.81
0.1	14.13	19.73	0.522	0.68

TABLE III. 2-STAGES-MNLM FILTER PERFORMANCE FOR REMOVING SALT AND PEPPER NOISE OF FIG.2

Noise variance	PSNR noisy dB	PSNR denoised dB	SSIM noisy	SSIM denoised
0.01	23.4	32.74	0.683	0.965
0.02	20.7	30.72	0.53	0.939
0.03	18.91	29.26	0.43	0.91
0.04	17.57	27.04	0.357	0.838
0.05	16.61	26.25	0.32	0.81
0.1	13.57	21.08	0.22	0.538

TABLE IV. 1-STAGE MNLM FILTER PERFORMANCE FOR REMOVING SALT AND PEPPER NOISE OF FIG.2

Noise variance	PSNR noisy dB	PSNR Denoised dB	SSIM noisy	SSIM denoised
0.01	23.61	31.79	0.688	0.9
0.02	20.72	28.23	0.53	0.82
0.03	18.84	26.49	0.43	0.73
0.04	17.5	24.75	0.358	0.66
0.05	16.6	23.38	0.315	0.589
0.1	13.62	19.34	0.22	0.377

TABLE V. 2-STAGES MNLM FILTER PERFORMANCE FOR REMOVING SALT AND PEPPER NOISE OF FIG.3

Noise variance	PSNR noisy dB	PSNR denoised dB	SSIM noisy	SSIM denoised
0.01	24.26	31.89	0.83	0.95
0.02	21.21	29.96	0.72	0.93

0.03	19.45	28.31	0.65	0.91
0.04	18.21	26.94	0.6	0.88
0.05	17.22	25.6	0.56	0.85
0.1	14.24	21.24	0.44	0.71

TABLE VI. 1-STAGES MNLM FILTER PERFORMANCE FOR REMOVING SALT AND PEPPER NOISE OF FIG.3

Noise variance	**PSNR noisy dB**	**PSNR denoised dB**	**SSIM noisy**	**SSIM denoised**
0.01	24.24	30.05	0.83	0.91
0.02	21.22	27.14	0.72	0.85
0.03	19.43	25.2	0.65	0.798
0.04	18.22	23.82	0.6	0.757
0.05	17.26	22.71	0.56	0.72
0.1	14.23	18.81	0.44	0.59

IV. CONCLUSION

Salt and pepper noise is due to sensors of MRI. Salt and pepper noise are added to colored images of MRI and then removed using 2-stages MNLM filter and 1-stage filter. PSNR and SSIM are parameters which are used to evaluate quality of denoising images. The parameters of 2-stages MNLM are over performed of values of 1-stage MNLM filter. In future, a new filter will be implemented to remove noise with higher PSNR and SSIM.

REFERENCES

[1] H. K. Kwan, "Intelligent digital filters with application to salt and pepper noise reduction in MR brain images," 2013 Constantinides International Workshop on Signal Processing (CIWSP2013), London, 2013, pp. 1-4, doi: 10.1049/ic.2013.0022.

[2] S. N. Sulaiman, S. M. C. Ishak, I. S. Isa and N. Hamzah, "De-noising of noisy MRI brain image using the switching-based clustering algorithm," 2014 IEEE International Conference on Control System, Computing and Engineering (ICCSCE 2014), Batu Ferringhi, 2014, pp. 1-6, doi: 10.1109/ICCSCE.2014.7072679.

[3] Bruni, Vittoria, D. Panella, and Domenico Vitulano. "Non local means image denoising using noise-adaptive SSIM." 2015 23rd European Signal Processing Conference (EUSIPCO). IEEE, 2015.

[4] B. Deepa and M. G. Sumithra, "Comparative analysis of noise removal techniques in MRI brain images," 2015 IEEE International Conference on Computational Intelligence and Computing Research (ICCIC), Madurai, 2015, pp. 1-4, doi: 10.1109/ICCIC.2015.7435737.

[5] I.S. Isa et al. "Evaluating denoising performances of fundamental filters for t2-weighted MRI images." Procedia Computer Science 60 (2015): 760-768.

[6] F. Mohanty, S. Rup and B. Dash, "A Thresholding-Based Salt and Pepper Noise Removal Using B-Spline Interpolation in MRI Images," 2015 International Conference on Computational Intelligence and Communication Networks (CICN), Jabalpur, 2015, pp. 246-251, doi: 10.1109/CICN.2015.56.

[7] H. M. Ali, "A new method to remove salt & pepper noise in Magnetic Resonance Images," 2016 11th International Conference on Computer Engineering & Systems (ICCES), Cairo, 2016,pp. 155-160, doi: 10.1109/ICCES.2016.7821992.

[8] X. Wang, et al. "Iterative non-local means filter for salt and pepper noise removal." Journal of visual communication and image representation 38 (2016): 440-450.

[9] S. Gupta and R. K. Sunkaria, "Real-time salt and pepper noise removal from medical images using a modified weighted average filtering," 2017 Fourth International Conference on Image Information Processing (ICIIP), Shimla, 2017, pp. 1-6, doi: 10.1109/ICIIP.2017.8313718.

[10] D. Chowdhury, S. Panda and S. Dutta, "Eradication of Salt and Pepper Noise from a Tumorous MRI image using SNPRB Filter," 2019 International Conference on Opto-Electronics and Applied Optics (Optronix), Kolkata, India, 2019, pp. 1-6, doi: 10.1109/OPTRONIX.2019.8862333.

[11] J.V. Manjón and P. Coupe. "MRI denoising using Deep Learning and Non-local averaging." arXiv (2019): arXiv-1911.

[12] Liu, Hong, et al. "Denoising 3D MR images by the enhanced non-local means filter for Rician noise." Magnetic resonance imaging 28.10 (2010): 1485-1496.

[13] Zhou, W., A. C. Bovik, H. R. Sheikh, and E. P. Simoncelli. "Image Qualifty Assessment: From Error Visibility to Structural Similarity."*IEEE Transactions on Image Processing*. Vol. 13, Issue 4, April 2004, pp. 600–612.