Comparative Analysis of Poisson Noise Removal Techniques in Medical Images

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Abstract

Removal of Poisson noise is one of the challenging task's in medical imaging. This work aims to evaluates, analyze and compare the medical images de-noising techniques and methodologies, giving a detail explanation, depicting the main points and the performance metrics for poison noise removal. In this context the performance of Non Local Mean, Wavelet transform and logarithm gradient representative flavors are analyzed. Non Local Mean (NLM) filter consists of three variants based on the fact that third order moment of the image makes the signal and the noise clearer and easier to be de-noised. In second approach, Discrete Wavelet Transform (DWT) with modified thresholding function is utilized for Poisson noise reduction. The third method is based on Hybrid Logarithmic Gradient. These methods are used on medical images i.e. X-Rays, PET, SPECT and general images. Experimental results are evaluated in terms of correlation comparison of all methods.

Keywords: NLM, Non Local Means, DWT, Discrete Wavelet Transform, Hybrid Logarithmic Gradient

1. Introduction

Noise is inherent to almost every type of image. Majority of noises in images occur because of phenomena called Poisson noise or shot noise [1]. We know that photons are quantum particles and they may strike a particular spot in different numbers. This variation in occurrence is called shot noise which is associated with particle nature of light. In electronics discrete nature of electric charge (either 1 or 0) is the cause of shot noise. Recently many techniques are proposed to remove Poisson noise from noisy images such as Median filter and linear smoothing filter which do not produce very clear results and also blur the edges

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[2], [3]. We presented comparison among three noise removal techniques used in [4] [5] and [6] known as

1. Third order Non Local Mean (NLM) Approach
2. Discrete Wavelet Transform with modified threshold
3. Hybrid Log Gradient method

The results of three methods are shown and compared.

2. Third Order Non Local Means

The technique herein shown can be schematically presented by the functional block diagram in Figure 1.

Three variations of NLM applied for de-noising the images corrupted by Poisson noise are shown below.

a. First Stage

In NLM-I (Stage-I) cube of image is taken and then NLM is applied on it. Mathematically may be represent as

$$NL(U^3(i)) = \sum_{j \epsilon \aleph_{i^3}} w^3(i,j)U^3(j) \quad (1)$$

Theoretically equation 1 describes that the NLM is applied over the cubic noisy image as taking the cube of the noisy image preserve its sign.

b. Second Stage

In NLM-I (Stage-II), which depends on NLM-I (Stage-I), square of estimated noise ($\tilde{\sigma}^2$) is subtracted from NLM-I (Stage-I) de-noising result of cube image and square root of difference is taken. Mathematically it can be represented as

$$Denoise\ Image = \sqrt{NL(U^3(i)) - \tilde{\sigma}^2} \quad (2)$$

c. Third Stage

In NLM-II, square of assessed noise ($\tilde{\sigma}^2$) is subtracted from cube of image and square root is taken followed by application of NLM on it. Let I be original image, U^3 define cube of noisy image and D define square root of difference of cubic noisy image U^3 and square of estimated noise, $\tilde{\sigma}^2$.

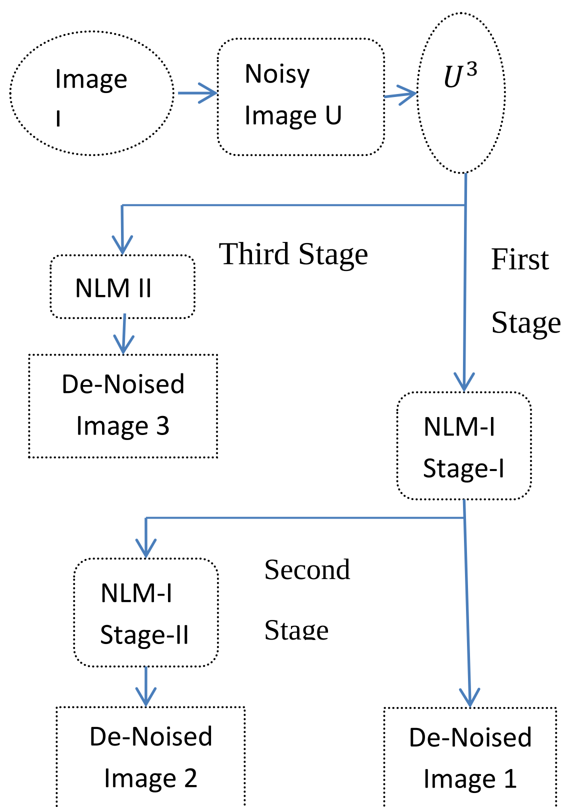

Figure 1: Complete De-Noising Procedure for Non Local Means

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Mathematically it is represented by following equation

$$D = \sqrt{U^3 - \tilde{\sigma}^2} \quad (3)$$

Therefore, NLM of above is given as

$$NL(D) = NL(\sqrt{U^3 - \tilde{\sigma}^2}) \quad (4)$$

It may also be given as

$$NL\big(D(i)\big) = \sum_{j\epsilon\aleph_i} w(i,j)D(j) \quad (5)$$

3. Discrete Wavelet Transform With Modified Threshold

Modification made by author [6] is in threshold process which is based on equation (6)

$$y_{j,k} = \begin{cases} w_{j,k}\left(\frac{|w_{j,k}|-T}{(|w_{j,k}|-T)+T}\right) & |w_{j,k}| > T \\ 0 & |w_{j,k}| \le T \end{cases} \quad (6)$$

The modified threshold is defined as, if absolute of coefficient is greater than the threshold value then coefficient is replaced by a value which is dependent on the threshold value and is calculated as shown in equation (6), however if coefficient is less than or equal to threshold value then it is replaced with zero. The replaced value is calculated by above given formula in equation (6), the coefficient is multiplied by the ratio of difference of absolute of coefficient and threshold value, $(|w_{j,k}| - T)$, to the sum of difference of absolute of coefficient and threshold value, and threshold value, $((|w_{j,k}| - T) + T)$.

4. Hybrid Logarithmic Gradient Method

This is a modified version of coordinate descent method [7] for Poisson noise removal in images. Coordinate descent method is basically a technique which works by optimizing a multi-variable function by targeting one coordinate of a function and moves on to the other variables in a cyclic manner. In Hybrid Logarithmic Gradient method, a 3x3 window of a given noisy image is taken. The central pixel of the image is considered as a reference. As shown in equation (7), the square of the neighborhood pixels in all directions is subtracted from the reference pixel. All pixels are log added, log of central pixel is subtracted from the result for bias reduction and square root is taken. The obtained value is a weight of the central pixel which is multiplied with noisy central pixel and the result is further smoothed out using Median filter. Hybrid Logarithmic Gradient method can be mathematically expressed as follows.

$$\omega i,j = \sqrt{\log\begin{Bmatrix}\left(P_{i,j} - P_{i+1,j}^2\right) + \\ \left(P_{i,j} - P_{i-1,j}^2\right) + \\ \left(P_{i,j} - P_{i,j+1}^2\right) + \\ \left(P_{i,j} - P_{i,j-1}^2\right)\end{Bmatrix} - \log(P_{i,j})} \quad (7)$$

The Hybrid Logarithmic Gradient is different from Steepest Descent Method in another way. In hybrid logarithmic gradient method the reference pixel always remain the same i-e the central pixel where as in steep descent method the reference pixel changes and moves in a cyclically.

Let $I_{\mathcal{N}}$ be the noisy image and P_i, define the current pixel, so weight for current image is computed by equation (7). After getting weights for whole image by Log-Gradient method, the new image $I\omega$ is formed by mean of formula given in equation (8) Moreover,

$$I_\omega = I_{\mathcal{N}} * exp(\omega_{i,j}) \quad (8)$$

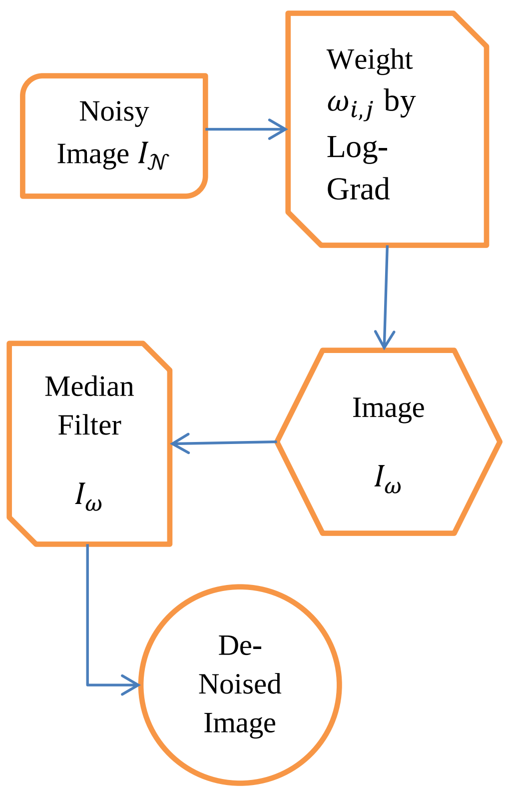

Figure 2: Complete De-noising Procedure for Log-Grad Method

After computing I_ω which contains low noise than noisy image Median filter is applied on I_ω for getting completely de-noised image. Figure 2 illustrates the block diagram for de-noising of general and medical images corrupted by Poisson noise.

5. Results and Discussion

Below are shown results of comparison among three techniques of de-noising.

In figure 3a one generic and two medical images are taken as test images. Firstly random noise is incorporated in original images are shown in row 2. In third row the noisy images are de-noised using NLM-I stage-I. In this method most of the noise is removed, however the edges are not as sharp as in original image and overall image is a bit blurred when compared with original image.

In fourth row NLM-I stage-II is applied. Here the result is almost analogous to result of stage-I but main difference is that black is not clear in this results and botched with white spots. In first row of figure 3b Third Stage, NLM-II is applied, here though noise is removed but still fine details of image are lost as edges are blurred and also like NLM-I method 2 blacks are botched with white spots affecting the contrast of the image. In second row of figure 3b noise is removed using discrete wavelet transform. This method of noise removal yields considerably better results when compared with three methods of NLM. DWT retains details of edges and image is much sharper and vivid.

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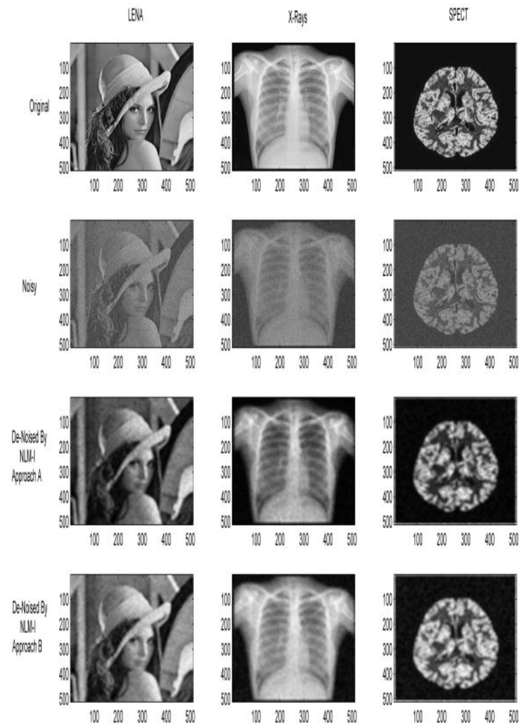

Figure 3a: Original, Noisy Images and Resultant Images De-noised by NLM-I Stage-I and Stage-II

In last row of figure 3b Hybrid Logarithmic Gradient method is applied for noise removal.

In a graph in figure 4, correlation of noisy SPECT image and its images de-noised through the discussed techniques is shown.

From a graph it is clear that correlation of noisy image decreases as noise in image increases.

Images de-noised through three techniques of NLM show almost same response i.e. their correlation remains same with increase in noise while image de-noised through DWT has better correlation when compared with NLM Images de-noised through Log Grad method show better correlation when compared with three variant NLM techniques.

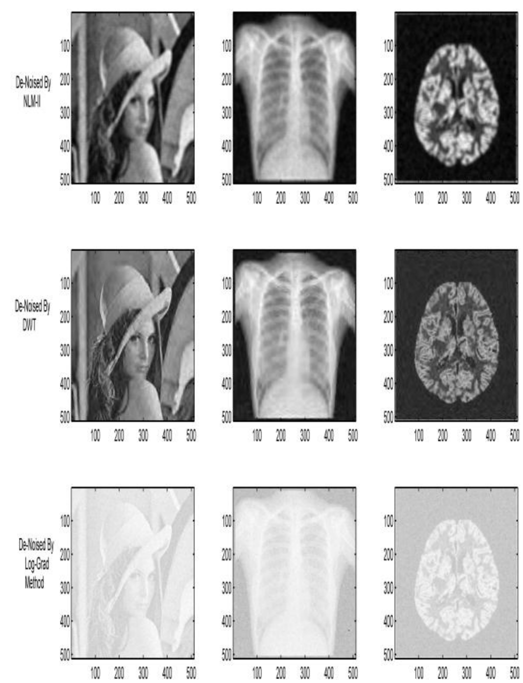

Figure 3b: Resultant Images De-noised by NLM-II, Variant DWT and Log-Grad Method

The comparison between DWT and Log Grad method shows that the correlation of image de-noised through DWT is better than image de-noised through Log Grad method. The correlation in all de-noised images remains almost the constant with increase in noise.

In a graph in figure 5, NLM, DWT and Log Grad methods are applied on X-ray Image and results are compared, from a graph

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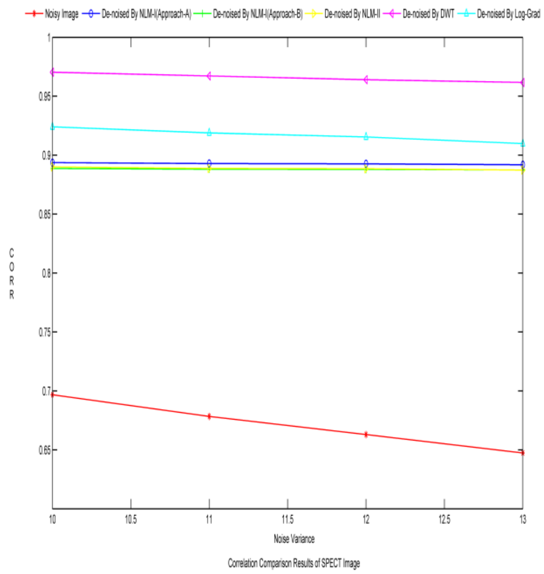

Figure 4: Correlation Comparison Result of SPECT Image De-noised by three discussed methods

it is clear that de-noised results of X-rays image are better than that of SPECT image.

Here correlation of all de-noised images lies between 0.95 and 1. While there is no significant difference between the de-noised results but still image de-noising through DWT yields better result. Here correlation of noisy X-rays image is better than correlation of noisy SPECT and LENA image.

A graph in figure 6 shows comparison between noisy and de-noised LENA image. The results in a graph show that results produced by NLM are considerably close to that of DWT with very small variation in correlation as noise increases. The image produced after application of Log Grad method has correlation that is not only less when compared with NLM and DWT but also decreases as noise in the image increases. Here we can observe that correlation of noisy image is less than both SPECT and X-rays image.

From the analysis of the graphs and images it is clear that among the three test images LENA image contains more details as compared to X-rays and SPECT image and when noise is induced to three images LENA is most affected as is evident from the small correlation coefficient. Also in de-noised results image with least details i.e. the X-rays image yields the best results.

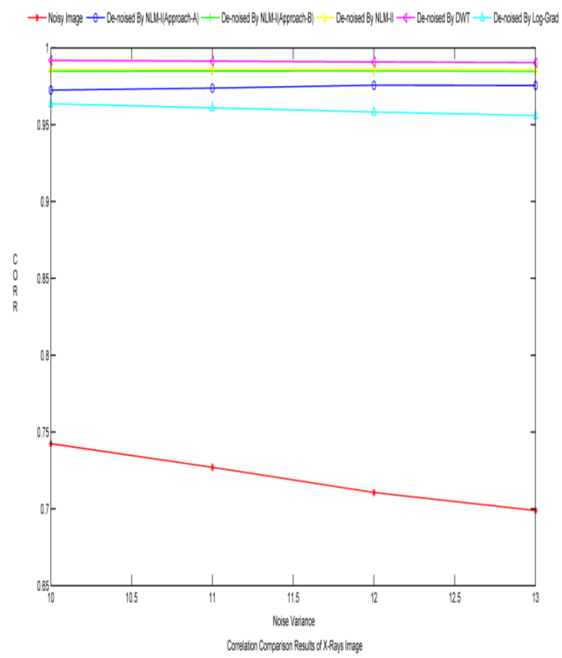

Figure 5: Correlation Comparison Result of X-Rays Image De-noised by three discussed methods

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Table 1: Tabulated Correlation Results

		LENA	X-Rays	SPECT
CORR of	Noisy Image	0.5672	0.7425	0.6967
	De-Noised By DWT	0.9572	0.9918	0.9704
	De-Noised By NLM-I (First Stage)	0.9305	0.9918	0.8937
	De-Noised By NLM-I (Second Stage)	0.9379	0.9848	0.8887
	De-Noised By NLM-II	0.9407	0.9861	0.8901
	De-Noised By Log Grad	0.9038	0.9636	0.9240

Table 2: Computation Time

De-Noised By	Computation Time (Sec) for		
	LENA	SPECT	X-Rays
DWT	0.1195	0.1235	0.1248
NLM-I (Stage-I)	320.5088	380.6960	294.8650
NLM-I (Stage-II)	320.5126	380.7075	294.8697
NLM-II	286.4139	320.6917	321.44
Log-Grad Method	1.0201	0.3233	0.5914

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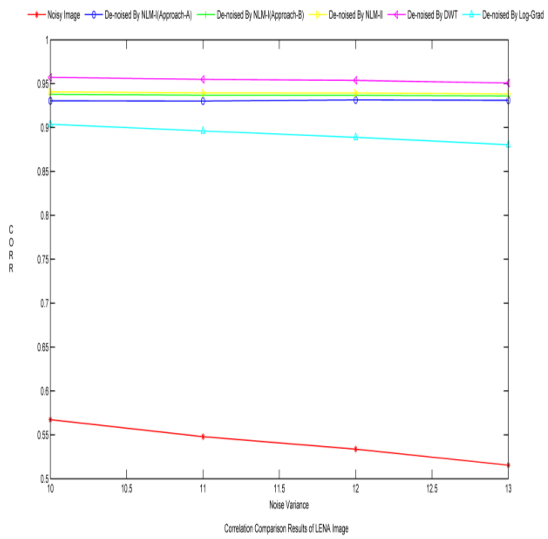

Figure 6: Correlation Comparison Result of LENA Image De-noised by three discussed methods

6. Conclusion

All mentioned techniques effectively remove Poisson noise in medical and general images. However, DWT produced good results among all other methods in term of correlation, MSE etc. DWT also preserve edges as compared to other methods. Among all techniques, DWT produced best results, along with preservation of details which is an important factor in determining the effectiveness of any technique.

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