A Comparative Study of Recent Image Denoising Techniques

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Abstract

This paper presents a review of recent algorithms for noise reduction in images. The techniques discussed here deals with the impulse, multiplicative and Gaussian noise. Image fusion technique is employed as a general model for impulse noise meanwhile the static based median filter is mentioned for the salt and pepper noise reduction. Multiplicative noise reduction techniques involve the application of adaptive windowing along with Lee filtering. Additive White Gaussian Noise reduction made use of a new technique called Sliding double window filtering, which is a frequency domain concept. Fibonacci Fourier Transform is used in this technique. The simulation results and the quantitative analysis show that these techniques possess good edge preserving as well as noise suppression capability.

Keywords: AWGN, IMF1, IMF2, Impulse Noise, Multiplicative Noise, Multiplicative Noise, Noise Reduction, SBM, SDWF

I. INTRODUCTION

Noise Corruption in digital images usually occur during acquisition by camera sensors and transmission in the channel Different types of noise that affect digital images include Additive White Gaussian Noise (AWGN), impulse noise, multiplicative noise etc [1]. Hence, the image denoising is one of the most common and important image processing operation. The impulse noise can be caused by a camera due to the faulty nature of the sensor or during transmission of coded images in a noisy communication channel. The nonlinear-median filter is widely used for impulse noise removal. Most of the median based techniques alter the entire image pixels and hence produces poor quality recovered images. In this paper a novel idea for impulse noise reduction is discussed, which employs the technique called image fusion [2] and a new algorithm using the Statistics Based Median Filter (SBMF) [3] to deal with the salt and pepper noise [1] is mentioned. Multiplicative noise, specifically called as speckle noise [4] usually appears in synthetic aperture radar (SAR) images, and it degrades the quality of images significantly. In this paper, an analysis of recent noise reduction algorithms for different noises is carried out. A brief discussion of a new filtering algorithm based on adaptive windowing [4] and local structure detection [5] is done. The filtering scheme employed in this scheme is Lee filtering [6].

A frequency domain technique for AWGN reduction based on Sliding Double Window Filtering (SDWF) is proposed in [7]. The sliding double window filter contains two window types, the transformed window and the spatial window. For AWGN reduction, several techniques such as averaging and Wiener filtering has already been implemented. The sliding double window algorithm relies on the concept of threshold filtering. The transform used here is the Fibonacci Fourier Transform [7], a modification of the Discrete Fourier Transform. The selection of a suitable noise reduction technique primarily depends on the noise type, its statistics, intensity and the application. So a comparison of different denoising techniques based on these aspects would be very useful. This paper aims to analyze different noise reduction techniques for the three commonly occurring noises in the images, namely impulsive, multiplicative and Gaussian, to determine the suitable methods for each type of noise. The paper provides only the analysis of different types of noises separately. The paper is organized as follows. In section 2 a review of noise reduction techniques for the three types of noise are discussed. In order to compare the performance of the discussed filtering algorithms with the conventional methods, some experimental results and a PSNR versus noise density plot are given in section 3. Finally, this paper is concluded in section 4.

II. REVIEW OF NOISE REDUCTION TECHNIQUES

A. *Impulse Noise Reduction:*

Impulse noise is very common in digital images. It is independent and uncorrelated to the image pixels and is randomly distributed over the image. There are different types of impulse noise namely salt and pepper and random valued [3] etc. For the general impulse noise model, two different techniques based on image fusion are briefly discussed in this section for obtaining better quality images. Fusion implies the method of combining two or more images captured by different sensors. It involves two closely related methods, the first one uses fusion followed by filtering, while the other relies on filtering followed by fusion. First technique (IMF1) involves the fusion of the images captured by different sensors with the help of a binary map. The fused image is filtered using median filter . In the second technique (IMF2) [2], each of the captured images is subjected to filtering with the help of a noise detection technique [8] and the creation of a binary map. The filtered images are further fused together using a fidelity factor [2]. First technique is computationally faster than the second technique, since each image is not denoised before fusion in it. Another technique called SBMF is employed exclusively for salt and pepper noise. This algorithm involves the application of a sliding window for each pixel and is a modification of the median filter with application of a robust estimation algorithm [3].

B. *Multiplicative Noise Reduction:*

Image yielded to multiplicative noise is represented by

$$y\,(i,j) \;=\; x\,(i,j).\,n\,(i,j), \qquad (1)$$

Where y(i, j) is the noisy image, x(i, j) is the original image and n(i, j) is the multiplicative noise. In the noisy image, the ratio of local standard deviation to local mean is called the coefficient of variation, C_{ij} [4]. In the image area with constant intensity, C_{ij} is equal to the standard deviation of noise, σ_n. However, the ratio is greater than the standard deviation of the noise in the area with the intensity changing. If the coefficient of variation in current window is less than or equal to the standard deviation of the noise, it means that the texture of the image is homogenous. Adaptive Window Based Lee Filtering (AWBLF) proposed by Zengguo Sun et.al [4] is a recent algorithm used for multiplicative noise reduction. The techniques involved in this algorithm are adaptive windowing and local structure detection. Adaptive windowing means the size of the window is changing according to the variation in C_{ij}. If C_{ij} is greater than a specified threshold T_{ij} [4], the window size is decreased continuously until its minimum, otherwise increased until its maximum predefined value. Local structure detection is employed to determine the appearance of point target and edge feature [4]. In order to determine the point target, the homogeneous semi-window using the gradient masks is fixed. Lee filtering is used in this technique.

C. *Gaussian Noise Reduction:*

The Sliding Double Window Filtering is a recently developed technique proposed by Sos S. Agaian et.al [7] for Gaussian noise reduction. This algorithm is based on the concept of threshold filtering and it uses two windows, a transformed window and a spatial window. The former is selected for filtering process, while the latter decides a sub-block within the former window for pixel replacement. Since the pixels in the spatial domain windows will be substituted after the filtering process, the method avoids overlapping between spatial domain windows. The transform employed in this algorithm is Fibonacci Fourier Transfor, which exploits the relationship between the conventional DFT and the Fibonacci numbers . This algorithm is compared with the Wiener filter and Wavelet Based Adaptive Thresholding (WBAT) technique in the following section.

III. RESULTS AND DISCUSSION

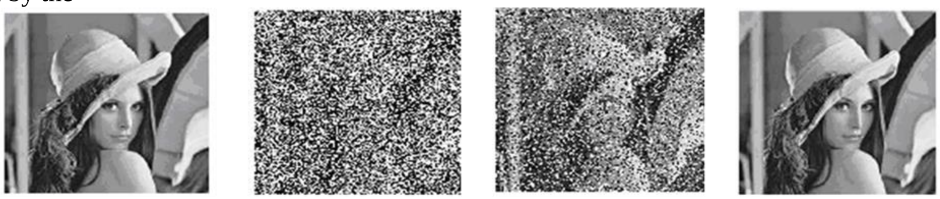
This section provides a comparison of the techniques discussed in the section 2 with the conventional methods for each noise. The algorithms are simulated using different 256 x 256, 8-bits/pixel standard images such as Pepper (Gray), Lena (Gray) etc. This paper includes only the simulation results obtained with Lena image lest of the brevity. The performance of the different techniques is tested for various noise levels. The performance of the discussed algorithms are quantitatively measured using Peak Signal to noise Ratio (PSNR). PSNR is given by the expression

$$PSNR = \frac{2^b - 1}{\frac{1}{MN}\sum_i \sum_j \,(r_{ij} - x_{ij})^2} \qquad (2)$$

Where b is the bit depth of the image and r_{ij} and x_{ij} denote the pixel values of the restored image and the original image respectively and M x N is the size of the image.

A. Impulse Noise:

A comparison between the impulse noise reduction techniques discussed in section 2 is done quantitatively through the noise density versus PSNR plot. The simulation is carried out with the test images yielded to noise densities ranging from 10% to 90%. Figure 1(b) and 1(c) shows the images recovered from those corrupted by salt and pepper noise, using SMF and SBMF techniques. It is obvious from the figure that SBMF performs much better than SMF. Figure 2 implies that the images recovered from those corrupted by the



(a) (b) (c) PSNR = 13dB (d) PSNR = 13dB

Fig. 1: Performance Of Different Techniques on Salt and Pepper Noise: (a) Original Lena image (b) Noisy image with 70% noise density. Restoration result of (c) SMF (d) SBMF

Impulsive noise which may include salt and pepper, random valued impulses etc. using fusion techniques IMF1 and IMF2.

(a) PSNR = 29dB (b) PSNR = 26dB

Fig. 2: Recovered Lena Image from the Impulsive Noisy Images Corrupted with Noise Densities 81, 85, 90 % by image fusion techniques (a) IMF1 (b) IMF2

Figure 3 shows the noise density versus PSNR graph for impulse noise reduction techniques. It gives a quantitative comparison between different techniques at various noise densities ranging from 10% to 90%.

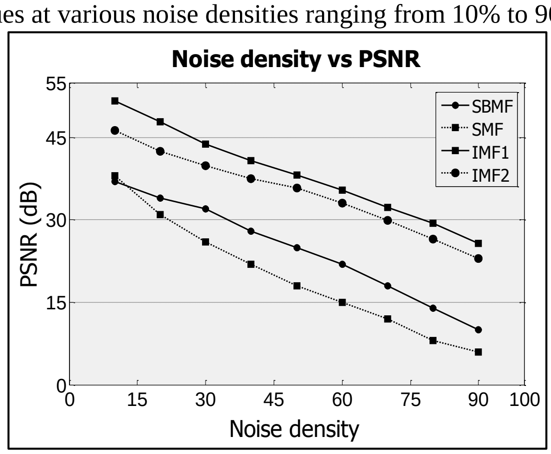
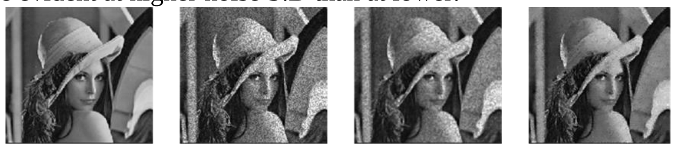


Fig. 3: Noise Density versus PSNR for Different Impulse Noise Reduction Techniques

The graph is plotted using the simulation results obtained with different standard images subjected to the noise densities ranging from 10 to 90 %. In the graph, PSNR at each noise density is an average value of the PSNR of each recovered image at that particular noise density. Figure 3 indicates that for lower noise densities, IMF1 performs much better than IMF2, while for higher noise densities IMF2 is also as good as IMF1, but IMF2 is computationally intensive. In short, IMF1 is algorithmically simple and computationally efficient and hence it is suitable for real-time application. Moreover IMF1 is better among the discussed techniques for the impulsive noise, whether it is salt and pepper or random valued.

B. Multiplicative Noise:

AWBLF algorithm for speckle noise reduction is compared with the median filter using the simulation results with the noisy images having the noise Standard Deviation (S.D) ranging from 0.15 to 0.3. The range of noise S.D selected is not arbitrary, rather it is the usual range of noise S.D for the multiplicative noise. The comparison is also done in terms of PSNR. Figure 4(c) and 4(d) show that for multiplicative noise, the image obtained from AWBLF algorithm is visually much better than the median filtered image. AWBLF algorithm is a better trade off between noise suppression and fine detail preserving compared to the conventional fixed-size median filtering, since this algorithm chooses different window size for homogeneous and heterogeneous area. Also the point targets and the edge details are appropriately preserved. From figure 5, it is obvious that efficiency of the AWBLF algorithm becomes more evident at higher noise S.D than at lower.



(a) (b) (c) PSNR=21dB (d) PSNR=48dB

Fig. 4: Comparison of the discussed technique for multiplicative noise reduction with median filtering (a) Original image (b) Image corrupted by multiplicative noise with unitary mean and 0.05 variance (c) Median filtered image with 3×3 window (d) Adaptive windowing with Lee filtered image with minimum window size 3×3 and maximum window size 11×11.

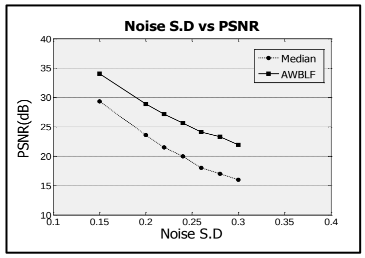


Fig. 5: Noise Density versus PSNR for Different Multiplicative Noise Reduction Techniques

In the graph, PSNR at each noise S.D is an average value of the PSNR of each recovered image at that particular noise S.D.

C. Gaussian Noise:

SDWF algorithm for the Gaussian noise reduction is compared with the wiener filter and the WBAT algorithm. SDWF algorithm is simulated with different window sizes and the experimental results reveal that the quality of the filtered images is better when the outer transformed window size is 5X5 and inner spatial window size is 1X1. The simulation is carried out at different noise S.D ranging from 0.03 to 0.09. The range selected is not arbitrary, rather it is the usual range of the Gaussian noise. Figure 6 shows the images recovered from those corrupted by AWGN, using different techniques. From the Figure 6(c), 6(d) and 6(e), the image obtained by wiener filtering is blurred, while the image obtained from the WBAT algorithm appears more noisy than that obtained using SDWF algorithm. It is obvious by visual inspection that SDWF performs better. Figure7 shows a quantitative comparison between these techniques using PSNR plot. SDWF algorithm performs much better than the wiener filter and the WBAT algorithm for the entire range of noise variance considered. However, the performance of WBAT algorithm approaches towards the SDWF at high noise variance. The graph is plotted using the simulation results obtained with different standard images subjected to the noise S.D ranging from 0.02 to 0.09. In the graph, PSNR at each noise S.D is an average value of the PSNR of each recovered image at that particular noise S.D. In this section, the simulation results show that for the three noise, the discussed algorithms have a good noise suppression capability while retaining the natural edges.

(a) (b) (c) PSNR=23dB (d) PSNR=27dB (e) PSNR=29dB

Fig. 6: Comparison Of The SDWF Algorithm With Wiener Filter And WBAT Algorithm Through Visual Inspection (A) The Original Image (B) Noisy Image, Added Gaussian Noise With Zero Mean And 0.005 Variance. (C) Wiener Filtered Image With Window Size 5 (D) Filtered Image Using WBAT Algorithm (E) Sliding Double Window Filtered Image With Outer Window Of Size 5X5, Inner Window 1X1 And Threshold Value 86%.

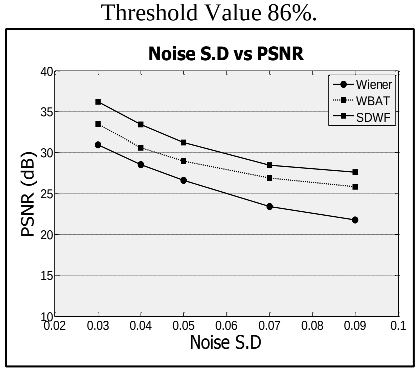


Fig. 7: Noise Density versus PSNR for Different AWGN Reduction Techniques

Table - 1
Comparison of Different Noise Reduction Techniques

Noise Type	Denoising Techniques	NSEPC	Optimum Technique
Impulsive	SMF	Low	IMF1
	SBMF	Medium	
	IMF1	High	
	IMF2	High	
Multiplicative	MF	Low	AWBLF
	AWBLF	High	
Gaussian	WF	Low	SDWF
	WBAT	Medium	
	SDWF	High	

IV. CONCLUSION

In this paper, an analysis of the recent image noise reduction algorithms for three common types of noise namely, impulsive, multiplicative and Gaussian is presented. Suitable techniques for denoising different types noises are also identified. The SDWF algorithm uses the window of fixed size and fixed threshold. It could be further optimized by introducing the adaptive windowing as well as adaptive thresholding. Digital images may often be corrupted by mixed noise as well. Hence further research should be focussed on an efficient algorithm, which combines the advantages of the novel techniques discussed, to deal the mixed noise.

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