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Performance Analysis of Nonlinear Decision Based Filter and Weighted Median ε-Filter for Salt and Pepper Noise Removal

Rejina A.S
M. Tech. Research Scholar, Dept of CSE
KMEA Engineering College
Aluva, India
rejina.a.s@gmail.com

M.Selin
Associate Professor, Dept of CSE
KMEA Engineering College
Aluva, India
selinahinus@gmail.com

A.Neela Madheswari
Associate Professor, Dept of CSE
KMEA Engineering College
Aluva, India
neela.madheswari@gmail.com

***Abstract*— Noise removal is the most important challenging preprocessing for almost all applications of Image Processing. This paper address the analysis of the efficiency of two efficient filtering technique called Nonlinear decision based filter(NDBF) and Weighted median ε-filter (WMεF) for removal of salt and pepper noise from grayscale images. The performance of these two filtering methods are tested with different grayscale images. Denoising performances are quantitatively measured by Mean Square Error(MSE), Peak-Signal to- Noise Ratio (PSNR) and Image Enhancement Factor(IEF). The experimental results and subjective analysis show that Weighted median ε-filter removes the noise effectively even at noise level as high as 50% and has better subjective quality when compared to Nonlinear decision based filter.It gives best result for removal of salt and pepper noise.**

***Keywords*— Salt and Pepper Noise, Noise Removal, Nonlinear Decision Based Filter, Peak-Signal to-Noise Ratio,Weighted Median ε-Filter.**

I.INTRODUCTION

With the recent advances in imaging technology, image denoising has found renewed interest among both researches and camera manufacturers. Impulse noise, which is often introduced into images during acquisition and transmission, has undesirable affects on different image processing purposes. Salt-and-pepper noise is one of the most famous types of impulse noise. There have been much more methods for removing impulse noise [13],[4].

In the presence of impulse noise, linear filters are quite ineffective. Nonlinear filtering techniques are preferred as they can cope with the nonlinearities of the image formation model and also take into account, the nonlinear nature of the human visual system [8]. These filters effectively preserve edges and details of images, while methods using linear filters tend to blur and distort them [1]. In switching median filter [11],[7] the decision is based on a pre-defined threshold value. The major drawback of this method is that defining a robust decision is difficult. Also these filters will not take into account the local features, as a result of which details and edges may not be recovered satisfactorily, especially when the noise level is high. Most of these filtering techniques assume the presence of salt and pepper type of impulse noise. The detection of salt and pepper type of noise is relatively easy as there are only two intensity levels in the noisy pixels.However, the study reveals that in case of uniformly distributed impulse noise, these techniques do not perform well.

A nonlinear decision based algorithm for the removal of blotches in the presence of impulse noise in grayscale images is proposed [2]. Extensive simulations show that proposed algorithm removes the noise effectively even at noise level as high and preserves the edges without any loss, thus producing better results in terms of the qualitative and quantitative measures of the image.On the other hand, ε-filter is a nonlinear filter introduced in speech processing for the first time. A conventional ε-filter is a nonlinear filter in the time domain, which can reduce noise while preserving the original signal [3],[12]. Despite its simple design, a conventional ε-filter has some desirable features for noise reduction. It does not need an advance noise estimate as well as it is easy to design and calculation costs are small. So, the median ε-filter was introduced based on ε-filter for impulsive noise removal [5]. The calculation cost of median ε-filter is small since it requires only switching operation. Moreover, its biggest advantage is that it prevents the non-corrupted pixels with noise from damaging. However, in the absence of noise it acts better than the normal median filter while its behaviour in the presence of noise is like the normal median filter. Therefore, it has the downsides of median filter.

A weighted median ε- filter for the removal of impulse noise in grayscale images is proposed [6].In this filter, calculating the outcome of ε-filter, the weighted median ε-filter gives various weights to the new resulted pixels and then computes their median. In addition, like weighted median (WM) [9], the weighted median ε- filter provides a degree of control of the smoothing behaviour through the weights that can be set. The weighted median ε- filter is also more flexible in preserving desired signal structures than the median ε-filter due to having a set of weights.The proposed method is simple and easy to implement. It is actually based on the switching operation of weighted median filter. So, it has the effective advantage of weighted median filter and the small calculation cost of switching operation

The challenge of any denoising algorithm is to suppress the noise while producing sharp images without loss of fine details. In this paper, we propose analysis of the efficiency of two efficient filtering technique called nonlinear decision based filter and weighted median ε- filter filter for removal of salt and pepper noise from grayscale images.

This paper is organized as follows: Section II discusses the impulse noise removal technique using nonlinear decision based filter. Section III discusses the impulse noise removal technique using weighted median ε- filter. Section IV presents the system model for the proposed work. Section V gives the experimental results and discussions. The paper is concluded in Section VI.

II. Nonlinear Decision Based Filter

In nonlinear decision based filter, algorithm is implemented in two stages. In the first stage, decision rule based on the switching threshold is applied to the whole image unconditionally to detect the pixels as corrupted or uncorrupted. In the second stage the new pixel value is estimated only for the corrupted pixels.

A. Detection of Corrupted Pixels

The detection is based on the assumption that a corrupted pixel takes a gray value which is substantially different than the neighboring pixels in the filtering window, whereas uncorrupted regions in the image have locally smoothly varying gray levels separated by edges [10]. In the median filter, the difference of the median value of pixels in the filtering window and the current pixel value is compared with a threshold to decide the presence of the noise. Now a 3×3 or a larger window W^x_{ij} depending on the density of noise, is taken whose central pixel is $x(i,j)$. For detection of corrupted or uncorrupted pixel, a binary flag image $b(i,j)$ is constructed such that $b(i,j)=1$, when the pixel $x(i,j)$ is corrupted and $b(i,j)=0$ for uncorrupted pixel.

$$b(i,j) = \begin{cases} 1; \text{if } |m^x_{i,j} - x(i,j)| > \text{threshold} \\ 0; \text{otherwise} \end{cases}$$

Where m^x_{ij} , represents the median value of the pixels inside the filtering window. In the next stage, the corrupted pixels are replaced by the median/mean of the pixels, depending on the number of corrupted pixels in the window W^x_{ij}. The threshold value is calculated in such a way that the edges or finer details are not modified as in standard median filters. The threshold value is calculated as$(x_{min}+x_{max})/4$, where x_{min} and x_{max} are the minimum and maximum values of the pixels in the window W^x_{ij} respectively.

B. Estimation of new pixel value for corrupted pixels

The corrupted pixels are obtained when the binary flag image $b(i,j)$ is 1. These pixels are replaced by the new estimated pixel value using median filter for lesser noise densities or mean filter for higher noise densities. To find the estimate, let the observed pixel be represented as $y(i,j)$ and the number of corrupted pixels in the window W^x_{ij} be "n." For illustration purpose, the corrupted pixels take values, x_{max} = 255 and x_{min} = 0.

Case 1: If the number of corrupted pixels "n" in the window W^x_{ij} is less than or equal to 4, that is, $n \le 4$, then two dimensional window of size 3×3 is selected and median operation is performed by row sorting, column sorting, and diagonal sorting.The corrupted pixel value $y(i,j)$ is replaced by the median value.

Case 2: If the number of corrupted pixels "n" in the window W^x_{ij} is between 5 and 12, that is, $5 \le n \le 12$, then 5×5 median filtering is performed and the corrupted values are replaced by the median value.

Case 3: If the number of corrupted pixels "n" in the window W^x_{ij} is greater than 13, that is, $n \ge 13$ increasing the window size leads to blurring, even with smaller window sizes, the output may happen to be noise pixels whenever the noise is excessive. In this case, the average of uncorrupted pixels in the window is found and the corrupted value is replaced by the average value instead of median value.

III. Weighted Median e-Filter

Weighted median ε-filter, which is based on giving different weights to the different pixels within the intermediate set of pixels before calculating median. For spatial filtering, a processing window is slid horizontally and vertically over the entire image in a way that the processing window is centered at a particular image pixel at each time. The weighted median (WM) filter assigns a weight to each position in the filter window. Define the output of a weighted median filter characterized by the set of positive weights $W1,W2,....,WN$ in responding to the given input samples $X1$, $X2,....., X N$ as Eq. (1)

$$Y = Med\,(W1 \Diamond X1, W2 \Diamond X2, ..., WN \Diamond X N) \qquad (1)$$

where ◊ is the replication operator defined as

$$W \Diamond X = X , X ,...., X \qquad (2)$$

Let $x(m,n)$ and $y(m,n)$ be the gray scale value of $(m,n)^{th}$ pixel in the input and output image respectively. Now, in order to filter an image using weighted median ε-filter,consider a $N \times N$ window centered around $(m,n)^{th}$ pixel, where N is an odd integer. Also define the set of pixels within the window as follow

$$\Theta_{(m,n)} = \left\{ x(i,j) \mid m - \frac{(N-1)}{2} \le i \le m + \frac{(N-1)}{2}, \right.$$
$$\left. n - \frac{(N-1)}{2} \le j \le n + \frac{(N-1)}{2} \right\} \quad (3)$$

Considering the set $\Theta(m,n)$, an intermediate set called $\Psi(m,n)$ is formed as bellow.

$$\Psi_{(m,n)} = \{ v(i.j) = x(i,j) + f(x(m,n) - x(i,j)) \mid$$
$$x(i,j) \in \Theta_{(m,n)} \} \quad (4)$$

where $f(\zeta)$ is a nonlinear function which satisfies the below constrained.

$$f(\zeta) \le \varepsilon; -\infty \le \zeta \le +\infty \quad (5)$$

Where ε is a constant number chosen by the user. . Moreover, various functions can be opted as $f(\zeta)$ [5]. One effective function is as follows.

$$f(\zeta) = \begin{cases} \zeta : -\varepsilon \le \zeta \le \zeta \\ 0 : Otherwise \end{cases} \quad (6)$$

Now that $f(\zeta)$ is determined, the pixels of intermediate set $\Psi(m,n)$ takes the below form.

$$v(i,j) = \begin{cases} x(m,n); \left| x(i,j) - x(m,n) \right| \le \varepsilon \\ x(i,j); \left| x(i,j) - x(m,n) \right| > \varepsilon \end{cases} \quad (7)$$

This intermediate set assures us that in the absence of noise within the window, the image won't be damaged by passing through the weighted median filter. Eventually, a specific weight is given to the each member of the intermediate set, $v(i, j)$. Then, the median of the weighted intermediate set will be calculated and the outcome will be placed in $(m,n)^{th}$ pixel of the output image. Therefore, the weighted median ε-filter is defined as Eq. (9).

$$y(m,n) = Med\ W(i,j) \lozenge v(i,j) \mid v(i,j) \in \Psi(m,n) \quad (8)$$

Indeed, the above procedure is as follows: sort the samples inside $\Psi(m,n)$, duplicate each sample $v(i, j)$, to the number of the corresponding weight $W(i, j)$, and choose the median value from the new sequence.

IV. System Model

Since impulse removal to be done by both nonlinear decision based filter and weighted median ε- filter , the standard images available from MatLab R2008a is used as samples. For experimentation, MatLab R2008a is used. The parameters considered for evaluation are as follows:

1) MSE stands for mean square error and it is calculated using the following equation:

$$MSE = \frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} \{ x(i,j) - y(i,j) \}^2 \quad (9)$$

2) PSNR: PSNR stands for Peak Signal to Noise Ratio and it is calculated using the following equation:

$$PSNR = 20 \times \log_{10}(255 / \sqrt{MSE}) \quad (10)$$

3) IEF: Image Enhancement Factor and it is calculated using following equation:

$$IEF = \frac{\sum_{i=1}^{M} \sum_{j=1}^{N} \{ n(i,j) - x(i,j) \}^2}{\sum_{i=1}^{M} \sum_{j=1}^{N} \{ y(i,j) - x(i,j) \}^2} \quad (11)$$

where $x(i,j)$ denote the original image pixel value, $y(i,j)$ denote processed image pixel value, $n(i,j)$ denote the noisy image pixel value and M,N denote the length and width of the image, respectively. Higher the values of PSNR and IEF, as well as lower the value of MSE ,the performance of algorithm increaces.

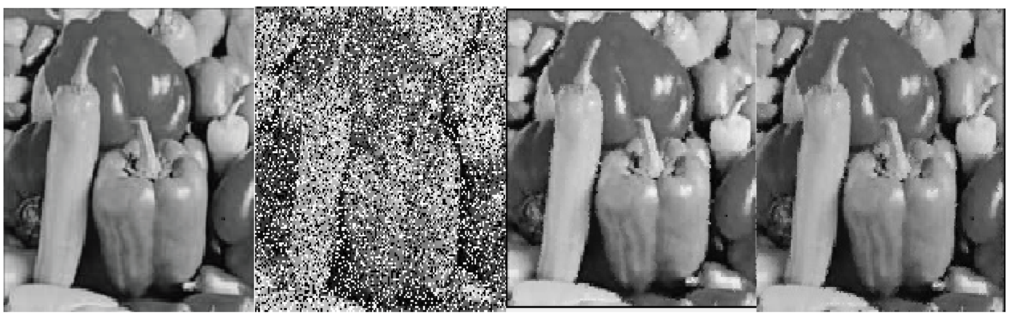
V. Experimental Results

The experimental results show that Weighted Median ε-Filter(WMεF) is much better than nonlinear decision based filter. The different variety of grayscale images are tested using both nonlinear decision based filter (NDBF)and Weighted Median ε-Filter(WMεF) .The performance of these two filters are evaluated quantitatively using the measures viz. mean square error (MSE),peak signal to noise ratio (PSNR in dB),and image enhancement factor (IEF). The values are tabulated in table1for Pepper image and in table II for Cameraman image.

The values in the tables show that weighted median ε-filter gives better performance even for high density salt and pepper noise of 50%.The table show weighted median ε-filter gives high PSNR and IEF values, as well as lower MSE value.Fig. 1 and fig. 2 show subjective visual perception.Fig. 1(a) and fig. 2(a) are original images. Fig. 1(b) and fig. 2(b) are noisy image corrupted by 50% of salt and pepper noise.The nonlinear decision based filter gives poor results for salt and pepper noise as well as visual appearance (fig. 1(c) and fig. 2(c)).The weighted median ε-filter removes salt and pepper noise at high noise density and has better visual appearance (fig. 1(d) and fig. 2(d).The experimental results prove that the weighted median ε-filter is showing high performance in salt and pepper noise removal when compared to nonlinear decision based filter.

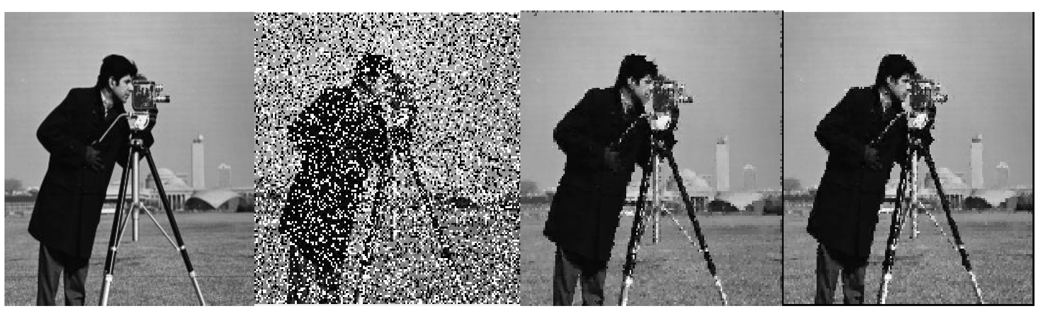
TABLE 1: MSE, PSNR,AND IEF FOR NDBF AND WMεF AT DIFFERENT NOISE DENSITIES FOR PEPPERS IMAGE

Noise density	**MSE**		**PSNR**		**IEF**	
	NDBF	**WMεF**	**NDBF**	**WMεF**	**NDBF**	**WMεF**
10%	4.34	2.06	41.74	44.98	2.94	6.20
20%	4.50	2.07	41.5	44.96	5.39	11.71
30%	4.71	2.13	41.39	44.8	7.69	17.008
40%	5.26	2.50	40.91	44.13	9.09	19.08
50%	5.59	2.62	40.65	43.9	10.48	22.3



(a) (b) (c) (d)

Fig. 1. (a) Original Pepper Image (b) Image with 50% Salt and Pepper Noise (c) Output of Nonlinear Decision Based Filter (d) Output of Weighted Median ε - Filter



(a) (b) (c) (d)

Fig. 2. (a) Original Cameraman Image (b) Image with 50% Salt and Pepper Noise (c) Output of Nonlinear Decision Based Filter (d) Output of Weighted Median ε-Filter

TABLE II : MSE, PSNR,AND IEF FOR NDBF AND WMεF AT DIFFERENT NOISE DENSITIES FOR CAMERAMAN IMAGE

Noise density	**MSE**		**PSNR**		**IEF**	
	NDBF	**WMεF**	**NDBF**	**WMεF**	**NDBF**	**WMεF**

10%	5.58	2.96	40.65	43.40	2.25	4.24
20%	5.79	3.01	40.50	43.33	4.33	8.38
30%	6.25	3.12	40.16	43.13	6.09	12.05
40%	6.79	3.68	39.80	42.46	7.62	14.05
50%	7.18	3.89	39.56	42.23	8.78	16.22

VI.CONCLUSION

In this paper, we have proposed an analysis of the efficiency of two efficient filtering technique called Nonlinear decision based filter(NDBF) and Weighted median ε-filter (WMεF) for removal of salt and pepper noise from grayscale images. The parameters considered are MSE, PSNR and IEF, for both the methods such as filtering using NDBF and WMεF. The performance evaluation of salt and pepper noise removal using the above mentioned methods are done for the standard pictures and the results are analysed .The experimental results show that Weighted median ε-filter removes the noise effectively even at high noise intensity and has better visual appearance.

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AUTHORS PROFILE

Rejina A.S received the B.Tech. during 2010 in Computer Science and Engineering from College of Engineering Kottarakkara,Cochin University of Science and Technology.She is pursuing her M.Tech. in Computer Science and Engineering from KMEA Engineering College, MG University,India. Her research interests are in image and video processing.

M.Selin recieved her B.Tech. during 2003 in Computer Science and Engineering from Cochin University of Science and Technology and her M.Tech. during 2010 in Computer Science with specialization in Digital Image Computing from Kerala University,India. She is currently a Associate Professor of computer science and engineering at KMEA Engineering College, MG University,India. Her research interests are in image and video processing.

A. Neela Madheswari recieved her B.E. during 2000 and her M.E. during 2006 in Computer Science and Engineering. She is pursuing her Ph.D. in computer science and Engineering from Anna university, Chennai, India. Her research interests are in parallel computing and web technologies.