Novel Median Filter for Impulse Noise Suppression from Digital Images

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ABSTRACT
Median filters and its variants are commonly used for impulse noise removal, but they result in loss of image details. Also, for high noise levels, they are not sufficient in completely removing the noise. The work presented in this paper aims at developing a Novel Median Filter (NMF) and its application to image restoration problem. The restoration problem considered here is an impulsive noise cleaning of the noisy and degraded grey scale images. MATLAB simulations are performed on hundreds of noisy images and the results are presented for impulse noise suppression of the well-known 'Lena' image. Performance analysis of the proposed NMF indicates that this new method effectively suppresses the impulse noise in the image while preserving the image edge information while enhancing the perception of the affected image as observed by the filtered images through visual analysis. Promising results obtained for Peak Signal to Noise Ratio (PSNR) and the Mean Square Error (MSE) are also compared to the standard median filter and its variants.

General terms
Image processing, image restoration, nonlinear filters.

Keywords
Median filter, impulse noise, PSNR, MSE, visual perception.

1. INTRODUCTION
The field of image processing is rapidly developing. An essential part of image processing system, which involves the estimation of a degraded image, is by noise suppression through filters [1]. Digital image filtering techniques can be categorized into two broad areas as spatial domain filtering and frequency domain filtering. The spatial domain filtering techniques are based on the direct manipulation of the image pixels while the frequency domain filtering techniques have to do with modifying the Fourier transform of the image. The spatial domain nonlinear filtering techniques are preferred in the presence of fixed value impulse noise[2] or the salt and pepper noise, since they can cope-up well with the nonlinearities of the image formation model and takes into account the nonlinear nature of the human visual systems[3,4].

In most of the cases, digital images are corrupted by impulsive type of noise caused by the errors generated during the conversion of an analog signal in to a digital signal using an analog-to-digital converter.Noise may also be added with the image during its transmission due to channel transmission errors [5], during storage or due to faulty sensors. There are two types of impulse noise, namely, salt and pepper or fixed valued impulse noise and random valued noise. Very frequently images are corrupted by salt and pepper noise and the contaminated pixels take either maximum (or '255') or minimum (or '0') gray level values presenting the appearance of black and white dots throughout the images. Hence impulse noise reduction is an important step in several image-processing applications [6,7],[8].As reported in the literature nonlinear filters such as median filters are found to be efficient in suppressing the impulse noise from the digital images [9]. Order statistic filters are nonlinear spatial filters whose response is based on ordering (ranking) the pixels contained in the image area encompassed by the filter and then replacing the value of the center pixel with that value determined by the ranking result [10]. The best-known order-statistic nonlinear filter is the median filter and the most common way to filter out the impulsive type of noise from the images is through the nonlinear median processing [10]. Examples include the standard median filter (SMF) [2], adaptive median filter (AMF) [3], the weighted median filter (WMF) [7], the center-weighted median filter (CMF) [10], and many more variants of the basic median filter.

As stated above, the standard median filter and its several variants have been proposed in the literature to remove impulsive type of noise. The standard median filter [1,2] is a simple rank selection filter that attempts to remove the impulse noise by changing the grey value of the center pixel of the filtering window with the median of the grey values of the pixels contained within the window. Median filter is simple and provides a reasonable noise removal performance but at the cost of removing thin lines and blurring the fine image details even at low noise densities. The weighted median filter [WMF] [7] and the center-weighted median filter [CWM] [10] are modified median filters that give more weight to the appropriate pixels of the filtering window. These modifications are proposed to avoid the inherent drawbacks of the standard median filter by maintaining the conflicting tradeoff between the noise suppression and detail preservation. Two stage switching median filters reported in the literature [13,14,15] are obtained by combining the median filter with a suitable impulse detector. The impulse detector [12] aims to determine whether the center pixel of a given filtering window is corrupted or not. If the pixel is identified by the detector as a corrupted pixel, then it is replaced with the output of the median filter, otherwise, it is left unchanged [9], [10], [11]. In the case where majority of the edge pixels in the image are corrupted by an impulse noise, filtering is incomplete because the switching median filter only works on the center value of the window and even for the smallest sized windows such as 3×3, it is not possible to have an edge pixel in the center of the sliding window. Adaptive window based Median Filter (AMF) is designed to eliminate the problems faced by the Standard Median Filter [11].Adaptive Filter (AMF) changes its behavior based on the statistical characteristics of the image inside the filter window. Adaptive filter performance is usually superior to non-adaptive counterparts. At the cost of added filter complexity, the improved performance is realized with this filter. In practice, this filter imposes a limit on the size of the working window size. When this limit is reached while the selected median is an impulse, the impulsive noise remains in that window of the image. The adaptive median filter achieves good results in most cases, but even so, computation time is proportional to the degree of corruption of the image being filtered.

In this work, we propose a Novel Median Filter, a spatial domain approach using an overlapping adaptive window to filter the images based on the selection of an appropriate median per window position. For each position of the window, a median is computed for all the pixels and is checked to see if it is an impulse. If it is unaffected by an impulse noise, it is confirmed as an appropriate median, otherwise a more representative value is sought and is used as an appropriate median for the replacement of noisy pixels.

This paper is organized as follows: Section 2 discusses the impulse noise removal technique using standard median filter. Section 3 presents the proposed novel median filtering technique and its implementation with an illustration using one window position. Experimental results are presented in Section 4 and finally the paper is concluded in Section 5.

2. REVIEW OF STANDARD MEDIAN FILTERING ALGORITHM (SMF)

The median filter is a non-linear order statistic based digital filtering technique in which the values from the surrounding neighborhood are first sorted into numerical order, and then the value of the pixel in question (i.e. reference pixel value) is replaced with the middle(median) pixel value. The neighborhood is referred to as the working window. Normally the median filter is performed using a square window containing an odd number of pixels. If the neighborhood under consideration consists of an even number of pixels, the median value selected is the average of the two middle pixel values. Figure (1) below illustrates an example of how the median filter calculation is performed in the window.

Input window			Sorted sequence	Output Window		
90	99	70	0,55,65,70,89,90,95,99,120 Median=Middle value of the sorted array= 89			
0	95	65			89	
55	89	120				

Fig (1) Illustration of Median Filter operation

As shown in the above example, the pixel values in the window are sorted in the ascending order and the median value is chosen. In this case the median value is ‘89’. Thus, the pixel in the output image corresponding to the original pixel value of ‘95’ in the input image is replaced with the value specified by the filter order, i.e. ‘89’. One of the advantages of median filter over the other rank order filters, such the mean filter is that the median value is a more robust average than the mean value.It is because the median value will not be affected significantly by the one very unrepresentative pixel values in the neighbourhood. The median value of the surrounding pixels is most likely to be the value of one of the pixels in the neighbourhood within the window. Thus the median filter is least likely to create new unrealistic pixel values, especially when the filter is working in transition zones such as sharp edge regions. For this reason, the median filtering technique is much better than the mean filtering technique in terms of preserving sharp edges[3],[14].Standard Median filter is simple and computationally efficient as it is a single stage algorithm and needs the only computaton of the median of the sorted array of pixels. An important shortcoming of the median filter is that its output is always constrained, by definition, to be the median value in the window. In an N X N window, if the number of corrupted pixels is greater than (N X N)/2 value, then the median computed will be an impulse and the noise will not be removed. On the other hand, the centre value replaced is not tested to find out if it is an impulse or not. Hence if it is not an impulse, it means a fine pixel of the image is removed unnecessarily. Thus median filter performs poorly when the intensity of the noise is high.

3. PROPOSED NOVEL MEDIAN FILTER (NMF) ALGORITHM

In the proposed method, the size of the window is small, and is fixed. The proposed novel median filter is designed to reduce the problem faced by the standard median filter under high noise conditions by providing the computation of an appropriate median.The procedure to compute an apprppriate median with our proposed Novel Median Filter (NMF) is as follows:

i) Select with the working window to cover a N X N array of pixels.

ii)Sort the pixels as in the standard median filter and compute the median from the sorted list of the current window.

iii)The procedure to compute an appopriate median under high noise conditions is now divided into three stages. The smallest and the largest pixel values in the working window P_{min} and P_{max} respectively are compared with impulse values ‘0’ and ‘255’. If P_{min} = ‘0’ or if P_{max} =’255’ then the window has an impulse noise and processing proceeds through stages 1,2 and 3.Otherwise the processing proceeds only through stage 3. The description of the various steps involved in the proposed algorithm are given below:

3.1 Stage 1

The selected median value is tested to verify if it is an impulse or not. If the median ‘P_{med}‘ is equal to the minimum or maximum value, then it is deemed to be an impulse. In this case a pixel with its value between the minimum and maximum values is searched for, starting from the immediate neighborhood of the median position. When it is realized that more than ‘half or (1/2)’ of the pixels in the window are impulses, then the median is computed as follows:

$$x_{med} = (p_{min} + p_{med} + p_{max})/3 \qquad (1)$$

In the above equation, p_{min} , p_{med} and p_{max} are the lowest, highest and the middle pixel intensity values in the sorted array from the current window. This computed median values ‘X_{med}‘ is referred to as an appropriate median in the high noise and the medium noise conditions.

3.2 Stage 2

All pixels in the window are inspected and the noisy pixels that are impulses are replaced with the computed median value X_{med}. This is the first stage of impulse noise rejection. In the next step,the pixels in the window are re-sorted and the proceeding is now towards the stage 3 processing.

3.3 Stage 3

In this stage, any distortions, if present, are removed. Processing at this stage is always performed even when no impulse noise is detected in the current window position. Processing starts with the differences 'D_i' being computed as:

$$D_i = (p_{i+2}) - (p_{i+1}) \quad (2)$$

for all $i = 1,2 \ldots\ldots 2n-2$, where $N^2 = 2n+1$

Next, we find

$$D_{max} = \underset{n \leq i \leq 2n-2}{\text{Max } D_i} \quad (3)$$

At this stage of processing, the computed 'D_{max}' is evaluated by the following computations for values at the extreme ends of the sorted list :

$$P_1 = \begin{cases} P_{med}, & if\ (P_2 - P_1) > D_{max} \\ P_1, otherwise \end{cases} \quad (4)$$

$$P_{2n+1} = \begin{cases} P_{med}, if\ (P_{2n+1} - P_{2n}) > D_{max} \\ P_{2n+1}, otherwise \end{cases} \quad (5)$$

3.4 Illustration of Novel Median Filtering

5	**55**	**35**
100	**0**	**255**
90	**80**	**220**

Fig (2) Input Window

Assuming the current window as shown in Figure 2, proposed Novel Median Filter (NMF) algorithm is descibed as below:

3.4.1 Stage 1

i) Arrange the pixel values in the window in the ascending order to get the sorted output as follows :

0,5,35,55,80,90,100,220,255.

ii) Compute the median value of the window 'P_{med}' from the above sorted array. In this example P_{med} = 80.

iii) Because this computed median value '80' is in between '0' and '255' we confirm it as an appropriate median in stage1 processing.

3.4.2 Stage2

i) Detect the number of impulse noise affected pixels in the working window. In this example only two (i.e.less than half of the total number of pixels in the working window) impulses are detected i.e. '0' and '255'.

ii) Replace these impulse noise affected pixel values with the computed 'P_{med}' as above.

3.4.3 Stage3

i) Prior to the third stage processing, re-sort all the pixels in the ascending order. Now processing continues with the third and final stages as follows:

ii) Firstly 'D_i' and hence 'D_{max}' are computed by considering the sub-list starting from the second value and ending at the eighth value. Computed 'D_i' are as follows : (55-35)=20, (80-55)=25, (80-80)=0, (80-80)=0, (90-80)=10, (100-90)=10. From these difference values 'D_{max}' is found to be equal to '25', i.e. D_{max} = 25.

iii) Now compare the differences between the adjacent pixel values in the re-sorted list with 'D_{max}' in order to restore any other distorted pixel values, for example as follows:

Considering the difference between the first and the second pixel values in the re-sorted list i.e.35-5='30' is greater than 'D_{max}'. Thus the pixel value '5' is replaced with an appropriate median value P_{med}='80.' The last two pixel differences 220-100= '120' is greater than 'D_{max}', hence the pixel value '220' is replaced with the median value '80'. The output window in Figure (3) shows these replacements.

Input window			Sorted sequence 5,35,55,80,80,80,90,100,220	Output window		
5	55	35		80	55	35
100	0	255	D_i =20,25,0,0,10,10	100	80	80
90	80	220	D_{max} = 25	90	80	80

Fig(3) Illustration of NMF algorithm

4. EXPERIMENTAL RESULTS

The novel median filter is implemented (using MATLAB software) and tested for several impulse noise corrupted images in order to evaluate the performance. Results obtained for 'Lena' image are presented in the Table (1) and (2) in comparision with those achieved using the standard median filter and its variants. The amount of noise that an image is corrupted is assessed through the peak signal-to-noise ratio (PSNR). This is defined as :

$$PSNR = 10 \log_{10}\{255^2 | MSE\} \quad (6)$$

$$MSE = \frac{1}{PQ} \sum_{i=1}^{P} \sum_{j=1}^{Q} \big(I(i,j) - O(i,j)\big)^2 \quad (7)$$

where, 'P' and 'Q' are the total number of pixels in the column and row of the image. 'I' denotes the noisy input image and 'O' denotes the filtered (or the output) image. To realize the effectiveness of the proposed novel median filter a well-known 'Lena' image is added with impulse noise in the percentages of 10 to 70 and is considered as an input noisy image. The quantitative results presented in table (1) and (2) are obtained for PSNR and MSE parameters. The qualitative results obtained for 'Lena' image corrupted with 40% and 60% noise density respectively are also presented in fig(4) and fig(5). From these tables and the perception of the visual results we can observe and conclude that the proposed novel median filter performed best in terms of impulse noise removal in a corrupted image as compared to its other counterparts such as the standard median method and the adaptive median filter methods.

Table 1.Peak to Signal to Noise Ratio (PSNR) results in (db)

Filter	Percentage of Noise Density		
	20	40	60
SMF	29.44	27.43	24.24
AMF	32.33	30.49	26.66
NMF(proposed)	39.25	33.72	30.41

Table 2. Mean Square Error (MSE) results

Filter	Percentage of Noise Density		
	20	40	60
SMF	258.6	1140.5	4100.3
AMF	187.7	988.5	3630.5
NMF(proposed)	111.67	188.63	477.58

a)Original b)Noisy c) SMF d) AMF e)Proposed

Fig (4): Results obtained for Lena image corrupted with 40% noise density

a) Original b)Noisy c) SMF d) AMF e)Proposed

Fig (5) Results obtained for Lena image corrupted with 60% Noise density

5. CONCLUSION

A nonlinear median filter in its basic form has proved itself as a simple and efficient filter in suppressing the images corrupted with low-density impulsive type of noise. In order to remove impulse noise of higher densities with detail preservation and enhance the degraded image quality, a novel nonlinear median filter is proposed and encouraging results have been obtained in comparison with the standard median filter and its variants.

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