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A Novel 'X' Based Detection Filter for Removal of Random Valued Impulse Noise in Digital Images

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Abstract

Restoration of images corrupted by impulse noises is a very common problem in the image processing. A novel and efficient 'X' based detection filter for restoration of images corrupted by random valued impulse noise is proposed in this paper. The filtering process consists of two stages – detection stage followed by a filtering stage. In the detection stage, the pixels selected to detect whether the center pixel is corrupted or not are in the shape of the alphabet 'X'. The uncorrupted pixels are unchanged and the pixels detected as corrupted are passed through a mid-point filter. Experimental results shows that the proposed filter can remove impulse noise effectively while preserving edges and it also demonstrates the superior performance in terms of visual quality and PSNR value.

1. Introduction

Digital images are often corrupted by Impulse noise during acquisition, storage and transmission. The impulse noise can be classified as salt and pepper noise and random valued noise. The pixel intensity which takes the extreme values (0 or 255) is classified as salt and pepper noise. The corrupted pixel which takes any value between 0 and 255 is classified as Random Valued Impulse Noise (RVIN). Such noises may severely have an impact on some image processing such as edge detection, image segmentation, data compression and object recognition. It is therefore the process of image restoration is an essential part of many image processing systems[1].

Further processing of an image for its enhancement needs this noise to be removed; otherwise the performances of image processing tasks such as segmentation, feature extraction, object recognition, etc. are severely degraded by noise[2]. Though there are various algorithms for removal of RVIN they are not efficient for high noise densities. So we focus on design of an efficient algorithm for removal of RVIN in digital images. Eng H.L and Ma[3] proposed a Noise Adaptive Soft-switching Median (NASM) filter. The filter uses a soft-switching noise-detection scheme to identify each pixel's characteristic, followed by proper filtering operation. In the noise-detection scheme, global (i.e., based on the entire picture) and local (i.e., based on a small window) pixel statistics are utilized in the first and the remaining two decision-making levels respectively.

S.J. Ko and Y.H. Lee proposed a center weighted median (CWM) filter, which is a special case of the weighted median(WM) filter that gives weight to only the central pixel in the filter window[17].

R. Lukac developed the nonlinear LUM(low-upper-middle) smoothers, which are a subclass of LUM filters that take advantage of the computational efficiency of order-statistics based operators, have been shown to be equivalent to the center-weighted medians[18].

Although the improved filter better preserves edges and fine details against salt–pepper impulsive noise and Gaussian noise than the median filter, its superior performance highly depends on correct direction estimation of oriented patterns[19] and the elliptical kernel function suffers from a high computational complexity.

Chen and Hong Ren Wu[4] proposed an Adaptive Center Weighted Median Filter (ACWMF). Jianjun Zhang[4] proposed a two phase median filter for removal of RVIN. The filter removes impulse noise from degraded images in 2 phases. In the first phase adaptive Center Weighted Median Filter (CWMF)[17] is used to identify noisy pixels. In the noise removal phase he used an iterative method based on median value.

Crnojevic et al proposed a median filter which performs filtering operation on a pixel to pixel basis. The proposed approach considers median of absolute deviations to identify the corrupted pixel. The basic principle of the proposed filter(PWMAD)[14] is to estimate the deviations of a pixel value from the median of the selected window. Though the filter performs better noise removal at low densities, it blurs the image at higher noise densities.

Jianjun Zhang[5] proposed an adaptive switching median filter for removal of RVIN. The novelty of the design is that setting global threshold is not necessary as in the case of conventional switching median filters. The algorithm works well for noise densities up to 60%.

Various rank order filters for removal of RVIN were proposed during various periods. Garnett et al, [6] proposed a TRIlateral Filter which uses Rank Order Absolute Difference statistics(ROAD-TRIF), Y.Dong etal[7] proposed a filter based on Rank Order Logarithmic Difference statistics and Edge-Preserving Regularization method(ROLD-EPR) and Hancheng Yu et al[15] proposed Rank order filter combining absolute and logarithmic differences statistics and used bilateral filters for filtering. The filter in[17] used image processed by Standard Median Filter(SMF)[17] as reference. The relative difference between input image and the reference image is calculated. The pixels which have this difference greater than a set threshold are identified as noisy. In second phase the corrupted pixels are removed using simple weighted mean filter. The algorithm in[16] performs well compared to[6] and[7]. However setting threshold for detecting noisy pixels poses a major problem.

A two-stage iterative method for RVIN is proposed by Chan et al[14]. The technique in [14] uses ACWMF[4] to identify the noisy pixels in phase 1. In phase 2 EPR technique is employed to preserve edges and fine details. The proposed filter(ACWMF-EPR) performs better compared to non-linear filters and preserves edges well.

Kalavathy and Suresh[8] Proposed a impulse noise removal method based on adaptive median filter and multistage median filter or the median filter based on homogeneity information are called "decision based" or 'switching' filters . Here, the filter identifies possible noisy pixels and then replaces them with median value or its variants by leaving all the other pixels unchanged. On replacing the noisy pixels with some median value in their vicinity, the local features such as the possible presence of edges are not taken into account. Hence details and edges are not preserved satisfactorily especially when the noise level is high.

Saradhadevi and Sundaram[9] Proposed a new two-stage noise removal technique to deal with impulse noise. An Adaptive Neuro-Fuzzy Inference System(ANFIS) is designed for fast and accurate noise detection such that various widespread densities of noisy pixels can be distinguished well from the edge pixels. The proposed ANFIS uses Modified Levenberg-Marquardt Training Algorithm for reducing the execution time. After suppressing the impulse noise, the image quality enhancement is applied to enhance the visual quality of the resultant images. It consists of fuzzy decision rules based on the Human Visual System (HVS) for image analysis and Neural Network (NN) for image quality enhancement. If a noise-corrupted pixel is in the perception sensitive region, the proposed NN module is applied to this pixel for further quality compensation. The proposed approach effectively eliminates the impulse noise while preserving most fine details.

Bhavana Deshpande et al[10] proposed a Modified median filter. The filter incorporated a decision based technique in which the corrupted pixels are replaced by either the median pixel or neighborhood pixel. At higher noise densities, the median value may also be a noisy pixel. In that case, median of already processed neighborhood pixels are used for replacement. This provides good correlation between the corrupted pixel and neighborhood pixel which in turn gives rise to better edge preservation. To remove any sort of Grayness ambiguity and Geometrical uncertainty present Fuzzy Rule based approach is used. However the restored images still contains some traces of salt-and-pepper noise.

Harale and Chitode[2] proposed an efficient impulse noise removal algorithm giving more weight to the central value of each window. The proposed filter in [2] gives better image restoration compared to the conventional median filter[11] and CWMF[12] for both low and high noise densities. However the algorithm suffers from setting a proper threshold, as it has to be set manually and depends on the type of image.

Most of the denoising algorithms usually perform well in terms of Peak Signal-to-Noise Ratio (PSNR) and Mean Square Error (MSE). However, the main disadvantage is that they have restricted performance in terms of false and missed detections. Therefore they may not perform well in terms of impulse noise detection and also they fail to preserve edges and fine details.

To reduce these effects and to detect the impulse noises efficiently, A "X" Based Detection Filter(AXBDF) for removal of random valued impulse noise is proposed. The proposed novel method is a two-stage method namely detection stage and filtering stage. In the first stage a novel detection technique based on the alphabet 'X' is employed which detects noisy pixel based on the threshold value. In the second stage we perform filtering by replacing the center pixel with the mid-point of maximum and minimum intensity value of uncorrupted pixels in the selected window.

The rest of the paper is organized as follows. In Section 2, we give a brief review of the AXBDF filter. Our denoising scheme is presented with an illustration in Section 3. Experimental results and conclusions are presented in Sections 4 and 5, respectively.

2. Proposed AXBDF Filter

The proposed AXBDF approach uses two stages to remove impulse noises. In the first stage a novel detection technique is used to identify the corrupted pixel. A 5 X 5 window is selected in which the center pixel is the processing pixel. The other pixels in the selected window which are considered for processing are in the shape of the alphabet 'X' as shown in the Figure 1.

$P_{i-2, j-2}$	$P_{i-2,,j-1}$	$P_{i-2,,j}$	$P_{i-2,,j+1}$	$P_{i-2,,j+2}$
$P_{i-1,,j-2}$	$P_{i-1,,j-1}$	$P_{i-1,,j}$	$P_{i-1,,j+1}$	$P_{i-1,,j+2}$
$P_{i,,j-2}$	$P_{i,,j-1}$	$P_{i,,j}$	$P_{i,,j+1}$	$P_{i,,j+2}$
$P_{i+1,,j-2}$	$P_{i+1,,j-1}$	$P_{i+1,,j}$	$P_{i+1,,j+1}$	$P_{i+1,,j+2}$
$P_{i+2,,j-2}$	$P_{i+2,,j-1}$	$P_{i+2,,j}$	$P_{i+2,,j+1}$	$P_{i+2,,j+2}$

Figure 1. Pixels selected for 'X' based detection in a 5 X 5 window.

All the 8 values which are considered for processing are summed and the resultant values are divided by the center pixel. The center pixel which is the processing pixel is identified to be corrupted of not by fixing a threshold value. Here the threshold value is fixed as 5. If the resultant value is less than the threshold value, then the processing pixel is assumed to be uncorrupted, else it is corrupted.

If the center pixel is detected as corrupted, then the pixel is replaced by processing it by a mid-point filter. In the second stage, filtering is applied to the selected window to replace the center pixel with the average of minimum and maximum intensity of uncorrupted pixels. The steps followed in the proposed AXBDF approach is as follows.

Algorithm steps

Steps for 'X' Based Detection Filter

1. Consider 5 X 5 window for X

$P_{i-2, j-2}$	$P_{i-2,,j-1}$	$P_{i-2,,j}$	$P_{i-2,,j+1}$	$P_{i-2,,j+2}$
$P_{i-1,,j-2}$	$P_{i-1,,j-1}$	$P_{i-1,,j}$	$P_{i-1,,j+1}$	$P_{i-1,,j+2}$
$P_{i,,j-2}$	$P_{i,,j-1}$	$P_{i,,j}$	$P_{i,,j+1}$	$P_{i,,j+2}$
$P_{i+1,,j-2}$	$P_{i+1,,j-1}$	$P_{i+1,,j}$	$P_{i+1,,j+1}$	$P_{i+1,,j+2}$
$P_{i+2,,j-2}$	$P_{i+2,,j-1}$	$P_{i+2,,j}$	$P_{i+2,,j+1}$	$P_{i+2,,j+2}$

2. Calculate the sum of the absolute difference(T1) between the center pixel and the pixels as given in the equation 2.1.

$$T_1 = \sum_{u=1}^{2} \sum_{v=1}^{2} \left(P_{i\mp u, j\mp v} \;\forall\; u = v\right) \tag{2.1}$$

Where
P – Pixel Intensity
i,j – Pixel position

3. Let S1 = T1/Pi,j
4. Check for the condition
   If S1 > 5 Pi,j = Corrupted
   Else Pi,j = Uncorrupted
5. If Pi,j is corrupted,
   a. Consider a 3 X 3 mask and replace the center pixel by the average of the maximum and minimum pixel intensity value among all the uncorrupted pixels in the selected window.
   b. If all the pixels in 3 X 3 window are corrupted, increase the window size by 2 (ie. 5 X 5)
   c. Follow the same steps for replacing the center pixel till the window size reaches 7 X 7.

3. Illustration of AXBDF

Lena Image if size 512 X 512 is taken for illustration.

a) Detection for Uncorrupted Pixel
   Consider 5 X 5 window

186	158	158	182	106
247	171	168	182	216
144	46	172	170	168

190	168	223	62	189
169	179	188	23	92

S1 = abs{(186-172)+(171-172)+(62-172)+(92-172)+(106-172)+(182-172)+(168-172)+(169-172)}/172

S1 = 288/172; S1 = 1.67
Here S1 = 1.67
1.67 < 5, therefore Pi,j is Uncorrupted

b) Detection for Corrupted Pixel
Consider 5 X 5 window

139	180	180	255	175
185	180	10	164	158
183	66	118	83	91
146	178	138	25	158
199	176	202	160	58

S2 = abs{(139-118)+(180-118)+(25-118)+(58-118)+(175-118)+(164-118)+(178-118)+(199-118)}/118

S2 = 770/118; S2 = 6.53
Here S2 = 6.53
6.53 > 5, therefore Pi,j is Corrupted

c) Filtering Stage
Consider 3 X 3 mask around Pi,j

$P_{i-1,,j-1}$	$P_{i-1,,j}$	$P_{i-1,,j+1}$
$P_{i,,j-1}$	$P_{i,,j}$	$P_{i,,j+1}$
$P_{i+1,,j-1}$	$P_{i+1,,j}$	$P_{i+1,,j+1}$

180	10	164
66	118	83
178	138	25

Based on the detection technique, Pi-1,,j-1, Pi-1,,j+1and Pi+1,,j-1 are detected as uncorrupted pixels. ie. 180, 164 and 178 respectively.

The corrupted center pixel Pi,,j (118) is replaced by the average of the minimum and maximum intensity values of the above 3 values.

Pi,,j = (164 + 180) / 2

= 172

The actual pixel value is 172

The main title (on the first page) should begin 1-3/8 inches (3.49 cm) from the top edge of the page, centered, and in Times 14-point, boldface type. Capitalize the first letter of nouns, pronouns, verbs, adjectives, and adverbs; do not capitalize articles, coordinate conjunctions, or prepositions (unless the title begins with such a word). Leave two 12-point blank lines after the title.

4. Experimental Results

The Proposed AXBDF discussed in section II is tested on three different images viz., Lena, Boat and Baboon for three different noise densities viz., 20%, 40% and 60%. The intensity values of all the gray level test images are maintained at 8 bits. To evaluate the performance of the proposed AXBDF, we processed the noisy images using SMF, ACWMF, PWMAD, ACWM-EPR, ROAD-TRIF, ROLD-EPR and RORD-WMF approaches and compared with our algorithm. The parameters of the filters used for comparison are taken as the values published in the references mentioned and slightly modified according to the test images and noise densities. The parameter used for comparison is PSNR defined in Equation (5.1)

$$PSNR\ in\ dB = 10\ \log_{10}\left(\frac{255^2}{MSE}\right) \qquad (5.1)$$

Where

MSE – Mean Square Error is defined as in Equation(5.2)

$$\text{MSE} = \frac{\sum_i \sum_j \left(Y(i,j) - \overline{Y}(i,j)\right)^2}{M\ X\ N} \qquad (5.2)$$

M X N is size of the image,
Y represents the original image,
$\overline{Y}$ denotes the de-noised image,

Table 1. PSNR values of lena, boat and baboon images denoised using proposed AXBDF and other existing approaches for noise density- 20%, 40% and 60%

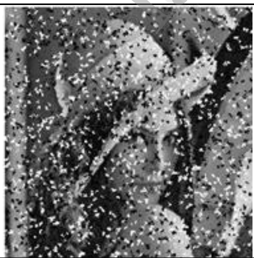
Algorithm	Lena			Boat			Baboon		
	20%	40%	60%	20%	40%	60%	20%	40%	60%
SMF	31.20	27.75	22.66	24.54	22.72	19.12	22.58	20.43	19.27
ACWMF	34.98	29.26	22.70	27.32	23.55	19.45	24.20	21.60	19.56
PWMAD	34.90	31.26	25.32	27.15	23.79	21.21	23.70	21.61	19.85
ACWM-EPR	34.95	31.35	25.78	27.49	24.66	21.36	24.02	21.65	19.70
ROAD-TRIF	35.02	31.30	26.70	27.65	24.67	21.89	24.23	21.68	19.81
ROLD-EPR	35.60	31.60	27.82	27.80	24.74	22.65	24.49	21.92	20.38
RORD-WMF	36.18	32.03	28.01	28.26	25.04	23.32	24.86	22.06	20.43
Proposed AXBDF	**36.91**	**34.23**	**32.28**	**34.68**	**28.45**	**26.09**	**27.32**	**25.98**	**24.12**

Restoration performances are evaluated quantitatively by using PSNR, which is defined as in equation 5.1. We compare AXBDF to other popular rank order filters and median-based filters. For all tested methods, a 3 X 3 filtering window is used, unless mentioned otherwise. As test images we adopted the well known images "Lena, "Boat" and "Baboon". The obtained mean PSNR values for different images are reported in Table I.

Results show that AXBDF performs better than other considered methods and achieved the image quality with best PSNR for random valued impulse noise. The output of various filters is compared with AXBDF using "Lena" and "Boat" images corrupted by 60% noise is shown in Figure 2.

Results show that AXBDF performs well for the tested range data corrupted with various noise percentages up to 60%. This reveals that AXBDF achieves good restoration in all range of noise percentage.

A graphical representation of PSNR comparison for lena image of noise density of 60% processed by AXBDF and previous approaches is shown in Figure 3. It is seen that our AXBDF approach demonstrates better PSNR estimate compared to all other previous approaches both at low and high noise densities.

Algorithm	Lena	Boat
SMF		
ACWMF		
PWMAD		

ACWM-EPR		
ROAD-TRIF		
ROLD-EPR		
RORD-WMF		
Proposed AXBDF		

Figure 2. Output of Lena and Boat images restored by proposed AXBDF and other filters for noise density of 60%.

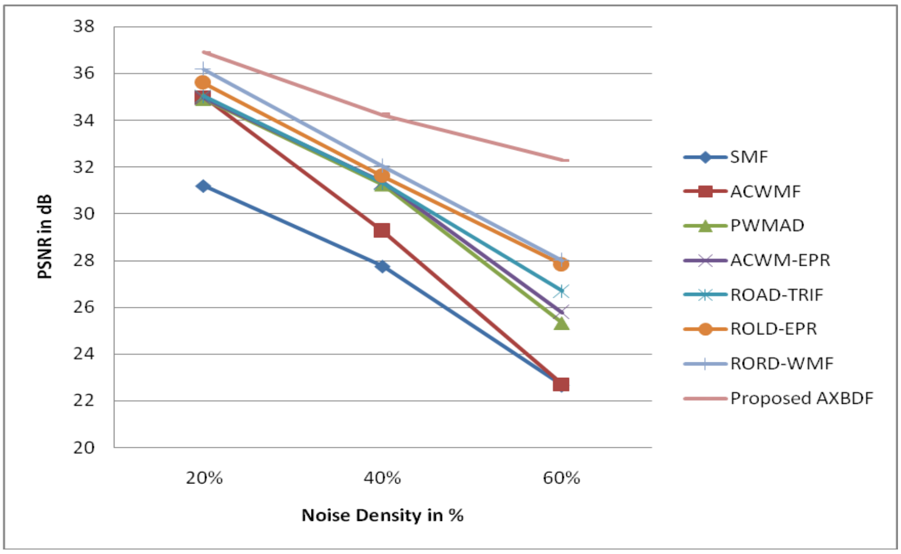


Figure 3. PSNR comparison of various filters with proposed AXBDF for noise densities of 20%, 40% and 60%.

5. Conclusion

In this paper, a new and efficient 'X' based detection filter for the removal of random valued impulse noise is presented. The proposed filter effectively removes random value impulse noise and efficiently preserves the edges and fine details. Extensive simulations of AXBDF reveal that better improvement of PSNR is seen even at a noise density of 60%. The performance of AXBDF is tested against varying noise densities and also against different images. The qualitative and quantitative results show that our algorithm outperforms some of the existing algorithms.

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