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An Improved Adaptive Filtering Technique to Remove High Density Salt-and-Pepper Noise Using Multiple Last Processed Pixels

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AN IMPROVED ADAPTIVE FILTERING TECHNIQUE TO REMOVE HIGH DENSITY SALT-AND-PEPPER NOISE USING MULTIPLE LAST PROCESSED PIXELS

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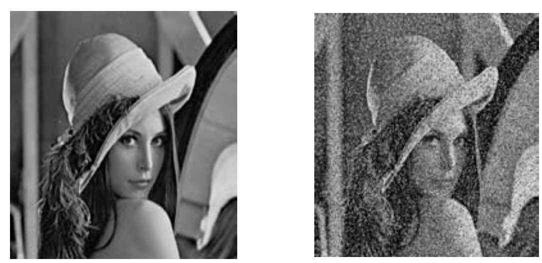
Mohammad Imrul Jubair [α], Imtiaz Masud Ziko [σ], Syed Ashfaqueuddin [ρ] & Md. Helal Uddin [ω]

Abstract - This paper presents an efficient algorithm which can remove high density salt-and-pepper noise from corrupted digital image. This technique differentiates between corrupted and uncorrupted pixels and performs the filtering process only on the corrupted ones. The proposed algorithm calculates median only among the noise-free neighborhoods in the processing window and replaces the centre corrupted pixel with that median value. The adaptive behavior is enabled here by expanding the processing window based on neighborhood noise-free pixels. In case of high density noise corruption where no noise-free neighborhood is found within the maximum size of window, this algorithm takes last processed pixels into the account. While most of the existing filtering techniques use only one last processed pixel after reaching maximum window, the proposed algorithm considers multiple last processed pixels rather than considering a single one so that more accurate decision can be taken in order to replace the corrupted pixel. Simulations on various images corrupted with different levels of noise density shows the result that, the proposed technique can perform significantly better than other existing techniques while preserving fine details and the image quality.

Keywords : salt-and-pepper noise, noise removal, adaptive median filter, last processed pixels.

I. Introduction

Impulse noise is a special type of noise where the intensity of the corrupted pixels has the tendency of being either relatively high or low [1]. The principal sources of impulse noise in digital images arise due to transmission errors, faulty memory locations or timing errors in analog-to-digital conversion [2]. Salt-and-pepper noise, a special case of impulse noise is the phenomenon where a certain percentage of individual pixels of an image are randomly digitized into the two extreme (maximum and minimum) intensities in the here dynamic range [3]. It is named 'salt-and-pepper' because of its appearance as white and black dots superimposed on the corrupted image [4].The presence of salt-and-pepper noise in digital image can severely damage image details and information. Therefore, removal of this type of noise is an important is an important issue in order to perform further processing on an image and it is critical for the extraction of reliable and accurate information from a digital image [5]. Non-linear filtering techniques are implemented widely because of their superior performance in removing salt-and-pepper and also preserving fine details of image while linear filters perform weakly and create blurring effect. Several researches on this area have been done to modify non-linear filters and to develop more efficient algorithm in removing this kind of noise from a digital image.



(a) (b)

Fig.1 : a) Shows an original image and b) Is the image corrupted by salt-and-pepper noise

In this paper, a developed algorithm has been proposed which exhibits better result than some recent techniques. In the next few sections of this paper, a study on the recently developed works will be discussed including some traditional adaptive filtering techniques as well. After that the proposed technique will be illustrated in details with the performance analysis followed by that.

II. Some Existing Noise Removal Techniques

Standard Median Filtering is the simplest non-linear technique where the value of each pixel is replaced by the median of the gray levels in the neighborhood of the corresponding pixel [4] regardless of whether it is corrupted or not. SMF is ineffective in presence of high density noise and exhibits blurring of the filtered image if the window size is large [2]. For noise level over 50% it fails to preserve the edge details of the original image [6]. Different techniques have been proposed to improve the performance of median

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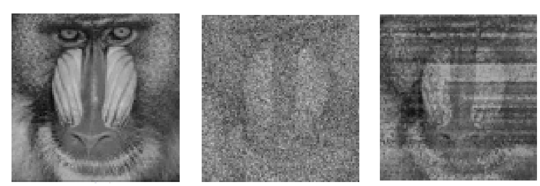
filtering, such as the Weighted Median Filter (WMF) [7], the Center Weighted Median Filter (CWMF) [8], and the Recursive Weighted Median Filter (RWMF) [9]. In these methods weights are assigned to the pixels covered by the processing window. Regardless of considering corrupted or uncorrupted pixels, these methods apply modification on the centre pixels of the window and the local features are not considered. Therefore, when the noise level is high, these filters fail to recover the details and edges satisfactorily [10]. Some research works deal with distinguishing between corrupted and uncorrupted pixels in order to further process such as Adaptive Median Filter (AMF) [11]. The basic difference between the AMF and the SMF is that, the AMF changes the window size during the filtering operation, depending on the noise density of the image. The variation of this window size depends on the median value of the gray-levels in the local neighborhood. The AMF starts with a 3×3 window and checks the value of the median in the corresponding neighborhood. If the median value is found to be an impulse, then the window size is increased and the process is repeated until a noise-free median value is found or the size of the filtering window reaches a threshold [5]. The other such techniques are the Tri-State Median Filter (TSMF) [12], the Progressive Switching Median Filter [13], the Multi-State Median Filter (MSMF) [14], and the Noise Adaptive Soft Switching Median Filter (NASSMF) [15] where corrupted pixels are selected for processing and uncorrupted ones are left unchanged. These techniques are effective for removing salt-and-pepper noises up to medium range of density. Furthermore, a two-stage Noise Adaptive Fuzzy Switching Median filter (NAFSM) has been proposed in [3], where the noise detection stage utilizes the histogram of the corrupted image to identify the noise pixels first. Then, the second stage of filtering process employs fuzzy reasoning to process the noise pixels only. Thus, this method handles the uncertainty present in the extracted local information, which was introduced by noise [5]. Besides, another kind of techniques have been developed where the sum of the distances between each vector pixel and the other vector pixels in the window is calculated for further processing such as Vector Median Filter (VMF) [16], Improved Vector Median Filter [17] and Enhanced Adaptive Vector Median Filter (EAVMF) [18]. In the EAVMF [18] a single last processed pixel is taken into account in case of extremely high density of salt-and-pepper noise. Besides, the Decision Based Algorithm (DBA) [2] has been proposed where only noisy pixels are replaced by the median value or by the mean of the previously processed neighborhood pixel values. However, at higher noise densities, it is likely that the median value is also a noise. Therefore, this method produces streaking when the noise density is high [5]. In [10], a Non-linear Adaptive Statistics Estimation Filter has been proposed to remove high density Salt-and-pepper noise, which reduces streaking at higher noise densities [5], but the image details is disturbed after the filtering process.

In case of worst case situation, the concept of considering last processed pixel has been adopted by several researches where the centre pixel of the processing window is replaced with the previously processed value of the pixel. EDBAMF [19] has been developed based on the above method of using last processed pixel. Moreover, in this approach an assumed threshold value is used to determine the pixel value in case of extreme situation. Image quality is degraded in the filtered image after applying EDBAMF. Recently, Enhanced Non-Linear Adaptive Filtering Technique (ENLAFT) [5] has been proposed which seeks for uncorrupted median in the processing window and continues to increase window until a noise-free median is found. After reaching the maximum allowable size, the technique does not expands its window and it considers the last processed pixel obtained from previous iteration. Decision is taken using statistical analysis on local features in order to use the last processed pixel. The techniques depending on a single last processed pixel may create streaking on the output image and thus decrease the image quality. Fig. 2 shows an example of streaking on image.



(a) (b) (c)

Fig. 2 : a) Original image and b) Image corrupted by salt-and-pepper noise c) Occurrence of streaking after filtering with considering single last processed

Furthermore, depending on a single last processed pixel leads these algorithms to have a weak decision in case of extreme level of noise density while other previously processed pixels are not taken into account.

In this paper, we present an improved approach to remove high density salt-and-pepper noise which overcomes the problems faced in other existing non-linear filtering methods. Drawbacks of depending on a single last processed pixel have been relaxed in this method where multiple last processed pixels obtained from previous steps are used for further decision making and processing. The proposed technique is able to reduce the occurrence of streaking on output image because the method does not depend on a single last processed pixel. Simulation applied on several input images exhibits satisfactory result and proves that the proposed method performs better than the other non-linear filtering techniques in removing salt-and-pepper up to 95% level of noise density.

III. Multiple Last Processed Pixels

The proposed method deals with multiple last processed pixels. This section of the paper will explain the concept of obtaining multiple last processed pixels and estimating values using them.

As mentioned before, the last processed pixel is obtained from the value that has been estimated from the previous iteration. In this case, the direction of image scanning is an important issue. To get an example, let X be an input grayscale image of size m×n. We know that any filtering procedure is done by sliding the window mask in every iteration on X from pixel to pixel keeping current processing pixel X(i,j) at the centre of the window, where i = 1,2,3…m and j = 1,2,3,….n. By convention, sliding starts from the first pixel of an image which is located at X(1,1) and it will be under processing. Let Y be the output matrix (initialized as an empty matrix) where the processed pixel obtained from all iterations are stored. Suppose X(i,j) is current centre pixel, so its processed value will be stored at Y(i,j), Similarly, after sliding to the next pixel X(i,j) where j=j+1, the processed value will be stored at Y(i,j) where j=j+1 and so on. If any pixel is needed to be left unchanged, then Y(i,j) would be equal to X(i,j) directly. In this manner the whole X will be scanned through X(1,1) to X(m,n) and simultaneously Y will be constructed with processed pixels as well. Here, we can see that if X(i,j) is a current pixel then its last processed pixel is Y(i,j-1). The concept of a single last pixel can be visualized from Fig. 3 where filter scanning direction starts from upper left corner of an image X(1,1) and ends at X(m,n).

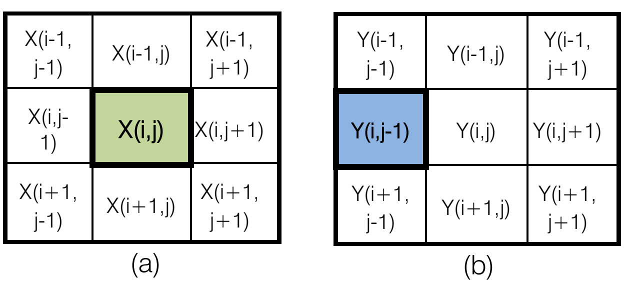


Fig. 3 : a) Shows current centre pixel X(i,j) and b) Shows its last processed pixel Y(i,j-1)

In case of multiple last processed pixel, only Y(i,j-1) is not selected, rather more than one pixels in Y are considered. Assuming that, conventional scanning direction is applied (from upper-left to lower-right) and for a current pixel X(i,j) at any iteration, we can consider four last processed pixel within a 3×3 mask from Y which are Y(i,j-1), Y(i-1,j-1), Y(i-1,j) and Y(i-1,j+1). The other remaining four pixels in Y covered by that window will not be considered because they have not been processed yet. The concept is shown in Fig. 4 (a).

The remaining last four processed pixel can be obtained through a reverse-direction scanning on X. That means the sliding procedure will start from X(m,n) and end at X(1,1). In this manner Y(i,j+1), Y(i+1,j+1), Y(i+1,j) and Y(i+1,j-1) are the last processed pixels for X(i,j) and similarly the other remaining pixels will not be selected. Fig. 4 (b) shows the idea.

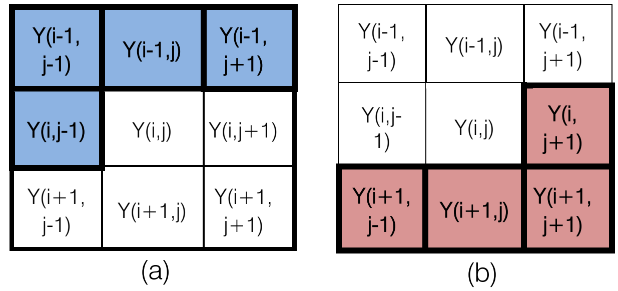


Fig. 4 : Multiple last processed pixel in a 3×3 window for the centre pixel shown in Fig. 3(a). Blue colored pixels are selected as last processed pixel in (a) and in (b) Red colored pixels are selected as last processed pixel for reverse -direction scanning

Overall, we need to filter the image twice (2nd one has the opposite direction of the other) in order to select multiple last processed. For a pixel P, let L_1 be the set of last processed pixels obtained from forward scanning (from upper-left to lower-right) and L_2 be the set of last processed pixels obtained from reverse scanning (lower-right to from upper-left). Then the set of all the selected last processed pixels L_P can be determined by combining both the elements of L_1 and L_2.

IV. Proposed Technique

The proposed method takes X as an input image of size M×N. A sliding window W of size (2a+1) × (2a+1) is defined where X(i,j) at the centre of W. The algorithm starts with a=1 from X(1,1) and checks whether X(i,j) is noisy (0 or 255) or not. If it is noise-free, W slides to next pixel and starts processing again. If X(i,j) is noisy then the neighborhood pixels are checked and among them only the noise-free neighborhoods are selected as the candidates for calculating median. The centre pixel X(i,j) is then replace with the median calculated from noise-free neighbors. If no noise-free neighbors is found in the current window, then W is expanded by incrementing a by 1 and the algorithm again seeks for noise-free pixels within the window area. This expansion process is continued up to a maximum window size W_{MAX}. After reaching W_{MAX}, the proposed technique does not expand its W anymore. This is the worst case scenario where no noise-free pixel exists within a maximum defined window. In this situation, set L_1 for the current pixel X(i,j) is determined and the current centre pixel X(i,j) is marked and its location is stored in order to processing later. In this procedure, the entire image is filtered by scanning once. The set L_2 for a pixel X(i,j) is determined from reverse scanning in similar procedure and as mentioned in previous section the set of selected last processed pixels L_P for a pixel X(i,j) can be determined using L_1 and L_2 . Finally, median is calculated from the values of L_P and the marked pixel X(i,j) is then replaced with that median value.

V. Simulations

The performance of the proposed algorithm is tested with different grayscale and color images using MATLAB. The Peak-Signal-to-Noise Ratio (PSNR), Mean Square Error (MSE), and Image Enhancement Factor (IEF) evaluation schemes are used to quantitatively assess the strength and quality of the restored images, where-

$$PSNR = 10 \times \log_{10}\left(\frac{255^2}{MSE}\right) \quad (1)$$

$$MSE = \frac{1}{MN}\sum_{i,j}\left(y_{i,j} - x_{i,j}\right)^2 \quad (2)$$

$$IEF = \frac{\sum_{i,j}\left(X(i,j) - Y(i,j)\right)^2}{\sum_{i,j}\left(Z(i,j) - Y(i,j)\right)^2} \quad (3)$$

$$MAE = \frac{1}{MN}\sum_{i,j}\left|y_{ij} - x_{ij}\right| \quad (4)$$

Here, X denotes the original image, Y denotes the corrupted image, Z is the restored image, and MN is the total number of pixel in the image. In our experiment, a total of 2 standard test images (Lena and Baboon) frequently used in literature are selected and contaminated with salt-and-pepper noise ranging from 10% to 95%. These images contain various characteristics, which are suitable for analyzing filtering performance. The performance of the proposed algorithm (PA) is compared with some state-of-the-art filters, namely AMF [11], DBA [2], NAFSMF [3], EDBAMF [19] and ENLAFT [5] based on the above parameters. Table 1-2 shows performance analysis of different algorithms for removing noise at different noise levels. In Table 1, different values exhibit that proposed algorithm performs better than the others by showing higher PSNR at different noise levels. In comparisons of MAE values among the algorithms, proposed algorithm shows satisfactory result which is shown is Table 2.

Table 1 : Comparisons of PSNR values for different algorithms at different noise levels for Lena image

Noise level (%)	SMF	AMF	DBA	NAFSMF	EDBAMF	ENLAFT	PA
10	33.9	41.8	31.7	42.6	40.1	43.4	44.9
20	29.6	37.2	29.3	38.7	36.5	39.6	40.2
30	24.1	34.3	26.5	36.3	34.3	36.9	37.7
40	19.1	32.1	23.6	34.3	32.6	35.1	36.2
50	15.3	29.9	21.1	32.5	31.0	33.5	34.1
60	12.3	27.4	19.0	30.8	29.6	31.9	33.7
70	9.9	22.2	17.3	29.3	28.3	30.4	31.6
80	8.0	16.3	15.5	27.4	26.7	28.6	30.1
90	6.5	10.5	13.7	23.7	24.4	26.0	27.9

Table 2 : Comparisons of MAE values for different algorithms at different noise levels for Lena image

Noise level (%)	SMF	AMF	DBA	NAFSMF	EDBAMF	ENLAFT	PA
10	2.7	0.4	1.6	0.4	0.5	0.3	0.3
20	3.4	0.9	2.2	0.8	1.1	0.7	0.5
30	4.9	1.5	3.4	1.3	1.7	1.2	0.9
40	8.9	2.2	5.4	1.8	2.4	1.7	1.4
50	16.7	3.0	8.5	2.4	3.2	2.2	1.8
60	29.2	4.1	12.5	3.1	4.0	2.8	2.3
70	47.4	6.8	17.7	4.0	5.1	3.6	2.7
80	70.9	15.1	25.3	5.1	6.4	4.7	3.8
90	98.1	43.3	36.1	7.5	8.6	6.4	5.1

Fig. 5 exhibits the analysis of IEF for the algorithms and the proposed approach is also significant in this case. Fig. 6-7 shows visual inspections performed on the filtered images in order to judge the effectiveness of different algorithms.

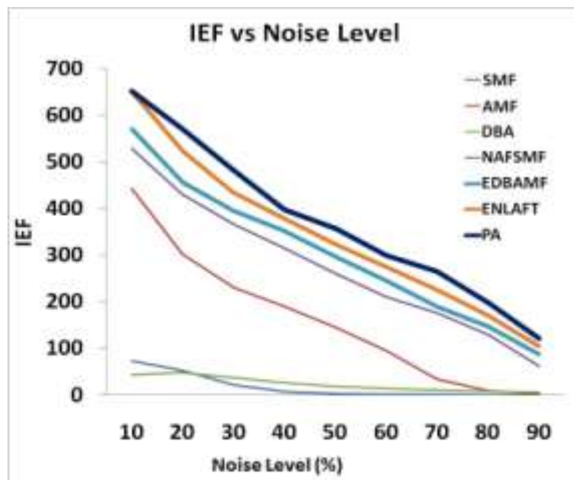


Fig. 5 : IEF values for different algorithms for Baboon image at different noise level

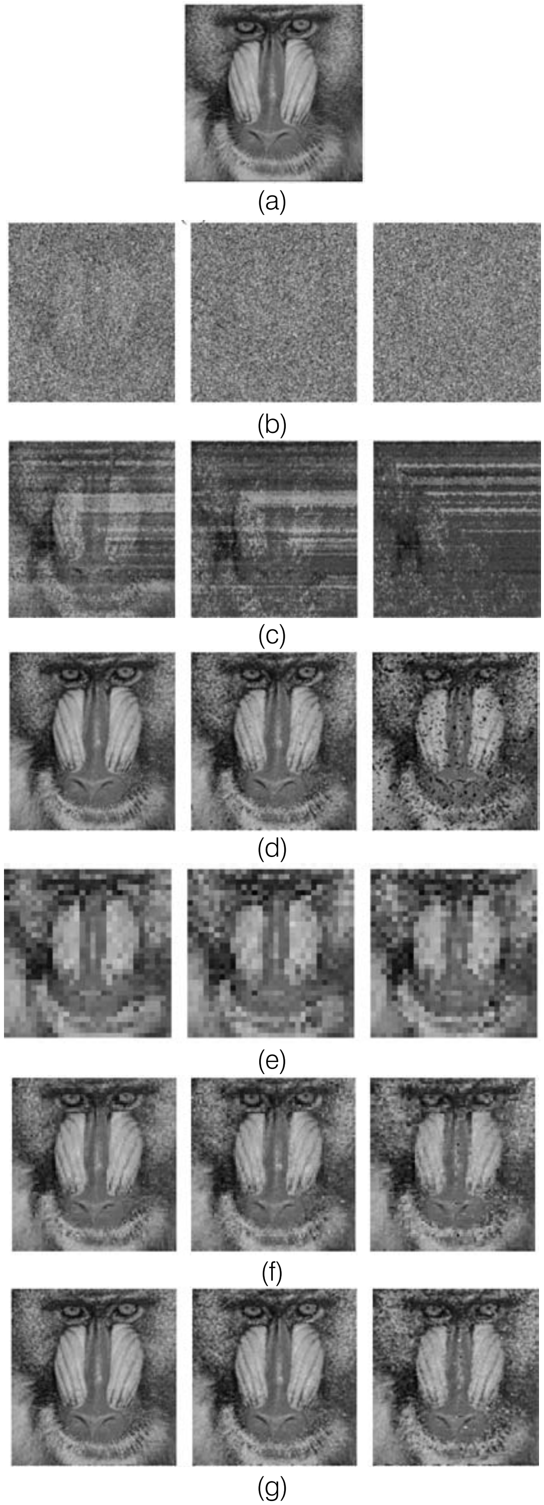


Fig. 5 : Results of applying different filtering methods on Baboon image corrupted with salt-and-pepper noise. Here, (a) is the original image and (b) shows images corrupted with 80%, 90%, and 95% salt-and-pepper noise, respectively from left to right. Row (c), (d), (e), (f) and (g) shows the results obtained by using DBA, NAFSMF, EDBAMF, ENLAFT and PA, respectively on the corrupted images of (b)

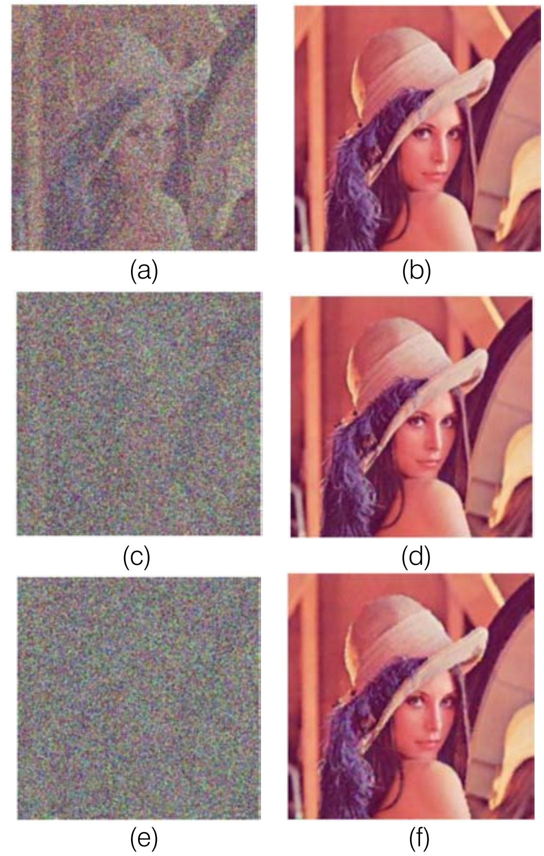


Fig. 6 : Results of applying the proposed filter on a color image corrupted with varying density salt-and-pepper noise, (a), (c) and (e) shows the Lena image corrupted with 70%, 90%, and 95% noise, respectively and (b), (d) and (f) shows the results of applying the proposed filter on images of (a), (c) and (e), respectively

VI. Conclusion

In this paper, an improved technique is presented that performs better than the other state-of-art methods in removing salt-and-pepper noise from digital images. The proposed technique introduces a concept of using multiple last processed pixels in case of extreme situation of high density noise. Several simulations based on different comparison parameters exhibit the superior performance of the proposed technique over some existing filtering techniques such as SMF, AMF, DBA, NAFSMF, EDBAMF and ENLAFT.

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