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AN AMELIORATED DETECTION STATISTICS FOR ADAPTIVE MASK MEDIAN FILTRATION OF HEAVILY NOISED DIGITAL IMAGES

Geeta Hanji[1], M.V. Latte[2] and K. Varsha[3]

[1,3]Department of Electronics and Communication Engineering, P.D.A. College of Engineering, India
E-mail: geetanjalipatil123@gmail.com, konin.varsha@gmail.com
[2]Department of Electronics and Communication Engineering, JSS Academy of Technical Education, India
E-mail: mvlatte@rediffmail.com

Abstract

Noise reduction is an important area of research in image processing applications. The performance of the digital image noise filtering method primarily depends upon the accuracy of noise detection scheme. This paper presents an effective detector based, adaptive mask, median filtration of heavily noised digital images affected with fixed value (or salt and pepper) impulse noise. The proposed filter presents a novel approach; an ameliorated Rank Ordered Absolute Deviation (ROAD) statistics to judge whether the input pixel is noised or noise free. If a pixel is detected as corrupted, it is subjected to adaptive mask median filtration; otherwise, it is kept unchanged. Extensive experimental results and comparative performance evaluations demonstrate that the proposed filter outperforms the existing decision type, median based filters with powerful noise detectors in terms of objective performance measures and visual retrieviation accuracy.

Keywords:

Rank Ordered Absolute Deviation (ROAD), Adaptive Mask, Noise Detector, Edge Preservation, Visual Retrieviation Accuracy

1. INTRODUCTION

Digital images are high information carriers and are often contaminated by an impulsive noise of fixed and random values due to errors in transmission, pixel element's malfunctioning in the camera sensors, and faulty memory locations [1]. An important and unique characteristic of fixed value impulse noise is that, it alters only a portion of the pixels' intensities at random positions into either relatively 'low' or 'high' intensity value enforcing those contaminated pixels with high intensity values to present themselves as white spots (or salt like dots) on the image, while pixels noised with low grey values to appear as black spots on the image (or pepper like dots), while the rest are unaltered. Impulsive noise pixels of this nature, termed as salt-and-pepper noise (SPN) corrupted pixels [1] possess a relatively high contrast toward their neighbourhood, even when the corruption percentage is low and can severely affect to degrade the appearance and the retrievation accuracy of the underlying image quite significantly [2]. Therefore, the essence and a prime goal in image restoration applications are to de-noise and reduce the salt and pepper impulsive noise effects [3-4].

In impulse detection, robust statistics, being capable of providing accurate estimates in the presence of unreliable data, plays a central role [5]. The most frequently used robust statistics are the Median, Centre Weighted Median (CWM), Median Absolute Deviation (MAD) and Rank Ordered Absolute Deviation (ROAD). Robust statistics based on absolute differences (ROAD) is a local image statistics and has been first proposed by Garnett et al [6] to identify the impulsive pixels. ROAD provides a measure of how close a pixel value is to its four most similar neighbours. ROAD statistic is very high for impulse noise pixels and much lower for uncorrupted pixels. The trilateral filter [6] was the first one to employ the rank-ordered absolute difference (ROAD) statistics. ROAD statistics has also been incorporated by several authors [7-11] for impulse noise detection in different filtering frameworks such as Adaptive Median Filter, AMF [8, 10], Bilateral filter [12] and proved its effectiveness and success. Though ROAD is a robust image statistics, it seriously blurs the images when the noise level is high.

Work presented in this paper proposes an ameliorated (modified) ROAD statistics to identify the noisy pixels in images corrupted with salt & pepper noise and has been introduced in the frame work of Adaptive mask Median Filter (AMF). Ameliorated ROAD statistics values quantify how different in intensity the particular pixels are from their most similar neighbours'. The first stage of the proposed method identifies the impulse noise using a modified ROAD statistics and in the second stage, the detected impulses are replaced by adaptive window median filtering concept. The proposed method is simple, fast and efficient compared to the competitive state-of-art filter techniques. Experimental results show that the proposed method removes low to high density fixed value impulse (Salt and pepper (SPN)) noise along with edge preservation, compared to the existing methods. This paper is organized as follows: Section 2 provides a brief review of the literature. Section 3 discusses the noise model considered in the proposed work. Details of the proposed noise detection and adaptive mask median filtration are given in section 4. Results and discussions are provided in section 5, followed by conclusions and scope for future work discussed in section 6.

2. LITERATURE SURVEY

De-noising is sometimes a goal itself and sometimes a fundamental pre-processing operation for subsequent operations in image processing chain, such as detection and retention of edge information, image segmentation, and object identification. De-noising (or noise excretion) basically aims at suppressing the effects of noise while preserving vital features and details of the images intact with a minimum computational cost. A variety of techniques has been proposed to remove impulse noise in the literature. Median filtration is one of the most popular methods to suppress noise with high computational efficacy due to its sensitivity towards outliers [1-4]. By defining a contextual region by using a sliding window of size $W \times W$, the standard median filter (SMF) [1] replaces the intensity value of the centre pixel [1-2]. However, a few drawbacks associated with SMF limits its applicability, in that the SMF is not able to filter the extremely noised images, does not differentiate healthy and noised pixels. Furthermore, SMF cannot perform very well in preserving lines and edges, often introduces blurring and destroys desirable details in the image since every pixel in the image is replaced by the median value in its local neighbourhood.

As an improvement, several variants and numerous offshoots of median filter have been developed and reported in the past such as the Weighted Median Filter (WMF) [13-14], Centre-Weighted Median Filter (CWMF) [15], Multi-State Median (MSM) Filter [16], Progressive Switching Median Filter (PSMF) [17] which weighs the pixels around each pixel differently according to the spatial positions of those neighbouring pixels that an impulse-free pixel turns out to replace a particular pixel during the filtering operation [13-16]. The adaptive median filter (AMF) [18] ensures that most of the impulse noise can be detected even at a high noise level provided that the window size is large enough. But, it increases the computational complexity, especially at higher density impulse noise situations and a serious blurring around the edge details due to the need of filtration mask of larger sizes.

Generally saying, these algorithms are indecisive in the sense that the noise filtration is applied with no ceil on all the healthy/impaired pixels of the digital image irrespective of the concentration impulse noise and the image statistics. Filtering algorithms with decision-based switching schemes have been developed and reported in the literature to detect and locate impulse noised pixel's spatial position in a distinct phase of impulse detection.

Another popular filter, a Decision Based Algorithm (DBA) [19] is capable of attenuating impulsive noise effects at very high noise densities such as 75% and above. Streaking at higher noise densities due to repeated neighbourhood pixel replacement is a serious limitation of this algorithm. Modified decision based un-symmetric trimmed median filter (MDBUTMF) [20] is able to provide improved performance of the standard median filter (SMF) to a certain extent. However, an increased computational complexity is a major demerit of this proposal.

Better noise removal methods with different kinds of noise detectors have been proposed over the years [21, 22, 23, and 24]. For example, the convolution-based impulse detector and a switching median filter (CD-SMF) algorithm [21] are able to distinguish whether the interest pixel is noised or not depending on a decision threshold determined by computer simulations. A new Impulse Detection and Filtering method for removal of Wide Range Impulse Noises, IDFRWRIN [22] processes the corrupted image by first detecting the impulse noise and then using a fixed 3 × 3 filter mask to handle the noised pixel for rejecting the effects of impulse noise. It has been found that CD-SMF [21] and IDFRWRIN [22], exhibited serious image blurring for impulsive type noise at higher noise scenarios. A synergized scheme, A New Impulse Noise Detection and Filtering Algorithm [23] attempted to overcome the limitations of CD-SMF [21] and IDFRWRIN [22] to a certain extent. A strong and powerful boundary discrimination based noise detection (BDND) and a filter [24-25] has been claimed to have a good performance in reducing the impulse noise at the expense of a long processing time.

In this paper, we propose to present a modified impulse noise detection strategy in the frame work of an adaptive mask median filtration to effectively suppress a wide range impulse noise from a variety (such as grey and colour images with low, medium and high details) of images with a stable performance while preserving the vital features and important details such as edges. Simulation results obtained in terms Peak Signal to Noise Ratio (PSNR), Mean Square Error (MSE) and the execution time are compared with SMF [1], AMF [13] and those reported in [21-23, 25]. Excellent performance achieved across a wide range of noise densities varying from 10% to 90% in terms of visual perceptions of de-noised images and edge detail's retention demonstrates the novelty and efficacy of the proposal. Section 3 presents the details of the proposed work.

3. NOISE MODEL

In a variety of impulsive noise models for digital images, contaminated pixels are quite often replaced with the values equal to or near the maximum or minimum of the allowable dynamic range [25]. This typically corresponds to fixed values '0' and '255' in the case of 8-bit images. Proposed work aims at de-noising fixed value (or salt and pepper) impulse noise in which pixels are randomly corrupted by two fixed extreme values, 0 and 255 (for 8-bit monochrome image), generated with the same probability '*p*'. The image corrupted with impulse noise '$X_{i,j}$' is now modelled as below,

$$X_{i,j} = \begin{cases} n(i,j) \text{ with}'p' \\ o(i,j) \text{ with}'1-p' \end{cases} \quad (1)$$

where, $n(i, j)$ denotes a noised image pixel, $o(i, j)$ denotes a noise free image pixel.

4. DESCRIPTION OF THE PROPOSED WORK

Proposed work primarily aims at suppressing the effects of fixed value (salt and pepper) impulse noise modelled as given in Eq.(1) from the digital images. Proposed 2-stage decision based adaptive mask median filtration scheme based on improved ROAD statistics is detailed as below.

4.1 PROPOSED AMELIORATED DETECTION STATISTICS FOR ADAPTIVE MASK MEDIAN FILTRATION (ADS-AMF)

The ADS-AMF method is a ROAD statistics based noise detector and an adaptive mask median filter and is explained in the following algorithm.

Let $X_{i,j}$ be the corrupted image of size $M \times N$ and let $X_{i,j}$ denote pixel location. Let '*S*' denotes the detection window size of $W \times W$ centered at $X(i, j)$, where, $W = 2L + 1$. The pixels in the detection window are defined as below,

$$S = X\,(I + k, j + l);\ -L \le k, l \le L. \quad (2)$$

4.1.1 Noise detection:

Step 1: A 3 × 3 detection window (S) centered at $X(i, j)$ is applied to the corrupted image. The absolute difference

(DAP) of all the pixel values with the centre pixel is obtained using the equation as below,

$$DAP = |X(I + k, j + l) - X(i, j)|;\ -L \le k, l \le L. \quad (3)$$

Step 2: The array {D(n); n = 1,2…8} is formed by sorting all absolute difference values in ascending order and the sum of the five smallest absolute differences (first five) is calculated. This gives 'ROAD(5)' value for the current pixels as shown in the equation below,

$$Road(5) = \sum_{n=1}^{5} D(n). \quad (4)$$

Step 3: An 'Ameliorated ROAD' value is computed as below,

$$AROAD = \frac{D_{AP(\max)}}{255} \times (ROAD(5)). \quad (5)$$

where, $D_{AP(\max)}$ is the maximum value of the absolute deviation between the reference (or test) pixel and the surrounding pixels in a 3 × 3 neighbourhood. Eq.(5) gives the modified ROAD value for the selected 3 × 3 mask.

Step 4: 'AROAD' value of the current pixel is checked against a pre-defined threshold value TD as mentioned in Eq.(6). Current pixel is detected as corrupted or uncorrupted if it satisfies Eq.(6). For optimum performance, the threshold value is found by experimentation and is set as TD = 50 for all the images. The above steps are repeated for the entire image and a binary image $B(i, j)$ of size M × N is obtained as defined in equation below,

$$B_{i,j} = \begin{cases} 1; & AROAD(i, j) < T_D \\ 0; & AROAD(i, j) > T_D \end{cases}. \quad (6)$$

4.1.2 Adaptive Mask Median Filtration:

For noise filtering an adaptive mask of size as given in Table.1 is chosen and median of all healthy pixels (pixels whose value is 1) in the binary image is computed for the replacement of a noisy, reference (centre) pixel. Though the major contributions of making the proposed filter as noise-adaptive, comes from ROAD statistics based impulse noise detection strategy as explained in section 4.1, in order to determine a suitable size for filtration mask, the limit of the maximum mask (or a working window) size is to be obtained. Table.1 for that matter is established empirically based on multiple sample (or test) images, in which variable size filtration masks are suggested for different noise-density levels of corruption estimated [6]. The noise density estimation performed is much simpler, and involves counting the number of 1's on the binary decision map obtained in the impulse-noise detection stage conducted earlier helps in estimating the noise density.

Table.1. Filtering window size for the proposed filter ADS-AMF

%Noise Density	**Up to 40%**	**40-70%**	**>70%**
Window size	3 × 3	5 × 5	7 × 7

5. RESULTS AND DISCUSSIONS

Images are artificially contaminated with different amounts of salt and pepper impulse noise densities and applied to the proposed filter and other existing filters reported in [1, 18, 21-24]. Qualitative and quantitative performances of all these filters are obtained by MATLAB (R2008a) simulations carried on a system with the following specifications:

- Windows 7 Ultimate (32-bit OS)
- Intel Pentium processor @ 2.2GHz

A variety of test images such as 'Lena grey and colour', 'Cameraman' and 'Baboon' of size 512 × 512, 8 bits/pixel are used in the proposed work. A quantitative evaluation and comparison between the proposed and existing filters namely, SMF[1], AMF[18], the filters proposed in [21-23] and a powerful noise detector based filter [24-25] are reported in graphical form in Fig.1 and Fig.2 in terms of PSNR and MSE respectively as given through Eq.(7) and Eq.(8) expressed below.

Peak Signal to Noise Ratio (PSNR) (dB) is expressed as,

$$PSNR = 10\log_{10}\frac{255^2}{MSE}. \quad (7)$$

Mean Square Error (MSE) for an image of size $M \times N$ is defined as,

$$MSE = \frac{1}{M \times N}\sum_{i=0}^{M-1}\sum_{j=0}^{N-1}[O(i, j) - Y(i, j)]^2. \quad (8)$$

where, $O(i, j)$ is the original, noise free image and $Y(i, j)$ is de-noised image.

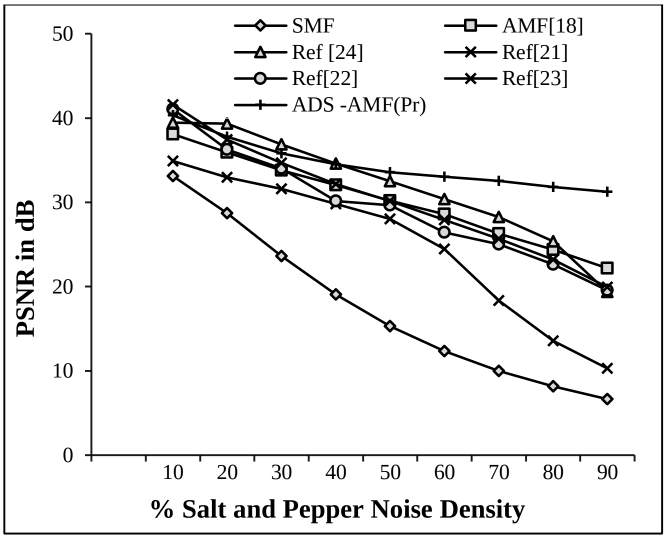


Fig.1. Peak Signal to Noise Ratio (PSNR) results comparison of the proposed and other filters

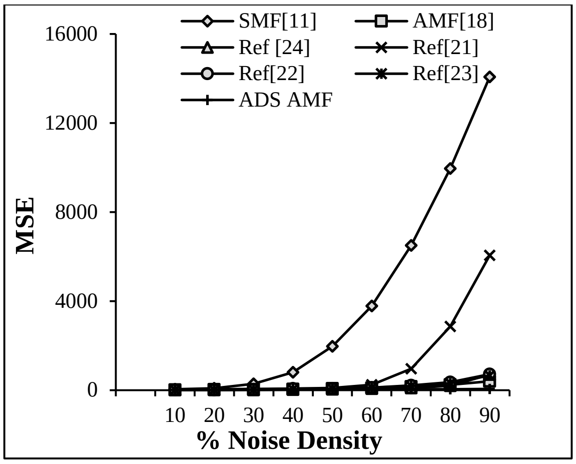


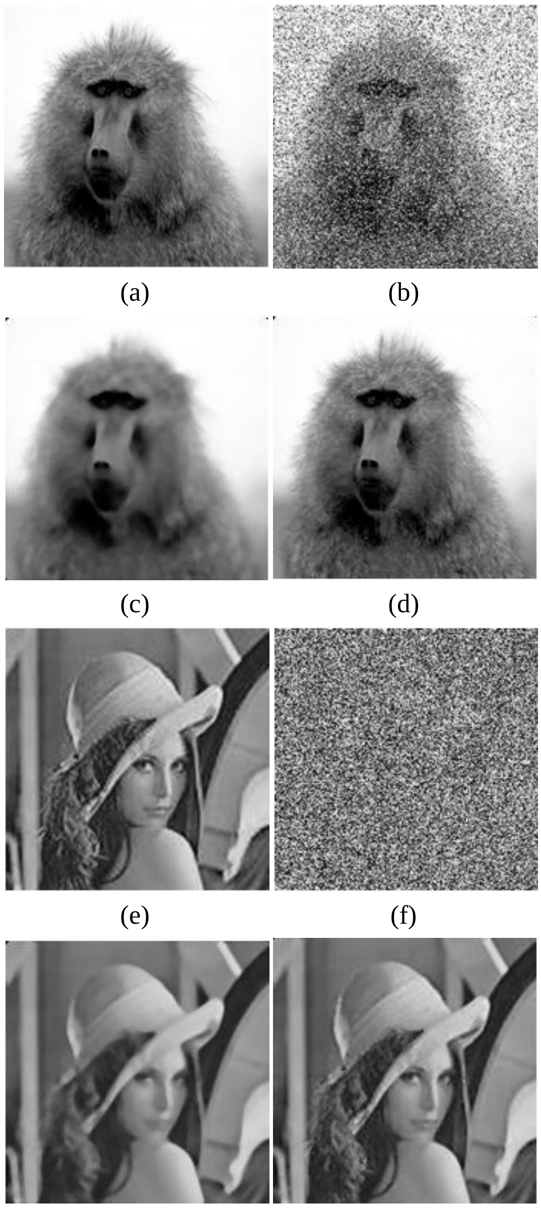
Fig.2. Mean Square Error (MSE) results comparison of the proposed and other filters

From the results, it is observed that all the filters except SMF perform quite effectively in de-noising images noised up to 40%. However, their de-noising performance deteriorates with images at higher noise densities (>40%). Above 40% and up to 70% noisy situations, method presented in [24] performs very well in de-noising with edge details preserved intact. However, the edge preserving de-noising performances of all other filters (except the proposed and method reported in [24]) are not much encouraging. Proposed ADS-AMF method is able to provide de-noising results of very high quality, in that the de-noised image edges are well preserved compared to the methods presented in [21-24]. It is seen that for higher noise densities (>80%), ADS-AMF alone performs excellently in edge preserving de-noising of both grey and colour images with low, medium and high amounts of details. For the method presented in [23], extensive simulations show that the algorithm converges with S = 2 iterations for noise density below 30%, with S = 4 iterations for noise density from 40% to 70%, and with S = 5 iterations for density higher than 80%. Execution time requirements of the proposed and other filters are given in Table.2.

For subjective evaluation and comparative analysis, Baboon (colour), Lena (colour), Cameraman (grey) and Sportsman (colour) images of size 512 × 512 have been tested with the proposed method and the results are presented in Fig.3-Fig.5. De-noised Lena (512 × 512 grey) images with the proposed and other methods and their corresponding edge details are shown in Fig.6.

Table.2. Execution time (ET) comparison of the proposed and other filters at 70% noise density for Lena (512 x 512 grey) image

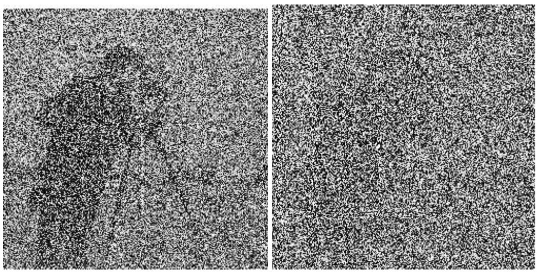
Filter	**SMF**	**R[24]**	**R[21]**	**R[22]**	**R[23]**	**Proposed**
Time (sec)	1.2	123.53	5.21	3.82	3.67	2.12



(a) (b) (c) (d) (e) (f) (g) (h)

Fig.3. De-noising results of SMF and proposed ADS-AMF at 40% and 90% noise density for colour images, (a, e) Original Baboon and Lena images, (b, f) Noised at 40% and 70 %, (c, g) De-noised with SMF (d, h), De-noised with the proposed ADS-AMF

(a) (b)



(c) (d)

(e) (f)

(g)

Fig.4. De-noising results of the proposed ADS-AMF (a) Original Cameraman image, (b-d) Noised at 70%, 80% and 90% density of salt and pepper impulse noise,(e-g) De-noised with the proposed ADS-AMF

(a) (b)

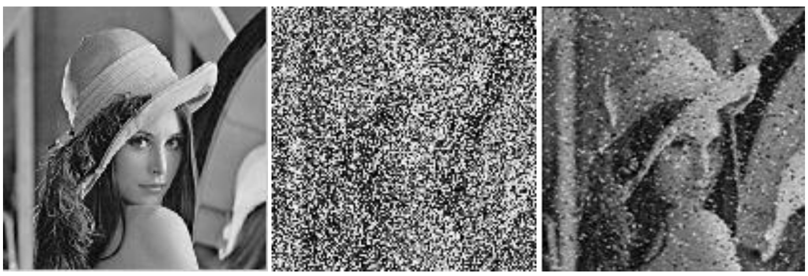
(c)

Fig.5. De-noising results of the proposed ADS-AMF (a) Original Sportsman image, (b) Noisy image, (c) De-noised with the proposed ADS-AMF

From the visual perceptions as observed through Fig.3-Fig.6, it can be honestly concluded that the proposed ADS-AMF method performs quite superior in providing edge preserved de-noised images even to the tune of 90% noise density situations.

6. CONCLUSIONS

Present work aimed at negotiating the negative impacts of fixed value impulse noise from digital images with details preserved intact. Presented work through this paper has an important and a major contribution in that, a modified ROAD statistics is introduced as an effective and a computationally efficient robust estimator that can be successfully utilized for fixed value impulse noise detection in the framework of adaptive mask median filtration (AMF). The proposed ADS-AMF is reliable and outperforms all other filters included in the comparison in terms of PSNR, MSE, and computational time. The proposed method is excellent in de-noising both grey and color images contaminated up to 90% salt and pepper noise without damaging the vital details of the images. Proposed filter has the ability of edge detail’s retention while acting on high-density impulse noise quite effectively. Compared to BDND type noise detector based filter [24], the proposed filter is fast in implementation and may find scope in real time de-noising applications. It is possible to further improve the capability of proposed filter in addressing random valued impulsive noise affected digital images.



(a) (b) (c)

Fig.6. De-noising results and the corresponding edge information of the proposed and other filters at 70% SPN. (a) Original Lena (512 × 512 grey), (b) Noised with 70% SPN. De-noised results of: (c) SMF, (g) AMF, (h) Ref [24], (i) Ref [21], (m) Ref [22], (n) Ref [23], (o) Proposed ADS-AMF. (d, e, f, j, k, l, p, q, r) Corresponding images with edge details

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