ADAPTIVE PDE-BASED MEDIAN FILTER FOR THE RESTORATION OF HIGH-DENSITY IMPULSE NOISE CORRUPTED IMAGES

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ABSTRACT

This proposed Adaptive PDE-based Median Filter (APM Filter) is devised to suppress the high-density fixed-value impulse noise that degrades the quality of images. It is apparent from the quantitative measure - the PSNR values and the qualitative measure - the human visual perception that the noise suppression potential of APM filter is significantly higher. This filter broadly finds application in the areas, such as image/video documentation, medical imaging and remote sensing.

KEYWORDS

Adaptive Median Filter, Fixed-Value impulse noise, Highly corrupted image, PDE-based Median filter, Image restoration

1. INTRODUCTION

The grayscale digital image is an aggression of intensity values, represented in the form of two-dimensional array. Normally, the digital images get corrupted by noise during acquisition and/or transmission, due to the influencing parameters of these processes such as faulty sensors, atmospheric turbulence [1], [2].

Noise is termed as any irrelevant data that obscures the authenticity of original data. Any noise-prone image has to necessarily undergo restoration process in order to make it suitable for subsequent higher order processing. Image restoration is an objective preprocessing technique that aims to estimate the original intensities of the corrupted pixels based on the mathematical model of noise, as noises are classified as impulse noise, gaussian noise, poisson noise, thermal noise, speckle noise, exponential noise, uniform noise etc., based on their pattern of distribution and characteristics [3]. This paper proposes an efficient adaptive non-linear filter to restore images corrupted with high-density fixed-value impulse noise. It is evident from the literature that, non-linear filters like median based filters outperform the linear filters like mean filters.

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Besides this noise filtering ability, median filters tend to promise detail and edge preservation in the restores images [4], [5].
The proposed filter, Adaptive PDE-based Median Filter (APM Filter) processes any given noise-prone input image and produces a restored image as its output. The performance of APM filter is measured as PSNR values and Human Visual Perception. Further, the PSNR values of APM Filter are compared with its fourteen contemporary high-performing median based filters for further analysis. It is found that PSNR values of APM filter are higher than those contemporary filters for most of the noise probabilities and highly comparable for the remaining ones.

The fixed-value impulse noise model is described in section 2 and the mathematical background of PDE is given in section 3. The principle of APM filter is detailed in section 4. The results and discussion is presented in section 5 and the conclusions in section 6.

2. Noise Model of Fixed-Value Impulse Noise

Impulse noise is categorized into fixed-value impulse noise and random-value impulse noise. This APM filter is designed to restore the images corrupted with fixed-value impulse noise, which assumes either minimum or maximum intensity value of the image and the percentage of noise distribution is evenly divided by those two intensity values. Random value impulse noise arbitrarily assumes any value between the minimum and maximum intensity value of the image [6], [7].

The fixed-value impulse noise corrupted image, $X'_{i,j}$ can be expressed as a composite component of corrupted and uncorrupted pixels as:

$$X'_{i,j} = \begin{cases} N_{i,j} & \text{with probability p} \\ \mathrm{U}_{\mathrm{i,j}} & \text{with probability (1 - p)} \end{cases} \tag{1}$$

where $N_{i,j}$ and $U_{i,j}$ denotes the corrupted and original pixels [8].

3. Partial Differential Equations

In physics, if a network region (mesh) is partitioned into small grids, then the central point of each grid is computed using Laplace Equation (Eqn.2) as[9]:

$$\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} = 0 \tag{2}$$

In the above equation, when the derivatives are replaced by their difference approximations (Eqn.3), it is known as Diagonal 5-point formula which is pictorially represented in Figure 1 and finds wider applications in image processing.

$$\mathrm{M}_{\mathrm{i,j}} = \frac{1}{4}\left[\mathrm{M}_{\mathrm{i-1,j-1}} + \mathrm{M}_{\mathrm{i+1,j-1}} + \mathrm{M}_{\mathrm{i+1,j-1}} + \mathrm{M}_{\mathrm{i+1,j+1}}\right] \tag{3}$$

$M_{i-1,j-1}$		$M_{i-1,j+1}$
	M_{ij}	
$M_{i+1,j-1}$		$M_{i+1,j+1}$

Figure 1. Neighborhood points of PDE

In APM filter for the purpose of denoising, the diagonal 5-point formula is modified in such a way that the central pixel M_{ij} is excluded and the median is computed using the remaining neighbouring pixels [10]-[12].

4. APM FILTER

The proposed APM filter performs denoising in two stages namely noise detection and noise correction.

4.1. Noise Detection

In a grayscale image of dynamic intensity range [0-255], fixed-value impulse noise corrupted pixels assume either 0 or 255. The APM filter partitions the corrupted input image into subimages of size n × n, checks if the central pixel is corrupted or not and every corrupted pixel is treated in the noise correction phase.

4.2. Noise Correction

In each subimage, if the central pixel is corrupted, then its original intensity value is estimated using the principle of neighbourhood processing. For this purpose, the neighbourhood pixels of every subimage with a corrupted pixel at the central position (M_{ij}) are classified into corrupted pixels (C_P) and uncorrupted pixels (U_P). Then, the median of those neighbourhood uncorrupted pixels is computed as U_{MED} and are respectively replaced in the output image Y′. Further, the median of diagonal pixels of W in Y′ is computed as D_{MED} and is used to replace respective pixel in the output image Y′. This process is uniformly repeated for the entire image.

4.3. Algorithm of APM Filter

Input: The corrupted image X′ and a copy of X′ as Y′

Output: The restored image Y′

Step 1: Read the corrupted image X′ and copy X′ into ′.

Step 2: Divide X′ and Y′ into subimages in the order of overlapping sliding window W of size n × n.

Repeat steps 3 to 5, for each W:

Step 3: Check whether the central pixel M_{ij} is corrupted or not

Step 4: If M_{ij} is uncorrupted, goto Step 3.

Step 5: If M_{ij} is corrupted,

i. Group the uncorrupted pixels of W as U_P and the corrupted ones as C_p.

ii. Compute the median of U_P pixels of W as U_{MED}

$$U_{MED} \leftarrow \text{Median } (U_P)$$

iii. Replace the corresponding C_P pixels of W in Y′ by U_{MED}.

iv. Compute the median of diagonal pixels of Y′ in W.

$$D_{MED} \leftarrow \text{Median } [\, M_{i-1,j-1}, M_{i+1,j-1}, M_{i+1,j-1}, M_{i+1,j+1}].$$

v. $M_{ij} \leftarrow D_{MED}$

Step 6: Update the respective value of M_{ij} in Y′.

Step 7: Stop

4.4. Flowchart of APM Filter

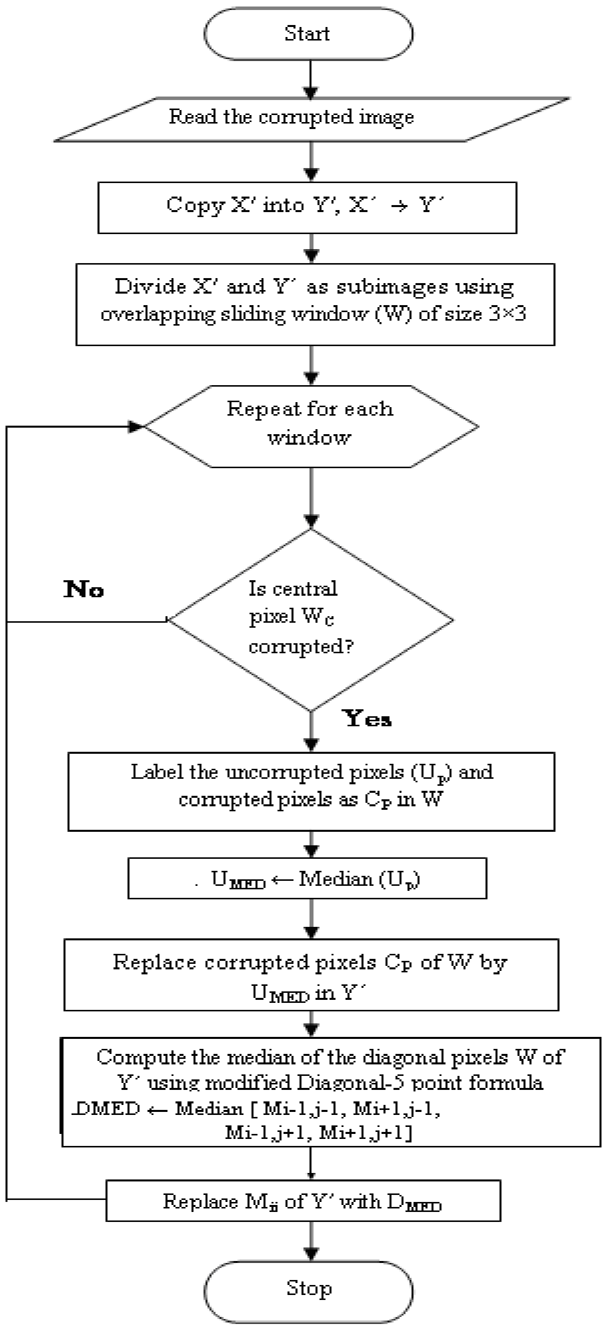

Figure 2. Flowchart of APM Filter

5. RESULTS AND DISCUSSION

The proposed filter is developed using MatLab 6.5. The standard images lena and mandrill are chosen as the test images. The images are corrupted with noise probabilities of 10% - 90% and the window size is chosen as 3×3. The performance of the proposed filter is measured in terms of PSNR and human visual perception.

The performance of the APM filter is comparatively analyzed with a few median based filters like Standard Median Filter (SM), Center Weighted Median Filter (CWM), Progressive Switching Median Filter (PSM), Iterative Median Filter (IMF), Signal Dependent Rank Order Median Filter (SDROM), Two-state Recursive Signal Dependent Rank Order Median Filter (SDROMR), Non-Recursive Adaptive-Center Weighted Median Filter (ACWM), Recursive Adaptive-Center Weighted Median Filter (ACWMR), Russo's Fuzzy Filter (RUSSO), Zhang's Filter (ZHANG), Sun and Neuvo's Switching Based Filter (SUN), Impulse Rejecting Filter (IRF) and Tri-State Median Filter (TSM) and Modified PDE Adaptive Two-Stage Median Filter(MPATS) [13],[14].

The recorded PSNR values of lena and mandrill are furnished in Table I and Table II. It is observed that except the noise probabilities of 10% and 20%, APM filter produces the highest PSNR values though for these noises, the PSNR value of APM filter is highly comparable with those of its contemporary filters.

It is further clear from Table II that APM filter has given the highest PSNR values than all of its contemporary filters. Additionally, the visual perception of the restored images of lena and mandrill for the noise probabilities of 50%, 60% and 70% depicted in Figure 4, substantiates the denoising capability of APM filter.

Table I. Comparison of PSNR values for Lena image

Method	**Noise Density (%)**								
	1	**20**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Corrupted	15.5	12.4	10.7	9.4	8.5	7.7	7.0	6.4	5.9
SM	28.7	26.4	22.6	18.3	15.0	12.2	9.8	8.1	6.5
CWM	29.7	24.1	19.5	15.7	13.0	10.8	8.9	7.6	6.3
PSM	30.7	28.7	26.9	23.7	20.0	15.2	11.1	8.3	6.4
IMF	27.2	26.7	26.1	25.1	23.9	21.2	16.6	12.1	8.0
SDROM	30.3	26.7	22.0	17.6	14.4	11.7	9.4	7.8	6.4
SDROMR	30.5	28.5	25.7	23.5	20.7	17.8	14.2	10.6	6.9
ACWM	30.9	27.2	22.4	18.1	14.8	12.1	9.7	8.1	6.5
ACWMR	31.4	28.8	25.8	23.3	20.8	18.1	15.0	11.8	8.1
RUSSO	31.0	27.6	24.9	22.7	20.3	17.6	14.7	11.7	8.6
ZHANG	32.8	28.2	23.3	18.6	15.3	12.5	10.0	8.3	6.7
SUN	31.0	27.5	23.0	18.4	15.0	12.2	9.8	8.1	6.5
IRF	30.2	27.0	22.5	18.2	14.9	12.2	9.7	8.1	6.5
TSM	30.3	24.4	19.6	15.5	12.7	10.4	8.4	7.1	6.0
MPATS	32.3	28.9	26.9	24.8	23.5	21.6	19.6	17.9	15.0
APM (Proposed Filter)	31.6	29.0	27.1	25.3	24.0	22.7	21.3	19.8	17.4

Table II. Comparison of PSNR values for Mandrill image

Method	Noise Density								
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**
Corrupted	15.7	12.6	10.9	9.6	8.6	7.9	7.2	6.6	6.1
SM	23.8	23.0	20.7	17.7	14.7	12.3	10.9	8.3	6.8
CWM	25.5	22.7	18.9	15.6	12.9	10.9	9.1	7.7	6.6
PSM	27.8	26.4	25.0	22.9	19.5	15.3	11.0	8.9	6.5
IMF	23.0	22.8	22.6	22.3	21.5	20.0	16.0	12.0	8.3
SDROM	26.0	24.0	20.8	17.4	14.3	11.8	9.6	7.9	6.6
SDROMR	25.8	24.6	23.2	21.8	19.7	17.6	14.2	10.8	7.1
ACWM	27.1	24.8	21.4	17.9	14.8	12.3	9.9	8.2	6.8
ACWMR	27.5	25.7	23.9	22.3	20.2	18.2	15.4	12.4	8.8
RUSSO	29.5	26.7	24.3	22.4	20.2	17.7	15.0	11.9	8.9
ZHANG	28.8	26.1	22.1	18.5	15.2	12.7	10.2	8.4	6.9
SUN	26.1	24.4	21.3	18.0	14.8	12.3	9.9	8.2	6.7
IRF	25.8	24.1	21.2	17.8	14.7	12.3	9.9	8.2	6.8
TSM	25.4	22.9	18.9	15.4	12.6	10.5	8.6	7.2	6.2
MPATS	29.6	27.0	24.8	23.8	22.4	21.1	19.9	18.2	17.1
APM (Proposed Filter)	29.6	26.9	24.8	24.0	22.6	21.7	20.7	19.5	18.0

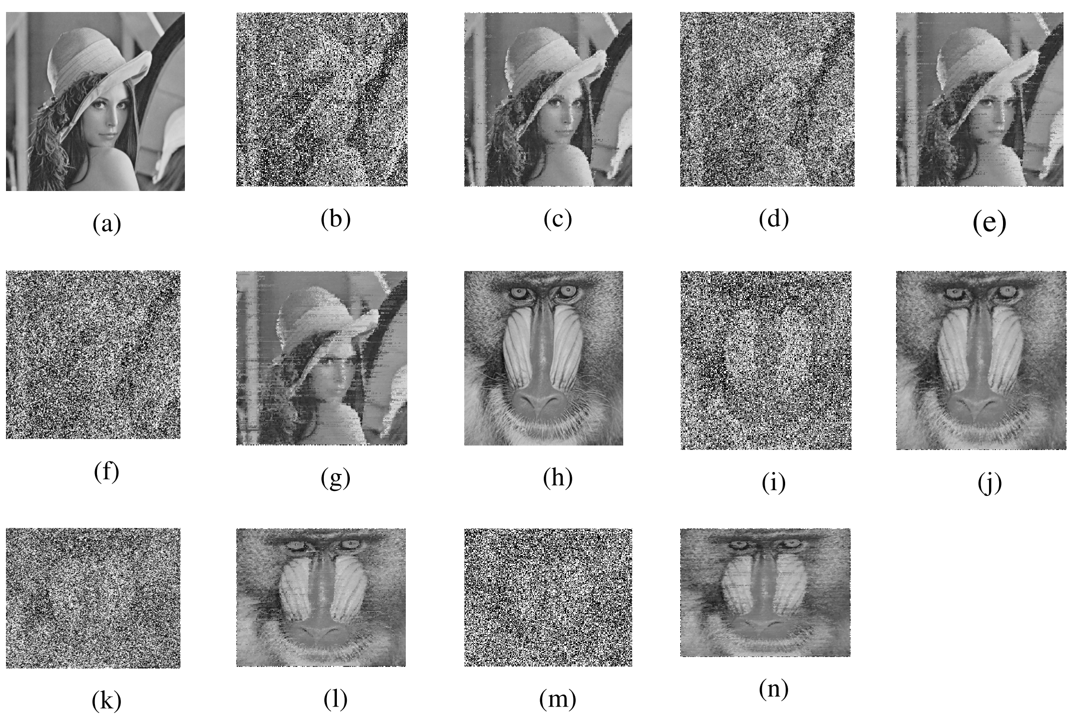

Figure 3. (a) Original image of Lena (b) Lena image with 50% noise; (c) Filtered Image of (b); (d) Lena image with 60% noise; (e) Filtered Image of (d); (f) Lena Image with 70% noise; (g) Filtered Image of (f); (h) Original Image of Mandrill (i) Mandrill Image with 50% noise; (j) Filtered Image of (i); (k) Mandrill Image with 60% noise; (l) Filtered Image of (k); (m) Mandrill Image with 70% noise; (n) Filtered Image of (m);

6. CONCLUSION

The APM filter promises a high degree of restoration of digital images, degraded by fixed-value impulse noise of density up to 90%. Hence, it is found to be very effective in denoising the highly corrupted images. Further, the proposed filter also ensures better preservation of the details and edges of the input images, which is confirmed quantitatively in terms of PSNR values and qualitatively as visual perception.

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