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A Randomness-Based Improved Adaptive Recursive Median Filter for Fixed-Valued Impulse Noise Removal

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Abstract
In the field of Digital Image Processing, one of the primary goals is the reconstruction or recovery of the original image from a degraded version. Various algorithms are employed for this purpose including the Median Filter, Recursive Median Filter, Cascade Median Filter, and Enhanced Recursive Median filter. The choice of algorithm often depends on the noise density in the image. This paper proposes an improved adaptive recursive median filter specifically designed for restoring grey scale images corrupted by fixed impulse noise. The proposed filter operates in two main steps: first, each pixel in the image will be tested to determine if it is corrupted by noise or not, with uncorrupted pixels being retained. In the second step, the entropy of the corrupted pixels is calculated, and the size of the structural element is adjusted based on the entropy value. The results are measured using Mean Square Error (MSE) and Peak Signal to Noise Ratio (PSNR).

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Keywords., Image denoising, Fixed Impulse Noise, Image Enhancement and recovery.

مرشح وسيط تكراري تكيّفي مُحسَّن قائم على العشوائية لإزالة ضوضاء النبضات ذات القيم الثابتة

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الملخص

يعد أحد الاهداف الاساسية في مجال معالجة الصور الرقمية هو استرجاع أو اعادة بناء الصورة الاصلية من صورة متأثرة بالضوضاء. ويستخدم لهذا الغرض خوارزميات متعددة، من بينها المرشح الوسيط، والمرشح الوسيط التكراري، والمرشح الوسيط المتسلسل، والمرشح الوسيط التكراري المحسن. ويعتمد اختيار الخوارزمية المناسبة غالبا على كثافة الضوضاء الموجودة في الصورة. يقترح هذا البحث مرشحا وسيطا تكيفيا تكراريا محسنا، صمم خصيصا لاستعادة الصور ذات التدرج الرمادي المتأثرة بضوضاء النبضات الثابتة. يعمل المرشح المقترح عبر خطوتين رئيسيتين، في الخطوة الاولى يتم اختبار كل بكسل في الصورة لتحديد ما إذا كان متأثرا بالضوضاء ام لا. ويتم الابقاء على البكسلات غير المتضررة دون اجراء اي معالجة عليها. اما في الخطوة الثانية فيتم حساب قيمة الانتروبيا للبكسلات المتأثرة بالضوضاء. واعتمادا على قيمة الانتروبيا التي تم حسابها يتم تعديل

http://www.doi.org/10.62341/istj-vol38-2-am34

حجم العنصر البنيوي . وقد تم تقييم اداء المرشح المقترح باستخدام معيار متوسط مربع الخطاء (MSE) ونسبة الاشارة الى الضوضاء (PSNR) .

الكلمات المفتاحية: ازالة الضوضاء من الصورة، ضوضاء النبضات الثابتة، تحسين واستعادة الصورة.

1. Introduction

In the field of digital image processing, one of the major important tasks is removing or suppression of noise from digital images, which often occurs during the image acquisition or transmission. The impulse noise is one of the most common types, typically caused by sudden transients. It occurs in two types fixed valued (salt and pepper) or random valued. In Salt and Pepper case the pixels are always corrupted with maximum or minimum values in grey level. The schemes used in impulse noise removal are classified into two categories, detection prior to filtering and filtering without detection. [1][2] The most widely used and simplest filters for impulse noise suppression reported in the literature are the Median Filter (MF). However, the standard (MF) fails to effectively restore images at high density of noise. Adaptive Median Filter (AMF), although suitable for low noise densities, and it is also suffering from performance degradation at higher noise levels and requires a large window size, which may lead to image blurring. In switching median filter (SMF), a fixed threshold value is employed as a govern of the filtering process. Nevertheless, selecting an optimal threshold is inherently challenging. Furthermore, this method fails to take into account the characteristics of the local image, resulting in a lack of preservation of edge details, especially under conditions of high noise density. [3]

The proposed algorithm, namely the Improved Adaptive Recursive Median Filter (IARMF), is designed to handle fixed impulse noise, operates only on pixels with values of 0 or 255. In contrast, the Median Filter (MF), the Recursive Median Filter (RMF), and the Center Weighted Median Filter (CWMF) all rely on a filtering mechanism without prior noise detection. Also, another feature in the proposed filter is that the filtering process employs variable window sizes that are adaptively adjusted according to predefined

http://www.doi.org/10.62341/istj-vol38-2-am34

threshold values. The entropy is utilized to measure the degree of randomness within each local window (mask), and the resulting value is used to determine an appropriate threshold for selecting the optimal window size.

2. Noise Models.

Noise can generally be defined as an unwanted component that affects data quality. Noise in digital images may arise from many sources, such as errors during image transmission or image acquisition. These degradations can manifest in different forms, including Gaussian noise, Periodic noise and Impulse noise (Salt-Pepper noise), etc. In this study, the primary focus is on impulse noise.

Impulse noise is generally modeled as a statistically independent and uncorrelated process with the image pixels, and is randomly distributed over the image. [4-5]

- **Model 1**

A common model of impulse noise assumes that image degradation occurs through random replacement of pixel with extreme grayscale values, in 8-bit gray level represent, (0 and 255). These values generated with the same probability. If N is noise density, then N1 the noise density of salt which equal N/2 and N2 is represent Pepper also N/2. This can be written mathematically as follows: [5]

$$y_{ij} = \begin{cases} zero\ or\ 255\ with\ probability\ N \\ x_{ij}\ with\ probability\ 1-p \end{cases} \quad (1)$$

Where y_{ij} represents the noisy image pixel, N is the total noise density and x_{ij} is the uncorrupted image pixel. [5]

- **Model 2**

This model is an extension of model 1. However, in this case, the probabilities of the two noise types are not equal N1≠N2. [5]

- **Model 3**

Impulse noise with fixed values has only two discrete intensity, a more realistically instead of two fixed values, the model can do it

http://www.doi.org/10.62341/istj-vol38-2-am34

by two fixed ranges that appear at the ends with a length of m, the interval [0, m] corresponds to salt noise, while [255-m, 255] represents pepper noise. Assuming a total noise density N, both noise component is equally N1=N2=N/2. [5]

$$y_{ij} = \begin{cases} n_{ij} \; with \; probability \; N \\ x_{ij} \; with \; probability \; 1-p \end{cases} \tag{2}$$

Where n_{ij} denotes the gray level value of the noisy pixel.

- **Model 4**

This model is similar to model 3. However, in this case, the probabilities of the two noise types are not equal N1≠N2. [5]

3. Denoising techniques

Image denoising is considered a fundamental and critical operation in image processing, yet it remains one of the most difficult to master. [6] Many different de-noising techniques have been proposed in literature, these techniques can be classified into three approaches. Spatial Filtering, Transform Domain Filtering and Wavelet Thresholding Method.

In this paper, we focus on Spatial Filtering, which is a technique applied directly to pixel values in the spatial domain to reduce noise or enhance images. It is generally classified into two types: linear filters and Nonlinear filters: [7]

- **Linear filters**

Linear filtering is typically employed when only additive noise is present. Common types of linear filters are Mean and Wiener Filters. [7]

- **Nonlinear filters**

In image processing problems, nonlinear filtering techniques are preferred as they can cope with the nonlinearities of the image formation model and also consider the nonlinear nature of the human visual system. Common type of Nonlinear filter is Median filter. [8] Median filter is a simple nonlinear smoother that can

http://www.doi.org/10.62341/istj-vol38-2-am34

suppress noise while retaining sharp sustained changes (edges) in signal values. To define the running median smoother, let { x (▪) } be a discrete time sequence. The running median passes a window over the sequence { x (▪) } that selects, at each instant "n". The median smoother operating on the input sequence { x (▪) }, this produce the output sequence {y}, at time index "n":

$$Y(n) = \text{MEDIAN}\,[x(n - NL), \ldots, x(n), \ldots, x(n + NR)] = \text{MEDIAN}\,[x1(n), \ldots, xN(n)] \qquad (3)$$

where NL and NR range in value over the nonnegative integers and N = NL + NR + 1 is the window size. That is, the samples in the observation window are sorted and the middle, or median, value is taken as the output. Recursive Median Filter (RMF) is a modification of the median filter defined in equation (3). Specifically, the output *y(k)* of the median filter of size *2N + 1* is given by: [9]

$$Y(n) = \text{MEDIAN}\,[y(n - N_L), \ldots, y(n - 1), x(n), \ldots, x(n + N_R)] \qquad (4)$$

The process of denoising the image can be illustrated as shown in figure (1)

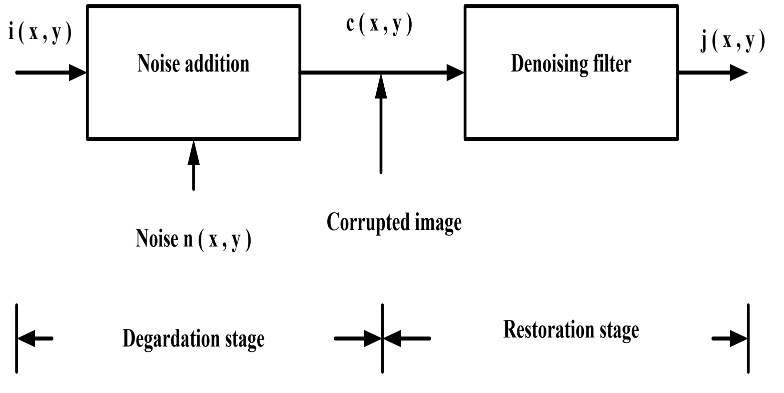

Figure. 1 process of denoising the image

http://www.doi.org/10.62341/istj-vol38-2-am34

Where: - i (x, y) is the original image
n (x, y) is the salt-and-pepper noise
c (x, y) is the corrupted image and
j (x, y) is the estimate of the original image i (x, y) after denoising.

4. Proposed approach

The Efficiency of the (MF) and (RMF) depends on the fixed size of the moving window. When a small window is used, the probability of selecting noisy pixel as the output increases which degrades the filtering performance. The (ARMF) based on entropy improved the quality of the output image compared to (MF) and (RMF) by dynamically adjusting the window size according to the level of randomness which was calculated by entropy. Entropy is a statistical measure of randomness. It is defined as: [10]

$$E = -\sum_{k=1}^{k} P_{(ak)} log_2 P_{(ak)} \qquad (5)$$

where $\{P(a_1), P(a_2)\ldots,P(a_k)\}$ is a set of probabilities.
However, applying this process to all pixels in the image reduces the overall efficiency of the filter. To overcome these limitations and enhance performance, the (IARMF) is proposed.
The proposed method operates only on pixels with values of 0 or 255 which may represent either corrupted or uncorrupted pixels, guided by a local randomness criterion.
Firstly, the method identifies candidate pixels based on these extreme values. Secondly, the level of randomness determines window size based on the predefined threshold values. If the randomness valueis less than 0.3 then the window size will be (3×3). If the randomness value is greater than or equal 0.3 and less than 0.8 then the window size will be (5×5). However, when the randomness value is greater than or equal 0.8 then the window size will be (7×7).

5. Performance Parameters

For comparing the original image and the filtered image, we calculate the following parameters:

http://www.doi.org/10.62341/istj-vol38-2-am34

1.Mean Square Error (MSE): The MSE is the cumulative square error between the original and processed image defined by: [11]

$$\mathrm{MSE} = \frac{1}{M * N} \sum_{X=0}^{M-1} \sum_{Y=0}^{N-1} [F(X, Y) - I(X, Y)]^2 \qquad (6)$$

Where: F(X, Y) is the original image I(X, Y) is the filtered image M and N are the number of rows and columns or (dimension) in the input image.

2. Peak signal to Noise ratio (PSNR): PSNR is the ratio between the maximum possible power of a signal and the power of distorting noise which affects the quality of its representation. It is defined by: [11]

$$\mathrm{PSNR} = 10\log_{10}\left(\frac{R * C}{\mathrm{MSE}}\right) \qquad (7)$$

Where: R is the number of rows of the original image, C is the number of columns f the original image.

6. Simulation results

The proposed technique (Improved Adaptive Recursive Median Filter (IARMF)) was implemented using MATLAB 2024Rb to simulate the results. The simulation results are presented in Table (1) with various densities of noise on 8-bit gray scale images.

Table -1 the performance of filters

Noise density	Filters type					
	RMF		ARMF		IARMF	
	MSE	PSNR	MSE	PSNR	MSE	PSNR
10%	98.64	30.36	196.47	25.19	16.10	36.06
20%	147.27	28.62	240.25	24.32	36.52	32.5
30%	227.59	26.72	332.37	22.91	61.11	30.26
50%	465.73	23.61	587.17	20.44	88.03	28.68
70%	2.10e3	17.07	1.78e3	15.60	342.59	22.78
80%	4.21e3	14.04	3.83e3	12.29	776.18	19.23

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As seen in Table 1, the image was corrupted with salt-and-pepper noise at low (10%) and high (80%) noise densities. Subsequently, the corrupted image was restored using the proposed adaptive filter with window sizes of 3×3, 5×5 and 7×7, which were adaptively selected based on the entropy (uncertainty) value. Figure 2 represent the sample for image denoising with three types of filters algorithms by density of noise (50%).

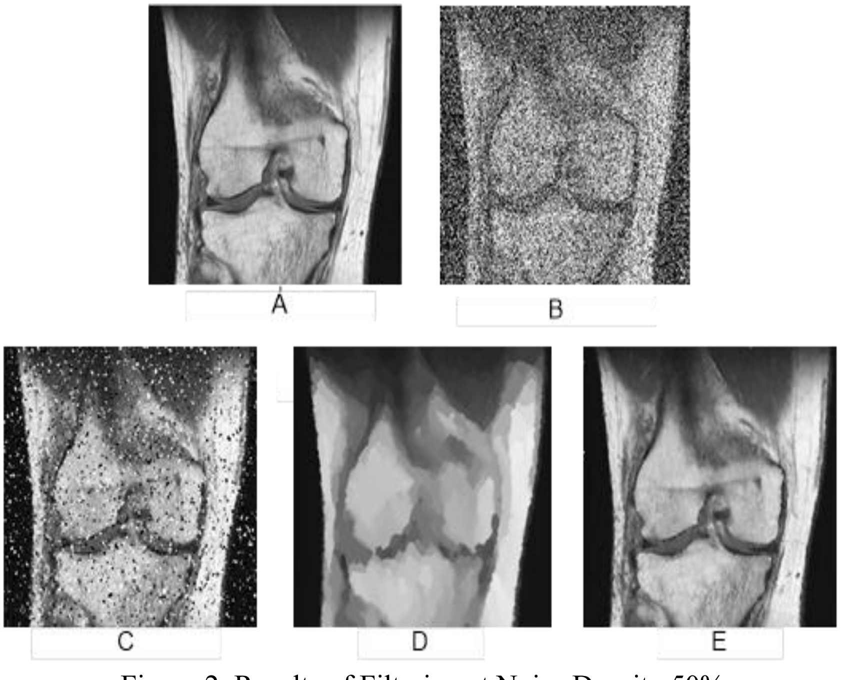

Figure 2. Results of Filtering at Noise Density 50%
(A) Original image, (B) Corrupted image, (C) RMF, (D) ARMF, (E) IARMF

The performance of the restoration process is quantified using Peak Signal-to-Noise Ratio (PSNR) and Mean Squared Error (MSE). The obtained results are compared with (RMF) and (ARMF) as shown in Figures 3 and 4.

http://www.doi.org/10.62341/istj-vol38-2-am34

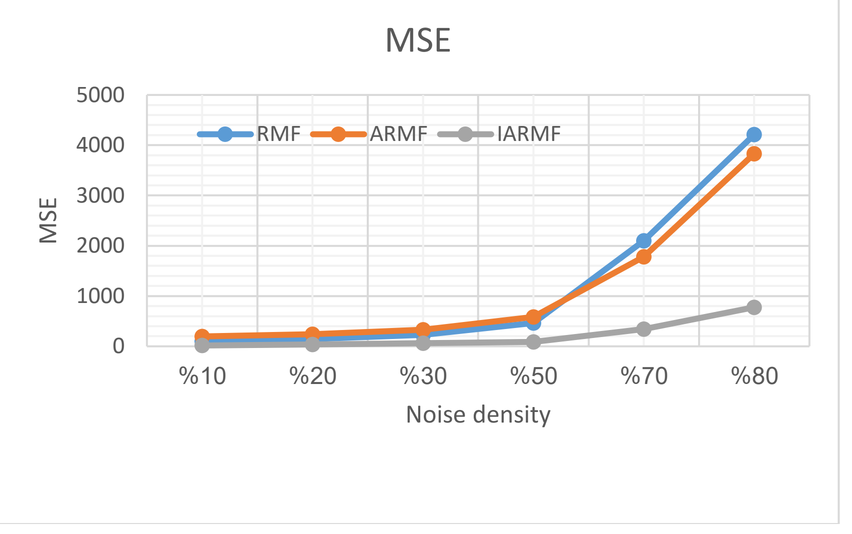

Figure3. The MSE of filtering techniques

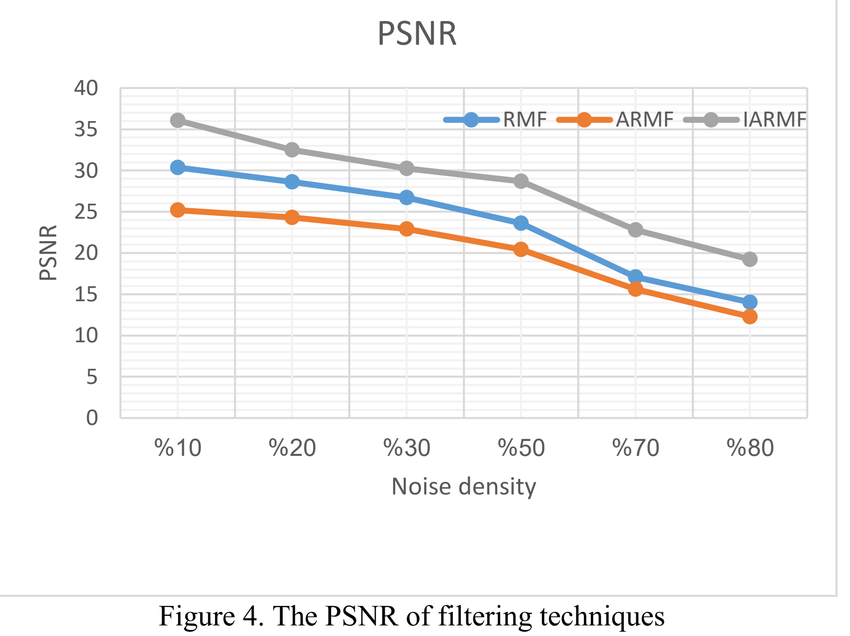

Figure 4. The PSNR of filtering techniques

http://www.doi.org/10.62341/istj-vol38-2-am34

7- Conclusion

In this paper, the proposed technique (IARMF)) demonstrated superior performance in enhancing grayscale images corrupted by low, medium, and high-density impulse noise compared with conventional filtering methods such as RMF and ARMF. The simulation results showed that the proposed method consistently achieved higher PSNR values and lower MSE values across all tested noise densities, particularly under severe noise conditions. This improvement is mainly attributed to the selective processing of corrupted pixels and the adaptive dynamic window mechanism based on threshold values, which effectively suppresses impulse noise while preserving important image details. The obtained results confirm the robustness and efficiency of the proposed approach for impulse noise reduction and grayscale image enhancement.

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