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An intensity independent fixed valued impulse noise detector for image restoration

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ABSTRACT

Most of the impulse noise detectors used for detection of fixed valued impulse noise are effective only for salt and pepper or a band type noise occurring at the extreme ends of the allowed range of intensity levels. The performance of these detectors deteriorates drastically when fixed valued impulses occur anywhere within the allowed gray scale. In this paper, an impulse detection scheme is proposed which can effectively detect all types of fixed valued impulse noise and also differentiates between noisy and noise-free pixels of identical intensity levels. The improved performance of the proposed method is verified through extensive simulations for various fixed valued impulse noise models.

1. Introduction

Digital images are often corrupted by impulse noise during their acquisition or transmission. Therefore, in any image processing task, impulse noise removal is considered an important preprocessing step [1]. In the literature, median-based methods for removal of impulse noise have been extensively studied due to their simplicity [2,3]. However, when median filter is applied on all the pixels of the image, it often results into blurring of image details. In order to overcome this problem, a switching median approach is used in which the filtering is preceded by impulse detection. This ensures that only noisy pixels are filtered by the filter, preserving the sharp image features from blurring [4].

By modifying the basic switching median filter, a number of techniques have been proposed. The weighted median filter and center-weighted median filter [5] are modified median filters which offer the trade-off between the noise suppression and image detail preservation by giving higher weight to some pixels of the filtering window. The progressive switching median filter [6] achieves the detection and removal of impulse noise in two separate stages. Another filtering scheme known as BDND [7] achieves impulse detection in two stages using two different window sizes. The min.-max. impulse detector [8], ACWM [9], DBA [10], Luo et al. [11], NASMBF [12] and ABDND[13] are some other schemes which are proposed for detection of salt and pepper noise and some of its variants.

In any impulse detection scheme, the detector should ideally have: (i) the ability to successfully detect an impulse irrespective of its gray value and (ii) the ability to distinguish a noise-free pixel from noisy pixel having same gray value.

Most of the existing impulse detection schemes do not perform satisfactorily when impulse occurs with values other than those on the extreme ends of the allowed intensity range. Further, some of these schemes cannot effectively distinguish noisy pixels from noise-free ones when they have identical intensity levels. This paper attempts to address these problems by detecting the fixed valued impulse noise in two steps. To effectively deal with different noise models, first of all, we identify the gray values which are affected by impulse noise and then in the second step if any of these gray values is found to be part of the image, then it is considered noise-free and not subjected to filtering.

The paper is organized as follows. In Section 2, the proposed impulse detector and filtering algorithm is presented. In Section 3 several experimental results are presented to demonstrate the performance of our scheme. Finally, the overall findings are summarized in Section 4.

2. Impulse detection and filtering

It is assumed that the image of size $M \times N$ has 8-bit gray pixel resolution. A filtering window $w^{(x)}_{n\times n}(i,j)$ of size $n \times n$ at location (i,j) has the center pixel value $x(i,j)$, where n is an odd integer.

The image is assumed to be corrupted by noise with probability p according to the following model.

$$x(i,j) = \begin{cases} o(i,j) \text{ with probability } 1-p \\ \eta(i,j) \text{ with probability } p \end{cases} \quad (1)$$

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where $o(i,j)$ and $\eta(i,j)$ represent the pixel values at location (i,j) of the original and the noisy images, respectively. In the present study three noise models are considered.

NM1: The impulse noise has two fixed valued gray levels corresponding to maximum '255' and minimum '0' of the gray scale occurring with equal probability.

NM2: In this model salt and pepper noise has small bands with equal probabilities. These bands are considered from 0 to 9 and 246 to 255 gray values.

NM3: This model considers noise having four equally likely and well separated intensity levels. Here, the gray values of noise impulses are 15, 25, 225 and 250 [14].

2.1. Detection of Noise

The detection of impulse noise is accomplished in following two steps.

2.1.1. Step I: Identification of Gray Levels of Impulse Noise

First of all, a record book is created with the help of a window $\underset{3\times 3}{w}^{(x)}(i,j)$ containing the probable gray levels of noisy pixels and their frequency of occurrences in the image. The pixel $x(i,j)$ is included as a member of the record book if

$$|x(i,j) - m(i,j)| \geq T_1 \tag{2}$$

where $m(i,j)$ denotes the median of the pixels in $\underset{3\times 3}{w}^{(x)}(i,j)$, and T_1 is a constant. If a gray value η appears in the record book with maximum frequency f_{max}, then all the gray values for which the frequency of occurrence $f \geq f_T$, are considered as gray levels of noise, where f_T is a threshold such that $0.4f_{\max} \leq f_T \leq 0.6f_{\max}$. However, it has been observed through simulations that $f_T = 0.45f_{\max}$ is most effective for all noise models considered in our study. Let the set of all such gray levels be denoted as S_η.

2.1.2. Step II: Separation of Noise-free Pixels from Noisy Pixels Having Identical Gray Levels

A binary noise flag image $\{f\}$ is created where $f(i,j) = 0$ indicates that the pixel at the location (i,j) is noise-free; for the noisy pixel $f(i,j) = 1$. Initially for any pixel $x(i,j)$, the flag $f(i,j) = 1$, if $x(i,j) \in S_\eta$. Now when the central pixel of the filtering window $\underset{3\times 3}{w}^{(x)}(i,j)$ is noise-free but $x(i,j) \in S_\eta$ then we separate this pixel as follows.

$$\text{If} \min_k |x(i,j) - d_{ave}(k)| \leq T_2; \quad k = 1, 2, 3, 4 \tag{3}$$

then pixel $x(i,j)$ is treated as noise-free and the corresponding flag is set to zero i.e. $f(i,j) = 0$. Here T_2 is a constant and $d_{ave}(k)$ denotes the average of pixels in the kth diagonal in the filtering window $\underset{3\times 3}{w}^{(x)}(i,j)$.

2.1.3. Filtering

In the noise adaptive median filtering technique, corresponding to every location (i,j) where $f(i,j) = 1$, filtering is done. For this purpose a window of size 3×3 centered at (i,j) in the input image $\{X\}$ is selected and noisy pixel is replaced by the median of noise-free pixels. If the number of noise-free pixels within this window is less than half of the total pixels, window size is increased to 5×5 and median of noise-free pixels replaces the noisy pixel.

$$y(i,j) = \begin{cases} m_{nf}(i,j) & \text{if} \quad f(i,j) = 1; \\ x(i,j) & \text{if} \quad f(i,j) = 0 \end{cases} \tag{4}$$

where $m_{nf}(i,j)$ represents the median of noise-free pixels in the filtering window.

Table 1
Number of false and missed detections for 'Lenna' image resulting from various filtering schemes for NM1.

Method		Noise percentage				
		20	30	40	50	60
Min-max	MD	202	110	49	9	4
	FD	3207	1040	312	108	68
NASMBF	MD	0	0	0	0	0
	FD	4146	1130	279	116	68
BDND	MD	0	0	0	0	0
	FD	225	229	189	187	179
ABDND	MD	0	0	0	0	0
	FD	131	88	82	75	67
Proposed	MD	0	0	0	0	0
	FD	65	61	61	55	54

3. Experimental results

The proposed scheme of impulse detection and image filtering is applied to several well known test images of size 512×512 having 8-bit resolution. The objective quantitative measure used for evaluating the image restoration performance is peak signal to noise ratio (PSNR), defined as

$$\text{PSNR} = 10\log_{10}\left(\frac{255^2}{\frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}(y(i,j) - o(i,j))^2}\right) \tag{5}$$

The noise density in the noisy images corrupted by fixed valued noise is varied from 10% to 60% in the steps of 10%. The threshold values T_1 in (2) is usually large so that an impulse with significantly different gray value can be distinguished from the noise-free pixels in the filtering window. Since, the step in (3) is used to separate a noise-free pixel $x(i,j) \in S_\eta$, a small value of threshold T_2 ensures that a noise-free pixel which is part of the image is not declared noisy. Accordingly, T_1 and T_2 are chosen as 80 and 2, respectively. Although it is observed that the performance is not very sensitive to the selection of these values. The performance of the proposed detection scheme is judged in terms of number of false and missed detections. These results in this exposition are shown by Tables 1–3 for 'Lenna', 'Boats', and 'Baboon' images, respectively. The criterion used to evaluate the filtering performance of the proposed scheme vis-à-vis other resent methods included in this study is PSNR. Tables 4–6 present the PSNR obtained for various images.

From Tables 1 and 2 it can be observed that among the existing approaches, ABDND performs better than other approaches for noise models NM1 and NM2. When impulse noise occurs anywhere in the allowed gray scale, none of the existing methods performs

Table 2
Number of false and missed detections for 'Boats' image resulting from various filtering schemes for NM2.

Method		Noise percentage				
		20	30	40	50	60
Min-max	MD	0	0	0	0	0
	FD	643	548	435	333	255
NASMBF	MD	0	0	0	0	0
	FD	786	647	433	400	276
BDND	MD	361	1241	3514	8121	16,343
	FD	426	385	289	272	239
ABDND	MD	0	0	0	0	0
	FD	607	513	379	341	260
Proposed	MD	0	0	0	0	0
	FD	174	176	157	168	153