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Salt and Pepper Noise Removal using Pixon-based Segmentation and Adaptive Median Filter

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Abstract
Removing the salt and pepper noise is an active research area in image processing. In this paper, a two-phase method is proposed for removing the salt and pepper noise, while preserving the edges and fine details. In the first phase, the noise candidate pixels that are likely to be contaminated by noise are detected. In the second phase, only the noise candidate pixels are restored using an adaptive median filter. In terms of noise detection, a two-stage method is utilized. At first, a thresholding is applied on the image for the initial estimation of the noise candidate pixels. Since some pixels in the image may be similar to the salt and pepper noise, these pixels are mistakenly identified as noise. Hence, in the second step of the noise detection, the pixon-based segmentation is used to identify the salt and pepper noise pixels more accurately. Pixon is the neighboring pixels with similar gray levels. The proposed method is evaluated on several noisy images, and the results show the accuracy of the proposed method in the salt and pepper noise removal and outperforms to several existing methods.

Keywords: *Salt and Pepper Noise, Noise Detection, Noise Removal, Pixon.*

1. Introduction
Images could be contaminated by noise during image transmission or during data capture from digital cameras. The value of impulse noisy pixels has the tendency of being either relatively low or relatively high. Thus it could severely damage the image quality [1]. The salt and pepper noise and the random-valued noise are two common types of impulse noise [2]. In impulse noise, a portion of an image pixel value is replaced by random values, leaving the remainder unchanged [3]. In the salt and pepper noisy image, single pixels are set alternatively to zero or to the maximum value in the dynamic range.
There have been many works on the restoration of salt and pepper noisy pixels. Linear filters such as average filter and Gaussian filter have a computational efficiency but lead to serious image blurring. Non-linear filters have been widely exploited due to their performance in terms of salt and pepper noise removal and detail preservation. The median filter is one of the most popular and robust non-linear filters. This filter sorts pixels according to their intensities within a filtering window, and replaces the center pixel with the median value. When the noise level is high, some edges and fine details of the original image are removed by this filter [4].
Various modifications of the median filter such as the weighted median filter [5], center-weighted median filter [6], adaptive median filter [7], multi-state median filter [8], and median filter based on homogeneity information [9, 10] have been introduced.
Most modifications of the median filter apply the median operation to each pixel without considering whether it is uncorrupted or corrupted. Hence, all pixels of the image are filtered, and this causes image quality degradation [1]. Indeed, modifying uncorrupted pixels may lead to blurring of details and change of image structure [11]. In order to overcome this problem, a salt and pepper noise detection mechanism should employ prior to filtering. In this mechanism, each pixel is labeled as corrupted or uncorrupted. Hence, the filtering

process is applied only on the pixels detected as corrupted, while the uncorrupted pixels would remain unchanged [11].

In this paper, a two-stage scheme is proposed for the salt and pepper noise removal. In the first stage, the noisy pixels are detected, and in the second stage, these noise candidates are restored using the adaptive median filter. Our proposed noise detection contains two steps. In the first step, two pre-defined threshold values are considered as the initial estimation of the noisy pixels. In the second step of noise detection, pixon-based segmentation is utilized.

The rest of this paper is structured as follows. Section 2 describes the impulse noise removal using the adaptive median filter. Several salt and pepper de-noising algorithms are reviewed in Section 3. Details of the proposed method are described in Section 4. The experimental results and conclusions are presented in Sections 5 and 6, respectively.

2. Adaptive median filter

The salt and pepper noise is randomly distributed over the image. In this type of noise, the corrupted pixels are substituted by two fixed values that appear in black and white. The standard median filter considers a filtering window in the image and replaces the central pixel with the median value. A major deficiency of this filter is that all pixels in the image including both the corrupted and uncorrupted ones are filtered. Hence, the visual quality of the image is deteriorated [12].

The adaptive median filter removes the noise in a two-step scheme. At first, the noisy pixels are detected via comparing each pixel with its neighboring pixels in various window sizes. If the pixel is similar to the majority of its neighbors but not structurally aligned with those pixels, it is labeled as noise. In the second stage, only the noisy pixels are filtered using the traditional median filter [12].

2. Related works

Several algorithms have been proposed in the literature to remove the salt and pepper noise. In [13], an adaptive fuzzy logic approach and the maximum-minimum filter have been used for impulse noise removal. In [14], a mixed noise removal has been proposed. In this paper, the white Gaussian noise and the impulse noise were considered as a mixed noise. A weighted encoding with sparse non-local regularization was utilized for mixed noise removal. In [15], a cost function and a piecewise smooth image model have been employed to remove the salt and pepper noise.

In another approach for the salt and paper noise removal, the noisy pixels are initially recognized. Then only these pixels are filtered.

In [16], a new impulse noise detection technique has been proposed for switching the median filters. This technique is based on the minimum absolute value of four convolutions.

In [17], an adaptive median filter has been employed to identify noisy pixels. In the filtering phase, the image is restored using a specialized regularization method.

In [18], noisy pixels have been detected via comparing the minimum absolute value of four mean differences in four directional windows with a pre-determined threshold value. Then an adaptive weighted mean filter has been employed for noise removal.

In [19], noisy pixels have been detected via convolving the noisy image with four 7×7 kernels and comparing the minimum absolute value of the results with a pre-determined threshold value. In the filtering stage, the conventional median filter is only applied to the detected noisy pixels.

In [20], the salt and pepper noisy pixels have been detected using statistical tools, and in the filtering stage, the adaptive network fuzzy inference system has been used to restore the noisy pixels.

In [21], the noise detection is based on a simple thresholding of pixels. In the filtering phase, the median filter has been utilized.

In [22], the noisy pixels have been detected based on the difference between the pixel and the arithmetic mean in a filtering window. Then the noisy pixels have been restored using the improved tolerance based on the adaptive masking selective arithmetic mean filtering and the wavelet thresholding process.

In [23], at first, the noisy pixels have been detected by a switching method. Next, the median filter has been employed on every noisy pixel. Finally, a post-processing has been done for a better restoration of the corrupted pixels.

In [24] a two-step method is proposed for removing impulse noise from MR images.

In [25] a two-step method is proposed for salt and pepper noise detection.

3. Proposed method

The salt and pepper noise is randomly distributed over the image. In this type of noise, the corrupted pixels are substituted by noise values that are either zero or 255. The proposed salt and pepper noise removal consists of two stages: noise detection and filtering. In the noise detection stage, two steps are performed. In the filtering stage, the adaptive median filter is employed only on the detected noisy pixels.

3.1. Noise detection

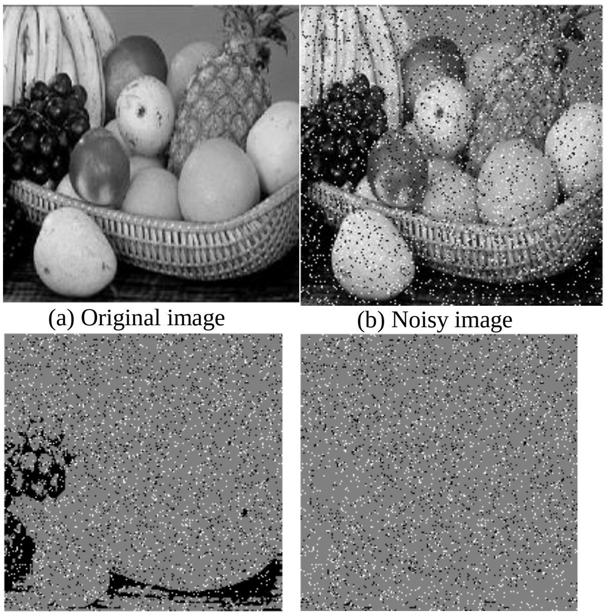
The first stage of the proposed method is the salt and pepper noise detection. In order to reach this purpose, two steps are carried out to specify whether a pixel is affected by noise or not. The first step is based on a simple thresholding of pixels. The second step is based on a pixon-based approach.

In the first step of noise detection, the pixels with the value of zero or 255 are considered as an initial estimation of the salt and pepper noisy pixels. For this purpose, the following equation is applied to the image:

$$n(x,y) = \begin{cases} I(x,y) & I(x,y) == 0 \; or \; 255 \\ 128 & Otherwise \end{cases} \quad (1)$$

where I is the noisy image, and n is a decision map with “128s” indicating the positions of the uncorrupted pixels and the extreme values for noisy pixels. In this approach, the extreme values of the image may mistakenly be judged as the noisy pixels. Hence, false detection is done through a pixon-based segmentation in the second step of the noise detection phase.

The pixon concept is a set of disjoint regions with different shapes and variable sizes. Indeed, the neighboring pixels with similar values are constituted as a pixon [25]. Eight neighbors of a pixel are considered for determining a neighboring pixel. Hence, all the pixels in the thresholding-based decision map are located in several pixons. Some of these pixons are noisy. In order to identify noisy pixons, the area of each pixon-the number of existing pixels in each pixon-is computed. The pixons with a small area are considered as noise. Accordingly, a final decision map is formed at the end of the noise detection stage. In this map, “128s” indicates the positions of the uncorrupted pixels, and the rest indicate the corrupted ones, i.e. low-intensity impulse noise and high-intensity impulse noise. Figure 1 shows the result of employing the proposed salt and pepper noise detection on a sample noisy image. As shown in figure 1(c), some uncorrupted pixels were mistakenly considered as noise. However, this problem has been refined using pixon-based segmentation (Figure 1(d)).



(a) Original image (b) Noisy image

(c) Initial decision map via thresholding (d) Final decision map

Figure 1. Result of the proposed salt and pepper noise detection.

3.2. Noise removal

The second stage of the proposed method is noise filtering. In this step, only the detected noisy pixels are restored using the adaptive median filter. Figure 2 shows the result of employing the proposed salt and pepper noise removal on the noisy image shown in figure 1.

Figure 2. Result of the proposed salt and pepper noise removal.

4. Experimental results

In this paper, a novel approach is proposed for the salt and pepper noise removal. In this experiment, the performance of the proposed method was evaluated on several noisy images. In order to evaluate the performance of the proposed method, the peak signal to noise ratio (PSNR) and the structural similarity index measure [26, 27] (SSIM) were used.

PSNR is a quantitative measure, which is defined as follows:

$$PSNR = 10\ log_{10} \frac{255^2}{1/(m\times n)\left(\sum_{i=1}^{m}\sum_{j=1}^{n}(I(i,j)-J(i,j))^2\right)}, \quad (2)$$

where I is the original image, J is the noise-free image removal image, and m and n represent the image width and height, respectively. The higher value for PSNR indicates a superior similarity between the original image and the denoised one.
SSIM is defined as:

$$SSIM = \frac{\sigma_{IJ}}{\sigma_I \sigma_J} \times \frac{2\bar{I}\,\bar{J}}{(\bar{I})^2 + (\bar{J})^2} \times \frac{2\sigma_I \sigma_J}{\sigma_I^2 + \sigma_J^2} = S(I,J) \times L(I,J) \times C(I,J), \quad (3)$$

S is the correlation coefficient between I and J, which measures the degree of linear correlation between them; L measures how much I and J are close in luminance; and C measures the similarity between the contrast of the images, where:

$$\bar{I} = \frac{1}{N}\sum_{i=1}^{N} I_i\ ,\ \bar{J} = \frac{1}{N}\sum_{i=1}^{N} J_i, \quad (4)$$

$$\sigma_I^2 = \frac{1}{N-1}\sum_{i=1}^{N}(I_i - \bar{I})^2, \quad (5)$$

$$\sigma_J^2 = \frac{1}{N-1}\sum_{i=1}^{N}(J_i - \bar{J})^2, \quad (6)$$

$$\sigma_{IJ}^2 = \frac{1}{N-1}\sum_{i=1}^{N}(I_i - \bar{I})(J_i - \bar{J}). \quad (7)$$

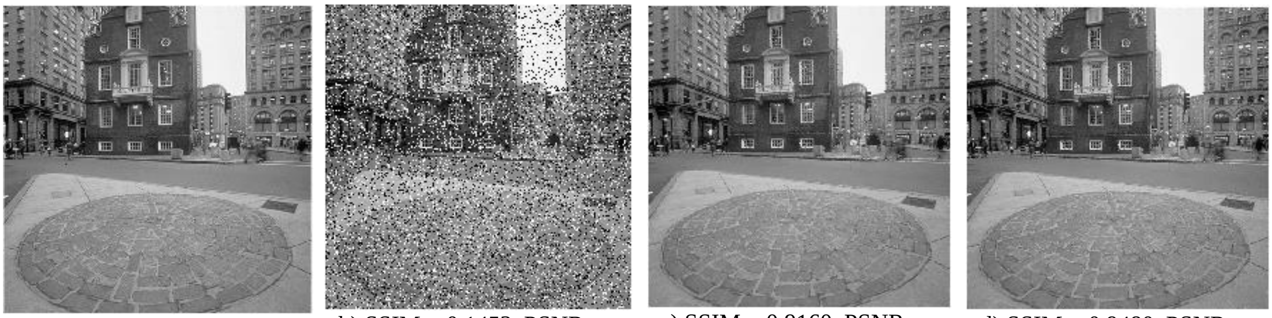
In the above equations, N is the number of pixels in the image. The dynamic range of SSIM is [0, 1]. The best value, 1, is achieved if $I = J$.
Figure 3 illustrates four instance results of the proposed method on the CSIQ dataset in comparison with the adaptive median filter. In this figure, the original images are contaminated by the salt and pepper noise with a noise density of 20%. As it can be seen, the salt and pepper noisy pixels are remarkably eliminated, whilst the edges and image details are efficiently preserved in the proposed method.
The proposed method and the adaptive median filter were applied to 30 noisy images of the CSIQ dataset with different noise rates. The average PSNR and SSIM values obtained from these methods are shown in table 1. In this table, the best results are indicated in boldface. The objective evaluation represents that the proposed method provides better PSNR and SSIM values than the adaptive median filter. Indeed, loss of edges and fine detail problem in the adaptive median filter decreases the SSIM value.
The proposed method was compared with the one proposed in [23]. Figure 4 shows the result of this comparison on Lena image with different noise rates. The results show that the proposed method is capable in the salt and pepper noise removal while preserving the edges and fine details. It is noteworthy that we compared the proposed method with [23] on the images reported in the paper.
Table 2 shows the performance of the proposed method and the one proposed in [23] on Lena image in terms of both the PSNR and SSIM values. In this table, the best results are indicated in boldface. The results represent that the proposed method obtains higher PSNR and SSIM values than the one proposed in [23].

5. Conclusions

In this paper, we have proposed a new method for the salt and pepper noise removal. The proposed method contains two phases: salt and pepper noise detection and filtering. In the first phase, the thresholding and pixon-based segmentation is used, and the adaptive median filter is utilized for the second phase. The proposed method is examined with a large number of images with different noise rates. The experimental results represent the superiority of the proposed method in terms of both the subjective and objective quality assessments.

a) | b) SSIM = 0.1460, PSNR = 11.8085 | c) SSIM = 0.9227, PSNR = 29.1713 | d) SSIM = 0.9507, PSNR = 30.6557

a) | b) SSIM = 0.1322, PSNR = 12.0939 | c) SSIM = 0.9004, PSNR = 25.3628 | d) SSIM = 0.9404, PSNR = 26.2381



a) | b) SSIM = 0.1453, PSNR = 12.5621 | c) SSIM = 0.9160, PSNR = 29.8274 | d) SSIM = 0.9480, PSNR = 31.3097

a) | b) SSIM = 0.1307, PSNR = 11.4013 | c) SSIM = 0.9361, PSNR = 29.8578 | d) SSIM = 0.9598, PSNR = 31.3071

Original image | Noisy image | Adaptive median filter | Proposed method

Figure 3. Comparison results of the proposed method with the adaptive median filter on four sample images of the CSIQ dataset.

Table 1. The average PSNR and SSIM results on the CSIQ database.

Noise rate	Noisy image		Adaptive median		Proposed method	
	PSNR	SSIM	PSNR	SSIM	PSNR	SSIM
10%	14.9076	0.2602	32.9086	0.9530	**36.0016**	**0.9830**
20%	11.9057	0.1415	31.0174	0.9390	**32.2678**	**0.9606**
30%	10.1422	0.0921	29.2006	0.9157	**29.8047**	**0.9315**
40%	8.8933	0.0640	27.5254	0.8846	**27.8136**	**0.8953**
50%	7.9280	0.0458	26.0459	0.8453	**26.1735**	**0.8518**
60%	7.1356	0.0324	24.5976	0.7946	**24.6453**	**0.7977**
70%	6.4657	0.0225	23.0797	0.7288	**23.0919**	**0.7299**
80%	5.8835	0.0145	21.4116	0.6410	**21.4135**	**0.6412**
90%	5.3751	0.0083	19.3396	0.5140	**19.3400**	**0.5140**

(a) Original image (b) Noisy image (90%) (c) Method proposed in [23] (d) Proposed method

Figure 4. Comparison results of the proposed method with the one proposed in [23] for Lena image on different noise rates.

Table 2. The PSNR and SSIM results for the images in figure 4.

Noise rate	Noisy image		Method proposed in [23]		Proposed method	
	PSNR	SSIM	PSNR	SSIM	PSNR	SSIM
30%	10.6679	0.0534	31.021	0. 9230	**34.1882**	**0.9508**
50%	8.4715	0. 0257	28.3071	0.8223	**30.3805**	**0.8949**
70%	6.9901	0.0141	23.2162	0.7629	**26.9424**	**0.8067**
90%	5.9025	0. 0061	19.2416	0.5074	**22.1459**	**0.6237**

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نشریه هوش مصنوعی و داده کاوی

حذف نویز نمک و فلفل با استفاده از قطعه‌بندی پیکسون و فیلتر میانه وفقی

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چکیده:

حذف نویز نمک و فلفل زمینه پژوهشی فعالی در پردازش تصویر است. در این مقاله، یک روش دو مرحله‌ای برای حذف نویز نمک و فلفل پیشنهاد شده است، به طوری که لبه‌ها و جزئیات ریز حفظ شوند. در مرحله اول، پیکسل‌های کاندیدای نویز که محتمل به نویز هستند، شناسایی می‌شوند. در مرحله دوم، فقط پیکسل‌های کاندیدای نویز با استفاده از فیلتر میانه وفقی بازیابی می‌شوند. در مرحله شناسایی نویز، یک روش دو مرحله‌ای استفاده می‌شود. در ابتدا، برای تخمین اولیه پیکسل‌های کاندیدای نویز، یک آستانه‌گذاری روی تصویر انجام می‌شود. از آنجایی که برخی از پیکسل‌های تصویر، مشابه نویز نمک و فلفل هستند، این پیکسل‌ها به اشتباه نویز شناسایی می‌شوند. از اینرو در مرحله دوم شناسایی نویز، قطعه‌بندی مبتنی بر پیکسون استفاده می‌شود تا پیکسل‌های نویز نمک و فلفل دقیقتر شناسایی شوند. پیکسون، پیکسل‌های همسایه با مقادیر سطح خاکستری مشابه هستند. روش پیشنهادی روی چند تصویر نویزی ارزیابی شد، و نتایج نشان‌دهنده دقت روش پیشنهادی در حذف نویز نمک و فلفل و برتری بر چند روش موجود است.

کلمات کلیدی: نویز نمک و فلفل، شناسایی نویز، حذف نویز، پیکسون.