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An efficient three-stage approach for removing salt & pepper noise from digital images

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ABSTRACT

In this paper, an efficient three-stage scheme for the removal of salt & pepper noise based on an efficient impulse detector, an adaptive mean-median filter and the total variation inpainting method was proposed. This approach removes salt & pepper noise by detecting, estimating and modifying noisy pixels in an image. If a pixel is classified as noise, its intensity is first estimated by a mean-median filter; and then an accurate estimation is obtained through the use of the total variation inpainting method. Conversely, the pixel value is kept unchanged when it is classified as noise-free, yielding the quality of the restored image being well maintained. Experimental results demonstrate that the proposed three-stage approach can not only remove salt & pepper impulse noise efficiently, but also preserve the detailed information of an image well.

1. Introduction

Corruption of images by noise is a regular phenomenon in image processing field. One of the most common noise types which corrupt images is impulse noise, also known as salt & pepper noise. Salt & pepper noise can corrupt images where the corrupted pixel takes either maximum or minimum gray level [1,2]. The occurrence of salt & pepper noise in an image may severely damage the information embedded in the original image. It is imperative to remove this kind of noise before subsequent image processing tasks such as edge detection or segmentation is carried out. One of the simplest ways to remove salt & pepper noise is by using the conventional median filter (MED) [3]. The MED filter has been established as a reliable method to remove salt & pepper noise without damaging the details. However, the major drawback of the MED filter is that it is only effective to work at low noise densities. This is due to the filter uniformly replaces the value of a pixel by a median of the intensity levels in the neighborhood of that pixel. Accordingly, some desirable details were also replaced, especially when the window size was large, yielding the restored image being blurred [2].

Recently, the two-stage denoising scheme has been demonstrated to be a powerful tool for the removal of salt & pepper noise, and has also been widely investigated and used. The basic idea of the two-stage scheme is that the noise candidates in an image are first determined by an impulse detector, and then filtering is utilized for the detected noisy pixels [4]. Among the recently proposed two-stage salt & pepper noise denoising schemes are the new fast and efficient decision-based algorithm (NFED) [5], the modified directional-weighted-median filter (MDWM) [2], the fast and efficient median filter (FEMF) [6] and the spatially adaptive total variation image deniosing method (SATV) [7]. The NFED directly recognizes the pixels with the smallest value and the highest value as impulse noises, and then removes only corrupted pixels by the median value or by its neighboring pixel value. The MDWM analyzes the neighbor information of the center pixel on twelve directions to weight the pixels in a local window; based on this, noise-corrupted pixels could be detected, and hence removed by the weighted median value on the optimum direction. The FEMF still recognizes the pixels with the smallest value and the highest value as impulse noises, and then utilizes a new median filter for finding proper medians to replace them. The SATV utilizes a noise detector based on the adaptive median filter applied in [8] to detect the noise-corrupted pixels, and then remove them by a spatially adaptive total variation image denoising method. Although these two-stage salt & pepper noise denoising schemes perform better than the conventional median filter due to the adoption of noise detection mechanism, they still tend to damage image details and introduce some kind of artifacts to some extent at high noise ratios.

In this paper, we propose an efficient three-stage denoising method for the removal of salt-and-pepper noise based on an efficient salt-and-pepper noise detector, an adaptive mean-median

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filter and the total variation inpainting method. We use an efficient noise detector (which is similar with Lu proposed in [2]) with twelve directions to identify salt-and-pepper noises, and then utilize an adaptive mean-median filter to obtain the initial estimation of these noisy pixels, and then the total variation inpainting method is utilized to calculate the final estimation of the gray-level of these corrupted pixels. Due to its effectiveness and accuracy, the total variation inpainting (TVI) model [9] is a well-known and commonly used model in image inpainting domain. Here we employ this model to obtain the final estimation of the gray-level of these noisy pixels for the purpose of removal of salt-and-pepper noise. This method takes full advantage of the surrounding information of these noise-free pixels in the reduction of noisy candidates. In this work, we test the proposed method on the two images degraded by salt-and-pepper noise with a wide range of noise levels varied from 10% to 80%, and compare it with other state-of-the-art filters, including the MED, the NFED, the SATV, the MDWM and the FEMF filters. Experimental results demonstrated that the proposed three-stage salt-and-pepper noise denoising method performs much better than the other five existing denoising methods not only in terms of visual quality but also of objective measures.

2. Salt & pepper noise detection

Similar to some other impulse detection algorithms [6,10], our impulse detector is developed by the same two prior assumptions on natural images: the first assumption is a noise-free image should be locally smoothly varying, and is separated by edges; and the second one is a noisy pixel will be with the pixel value considerably larger or smaller than those of its neighbors. In this paper, we focus on only salt & pepper impulsive noise with two significant features described as follows:

(1) a portion of the image pixels is corrupted; other pixels are noise-free;
(2) a noisy pixel takes either a very large value as a positive impulse or a very small value as a negative impulse.

In this work, we propose to use twelve directions to detect the edge direction of an object, this is similar to the method proposed by Lu [2]. But the twelve directions proposed in our work are more delicate than that of Lu's, which enabling the detection accuracy to be improved. Fig. 1 shows the proposed twelve directions for edge detection.

As shown in Fig. 1, a 7 × 7 window centered at (i, j) is used for edge detection. Let $S_{i,j}^k$ ($k = 1$ to12) denotes the set of pixels aligned with the k-th direction centered at (i, j), i.e.

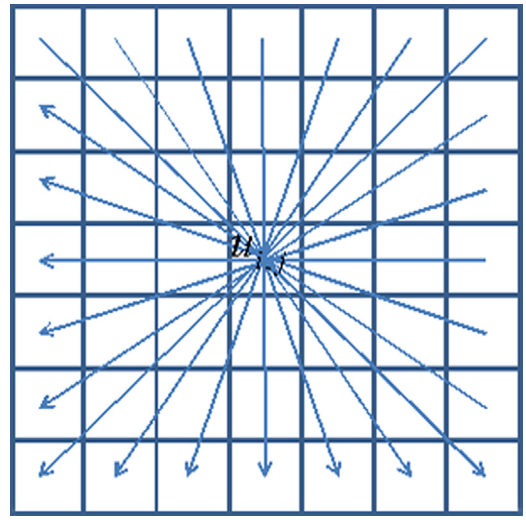

Fig. 1. Twelve directions for edge detection.

Based on $S_{i,j}^k$ ($k = 1$ to12), the absolute differences of gray-level values $d_{i,j}^{(k)}$ between the center pixel $u_{i,j}$ and its neighbors in S^k are calculated as follows:

$$d_{i,j}^{(k)} = \sum_{m=1}^{7} \omega_m \left| S_{i,j}^k(m) - u_{i,j} \right| \tag{2}$$

This can be used for noise detection. Here k denotes the direction index, ω_m is the weight. When an adjacent pixel and the center one are belong to the edge of an object or in the same smoothly varying area, their gray-level value should be close, i.e. the gray-level value difference given in (2) should be small. Therefore, a larger weight ω_m needs to be assigned to the gray-level value difference between the two closest pixels than that of the pixels which are not adjacent. Through extensive simulations, we choose ω_m as the following decreasing function:

$$\omega_m = \frac{2}{1 + (m - 4)^2} \tag{3}$$

Then, the minimum value of these twelve $d_{i,j}^{(k)}$ is considered for impulse noise detection, which can be indicated as:

$$d_{i,j}^{(k^*)} = \arg\min_k \left\{ d_{i,j}^{(k)}, 1 \le k \le 12 \right\} \tag{4}$$

The value of $d_{i,j}^{(k^*)}$ can be utilized to detect whether the center pixel $u_{i,j}$ of a local window is either noise-free or noisy because of the following reasons: (1) $d_{i,j}^{(k^*)}$ is large when the present pixel is an isolated impulse as the twelve $d_{i,j}^{(k)}$ are large; (2) $d_{i,j}^{(k^*)}$ is small when the present pixel is a without noise flat-region pixel as the twelve

$$\begin{aligned}
S_{i,j}^1 &= \left\{ u_{i-3,j-3}, u_{i-2,j-2}, u_{i-1,j-1}, u_{i,j}, u_{i+1,j+1}, u_{i+2,j+2}, u_{i+3,j+3}, \right\} \\
S_{i,j}^2 &= \left\{ u_{i-3,j-2}, \frac{u_{i-2,j-2} + u_{i-2,j-1}}{2}, \frac{u_{i-1,j-1} + u_{i-1,j}}{2}, u_{i,j}, \frac{u_{i+1,j} + u_{i+1,j+1}}{2}, \frac{u_{i+2,j+1} + u_{i+2,j+2}}{2}, u_{i+3,j+2} \right\} \\
S_{i,j}^3 &= \left\{ u_{i-3,j-1}, \frac{u_{i-2,j-1} + u_{i-2,j}}{2}, \frac{u_{i-1,j-1} + u_{i-1,j}}{2}, u_{i,j}, \frac{u_{i+1,j} + u_{i+1,j+1}}{2}, \frac{u_{i+2,j} + u_{i+2,j+1}}{2}, u_{i+3,j+1} \right\} \\
S_{i,j}^4 &= \left\{ u_{i-3,j}, u_{i-2,j}, u_{i-1,j}, u_{i,j}, u_{i+1,j}, u_{i+2,j}, u_{i+3,j} \right\} \cdots \\
S_{i,j}^{12} &= \left\{ u_{i-2,j-3}, \frac{u_{i-2,j-2} + u_{i-1,j-2}}{2}, \frac{u_{i-1,j-1} + u_{i,j-1}}{2}, u_{i,j}, \frac{u_{i,j+1} + u_{i+1,j+1}}{2}, \frac{u_{i+1,j+2} + u_{i+2,j+2}}{2}, u_{i+2,j+3} \right\}
\end{aligned} \tag{1}$$