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Modified directional weighted filter for removal of salt & pepper noise ☆

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ABSTRACT

Switching median filter is a popular type of salt & pepper noise removal technique in recent years. It first detects noise pixels in an image, and then only restores the noise pixels by using the median or its variant of filtering window. Existing directional weighted median filters suffer their own deficiencies when detecting and restoring noise pixels. In this paper, after deeply analyzing the reasons that cause the deficiencies, we propose a modified directional weighted filter to alleviate the issues. The new filter first detects salt & pepper noise by combining existing directional gray level differences with additional judgment of gray level extremes. Then the noise density of each noise pixel's non-recursive local window is estimated, and an innovative weighted gray level mean of a recursive or non-recursive filtering window is taken as the restored gray level according to noise density. Experimental results on a series of images show that the proposed algorithm achieves significant improvements in terms of noise suppression and detail preservation, especially when the noise density is high.

1. Introduction

Impulse noise usually emerges due to bit errors in the process of image acquisition and transmission [1,2]. Typically, there are two types of impulse noise, i.e., random valued noise and salt & pepper noise [3]. Salt & pepper noise is one of the key factors causing image contamination and quality deterioration, and the noise pixels take gray level extremes (either 0 or 255, for an 8-bit image). Because the noise pixel differs from most of its local neighbors, it has the same large gradient value as edge pixel, which causes great difficulty for image analysis, especially for edge detection [4]. How to effectively remove salt & pepper noise is still of great importance to image denoising.

It is well known that median filter is a classical salt & pepper noise removal method. Standard median filter needs large filtering window to suppress serious noise. However, a large window is prone to generate blurry image details due to its undiscriminating gray level replacement operation on each pixel. To improve noise suppression and detail preservation simultaneously, many modified median filters [5,6,7,8] have been developed in the last decades. For example, adaptive median filter [6] can automatically adjust the size of filtering window according to local patches of noise pixels.

Switching filter is a popular type of salt & pepper noise removing technique in recent years due to its good performance and easy implementation. This type of filter first detects noise pixels in an image, and then only replaces noise pixels with the median or its variants of their own local neighbors. For example, modified decision based unsymmetric trimmed median (MDBUTM) filter [9] detects noise pixels via the gray level extremes, 0 and 255, and then adaptively chooses the mean or median variants of their own 3×3 filtering windows as restored gray levels according to the number of gray level extremes in the filtering windows. Switching median filter with boundary discriminative noise detection (BDND) [10] adopts two-stage detection with different filtering window sizes to identify noise pixels, and replaces each noise pixel with the median of remaining pixels excluding noise neighbors in its adaptive filtering window. Unfortunately, the second stage, namely validation stage, in BDND's noise detection lacks statistical significance due to the small filtering window of 3×3. To remedy the issue, a highly effective impulse noise detection (HEND) algorithm [11] utilizes directional gray level differences to further affirm noise pixels in validation stage. HEND only involves noise detection. Directional weighted median (DWM) filter [12] uses the minimum sum of directional weighted gray level differences to detect noise pixels, and replaces each noise pixel with the weighted median of filtering window. Differing from DWM, its modified version namely MDWM [13] considers more edge directions in noise detection, and takes the weighted median excluding

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gray level extremes on the optimum direction as restored gray level of current noise pixel.

After deeply analyzing DWM and MDWM, we found that: (1) DWM's noise detection scheme neglects the fact that noise pixels only take gray level extremes, which may cause false alarm, i.e., misclassifying noise-free pixel as noise. (2) Their restoration schemes are unreasonable, which have negative effect on noise suppression and image detail preservation. To alleviate these issues, we propose an innovative directional weighted filter in this paper. Differing from DWM, the proposed algorithm performs the judgment of gray level extremes in noise detection for further reducing false alarm. Moreover, the main contribution of this paper is that we present a novel noise restoration scheme, which takes the weighted mean of each noise pixel's recursive or non-recursive filtering window as its restored gray level. Experimental results show that the proposed algorithm outperforms DWM and MDWM in terms of noise suppression and detail preservation, especially when the noise density is high.

The rest of this paper is organized as follows: Section 2 briefly introduces two existing directional weighted median filters, and discusses their deficiencies. Section 3 describes the proposed algorithm in details. Experimental results on a series of images are shown in Section 4. Conclusions are drawn in Section 5.

2. Existing directional weighted median filters

2.1. Noise detection

In this section, we will briefly introduce two existing directional weighted median filters (DWM and MDWM), and discuss their deficiencies in noise detection and restoration. In the process of noise detection, both DWM and MDWM first calculate the sum of weighted absolute gray level differences between central pixel and its neighbors on each edge direction, then find out the minimum of sums on different directions, and finally determine those image pixels with large minimum values as salt & pepper noise. In noise detection, DWM and MDWM consider 4 and 12 directions illustrated in Fig. 1(a) and (b), respectively. The underlying principle of the above noise detection is as follows:

(1) If p is a current noise-free pixel in a flat image region, absolute gray level differences between p and its neighbors on each direction should be small. The sum of absolute gray level differences on each direction should be also small. Thus the minimum of those sums should be also small.
(2) If p is a true edge pixel, absolute gray level differences between p and its neighbors on the edge direction should be small. The minimum sum of absolute gray level differences on all directions should be small because at least one of directions is small.
(3) If p is a noise pixel in a flat image region, absolute gray level differences between p and its neighbors on each direction should be large. The minimum sum of absolute gray level differences on all directions should be also large.
(4) If p is a noise pixel located on an edge, absolute gray level differences between p and its neighbors on the edge direction should be large. In addition, absolute gray level differences between p and its neighbors on other directions should be also not small. Therefore, the minimum sum of absolute gray level differences on all directions should be large.

From the above explanations, it can be learned that directional absolute gray level differences can be utilized to distinguish noise pixels and noise-free ones. However, DWM neglects the fact that noise pixels in an 8-bit image can only take gray level extremes, either 0 or 255. The false alarm will be further reduced if the judgment of the gray level extremes is added.

2.2. Noise restoration

When restoring a detected noise pixel, DWM first calculates standard deviations of local window excluding central pixel on four directions, and chooses the direction with minimum standard deviation as the optimum direction. The next step is to assign weights to the pixels in its 3×3 filtering window according to direction information and replace central noise pixel with the weighted median of the filtering window. When calculating the weighted median, DWM does not exclude noise pixels in the

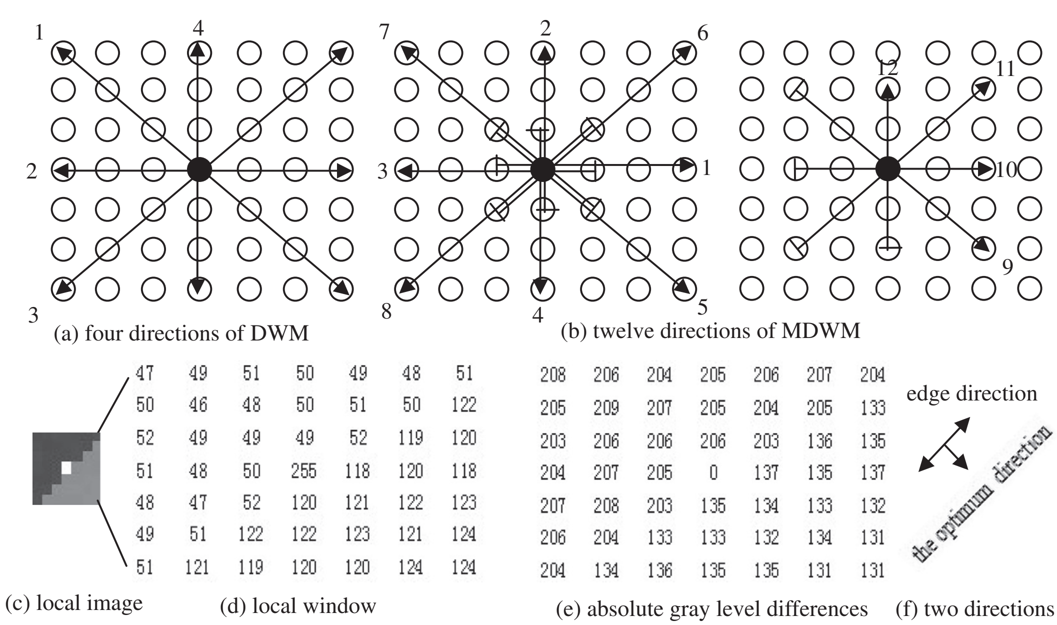

Fig. 1. Direction information of two directional weighted median filters and an example demonstrating MDWM's erroneous estimation for true edge direction.