Image Denoising Based on Adaptive Sector Rotation Median Filter

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Abstract. By analyzing the characteristics of different median filtering algorithms, an adaptive fan rotation median filtering method based on the standard median filtering method is proposed to restore the details of the image to the maximum extent for achieving better pepper and salt noise removal effect. The proposed method can change the window size adaptively according to the pollution degree in the window, and calculate the gray difference value for different areas, judge the correlation between the center point and different areas according to the gray difference value, and take the median value of the highest correlation area as output, which can restore the details of the image while removing the noise. The experimental results show that the new algorithm has a high similarity with the original image structure and a high peak signal-to-noise ratio after filtering, and can better recover the image details. Compared with other methods, the noise removal effect and detail recovery effect are better.

Keywords. Salt and pepper noise; Median filtering; Adaptive sector rotation median filtering

1. Introduction

In the process of image processing, the image may be polluted inevitably to different degrees due to the environment and equipment factors of image acquisition, and these noise pollution will cause great interference to the subsequent image processing. Therefore, how to effectively remove noise pollution and restore the image to the maximum extent has become the focus of image processing. Standard median filter [1] has a good effect to salt and pepper noise, but in a larger window (more than 5 x 5 window) filter the image detail is destroyed by the ranking of median value of. In addition, the noise points are processed identically by fixed window, and the detail become more blurry. Therefore, various improved algorithms have been proposed by different scholars. Khan S [2] et al proposed an adaptive weighted median filtering algorithm, which used a weighted operator based on Gaussian surface to perform weighted operation on signal pixels in the field, and then took the median value as the output. The weighted operation improved the noise filtering effect, but the image edge detail recovery was poor, and the algorithm complexity was increased. Qiao Kun [3] et al proposed an adaptive switching median filtering algorithm to detect noise at the central pixel point by multi-stage switching, which can effectively remove high-density noise, but the problem of image detail blur has not been solved yet. Zeng Xianyou [4] et al proposed a new adaptive fuzzy median filtering algorithm,
which can adaptively adjust the filtering window to calculate the fuzzy coefficient, and has good filtering effect on low-density noise images. However, when there are more extreme points in the window, the values of fuzzy coefficient and fuzzy variable are poor, so the filtering effect of images with high pollution degree is poor. Shao-ping Xu [5] put forward a kind of noise estimation based on the adaptive switching median filtering algorithm, support vector regression analysis was used to estimate the noise in the image, and different filtering methods are applied to the image with different proportion noise, Image denoising effect has been improved, but for the image with low pollution degree, the denoising effect is general, and the detail recovery is not very good. In order to overcome the deficiency of the existing median filtering algorithm, after studying the existing median filtering method, this paper proposes an adaptive fan rotation median filtering method, which is used to restore the image polluted by salt and pepper noise, and retain the image details at the same time of removing noise. In the filtering process, first judged whether the center point is a noise point, then used a smaller filtering window (such as a window below 7×7) for the image part with a lower degree of pollution and a larger window (such as a window above 5×5) for the image part with a higher degree of pollution to realize automatic adjustment of the filtering window. At last, the difference value of the center point in different directions is calculated to evaluate the correlation according to the difference value, and the gray value of the highest correlation region is taken as output.

2. Standard median filtering

Median filtering, similar to convolution, is a neighborhood operation, but it does not calculate the weighted sum. Instead, it sorts the pixels in the neighborhood according to their gray values, and then selects the sorted median value as the gray value of the central pixel in the neighborhood for output.

Assume that the input image for I, the pixel matrix (height R, width C) wide, for image in any position (R, C), (0≤r<R, 0≤c<C), take (R, C) centered, width of W, high neighborhood for H, W and H are odd, pixel gray value of the neighboring domain to sort, then take the median, as the output image (R, C) location of grey value. Take image matrix

\[
\begin{bmatrix}
133 & 24 & 56 & 52 \\
145 & 149 & 254 & 103 \\
52 & 123 & 58 & 231 \\
231 & 240 & 33 & 42 \\
\end{bmatrix}
\]

for example, Take the 3×3 neighborhood with position (1,1) as the center, and sort the gray value of pixel points in the neighborhood from small to large:

\[
\begin{bmatrix}
24 & 52 & 56 & 58 & 123 & 133 & 145 & 149 & 254 \\
\end{bmatrix}
\]

It can be seen that 123 is the median of the gray values of this group, so the output image O(1,1)=123, and so on, the gray values of all pixels of the output image will be obtained.

3. Improved algorithm

Standard median filter denoised every pixel in the image after the filter window is selected. When the window center pixel is located in the edge details of the image, the median value is selected to replace the center point for output in a larger window range. When the value is close to the center pixel value, the image details are maintained well, and the image details are destroyed when the value is larger than the center pixel value. Because the median value is not regular in the window, the details of the image are inevitably destroyed, and whether it is a noise point is not judged, but each pixel is filtered, which also causes damage to the unpolluted part of the image. The filter window is smaller, the details are better, but the filter effect is worse for the image with higher density noise.

3.1. Principle

In order to overcome the defect of standard median filter, the filtering algorithm in this paper is proposed. When filtering the pixels in the window, the extreme value of the center pixel point is judged first. If the gray value of the center pixel point is the extreme value of the gray value in the window, then the center pixel point has been polluted and the filtering operation is required. If it is not
the extreme value, it means that the pixel point is not polluted, and then the output is carried out
directly. For the image area window with low pollution degree, it should be smaller. The small
window can retain more image details while de-noising and the computation is small. For the image
with higher pollution degree, the larger window should be selected. The larger window can filter out
more noise in the image. In this paper, the filter window adaptive method is used to remove salt and
pepper noise, and the filter is completed by changing the size of the window adaptively according to
the pollution degree in the window. The rotation rule of filtering sector of $5 \times 5$ window is shown in
Figure 1.

![Figure 1. 5×5 window rotation diagram](image)

In Figure 1, A, B, C, D, E, F, G and H are the eight difference points. During filtering, the extreme
value detection is carried out for all the difference points. Except for the central pixel point, if the
difference point is the extreme value of gray value in the window, the difference point is discarded,
and the other difference points are calculated for the difference value in the sector region, respectively.
The fan region with a small difference indicates a high correlation with the pixel value of the
unpolluted center. At this time, take d the median value of the fan region for output to complete the
filtering.

When the difference points in the window are all extreme values, it means that the pollution degree
is high at this time, and it is necessary to expand the window for filtering. Figure 2 shows the diagram
of sector rotation filtering after expanding the window.

![Figure 2. 7×7 window rotation diagram](image)

In Figure 2, I, J, K, L, M, N, P and Q are the difference points after the enlarged window. Used the
difference point after the extended window to repeat the small window filtering operation to complete
the filtering.

Set the gray value of the central pixel point $(x, y)$ as $f(x, y)$, then the $5\times 5$ sector rotating filtering
window can be represented as shown in Figure 3.
The formula for evaluating the difference of the eight difference points is shown in Equation 2.

\[
\begin{align*}
& a(x-1,y) = -f(x-1,y) - f(x-2,y) - f(x-1,y+1) \\
& b(x+1,y+1) = 2f(x+1,y+1) - f(x,y+1) - f(x+2,y+1) \\
& c(x+1,y) = 2f(x+1,y) - f(x,y) - f(x+2,y) \\
& d(x+1,y+1) = 2f(x+1,y+1) - f(x,y+1) - f(x+2,y+1) \\
& e(x+1,y) = 2f(x+1,y) - f(x,y) - f(x+2,y) \\
& f(x+1,y+1) = 2f(x+1,y+1) - f(x,y+1) - f(x+2,y+1) \\
& g(x,y+1) = 2f(x,y+1) - f(x+1,y) - f(x+2,y+1) \\
& h(x+1,y) = 2f(x+1,y) - f(x,y+1) - f(x+2,y+1) \\
\end{align*}
\]

Let \( u \) be the minimum value of absolute value in \( a(x-1,y), b(x-1,y+1), c(x,y+1), d(x+1,y+1), e(x+1,y), f(x+1,y+1), g(x,y+1), h(x,y-1) \), namely:

\[ u = \min \{ |a(x-1,y)|, |b(x-1,y+1)|, |c(x,y+1)|, |d(x+1,y+1)|, |e(x+1,y)|, |f(x+1,y+1)|, |g(x,y+1)|, |h(x+1,y)| \} \]

When there are more noise points in the sector, the gray difference of the sector must be larger, when there are few or no noise points in the sector, the gray difference of the sector must be small. When there is no noise in the sector region and it is in the grayscale flat region, the grayscale difference of this region must be very small, indicating that the correlation between the central noise point and this region is the highest. In this case, the median value of this sector region is taken instead of the grayscale value of the central noise point as output, which can better restore the image details.

### 3.2. Filtering steps

The median filter algorithm of adaptive sector rotation makes noise judgment first, then noise filtering. All steps of the algorithm are processed from high to low according to the priority of the processing scheme. If the current condition is satisfied, the current processing is performed to end the filtering of the current pixel, otherwise, the current step is directly skipped and the next processing is entered. The specific steps of the algorithm are as follows:

1. The center point of the filtering window is firstly tested for its extreme value. If the center point is not the extreme value of the pixel value in the window, the signal point directly outputs the pixel value of the center point. If the center point is the extreme value of the pixel in the window, step (2) is performed.
2. Take the center pixel point as the center and take the 5×5 window to perform sector rotation filtering.
3. If the eight difference points do not meet the filtering conditions, step (3) is performed.
4. At this time, it means that the image pollution is relatively serious, and filtering needs to be carried out by increasing the window.
5. If the difference point does not meet the filtering condition, then continue to increase the filtering window and repeat this step for filtering.
If it increases to the maximum window (above 11×11 window), it means that the pollution is very serious at this time, and the median value in the filtering window is directly calculated for output.

- Sum the output pixel points without filtering operation and the output pixel points after filtering operation so as to obtain a complete restored image.

The flow chart of median filtering for adaptive sector rotation is shown in Figure 4.

4. Experiments and results

The mean square error (MSE), peak signal-to-noise ratio (PSNR) and structural similarity (SSIM), three objective evaluation indexes, can effectively evaluate the filtering effect of the filtering algorithm. By calculation, the smaller the mean square error is, the better the filtering denoising effect will be. The larger the PSNR is, the better the image detail recovery will be. The structural similarity value is [0,1], and the better the image recovery degree is, the closer it is to 1. The formulas of mean square error, peak signal-to-noise ratio and structural similarity are as follows:

\[
MSE = \frac{\sum_{x=0}^{M-1} \sum_{y=0}^{N-1} (f^*(x, y) - f(x, y))^2}{M \times N}
\]

\[
PSNR = 10 \cdot \log_{10} \left( \frac{255^2}{\frac{\sum_{x=0}^{M-1} \sum_{y=0}^{N-1} (f^*(x, y) - f(x, y))^2}{M \times N}} \right)
\]

\[
SSIM(f^*, f) = \frac{(2\mu_{f^*}\mu_f + c_1)(\sigma_{f^*f} + c_2)}{((\mu^2_{f^*} + \mu^2_f + c_1)(\sigma^2_{f^*} + \sigma^2_f + c_2))}
\]

where \( f \) represents the original image, \( f^* \) represents the restored image, \( \mu_{f^*} \) and \( \mu_f \) represents the mean value of \( f \) and \( f^* \) respectively, \( \sigma_{f^*} \) and \( \sigma_f \) represents the standard deviation of \( f \) and \( f^* \), respectively, \( \sigma_{f^*f} \) represents the covariance of \( f \) and \( f^* \), \( c_1, c_2 \) and \( c_3 \) are constants.
In order to prove the superiority of this algorithm, in this paper, after adding different concentrations of pepper and salt noise to the original images in Figure 5 and Figure 6, respectively, comparison was made between the standard median filtering 3×3 window (SMF(3×3)), the standard median filtering 5×5 window (SMF(5×5)), and the switching median filtering algorithm and the proposed algorithm. Figure 7 and Figure 8 show the simulation results of standard median filter and switching median filter and the method presented in this paper.

Figure 5. Original image

Figure 6. Original image

Figure 7. Experimental simulation results of the original Figure 5
Figure 8. Experimental simulation results of the original Figure 6

It can be seen from the experimental results in Figure 7 and Figure 8 that SMF (3×3) has a better denoising effect when the pollution degree is 10% and 20%, and SMF (5×5) has a better denoising effect when the pollution degree is 30% and 40%. When the pollution degree of switch median filter is 10%, 20%, 30% and 40%, good denoising effect is achieved, but the detail recovery is poor. The proposed method achieves good denoising effect and detail recovery effect when the pollution degree is 10%, 20%, 30% and 40%.

Figure 9 and Figure 10 are simulation results of mean square error (MSE), peak signal-to-noise ratio (PSNR), and structural similarity (SSIM) after adding 10%, 20%, 30%, and 40% salt and pepper noise in Figure 5 and Figure 6, respectively, after filtering by traditional median filtering method, switching median filtering method and filtering method of this paper.
When the noise intensity is 10%, 20%, 30% and 40% respectively, it can be seen from the experimental simulation results in Figure 9 (a) and Figure 10 (a) that the mean square error obtained by the proposed algorithm is smaller than that obtained by the other three methods, it can be seen from Figure 9 (b) and Figure 10 (b) that the PSNR value of this method is higher than that of the other three methods, it can be seen from Figure 9 (c) and Figure 10 (c) that the structural similarity between the
results filtered by the proposed method and the original image reaches more than 99%, indicating that the image filtered by the proposed method is most similar to the original image and the degree of image detail recovery is higher than the other three methods. Since the difference values of eight central noise points in different directions were obtained during the filtering of the proposed algorithm to evaluate the gray value differences of eight different areas and unpolluted center points, the median value of the minimum difference region was taken instead of the central noise point for output, Figure 9 (b) and Figure 10 (b) show that the proposed method can filter out salt-and-pepper noise and at the same time restore image details to the maximum extent. Experimental results show that the filtering effect of this method is better than the other three methods when the noise intensity is greater than 40%.

5. Conclusions
By analyzing the shortcomings of different median filtering methods in image denoising, based on the standard median filtering, an adaptive fan rotating filtering method is proposed to denoise the image and restore the image details at the same time. The filtering is completed by calculating the difference value in different directions in the filtering window and looking for the gray median value of the region of the highest correlation with the noise filtering point. Experiments show that this algorithm is superior to standard median filtering and switching median filtering, and the image achieves better noise removal effect, with small mean square error and high structure similarity, and at the same time, recovers the image details to a great extent, and has a high peak signal-to-noise ratio.

6. Reference
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