映像復原을 위한 變形된 適應 스위칭 메디안 필터

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A Modified Adaptive Switching Median Filter for Image Restoration

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요 약

본 논문에서는 임펄스 잡음검출과 필터링을 기반으로 하는 변형된 적응 스위칭 메디안 필터 알고리즘을 제안하였다. 임펄스 잡음검출 과정에서는 마스크 내의 화소값의 차에 의해 설정된 임계값을 사용하며, 이때 잡음으로 판단된 화소들에 대하여 필터링 과정을 수행한다. 제안한 필터링 방법은 국부 잡음밀도에 상응하여 마스크 크기를 가변하며, 필터링을 반복 수행한다. 그리고 제안한 방법의 시뮬레이션을 위해, 다양한 밀도의 임펄스 잡음을 원영상에 중첩하여 테스트 영상으로 사용하였으며, 기존의 방법과 비교하였다. 또한 평가를 위한 기준으로 PSNR을 적용하였으며, 시뮬레이션 결과에서 제안한 알고리즘은 우수한 성능을 나타내었다.

ABSTRACT

A modified adaptive switching median filter for impulse noise removal, which has the noise detection step and the noise filtering step, is proposed in this paper. In the noise detection step, we use the detection threshold which is earned by calculating the intensity differences between pixels nearby with each other in localized window, to determine whether the pixels in the image are noise or not. Then in the noise filtering step, we will only remove the corrupted pixels and remain the good pixels. By the noise detection result, we can easily get the local noise density of the image, and use it to consider the filtering mask size and the times of filtering iteration according to different localized noise corruptions. For getting the simulation result, we compared the proposed method to conventional median filters with several test images corrupted by various impulse noise densities. We also use the peak signal-to-noise ratio (PSNR) to evaluate restoration performance, the simulation results demonstrate that the proposed method shows better results than other median-based type filters.

키워드

impulse noise, median filter, noise detector, image restoration

Ⅰ. Introduction

For the extension of multimedia technology in recent years, digital image processing has been greatly progressed besides the development of interrelated theories and researches. Data transformation from analog to digital is very important, and digital images are often corrupted by impulse noise during image acquisition or transmission. A large number of algorithms have been proposed to remove impulse noise while preserving image details. One of the most popular nonlinear filter is the standard median (SM) filter, which exploits the rank-order information of pixel

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intensities within a filtering window and replaces the center pixel with the median value [1]. Due to its effectiveness in image restoration and simplicity in implementation, various modifications of the SM filter have been introduced [2]-[6].

Nevertheless, for those modified median filters are implemented uniformly across the image, they also tend to modify undisturbed good pixels. The so-called adaptive switching median filter, which has the noise detection step before the noise filtering step, was developed and the detection results are used to determine whether a pixel should be modified [7]-[11]. Though having variable window size for removal of impulse noise, the adaptive switching median filter also has a weakness for ignoring the local area situation in determination of the mask size [12]-[16].

A modified adaptive switching median filter, which is based on two main steps, is proposed in this paper to overcome the disadvantage. First, an impulse detection step is used to determine whether the current pixel is corrupted or not, by classifying the intensity difference between each pair of adjacent pixels in localized window. Then, only the corrupted pixels are removed by adaptive median filtering, and the mask size and the number of filtering iteration are variable with the local noise density. We used several test images which are corrupted with various noise densities in simulation, and also used peak signal-to-noise ratio (PSNR) to evaluate restoration performance.

Ⅱ. Adaptive switching median filter

2.1. Noise detection step

The impulse noise mainly has salt-and-pepper noise and random valued noise. The noise model used in this paper is 8 bits salt-and-pepper noise from 0 to 255, which is mathematically expressed as equation (1).

$$x_{i,j}=\begin{cases} 0 & \text{with probability} \quad p \\ 255 & \text{with probability} \quad p \\ \psi_{i,j} & \text{with probability} \quad 1-2p \end{cases} \qquad (1)$$

where $x_{i,j}$, p, $\psi_{i,j}$ are denoted as the values of current pixel value, the probability of the noise, and the uncorrupted pixel values respectively. And the set of the pixels within the mask is represented as $\Omega_{i,j}^{W}$ in equation (2).

$$\Omega_{i,j}^{W}=\left\{ i,j \left| \begin{array}{l} i-(W-1)/2\le i\le i+(W-1)/2, \\ j-(W-1)/2\le j\le j+(W-1)/2 \end{array}\right.\right\} \qquad (2)$$

W is an odd integer not smaller than 3 in the mask size $W\times W$. To make the pixels in the mask in an ascending order, which denotes as equation (3).

$$\hat{x}_k=\{X[1],X[2],\cdots,X[N]\},(N=W\times W) \qquad (3)$$

The median value in value sequence $\hat{x}_k$ is represented as $m_{i,j}$ in equation (4), and the intensity difference between each pair of adjacent pixels in $\hat{x}_k$ is denoted as equation (5).

$$m_{i,j}=Med\{\hat{x}_k \mid k\in\Omega_{i,j}\},(X[1]<m_{i,j}<X[N]) \qquad (4)$$

$$D[n]=X[n+1]-X[n],(1\le n\le N-1) \qquad (5)$$

Dividing by the median value as in following equation (6), b_1, b_2 are identified for the boundaries by finding the maximum intensity differences in two clusters which are divided by median value. b_1 is the maximum difference between min value to median value, besides b_2 is the maximum difference between median value to max value.

$$\begin{array}{l} b_1=Max\{D[\cdot] \mid X[1]\le X[\cdot]\le X[(N+1)/2]\} \\ b_2=Max\{D[\cdot] \mid X[(N+1)/2]\le X[\cdot]\le X[N]\} \end{array} \qquad (6)$$

If the current pixel belongs to the cluster $b_1 \le x_{i,j} < b_2$, it would be classified as uncorrupted pixel. Otherwise, it would be considered as noise, when it belongs in either of these two clusters $0\le x_{i,j} < b_1$ or $b_2 \le x_{i,j} \le 255$. And the output value $f_{i,j}$ of noise detection is denoted as equation (7), after the noise detection procedure. The logic value sequence, $f_{i,j}=1$ means the current pixel is a noise and $f_{i,j}=0$ means it is a good pixel.

$$f_{i,j}=\begin{cases}0, & \text{if } b_1 \le x_{i,j} < b_2 \\ 1, & \text{otherwise}\end{cases} \tag{7}$$

2.2. Noise filtering step

Using the noise detection result, only those pixels identified as corrupted pixels would be removed by the filtering step, and it can be expressed as equation (8).

$$y_{i,j}=\begin{cases}m_{i,j}, & \text{if } f_{i,j}=1; M>(W_F\times W_F)/2 \\ y_{i,j}, & \text{otherwise}\end{cases} \tag{8}$$

In equation (8), $y_{i,j}^{(n)}$ is considered as filtering result value, $m_{i,j}$ means the median value, $W_F\times W_F$ is denoted as the filtering mask size, and the M means the number of good pixels in the filtering mask. The median value here is selected from only good pixels when the center pixel is considered as noise. And the median value would replace the noise when the number M is larger than half number of pixel in the mask, the mask size will be increased until it belongs to the condition. However, the considering of the mask size in conventional adaptive switching median filter is fixed by threshold value $TH=50\%$, the removement of the corrupted pixels would contaminate a great many image details.

Ⅲ. The proposed algorithm

The modified adaptive switching median filter, which is proposed in this paper, is based on two main steps. We used the conventional algorithm as the impulse detection step in [14], by classifying the intensity difference between each pair of adjacent pixels in localized window. Then, we use the noise detection result to take the noise filtering step.

The proposed filtering algorithm, which is different from the conventional algorithms, changed the mask size adaptively for representing the image local situations, and took the filtering iteration for removing noise effectively. It calculates the local noise densities under the filtering mask, and the mask size will be increased according to whether the calculation result is over or less than the threshold value $P_{TH(W_F\times W_F)}$.

At first, using the noise detection result, only corrupted pixels will be taken the median filtering method. The typical mask size for filtering is 3×3, and will cover the current pixel in the center of mask. Then calculate the local noise density p in the 3×3 mask, if p is less than $P_{TH(3\times3)}$. We will figure out the median value, which is only chosen from good pixels in the mask, to replace the noise. Furthermore, if p is larger than $P_{TH(3\times3)}$, the mask size will be increased to 5×5. Then calculate the noise density p in the new mask size again, and take the median filtering step when p is less than $P_{TH(5\times5)}$. So if p for 5×5 mask size is still larger than $P_{TH(5\times5)}$, the pixel will be remained for next filtering iteration, which means the filtering mask will move to next pixel.

Taking the median filtering to corrupted pixels from beginning to the end, the pixels which replace by median value would be considered as good pixel, and regulate the noise detection logic values with those information. The advantage in this way is that those corrupted pixels which had not removed for the high local noise density would have another chance. Then the median filtering step will iterate again same as the first time. After second median filtering, if there still have pixels which have not remained, then all of them will have to replace by median value in 7×7 mask size.

The proposed method for the noise filtering step, which has iteration execution, generates a pixel value sequence $\{y_{i,j}^{(0)}, y_{i,j}^{(1)}, \cdots, y_{i,j}^{(n)}\}$ and a logic value sequence $\{h_{i,j}^{(0)}, h_{i,j}^{(1)}, \cdots, h_{i,j}^{(n)}\}$. We use $y_{i,j}^{(0)}$ to denote the pixel value at position (i,j) in the noisy image to be filtered and use $y_{i,j}^{(n)}$ to represent the pixel value after the n th $(n \le 3)$ iteration. Besides, the value $h_{i,j}^{(n)}=0$ means the current pixel is a good pixel, and $h_{i,j}^{(n)}=1$ means it is a noise that should be filtered. And the noise detection result, $f_{i,j}$ is taken to be the input value of noise filtering step as $h_{i,j}^{(0)} = f_{i,j}$. The relationship between $(n-1)$th and nth logic value can be denoted as equation (9).

$$h_{i,j}^{(n)} = \begin{cases} h_{i,j}^{(n-1)}, & \text{if } y_{i,j}^{(n)} = y_{i,j}^{(n-1)} \\ 0, & \text{if } y_{i,j}^{(n)} = m_{i,j}^{(n-1)} \end{cases} \tag{9}$$

From the equation, the logic value of the pixels, which have not be considered as noise or not fit for the filtering condition, will remain as before. On the other hand, the logic value of removal pixels will be changed from noise to good pixels.

In the nth iteration, for each pixel value $y_{i,j}^{(n-1)}$, we first find its median value $m_{i,j}^{(n-1)}$ of a $W_F \times W_F$ window centered about it. The median value here is only selected from good pixels with $h_{i,j}^{(n-1)} = 0$ in the window. Depending on the M is an odd number or an even number, the $m_{i,j}^{(n-1)}$ can be respectively denoted as equation (10) or equation (11) as follows.

$$m_{i,j}^{(n-1)} = Med\left\{ y_{s,t}^{(n-1)} \mid h_{s,t}^{(n-1)} = 0, (s,t) \in \Omega_{i,j}^{W_F} \right\} \tag{10}$$

$$m_{i,j}^{(n-1)} = \left(Med_L\left\{ y_{s,t}^{(n-1)} \mid h_{s,t}^{(n-1)} = 0, (s,t) \in \Omega_{i,j}^{W_F} \right\} + Med_R\left\{ y_{s,t}^{(n-1)} \mid h_{s,t}^{(n-1)} = 0, (s,t) \in \Omega_{i,j}^{W_F} \right\} \right) / 2 \tag{11}$$

From above, the boundary of s and t, which can be denoted as $\{i-(W_F-1)/2 \le s \le i+(W_F-1)/2\}$, and $\{j-(W_F-1)/2 \le t \le j+(W_F-1)/2\}$. Where $Med_L\{\cdot\}$ is the $(M/2)$th largest value and $Med_R\{\cdot\}$ is the $(M/2+1)$th largest value of the sorted data. The value of $y_{i,j}^{(n)}$ is modified only when the pixel (i,j) is considered as a noise in equation (12). And the block diagram of the proposed noise filtering step is determined as figure 1.

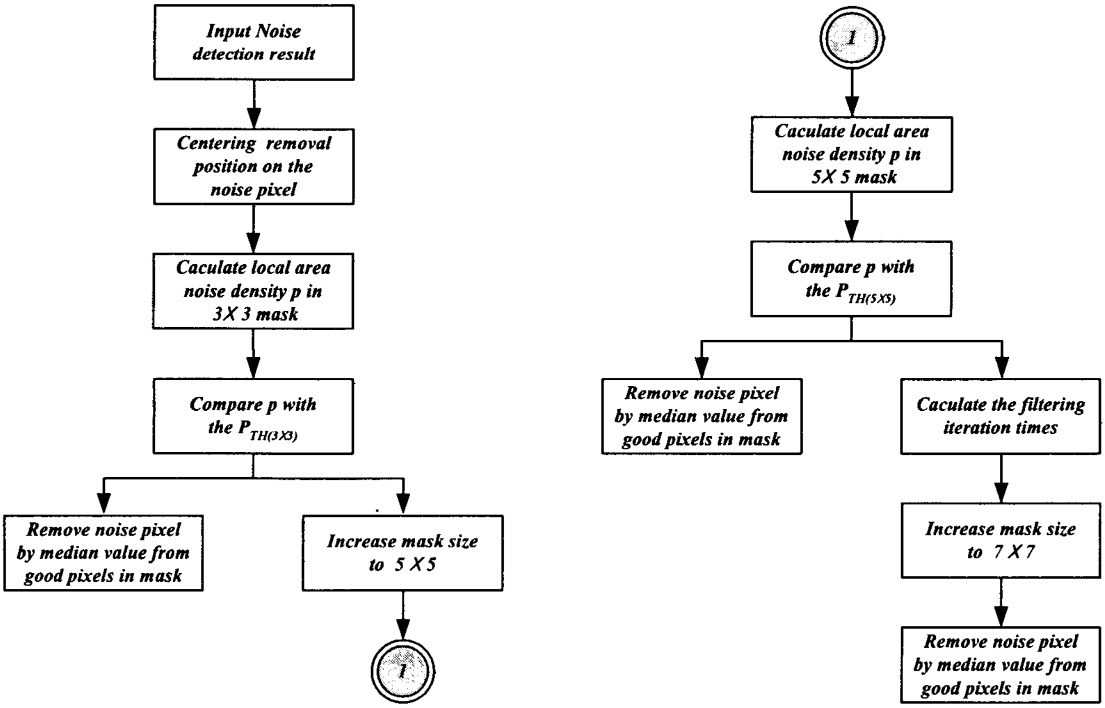


Fig. 1. Block diagram of proposed algorithm.

$$y_{i,j}^{(n)} = \begin{cases} m_{i,j}^{(n-1)}, \text{if } h_{i,j}^{(n-1)} = 1; p < P_{TH(W_F \times W_F)} \\ y_{i,j}^{(n-1)} \text{ ,otherwise} \end{cases} \quad (12)$$

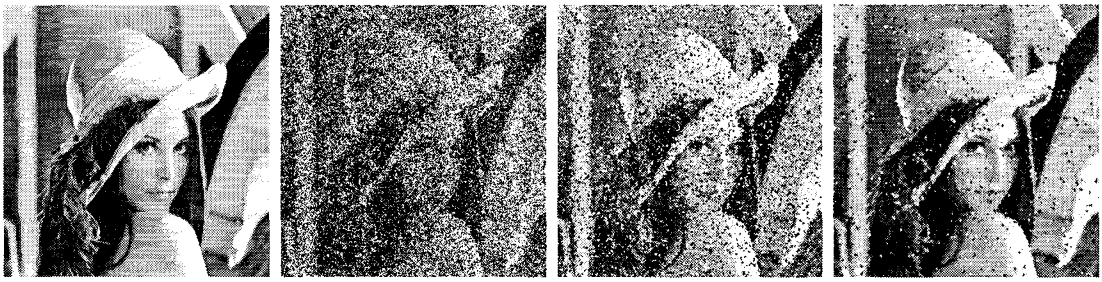
Ⅳ. Simulation results

For the simulation with the modified switching median filter proposed in this paper, we corrupted various density of salt-and-pepper noise to several 512 × 512 images. We took the restoration results from different filtering methods, and provided the PSNR to evaluate restoration performance. We have found through experimentation that good initial values of $P_{TH(3\times 3)} = 33.3\%$. Experimental results have shown that the $P_{TH(5\times 5)}$ for most images is around 40%, for the values of the threshold to $P_{TH(W_F \times W_F)}$. It clearly showed that the proposed $P_{TH(W_F \times W_F)}$ represents a better preservation of edge details than other threshold values.

Figure 2 shows the simulation results of the proposed algorithm and conventional median-type filters with the original "Lena" image corrupted with salt-and-pepper noise, (a) is the orignal image, and (b) is the noisy image corrupted with 60% impulse noise. Furthermore (c), (d), (e), (f), (g), and (h) are the noise removal results of SM filter with window size 3 × 3, center weighted median (CWM) filter with window size 5 × 5 and a center weight value of 3, iterative median (IM) filter with 3 × 3 and 8 iteration, adaptive median (AM) filter with the window size from 3 × 3 to 7 × 7, adaptive switching median (ASM) filter with the window size from 3 × 3 to 7 × 7, and the proposed method also with the size from 3 × 3 to 7 × 7.

The figure 3 and figure 4 provide the PSNR performance where the original test image "Lena" and "Peppers" are corrupted with different noise densities. The figures demonstrate that the proposed algorithm shows better PSNR performance than conventional methods in any noise density.

Moreover the table 1 and table 2 show the simulation results of four test images with PSNR, which include the proposed method and other median-type methods, with the noise density in 30% and 60% for "Lena", "Boat", "Baboon", and "Peppers" image. The proposed method showed a better performance than others.



(a) Original Image (b) Noisy Image (c) SM (d) CWM

(e) IM (f) AM (g) ASM (h) Proposed Method

Fig. 2. Restoration results (impulse noise p=60%).

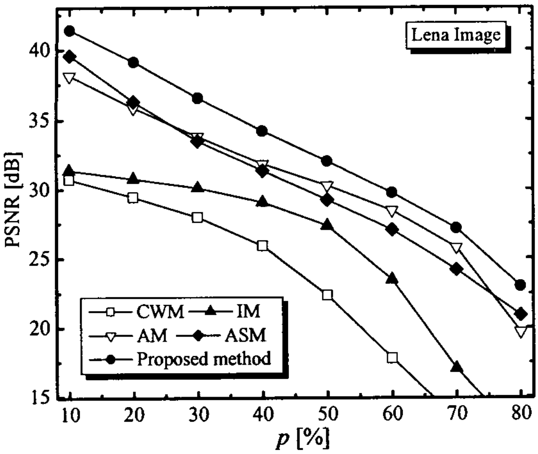


Fig. 3. PSNR with variation of noise density.

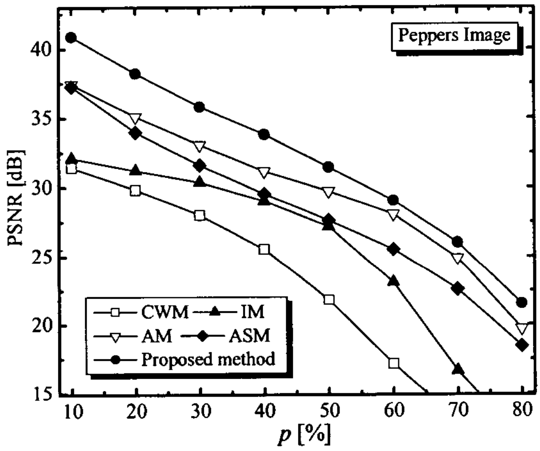


Fig. 4. PSNR with variation of noise density.

Table 1. PSNR with various test images (p=30%)

Image	PSNR [dB]			
Method	Lena	Boat	Baboon	Peppers
Before Restoration	10.64	10.68	10.80	10.81
CWM	27.99	25.53	21.21	28.01
IM	30.10	26.63	21.36	30.36
AM	33.83	30.25	24.77	33.07
ASM	33.53	29.00	23.61	31.38
Proposed	36.57	31.94	26.77	35.83

Table 2. PSNR with various test images (p=60%)

Image	PSNR [dB]			
Method	Lena	Boat	Baboon	Peppers
Before Restoration	7.67	7.69	7.78	7.78
CWM	17.78	17.32	16.00	17.14
IM	23.46	21.98	19.10	23.06
AM	28.44	25.67	21.13	28.05
ASM	27.06	23.83	20.92	25.53
Proposed	29.72	26.70	22.55	29.02

V. Conclusion

A modified adaptive switching median filter, based on impulse noise detection and noise filtering has been proposed in this paper.

In the noise detection algorithm, it classifies the pixels of a localized window, centering on the current pixel, in an ascending order, then uses the median value to divide the pixels into two groups, then classifies by the intensity difference among adjacent pixels. Only corrupted pixels are taken with adaptive median filtering, the mask size is changable by the local noise density in the filtering mask comparing with the threshold value to the mask. And we only use the good pixels in the mask to take the median value, and iteration way would make sure that all noise would be removed.

Simulation results demonstrate that the proposed algorithm preserved image details like edge details, and showed better PSNR results. Consequently, the proposed method would be widely used in the image recognition and image restoration.

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