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An Improved Adaptive Median Filter for Image Denoising

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Abstract—In this paper, we proposed a new adaptive median filter for image denoising. In our method, two thresholds have been involved for detecting noises in variable-sized windows. The median filter and the mean filter are combined for changing the value of the corrupted pixels. The filter can preserve the fine details of image while suppressing the impulsive-type noise. The results of the experiments proved that our method is better than the traditional median filters.

Keywords-Salt & pepper noise, adaptive median filter, standard median filter, extreme median filter

1. Introduction

Images are always easily corrupted by positive or negative impulses, which are caused by noisy channels while information transmitting. Impulse noise is a common kind of noise in electronic communication. It changes some bits or pixels of an image, for example, turning the white spot into black or black into white. The most common type of such noise is the salt-and-pepper noise. It is important to remove it in many image processing applications.

The linear filter can remove the impulse noise, but it also smoothes the sharp edges. One-dimensional (1-D) median filter is a typical representation of the linear filter. In [1], the 1-D schema performs poorly for mixed impulse noise[1]. The non-linear filter makes a breakthrough of the linear filter. It can decrease the blur of image while removing the noise. The two-dimensional (2-D) median filter (the following median filter mentioned in this paper means 2-D median filter) has been popular in removing impulse noise for a long time. Although, it still has some drawbacks. The result of the filter depends on the window size. It can not remove the noise while the window size is too small, and blur the original image while the window size is too big. Nowadays, many researches have been done to improve the performance of median filter, such as the median filter in [2], the mix-max median filter[7], the weighted median filter[3][4], the center weighted median filter[11], the tri-state median filter[5], and the adaptive soft-switching median filter[6]. Those researches have made a great contribution to image denoising. In the following section, we shall first give an introduction to the former median filters, and then proposes a new adaptive filter for eliminating the impulse noises.

In Section II, we shall introduce the standard median filters and the mean filter[9]. The theme of the new algorithm will be depicted in Section III. The simulation results will be given in Section IV. And in Section V, there is a conclusion

2. A review of median filters

2.1 The standard median filter

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The standard median(SM) filter is simple and efficient in removing the impulse noise. It has been very popular for decades. In this method, there is a square window for filtering, and the window size is variable. The center pixel in the window is the one to be de-noised. Its gray value will be changed into the value of the standard median value of the square window which has been sorted.

2.2 The mean filter

The mean filter proposed in [9] is a new type of filter. The main difference between median filter and mean filter is that it uses the mean value for replacing the center pixel which is to be filtered. There are three steps of this method. Firstly, creating a given size $N*N$ (e.g. N=3) window, supposing $I'(i,j)$ is the center of the window (Figure1). Sum all the pixels in the square window, recorded as S. $S=\sum_{i=1}^{n}\sum_{j=1}^{n} I'(i,j)$. Secondly, detecting the maximum and the minimum pixel value in this window, subtracting the value of those pixels from S, recorded as S'. At the same time, the number of the rest pixels in the window is marked as x. Computing the mean value with the equation: $M = S'/x$. In the third step, replacing the value of $I'(i,j)$ with M.

$$\begin{matrix} (i-1,j+1) & (i,j+1) & (i+1,j+1) \\ (i-1,j) & (i,j) & (i+1,j) \\ (i-1,j-1) & (i,j-1) & (i+1,j-1) \end{matrix}$$

Fig.1. 3*3 window

As we saw, the median filter and the mean filter change all of the pixels, no matter it is a noise spot or a signal spot. It is inevitable to smooth the sharp edges, and add the calculated amount. So the new algorithm proposed in this paper will firstly separate the probable noise spots from the signal spots. The same work has been done in [10]. In [10], the paper supposes that the spot is pepper noise when the gray value equals to 0, and salt noise when the gray value equals to 255. In this paper, considering the error scope, we suppose the pixel value ranging from 0 to 5 be the pepper noise, 250 to 255 be the salt noise. The two intervals are: [0,5] and [250,255]. It means that the pixel value falls in these two intervals will be treated as the probable noise. In the processing phase, the filter will just process those pixels, without processing all of the pixels in the image.

Also the proposed algorithm takes two variable thresholds, T_1 and T_2. T_1 and T_2 are adaptive selected from 0 to 255. In the processing phase, T_1 and T_2 will separate the pixels with different gray value into three different processing states. In brief, our paper uses two noise intervals for detecting probable noise spots firstly. And then takes two thresholds T_1 and T_2 to check whether it is a real noise spot or not in the detecting phase, and determine which state the pixels should belong to. Finally, in the processing phase, the mean filter and median filter will be combined together to process the different state of the pixels processed by T_1 and T_2.

3. The proposed schema

The first step is detecting the noisy spot of the image. In order to avoid the error of detecting noise, the new filter involves two noise intervals: x_1[0,5] and x_2[250,255]. x_1 indicates the probable pepper noise, while x_2 indicates the probable salt noise. All of the probable noise spots will be collected in set N. In the second step, the new filter in this paper has to check whether the spot in N is a real noise spot or not. The new filter uses adaptive window with variable size for the sake of avoiding the error of the estimation of the noise spot. The minimum window size and the maximum window size are marked as Wmin and Wmax respectively. Here, Wmin=3, and Wmax=7. According to the correlation of the pixels in the neighborhood[12], the pixel in the Wmin might be detected as a noisy spot, but when enlarging the window, it can be a signal spot.

113	113	114	114		113	113	114	114
113	255	255	114		113	255	255	255
157	255	255	114		157	255	255	255
157	156	150	150		157	156	255	255
	(a)					(b)		

Fig.2. Distribution of gray value of an image

In Figure2, (a) shows us that the gray value of the center pixel has a great difference from the neighboring pixels in the window 3*3. The same situation can be found in (b), but when the window size becomes 5*5 in (b), the center pixel correlates the neighborhood closely, which is not in (a). And we can say that it is a noise spot in (a), but a signal spot in (b). So it is necessary to check the noise spot in an iterative method with variable window size.

In this paper, the new filter combines the median filter and the mean filter. After doing some research of the former filters, we find that using the median value or the mean value to change the pixel value which is to be de-noised may bring some error. So in order to avoid this problem, we use $(mean+med)/2$ to change the original pixel value.

Suppose *f(i,j)* is the original image, *f'(i,j)* is the corrupted image, *I'(i,j)* is the pixel to be filtered, *H(i,j)* is the output value of *I'(i,j)*. *Wcurrent* stands for the current window size. *W*max *is the maximum of the window, and W*min *is the minimum of the window*. *Wcurrent* starts with *W*min. The process of the filter is as follows:

(1) Creating two intervals for detecting noise pixels: x_1[0,5] and x_2[250,255]. x_1 for the pepper noise, x_2 for the salt noise. *N* is the set recording those noise pixels.
(2) Choosing a pixel *I'(i,j)* from *N*. Creating a window centered with *I'(i,j)* in *f'(i,j)*. The window size starts with *W*min.
(3) Computing the mean value in the window with the current window size, marked as *mean*. The method how to compute *mean* has been introduced in Section II. $d=|mean-I'(i,j)|$. If $d<T_1$, $H(i,j)=I'(i,j)$; If $d \ge T_1$, go to Step(4).
(4) Enlarging the size of *Wcurrent*. If $Wcurrent < W\max$, go to Step(3); If $Wcurrent = W\max$, go to Step(5).
(5) Computing the median value of the current window, recording it as *med*. $med = median(Wcurrent)$. Outputting the value of *H(i,j)* according to the following equation:

$$H(i,j)=\begin{cases} I'(i,j) & d<T_1 \\ (med+mean)/2 & T_1 \le d \le T_2 \\ med & d>T_2 \end{cases} \tag{1}$$

4. Experiments

The simulation experiments in this paper work on the MATLAB7.0. The first experiment we have to do is to determine the value of T_1 and T_2. We take image *Lena* as an example. Because there are two thresholds: T_1 for the lower bound, T_2 for the upper bound ($T_2 > T_1$). In [5], it suggests MSE as a well-established criterion for testing the thresholds. And we still use it in our paper. Because there are two thresholds, we firstly use $\Delta T = T_2 - T_1$ to test the relationship between MSE and ΔT . And secondly, according to the best value of ΔT , we adaptive choose the value of T_1 and T_2. Figure3 shows the relationship between MSE and ΔT .

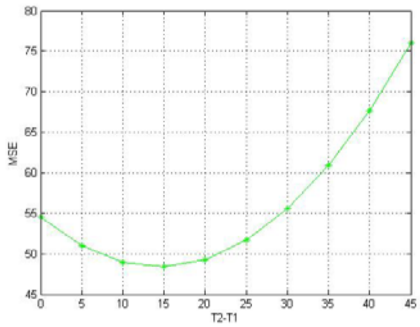

Fig.3. MSE value with different value of ΔT (Image: 168*184 Lena; Noise Ratio: 20%;)

Through the above figure, the value of ΔT shall be 15. And now ΔT has been ascertained, it becomes easier to determine the value of T_1 and T_2. Any one of them can ascertain another. Here we choose T_1 to do the experiments. T_1 sets to be zero at first, and then increases 5 each time. The result is displayed in Figure4.

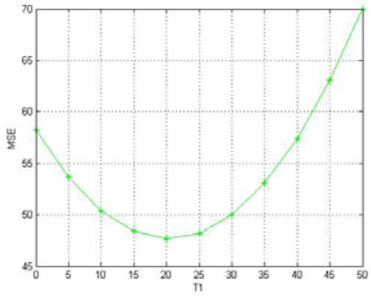

Fig.4. MSE value with different value of T1 (Image: 168*184 Lena; Noise Ratio: 20%;)

The experiments show that T1 shall be set to 20. T2 shall be set to 35. By now the thresholds have been established. The next experiment is to evaluate the performance of our filter. PSNR (Peak Signal to Noise Ratio) is always taken as the criterion for evaluating the performance of image filters. We also adopt it in our paper. Suppose *f(i,j)* is the original image, *f'(i,j)* is the corrupted image, *g(i,j)* is the de-noised image. The definition of PSNR is:

$$PSNR = 10 \times \lg \frac{255^2}{\frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}[f(i,j)-g(i,j)]^2} \tag{2}$$

In [8], it has made a comparison of the performance of different filters. So we just make a comparison of our filter to the standard median (SM) filter and the extremum median(EM) filter in [10], and the filter in [13]. The results have been shown in Tab.1. The experiment takes the *Baboon* image because it has lots of detail information, which can show the good performance of our filter for preserving the fine details of the image while removing the noise at the same time. *Tab.1* gives the quantitative analysis, and Figure5 shows the qualitative analysis.

TABLE I COMPARISON BETWEEN OUR FILTER AND THE OTHERS

	χ =0.1	χ =0.2	χ =0.3	χ =0.4	χ =0.5
SM	33.79	29.34	23.83	19.22	15.34
Method in [13]	35.55	30.48	25.61	21.38	17.49
EM	38.77	32.01	26.25	22.99	19.91
Our filter	39.13	32.37	30.07	28.36	26.61

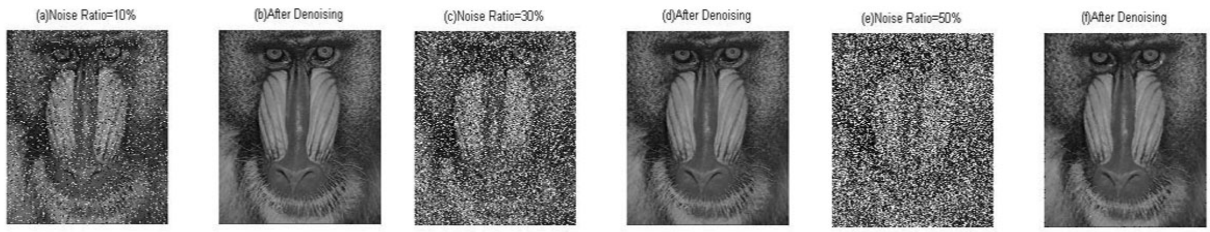

Fig.5 Experiment results of test image baboon

5. Conclusions

In this paper, we have introduced a new filter for removing impulse noise. Through the comparison of our filter to the standard median filter, the extreme median filter in [10], the filter in [13], it proved that our algorithm can remove the pepper & salt noise very well.

We have also introduced some other median filters, our method is also based on the median filter. But the experiments show that our algorithm has a high performance on preserving the details of the image, while other methods are not.

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