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An Improvement Method of PAV Filters for the Removal of Impulse Noise from Highly Corrupted Images

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Abstract– This paper proposes an improvement method for Peak-and-Valley (PAV) filters for the impulse noise reduction. The PAV filter has no parameter and the good performance for a low corrupted image. However the performance for a highly corrupted image is unsatisfactory. In this paper, the processing directions of the PAV filter are reconsidered for the improvement of the noise reduction performance for the highly corrupted image. The proposed method has no parameter to be adjusted and less processing time than that of progressive switching median (PSM) filters. Simulation results show almost the same performance with the PSM filters.

1. Introduction

Several elegant and powerful nonlinear filters for the removal of impulse noise have been proposed [1], [2]. These filters usually require some parameters to be adjusted. The parameters have been used for improving the noise reduction and/or the edge and detail preservation. They play an important roll for the filter performance; however it is difficult to adjust them to various images because of their sensitiveness.

Switching median (SM) filters and progressive switching median (PSM) filters [3] are families of nonlinear filters. The parameters which are included in them are used for the selection of the degraded pixel or the undegraded one. Only the degraded pixels are filtered. This selection can greatly contribute to the improvement of the detail preservation in the corrupted image. However the difficulty of the adjustment is also same.

Peak-and-valley (PAV) filters [4] which have no parameters to be adjusted have been proposed. The PAV filters also process only degraded pixels and have the good noise reduction performance and high speed processing capability. However for highly corrupted images, their performance becomes poor.

This paper proposes a new nonlinear filter for reduction of impulse noise. The proposed filter is based on the PAV filters and only the degraded pixels are removed. For the crowded noise, the filtering from several predefined directions is applied and the proposed filter can reduce the noise in the highly corrupted image. As a result, an effective impulse noise reduction filter with no parameters for the highly corrupted image can be implemented. Simulation results show the good performance of the proposed filter for the corrupted images by the impulse noise with several probabilities.

2. Peak-and-Valley (PAV) Filters

In this section, the peak-and valley filter [4] is described. The reduction of impulse noise by the median filter shows the good performance, however it processes all the pixels in the image, not only the degraded pixels but also the undegraded pixels. This causes degradation of the processed image quality. To avoid this problem, several nonlinear filters have been proposed. The PAV filter is also this kind of filters.

This filter replaces positive impulse noise having near maximum intensity with a pixel value in the neighborhood by “cutting” operation and negative one by “filling” operation. These operations can prevent the degradation of edges because of its characteristics in which these one replace the processing point with the maximum or minimum values in the neighborhood. This is similar to one of the median filter. Therefore the PAV filter satisfies the major characteristics of the impulse noise reduction filters.

This filter judges whether the processing point is the impulse noise or not and according to this decision, only the degraded pixels are filtered. In this filter, degradation by filtering is prevented because of no processing for undegraded pixels. For the impulse noise with high probability, the repetition of filtering can reduce it. Since only degraded pixels are processed, the high speed processing may be expected.

2.1. Cutting Operations and Filling Operations

The denoising procedure of the PAV filters becomes from "cutting" and "filling" operations. Figures 1 and 2 show these operations, respectively. These figures show the line of three pixels and the height of each pixel means its magnitude. Figure 1 shows the cutting operation and the center pixel indicates the processing point. The cutting operation replaces the value of the processing point to the maximum one in the neighbor pixels of both sides, if the value of the processing point is greater than one of the neighbor pixels in both sides. As shown in Fig. 2, the "filling" operation replaces the value of the processing

point to the minimum one, if the value of the processing point is less than one of the neighbor pixels.

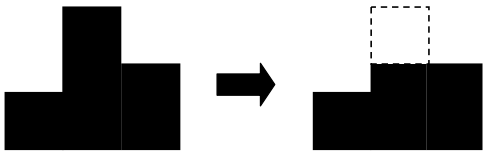

Fig. 1 “Cutting” operation.

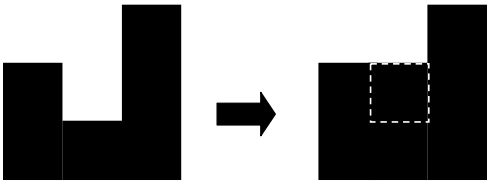

Fig. 2 “Filling” operation.

2.2. “Cutting-otherwise-filling” Condition

In one-dimensional PAV filter, the processing procedure by the “cutting-otherwise-filling” condition is described as

$$y(n)=\begin{cases}\max(x(n-1),x(n+1)), \\ \qquad x(n)>\max(x(n-1),x(n-1)) \\ \min(x(n-1),x(n+1)), \\ \qquad x(n)<\min(x(n-1),x(n+1)) \\ x(n),\ \ otherwise\end{cases} \tag{1}$$

where $x(n)$ and $y(n)$ mean an input signal and an output one, and $\max()$ and $\min()$ indicate the maximum function and the minimum one, respectively.

Equation (1) can easily extend to the two-dimensional case such as 3x3 filter windows. The processing procedure by the “cutting-otherwise-filling” condition in the two-dimensional case is also described as

$$y(i,j)=\begin{cases}\max(W), & x(i,j)>\max(W) \\ \min(W), & x(i,j)<\min(W) \\ x(i,j), & otherwise\end{cases} \tag{2}$$

where

$$W=\{x(i-1,j-1),x(i-1,j),x(i-1,j+1),x(i,j-1), \\ x(i,j+1),x(i+1,j-1),x(i+1,j),x(i+1,j+1)\} \tag{3}$$

which represents 8-neighbors around the processing point and $x(i,j)$ and $y(i,j)$ mean an input pixel value and an output one, respectively.

2.3. Processing Procedure

2.3.1. One-dimensional Case

In one-dimensional processing case, two direction processing is applied. First, horizontal lines for an input image are processed, and then vertical lines for the horizontal processed image are processed. The combination of these procedures is repeated to the processed image. The procedure can be described as follows:

[Step 1] Let $P(i,j)$ mean an input image, $y_n(i,j)$ the processed image at n-th times and $y'_0(i,j)=P(i,j)$.

[Step 2] Let $y_n^H(i,j)$ mean the output image from the horizontal processing. $y_n^H(i,j)$ can be obtained by

$$y_n^H(i,j)=\begin{cases}\max(y_{n-1}(i,j-1),y_{n-1}(i,j+1)), \\ \quad y_{n-1}(i,j)>\max(y_{n-1}(i,j-1),y_{n-1}(i,j+1)) \\ \min(y_{n-1}(i,j-1),y_{n-1}(i,j+1)), \\ \quad y_{n-1}(i,j)<\min(y_{n-1}(i,j-1),y_{n-1}(i,j+1)) \\ y_{n-1}(i,j)\ \ :\ \ otherwise\end{cases}. \tag{4}$$

[Step 3] The input signal in this step is $y_n^H(i,j)$ which is the output from Step 2. $y_n(i,j)$ can be obtained by

$$y_n(i,j)=\begin{cases}\max(y_n^H(i-1,j),y_n^H(i+1,j)), \\ \quad y_n^H(i,j)>\max(y_n^H(i-1,j),y_n^H(i+1,j)) \\ \min(y_n^H(i-1,j),y_n^H(i+1,j)), \\ \quad y_n^H(i,j)<\min(y_n^H(i-1,j),y_n^H(i+1,j)) \\ y_n^H(i,j)\ \ :\ \ otherwise\end{cases}. \tag{5}$$

[Step 4] If $n=N_e$ is satisfied, let $y(i,j)=y_n(i,j)$ and the procedure is finished or if not, $n=n+1$ and go to Step 2. N_e means the predefined number of repeating times.

2.3.2 Two-dimensional Case

In two-dimensional case, 3x3 filter window is applied. The procedure can be described as follows:

[Step 1] Let $P(i,j)$ mean an input image, $y_n(i,j)$ the processed image at n-th times and $y_0(i,j)=P(i,j)$.

[Step 2] The update procedure of $y_n(i,j)$ is described as

$$y_n(i,j) = \begin{cases} \max(W_{n-1}),\ y_{n-1}(i,j) > \max(W_{n-1}) \\ \min(W_{n-1}),\ y_{n-1}(i,j) < \min(W_{n-1}) \\ y_{n-1}(i,j),\ otherwise \end{cases} \tag{6}$$

where

$$W_n = \{y_n(i-1,j-1), y_n(i-1,j), y_n(i-1,j+1), y_n(i,j-1), y_n(i,j+1), y_n(i+1,j-1), y_n(i+1,j), y_n(i+1,j+1)\}$$

which means 8-neighbors for the processing image at n-th times.

[Step 3] If $n = N_e$ is satisfied, let $y(i,j) = y_n(i,j)$ and the procedure is finished or if not, $n = n+1$ and go to Step 2. N_e means the predefined number of repeating times.

3. Proposed Technique

The PAV filter shows the excellent performance for the noise reduction and edge preserving, however the blotch of noise can not be removed sufficiently. This paper proposes the noise reduction method based on the PAV filter for a highly corrupted image which frequently includes the blotch of noise.

From the procedure of the PAV filter, the insufficient reduction of noise means that the corrupted signal passes through the filter because of no application of the "cutting" and "filling" operation. Figure 3 shows an example of such a case. In this case, since the pixel value of the processing point is equal to the one of the left pixel, "cutting-otherwise-filling" condition can not be adopted and the "cutting" and "filling" operation are not applied. If the processing point is noise in such a case, the noise can not removed. If the processing pixel and each neighbor pixel are corrupted, then both noises can not be reduced. This is the reason of difficulty of the reduction of blotch noise.

Next we consider the 2-D case. Figure 4 shows an example of the 2-D case. In this figure, the center point indicates the processing point and the pixels, whose value is 0, mean the noise. In this case, the horizontal operation and the vertical one can not affect the processing point and the noise is left. After all, if there is the same pixel value with one of the processing point in its neighbor, the operation can not work well. The repetition of the operation also brings the same result. Therefore any solution for such a case should be required.

Fig. 3 Example of the blotch noise.

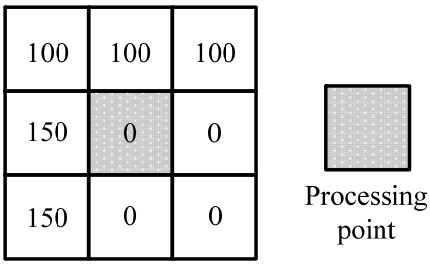

Fig. 4 Example of 2-D case.

3.1. Discrimination of noise

In the PAV filter, "cutting-otherwise-filling" condition is used for discrimination of the noise. The proposed filter adopts modified 2-D "cutting-otherwise-filling" condition, namely, if the pixel value of the processing point is greater or equal to the maximum one or it is less or equal to the minimum one in the window, then it is classified as the noise.

If the processing point is judged as the noise, this noise should be classified as the solicited one or the part of blotch. In the proposed method, if the pixel value of the processing point is equal to the maximum or the minimum in the neighborhood, then this is classified as the part of blotch, another case the solicited one.

3.2. Processing for solicited noise

If the processing point is solicited noise, 2-D "cutting-otherwise-filling" condition is used for the noise reduction. Application of 2-D processing can make the high-speed processing. An example of 2-D "filling" operation is shown in Fig. 5.

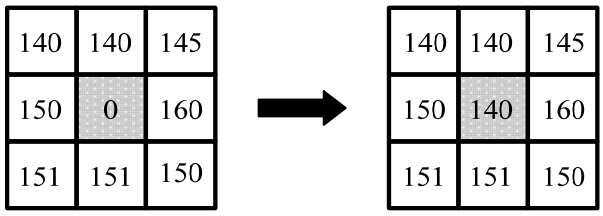

Fig. 5 Example of 2-D "filling" operation.

3.3. Processing for blotch noise

In the above discussion, only the vertical and horizontal processing is insufficient for the reduction of the blotch of noise. This paper proposes diagonal and anti-diagonal processing added to the vertical and horizontal processing. The diagonal processing is defined as

$$y(i,j)=\begin{cases}\max(x(i-1,j-1),x(i+1,j+1)),\\ \quad x(i,j)>\max(x(i-1,j-1),x(i+1,j+1))\\ \min(x(i-1,j-1),x(i+1,j+1)),\\ \quad x(i,j)<\min(x(i-1,j-1),x(i+1,j+1))\\ x(i,j),\quad otherwise\end{cases} \tag{7}$$

and the anti-diagonal processing is also described as

$$y(i,j)=\begin{cases}\max(x(i-1,j+1),x(i+1,j-1)),\\ \quad x(i,j)>\max(x(i-1,j+1),x(i+1,j-1))\\ \min(x(i-1,j+1),x(i+1,j-1)),\\ \quad x(i,j)<\min(x(i-1,j+1),x(i+1,j-1))\\ x(i,j),\quad otherwise\end{cases} \tag{8}$$

which $x(i,j)$ and $y(i,j)$ mean an input pixel value and an output one, respectively. Figure 6 shows the diagonal processing. Figure 7 shows the anti-diagonal processing and its application to the example in Fig. 4. For example, in Fig. 4, if the anti-diagonal processing is applied in this case, the pixel value of the processing point can be changed to undegraded one. The repetition of the proposed method can be reduced the blotch of noise.

In the proposed method, the order of the processing direction is an important issue. We applied several orders of the direction to the images, experimentally and found the order of the diagonal, anti-diagonal, horizontal and vertical directions is best. This order is adopted the proposed method.

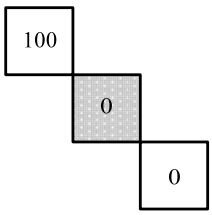

Fig. 6 Diagonal Processing.

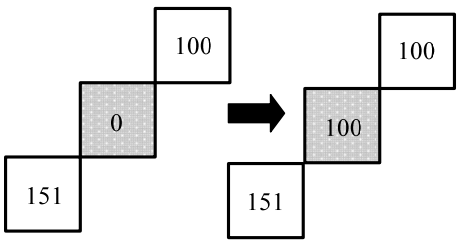

Fig. 7 Anti-diagonal Processing.

4. Simulation

The "Lenna" and "Pepper" images were adopted as the original image. The size of this image was 512 x 512 pixels and their gray levels 256. Tables 1 and 2 show the comparison with other nonlinear filters by mean square errors (MSE) for the "Lenna" and "Pepper" images, respectively. We selected the best parameter for each filter. From this table, the proposed filter shows the good performance compared to the other filters. Especially almost same result with the PSM filter [3] was given.

Table 1 Processing result (Lenna).

	Probability		
	10%	30%	50%
Degraded	1845	5564	9226
PAV[4]	27.50	174.8	1164
Median	27.43	266.8	1869
PSM[3]	18.18	35.39	65.43
Proposed	20.77	32.56	53.05

Table 2 Processing result (Pepper).

	Probability		
	10%	30%	50%
Degraded	1890	5696	9513
PAV[4]	27.02	163.5	1167
Median	13.26	51.2	150.9
PSM[3]	19.22	39.25	81.98
Proposed	27.02	35.63	61.85

5. Conclusion

This paper has proposed a new nonlinear filter based on the PAV filters for the impulse noise reduction. The proposed filter has no parameter to be adjusted like as the PAV filter. The noise reduction performance of the proposed one is good for the highly corrupted images for which the PAV filter can not perform sufficient noise reduction. The simulation result also shows the effectiveness of the proposed method.

References

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