Adaptive Rank Order Filter for Image Noise Removal

Cheng-Hsiung Hsieh and Po-Chin Huang
Department of Computer Science and Information Engineering
Chaoyang University of Technology
Email: chhsieh@cyut.edu.tw

Abstract

This paper presents an adaptive rank order filter (AROF) which is applied to image noise removal. By two observations on the adaptive median filter (AMF) in [4], the AROF is motivated and developed. First, the expansion of window size in the AMF is determine by the criterion if the median is a noisy pixel or not. This criterion is not appropriate when the noise density is moderate or high. Second, the pixels processed by the AMF are reused in the filtering of AMF. This doing degrades the visual quality of restored image. To avoid the two problems found in the AMF, we proposes the AROF. In the AROF, the criterion to expand window size is all pixels in the window are noisy. If it is not the case, the center pixel is replaced by either median or non-median whcih is not noisy. Moreover, the pixels processed by the AROF are not put into account in the following filtereing process. Simulation results show that the proposed AROF has better performance than the AMF when the noise density is moderate or high while remains similar PSNR to those for the AMF in the case of low noise density.

Keywords: image noise removal, adaptive median filter, rank order filter

1. Introduction

Nowadays, digital images are usually transmitted through satellites, wired, and wireless networks. However, it is quite often to introduce impulse noise in the transmission. One type of impulse noise is the salt and pepper noise. In an 8-bit gray image, the salt and pepper noise takes value 0 or 255. Since the salt and pepper noise degrades not only visual quality but also the performance of following image processing system. Consequently, noise removal schemes are sought and considered as an important research area in digital image processing.

A popular scheme to deal with the salt and pepper noise is the median filter [1] and its variations, such as weighted median filter [2] and center weighted median filter [3]. The advantages of the median filter based approaches are low computational complexity and of good results in cases of low noise density. However, the performance of approaches in [1-3] deteriorates significantly as the noise density increases. Even worse, they may not able to remove noise since the median can be a noisy pixel as well. To get rid of the problem, the adaptive median filter (AMF) was proposed in [4]. The adaptability in AMF is that the window size can be expanded when needed while the window size of median filter in [1] is fixed. Given an initial window size, the AMF consists of the following steps. First, check if the center pixel in the window noisy. If it is, then sort pixels within the window. Otherwise, move to next pixel and redo this step. Second, check if the median is noisy. If this is the case, then expand the window size and sort the pixels within the window until the non-noisy median is found. Third, replace the center pixel with the median.

By the expansion of window size, the AMF is able to deal with highly corrupted image by salt and pepper noise. However, it is noted that poor visual quality in the restored image is found when a larger window is employed. Therefore, in the AMF the criterion for window expansion, based on the median, should be reconsidered for better noise removal performance. In a given window, there may be some pixels not noisy when the median is noisy. In this case, we may simply replace the center pixel with some non-median pixel. By this doing, the filter becomes a kind of adaptive rank order filters. Besides, the window needs not to expand and better restored image can be obtained in cases with moderate or high noise density. Another reason to degrade the performance of the AMF is that the pixels being processed are used in the following filtering process. To get rid of the problem, a scheme to avoid reusing the processed pixels is given in the proposed approach which will be presented in Section 3.

978-0-7695-3507-4/08 $25.00 © 2008 IEEE
DOI 10.1109/CSIE.2009.737

Based on the observations described above, the paper presents a removal scheme for salt and pepper noise called adaptive rank order filter (AROF) to improve the quality of restored image in the cases with moderate and high noise density. There are two types of adaptability in the AROF: (i) to expand window if all pixels within the current window are noisy, and (ii) to replace the center pixel with non-median pixel if the median is noisy. This paper is organized as follows: Section 2 gives a brief review of the AMF where an example is provided to show the inappropriateness in the window expansion for cases of moderate and high noise density. Section 3 describes the proposed AROF and a scheme to avoid using filtered pixels for better visual quality. Section 4 provides examples to verify the AROF where the comparison results with the AMF are given as well. Finally, conclusion is made in Section 5.

2. Review of AMF

In this section, the AMF proposed in [4] is briefly reviewed where an example is given to demonstrate a problem in the AMF when the noise density is moderate or high. Given a noisy image and initial window size 3×3, the implementation steps of AMF are described as follows:

Step 1 Check if the center pixel is noisy. If yes, then go to Step 2. Otherwise, move the center of window to next pixel and redo Step 1.

Step 2 Sort all pixels within the window in the ascending order and find the minimum $f_{\min}$, median f_{med}, and maximum $f_{\max}$.

Step 3 Determine if f_{med} is noisy by $f_{\min} < f_{\text{med}} < f_{\max}$. If it holds, f_{med} is not a noisy pixel and jump to Step 5. Otherwise, f_{med} is noisy and go to Step 4.

Step 4 Expand the window and go back to Step 2.

Step 5 Replace the center pixel with f_{med}.

Step 6 Reset window size and move the center of window to next pixel.

Step 7 Repeat the steps until all pixels are processed.

To observe the case of moderate or high noise density, an example is given to show how the AMF works. Assume a 5×5 noisy image block is given in Figure 1 where the center pixel is shadowed.

255	64	0	52	57
50	0	0	0	0
255	0	255	255	55
59	255	0	62	0
0	67	255	60	65

Figure 1. A 5×5 noisy image block

By the steps described in this section, the process of AMF to remove the noisy pixel is given in the following:

A. All pixels within the 3×3 window are sorted in the ascending order whose result is shown below:

$[0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 62 \;\; 255 \;\; 255 \;\; 255]$

The $f_{\min}$, f_{med}, $f_{\max}$ are 0, 0, 255, respectively.

B. Determine if f_{med} is noisy. Since $f_{\min} < f_{\text{med}} < f_{\max}$ does not hold, the f_{med} is considered noisy. Consequently, the window is expanded to 5×5.

C. Sort all pixels within the 5×5 window whose result is given in the following:

$[0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 50 \;\; 52 \;\; 55 \;\; 57 \;\; 59$
$60 \;\; 62 \;\; 64 \;\; 65 \;\; 67 \;\; 255 \;\; 255 \;\; 255 \;\; 255 \;\; 255 \;\; 255]$

Now, the $f_{\min}$, f_{med}, $f_{\max}$ are 0, 57, 255, respectively. Since $0 < 57 < 255$ holds, thus f_{med} is not thought as a noisy pixel.

D. Replace the center pixel with $f_{\text{med}} = 57$. The result is shown as in Figure 2.

255	64	0	52	57
50	0	0	0	0
255	0	57	255	55
59	255	0	62	0
0	67	255	60	65

Figure 2. The center pixel is replaced by 57

In the given example, it indicates that not all pixels within the 3×3 window are noisy though f_{med} is noisy. In this example, the center pixel may be replaced by the pixel 62 and no window expansion is required. And the pixel 62 is more suitable than 57 which is obtained in the window size 5×5, since the former one is closer to the center pixel. It is well known closer neighborhood pixels have stronger correlation. Therefore, it can be expected to have better visual quality of restored image obtained from the 3×3 window. The idea will be verified in Section 4.

3. The Proposed AROF

In this section, an adaptive rank order filter (AROF) to remove image noise is proposed. As described in the previous section, it is not appropriate in the AMF to replace the center pixel with the median when noise density is moderate or high. The reason is that the window should be expanded to find a median which is not noisy. This may cause degradation of restored image. To avoid the expansion of window, one may use some non-median pixel which is noise-free to replace the center pixel. Note that the median filter is a special case of the rank order filter (ROF) and that the output of ROF can be any sorted element. Thus, the ROF is employed in this paper. Besides, two types of adaptation are incorporated into in the ROF: (i) adaptive filtering output and (ii) adaptive window size. For the aspect of adaptive filtering output, in the AROF the output may be noise-free median or an noise-free non-median which is then used to replace the center pixel. As for the adaptive window size, a similar window expansion scheme in the AMF is adopted where the criterion to expand window is all pixels within the current window are noisy, instead of only checking the median as in the AMF. The ROF with these two adaptations is called AROF which is proposed in this paper and employed to remove image noise.

Given noisy image ***A*** and initial window size 3×3, the proposed AROF is implemented as follows:

Step 1. Duplicate noisy input image ***A*** to output image ***B***.

Step 2. Check if the center pixel in input image ***A*** is noisy. If yes, then go to Step 3. Otherwise, move the center of window to next pixel and redo Step 2.

Step 3. Sort all pixels within the window in the ascending order and find the minimum $f_{\min}$, median f_{med}, and maximum $f_{\max}$.

Step 4. Determine if f_{med} is noisy by $f_{\min} < f_{\text{med}} < f_{\max}$. If it holds, f_{med} is not a noisy pixel and jump to Step 5. Otherwise, f_{med} is noisy and go to Step 6.

Step 5. Replace the corresponding center pixel in output image ***B*** with f_{med} and go to Step 8.

Step 6. By $f_{\min} < f_{\text{med}} < f_{\max}$, check if all other pixels are noisy. If yes, then expand window and go back to Step 3. Otherwise, go to Step 7.

Step 7. Replace the corresponding center pixel in output image ***B*** with the noise-free pixel which is the closest one to the median.

Step 8. Reset window size and move the center of window to next pixel.

Step 9. Repeat the steps until all pixels are processed.

The flowchart of AROF is shown in Figure 3. In the proposed AROF, input image ***A*** is duplicated to output image ***B***. The input image ***A*** remains unchanged in the filtering process while noisy pixels in the output image ***B*** are replaced with the output of AROF. This doing is to avoid reusing the pixels processed by the AROF and thus the visual quality of restored image is expected to be better. The idea will be justified in Section 4.

4. Simulation Results

In this section, three examples are provided to verify the proposed AROF. Moreover, the results obtained from the AROF are compared with those from the AMF to justify the ideas described in Section 2. Three images used in the simulation are Lena, Lake, and Boat which have same size of 512×512. Since the salt and pepper noise is quite singular in an image, thus pixels with value 0 or 255 are considered as noisy pixels in the simulation. As for the noise density, it varies from 10% to 90%. Both subjective and objective assessments are employed to evaluate the performances of AROF and AMF. The objective assessment used here is the peak signal to noise ratio (PSNR) which is defined as

$$PSNR = 10\log\frac{255^2}{MSE}$$

where

$$MSE = \frac{1}{N^2}\sum_{i=1}^{N}\sum_{j=1}^{N}[O(i,j)-\hat{O}(i,j)]^2$$

and $N\times N$ denote the image size and $O(i,j)$, $\hat{O}(i,j)$ are elements of original image and restored image, respectively.

With various noise densities, the corresponding PSNR for images Lena, Lake, and Boat obtained from AROF and AMF are recorded in Table 1. The simulation results in Table 1 indicate that the AROF has similar performance to the AMF in cases of 10% to 40% noise density. However, in moderate and high noise density cases the AROF outperforms the AMF in PSNR. As the noise density increases, the PSNR from AROF is getting better than that from AMF for all examples. This justifies the median-based criterion to expand window in the AMF is not appropriate in moderate or high noise density. Moreover, the results also suggest that using output of AROF with a smaller window, as expected, is a better choice to replace the center pixel than using the median in a larger window.

With noise removal by AMF and AROF, the restored images for 90% noise density are given in

Figures 4(a) to 4(c) for the AMF and 4(d) to 4(f) for the AROF, respectively. As shown in those figures, the visual quality for the AROF restored images are much better than those for the AMF. To sum up, the proposed AROF appraoach achieves better performance both in PSNR and visaul quality when compared with the AMF in cases of moderate and high noise density and has similar performance to the AMF in the low noise density cases.

5. Conclusion

According to observations on the AMF, the paper has presented a noise removal approach called adaptive rank-order filter (AROF). There are at least three differences between the AMF and the AROF. First, the AMF employs the median to replace with the noisy center pixel and the AROF with the median or non-median pixel. Second, the criterion to expand window size in the AMF is by determining whether the median is noisy while the AROF checks if all pixels within the window are noisy. Third, the AMF reuses the pixels replaced by medians and the AROF avoids it. The proposed AROF are verified and compared with the AMF through three examples. As expected, the performance of AROF is better than that for AMF not noly in PSNR but also in visual quality of restored image when moderate or high noise density is under consideration.

Acknowledgement

This work was supported by the National Science Council of the Republic of China under grant NSC 97-2221-E-324-032.

References

[1] Ioannis Pitas and Anastasios N. Venetsanopoulos, "Order Statistics in Digital Image Processing," *Proceedings of the IEEE*, Vol. 80, No. 12, pp. 1893-1921, Dec. 1992.

[2] D. R. K. Brownrigg, "The Weighted Median Filter," *Communications of the ACM*, Vol. 27, No. 8, pp. 807-818, Aug. 1984.

[3] Sung-Jea Ko and Yong Hoon Lee, "Center Weighted Median Filters and Their Applications to Image Enhancement," *IEEE Transactions on Circuits and Systems*, Vol. 38, No. 9, pp. 984-993, Sept. 1991.

[4] R. H. Chan, Chung-Wa Ho, and M. Nikolova, "Salt-and-Pepper Noise Removal by Median-Type Noise Detectors and Detail-Preserving Regularization," *IEEE Transactions on Image Processing*, Vol. 14, No. 10, pp. 1479-1485, Oct. 2005.

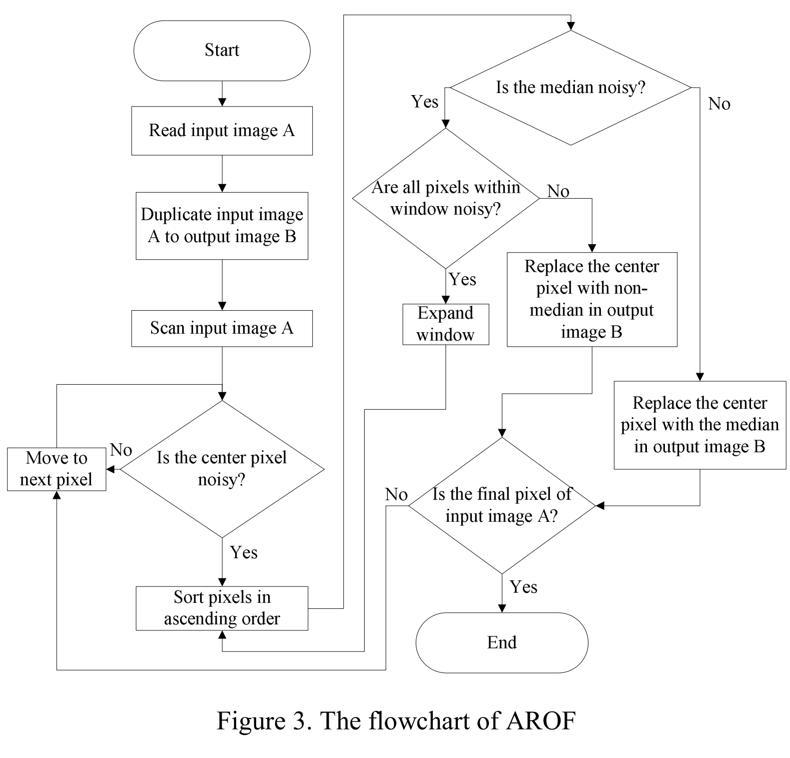
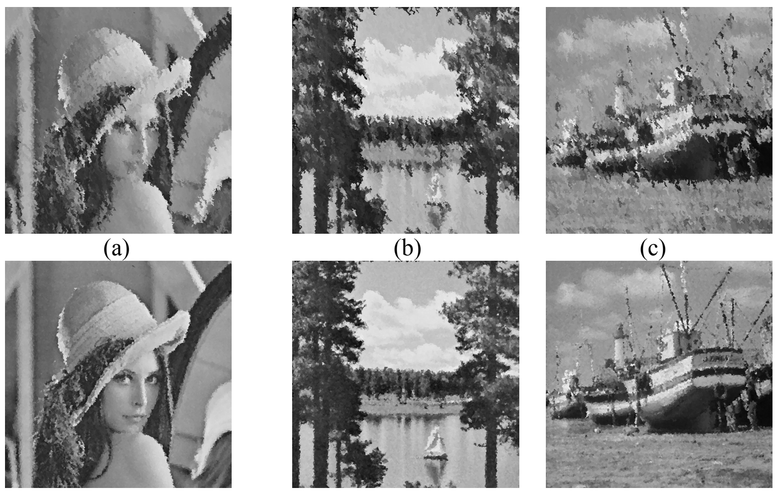


Figure 3. The flowchart of AROF

Table 1. The PSNR for AROF and AMF with various noise density

	Lena		**Lake**		**Boat**	
Noise Density (%)	AROF	AMF	AROF	AMF	AROF	AMF
10	41.33	41.70	37.02	37.29	37.74	37.88
20	37.14	37.60	32.97	33.27	33.67	34.02
30	34.27	34.69	30.43	30.67	30.88	31.19
40	32.37	32.56	28.41	28.44	29.08	29.36
50	30.62	30.07	26.96	26.44	27.58	27.31
60	29.35	27.82	25.78	24.42	26.33	25.49
70	28.28	26.25	24.68	22.45	25.30	23.72
80	26.93	23.61	23.43	20.20	24.09	21.34
90	24.92	20.00	21.56	17.11	22.45	18.36



(d) (e) (f)

Figure 4. (a)Restored Lena by AMF (b)Restored Lake by AMF (c)Restored Boat by AMF (d)Restored Lena by AROF (e)Restored Lake by AROF (f)Restored Boat by AROF