IMPULSE NOISE REMOVAL IN HIGHLY CORRUPTED COLOR IMAGES

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ABSTRACT

We present in this paper a novel and efficient technique for the restoration of color images which are highly corrupted with impulse noise. This is a detection-estimation based approach in which outliers are first detected using a Teager-like operator followed by a locally adaptive threshold. Center pixels whose "energy" exceeds some threshold are replaced with the local marginal median. Simulation results show the superior performance of the proposed filtering algorithm compared to the renowned vector median (VM [1]) and generalized vector directional filter (GVDF [3]), which are commonly used for color image restoration in the literature. Monte Carlo simulations show the edge preservation and impulse noise attenuation capabilities of the proposed technique. The efficiency of the algorithm stems from its simple arithmetic operations compared with more demanding ones, e.g. computation of distances and angles in the case of VMF and GVDF, respectively.

1. INTRODUCTION

Order statistics and polynomial based techniques figure among the most successful approaches used in the literature for the restoration of color images corrupted by impulsive type noise. The vector median [1] has proved to be particularly useful in preserving edges and removing impulses from color images. However, when images are highly corrupted with impulse noise, VMF may cause distortion leading to poor visual image quality. An alternative scheme to process highly corrupted images is to first detect impulses and replace them at the output with the local mean, excluding of course the outlier. The success of the latter approach depends heavily on the underlying detection mechanism and in any case will be very limited by the averaging operation used in the second stage.

The proposed approach is an attempt to cure the deficiencies of the latter approach. In the detection part of this detection-estimation technique, the local "energy" of each pixel is evaluated and compared to a locally adaptive threshold. Outliers, which are those pixels whose "energy" exceeds the threshold, are replaced with the median value inside the filter window. This "energy" is a Teager-like measure, hence the name "energy", which is commonly used in speech processing, and it is an enhanced version of the quadratic operator used by Mitra et. al. [2]. The median operation is selected in the estimation phase for its edge preserving property. In the following sections, we describe the algorithm, highlight some of its important characteristics and assess its performance with natural color images.

2. PROPOSED ALGORITHM

Denote by $X(m,n)$ the pixel value at location (m,n). Since the proposed scheme is a component-wise technique, $X(m,n)$ denotes one component of the three-valued pixel of a color image at location (m,n). First, apply the Teager-like quadratic operator at location (m,n) to determine the "energy" of that pixel.

$$E(m,n) = max(E_1(m,n), E_2(m,n)) \tag{1}$$

where:

$$\begin{aligned} E_1(m,n) = &|2*(X(m,n)-\mu)^2 \\ &-(X(m-1,n)-\mu)*(X(m+1,n)-\mu) \\ &-(X(m,n-1)-\mu)*(X(m,n+1)-\mu)|, \end{aligned} \tag{2}$$

$$\begin{aligned} E_2(m,n) = &|2*(X(m,n)-\mu)^2 \\ &-(X(m-1,n-1)-\mu)*(X(m+1,n+1)-\mu) \\ &-(X(m+1,n-1)-\mu)*(X(m-1,n+1)-\mu)|, \end{aligned} \tag{3}$$

and μ is the local mean of the pixels inside the processing window.

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This operator is an enhanced version of the one used in [2]:

$$E(m,n) = 2*X(m,n)^2 - X(m-1,n)*X(m+1,n) - X(m,n-1)*X(m,n+1) \quad (4)$$

which produces different values for impulses with the same magnitude located in different backgrounds.

This "energy" is then compared against a locally computed threshold:

$$Th = \frac{\alpha}{N} \times \sum_{n=1}^{N} E_n, \quad (5)$$

where E_n is the "energy" of the n'th pixel in the surrounding neighborhood N_G containing N pixels, and α is a constant determined empirically (here alpha is 1.9). Those pixels whose "energy" exceeds Th, are replaced at the output by the median of the pixels inside the filter window. Otherwise, the pixel value is retained.

In order to successfully treat negative impulses, the proposed technique is applied a second time to the complemented output of the first filtering operation.

2.1. Advantages of the proposed filter

Among the most important properties of the proposed filter, we note that the adaptive thresholding Eq.(5) leads to a better detection of the impulses. Furthermore, the modified"energy" operator output does not depend on the background. For illustration, let the "energy" of an impulse of magnitude 100 in two different backgrounds be computed using the quadratic operator Eq.(4) introduced in [2] and the modified operator Eq.(1-3).

W_1

100	100	100
100	200	100
100	100	100

W_2

50	50	50
50	150	50
50	50	50

The "energies" $E_{W_1} = 6 \times 10^4$ and $E_{W_2} = 4 \times 10^4$ are obtained using Eq.(4), while $E_{W_1} = E_{W_2} = 1.556 \times 10^4$ is obtained using the modified operator.
Furthermore, note that only one parameter needs to be set in order to determine the behavior of the filter; and only the "corrupted" pixels are filtered, which reduces the required processing time and preserves better the original image details. Finally, a small filter window is used to save computation.

3. SIMULATION RESULTS

To test the performance of this approach in filtering out salt and pepper noise (i.e. positive and negative impulses) from natural color images, color image "Lena" is corrupted with 6% salt and pepper noise in each channel (i.e. a total of 18% impulse noise in the image). The noisy image is then filtered with several nonlinear filters and the new filter. The results are shown in Table 1. The new filter performs remarkably better than all the other filters for all three objective criteria (NMSE and MAE are the normalized mean squared and mean absolute errors, and MCRE is the mean chromaticity error) used. Some images are shown in Figure 2 for visual comparison (gray level images are shown due to the color printing restriction in these proceeding).

Next, to further assess the edge preservation and noise attenuation capabilities of the new filter, Monte Carlo simulations are run using 1000 filtering operations on an ideal multispectral (3-channel) edge corrupted with 20% salt and pepper noise in each channel. The average responses of the marginal median, the vector median and the new filter are displayed in Figure 3. A much smoother response in constant areas and a sharper edge are obtained with the new filter.

4. CONCLUSION

A new technique for the restoration of highly corrupted color images with impulse noise was introduced in this paper. This approach combines the enhanced "energy" operator with adaptive thresholding for impulse detection. The median is used for the estimation of the corrupted pixels.

The experimental results have demonstrated the efficiency of the proposed filter. This filter outperforms all the other filters such as the marginal median (MM), the vector median (VM), the generalized vector directional filter (GVDF), the directional-distance filter (DDF) [4] and the fuzzy vector directional filter (FVDF) [5]; in removing impulses and preserving image details and color chromaticity. Moreover, the processing time is reduced considerably by only processing the "corrupted" pixels and avoiding expensive operations such as computing distances and angles.

5. REFERENCES

[1] J. Astola, P. Haavisto, and Y. Neuvo, "Vector median filter", *Proc. of the IEEE*, vol.78, pp.678-689, Apr.1990.

[2] S.K. Mitra, T.H. Yu, R. Ali, "Efficient detail-preserving method of impulsive noise removal from highly corrupted images",*SPIE Proc. on Image and Video Processing*, vol. 2182, pp. 43-48 1994

#	Noisy Image	VM	MM	$FVDF_1$	$FVDF_2$	GVDF	DDF	New filter
NMSE (10^{-2})	5.913	0.186	0.157	0.268	0.236	0.193	0.193	0.054
MAE	23.035	10.780	9.706	13.069	11.768	11.450	11.040	2.304
MCRE (10^{-2})	5.628	1.546	1.555	1.829	1.687	1.542	1.543	0.525

Table 1: Filtering results of the color image "Lena" corrupted by 6% of impulsive noise in each channel, with various algorithms.

[3] P.E. Trahanias, A.N. Venetsanopoulos, "Vector directional filters: A new class of multichannel image processing filters",*IEEE Trans. on Image Processing*, vol. 2, no. 4, pp. 528-534, October 1993.

[4] D. G. Karakos and P. E. Trahanias, "Combining Vector Median and Vector Directional Filters: the Directional Distance Filters," *Proceedings of ICIP-95*, Vol. 1, pp. 171-174, Oct. 1995.

[5] K.N Plataniotis, D. Androutsos and A.N Venetsanopoulos, "Color Image Processing Using Fuzzy Vector Directional Filters", *IEEE Workshop on Nonlinear Signal and Image Processing*, Halkidiki, Greece, June 1995, vol. 2, pp. 535-538.

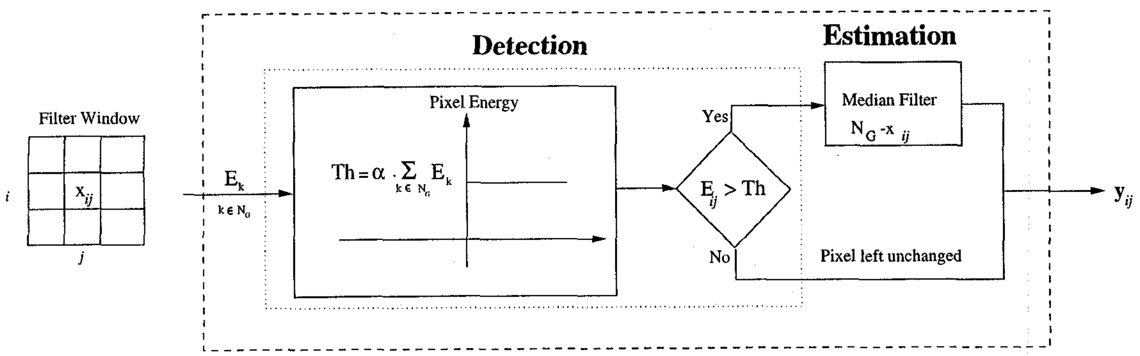
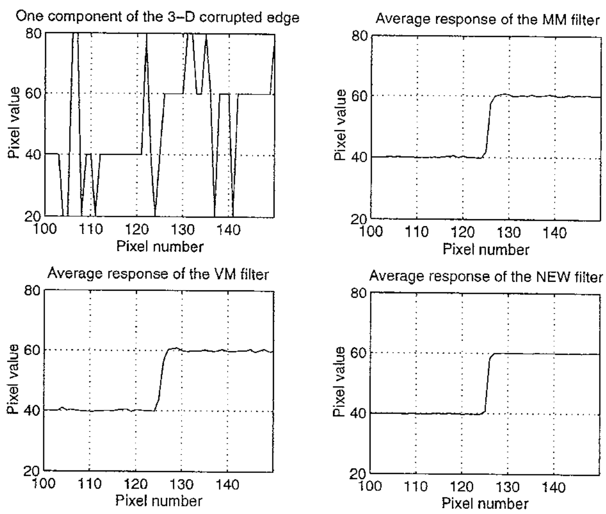


Figure 1: Block Diagram of the proposed filter.

(a)	(b)
(c)	(d)

Figure 2: (a) Noisy image corrupted with 18% salt&pepper, (b) output of the marginal median filter, (c) output of the vector median filter, and (d) output of the proposed new filter.



(a)	(b)
(c)	(d)

Figure 3: (a) One channel of the 3-component noisy edge, (b) average response of the marginal median filter, (c) average response of the vector median filter, (d) average response of the new filter.