Adaptive Impulse Noise Filtering by Using Center-Weighted Directional Information

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Abstract

This paper focuses on color image filtering, where input multichannel samples determined by a 3×3 window are adaptive directional processed in accordance with local image statistics. Thus, to form an estimate, two smoothing characteristics provided by identity filter (IF) and basic vector directional filter (BVDF) can be used. The adaptive alternation of these smoothing characteristics is based on detection criteria, where besides IF and BVDF all another outputs of 3×3 center-weighted vector directional filters (CWVDF) (a class of CWVDF includes both IF and BVDF as special cases with minimal and maximal amount of smoothing) play important role for the determination of corrupted samples. By consideration this determination, only affected multichannel samples are estimated by BVDF, whereas noise free samples are passed through IF.

The proposed method extends possibilities of directional processing and represents excellent tool for impulse noise suppression with simultaneous preservation of color chromaticity, too.

Introduction

Probably the most important filtering methods for impulse noise removing are based on order statistics. These order statistic filters [6] constitute a wide nonlinear filter class, where median-based filters are typical representatives that are characterized by robust noise attenuation (smoothing) characteristics against the impulse noise and all the same time, with the edge and details preserving characteristics, too.

In the case of color images and satellite images that are taken as vector-valued images (called also multivariate, multichannel, etc.) signals, the ordering [7],[10] of observed samples spawned by a filter window is very susceptible concern, since inherent correlation that exists between image channels. Thus, very important is the choice of ordering criteria, where both magnitude [1],[2] and direction [5],[8],[11] of multichannel samples can be considered. In general, vectors' magnitude takes a measure of their brightness, whereas direction of vector samples wreaks their chromaticity [3],[12]. According to used characteristic of multichannel samples, the methods for color image processing can be divided into two classes such as a class based on magnitude processing and a class based on directional processing.

In this paper, a new method for directional processing is presented. The proposed method utilizes an adaptive alternation [4] of two smoothing levels, namely smoothing levels given by IF and BVDF. As a switch between these smoothing levels are used three remaining possible smoothing levels of a 3x3 CWVDF. By this way, the proposed method improves both color chromaticity preservation and impulse noise suppression of BVDF and CWVDF filters.

Directional Processing

Let $y(x): Z^l \rightarrow Z^m$ represent a multichannel image, where l is a image dimension and m characterizes a number of channels. If $m \geq 2$, then is the case of m-channel image processing. In the case of standard color images $l = 2$ and $m = 3$.

Let $W = \{\mathbf{x}_i \in Z^l \ ; \ i = 1,2...,N\}$ represent a filter window of a finite size N, where $\mathbf{x}_1, \mathbf{x}_2, ..., \mathbf{x}_N$ is a set of noised samples. Note, that a position of filter window is determined by the central sample $\mathbf{x}_{(N+1)/2}$. Each input vector $\mathbf{x}_i$ is associated with angle distance α_i that is defined by [3],[5],[8],[11],[12]

$$\alpha_i = \sum_{j=1}^{N} \mathrm{A}(\mathbf{x}_i, \mathbf{x}_j) \quad \text{for } i = 1,2,...,N \tag{1}$$

where

$$\mathrm{A}(\mathbf{x}_i, \mathbf{x}_j) = \cos^{-1}\left(\frac{\mathbf{x}_i . \mathbf{x}_j^T}{|\mathbf{x}_i| . |\mathbf{x}_j|}\right) \tag{2}$$

represents the angle between two m-dimensional vectors $\mathbf{x}_i = (x_{i1}, x_{i2}, ..., x_{im})$ and $\mathbf{x}_j = (x_{j1}, x_{j2}, ..., x_{jm})$. If angle distances (1) serve as an ordering criterion, i.e.

$$\alpha_{(1)} \leq \alpha_{(2)} \leq ... \leq \alpha_{(r)} \leq ... \leq \alpha_{(N)} \tag{3}$$

then it means that the same ordering is implied to input set $\mathbf{x}_1, \mathbf{x}_2, ..., \mathbf{x}_N$, what results in ordered input sequence

$$\mathbf{x}^{(1)} \leq \mathbf{x}^{(2)} \leq ... \leq \mathbf{x}^{(r)} \leq ... \leq \mathbf{x}^{(N)} \tag{4}$$

If a filter output is given by the sample from input set that minimizes the sum of angles with other vectors, then a filter performs BVDF filtering operation, i.e. [11]

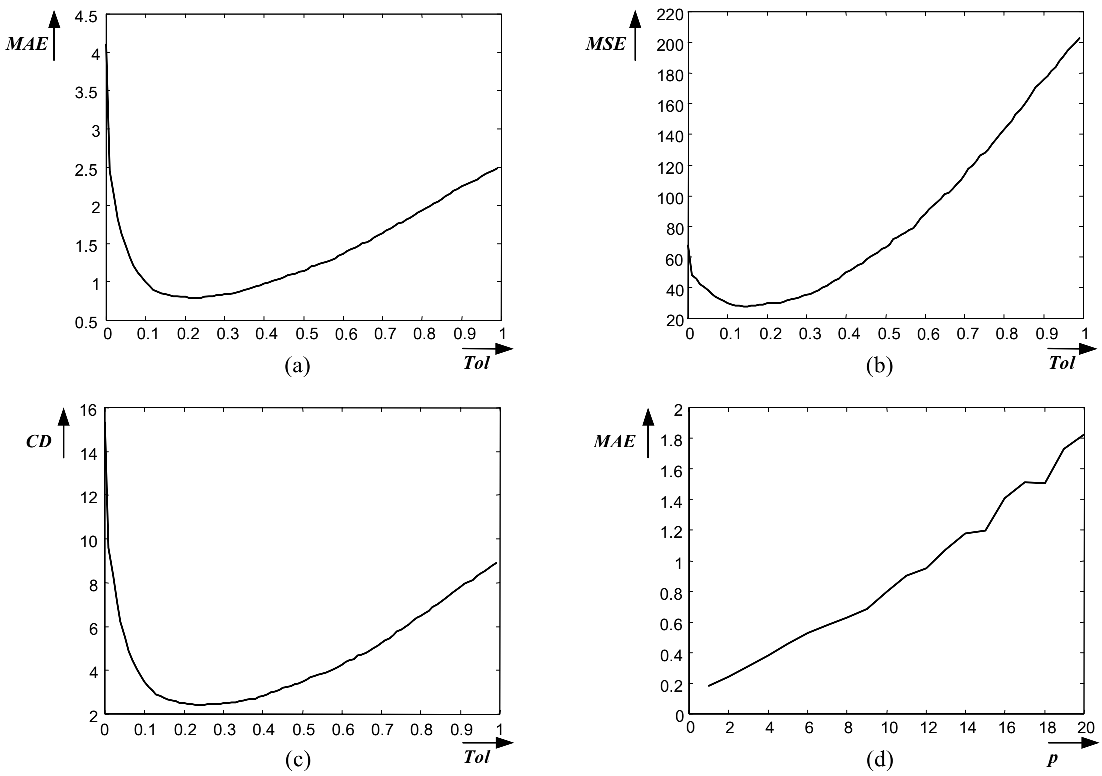

Figure 1. *Performance of the proposed method in dependence on threshold value Tol and degree of the noise corruption p.*
(a) Mean absolute error vs. threshold value Tol (b) Mean square error vs. threshold value Tol
(c) Color difference vs. threshold value Tol (d) Mean absolute error vs. degree of the noise corruption p.

$$\mathbf{y}_{BVDF} = \mathbf{x}^{(1)} \tag{5}$$

where sample $\mathbf{x}^{(1)}$ is associated with minimal angle distance $\alpha_{(1)}$.

Proposed Method

Let $\mathbf{x}_1, \mathbf{x}_2, ..., \mathbf{x}_N$ be an input set determined by a filter window and N represent a window size. Let us assume that $w_1, w_2, ..., w_N$ defined by [5],[6]

$$w_j = \begin{cases} N - 2k + 2 & \text{for } j = (N+1)/2 \\ 1 & \text{otherwise} \end{cases} \tag{6}$$

represent a set of nonnegative integer weights so that each weight w_j for $j = 1,2,...,N$ is associated with the input sample $\mathbf{x}_j$. Then the weighted angle distance β_i associated with the input sample $\mathbf{x}_i$ is given by

$$\beta_i = \sum_{j=1}^{N} w_j \mathrm{A}(\mathbf{x}_i, \mathbf{x}_j) \quad \text{for } i = 1,2,...,N \tag{7}$$

where $\mathrm{A}(\mathbf{x}_i, \mathbf{x}_j)$ is the angle (2) between two m-dimensional vectors $\mathbf{x}_i$ and $\mathbf{x}_j$. The output of center weighted vector directional filter (CWVDF) can be expressed as [5]

$$\mathbf{y}_k = \mathbf{x}^{(1)} \tag{8}$$

where $k = 1,2,...,N$ is the smoothing parameter and $\mathbf{x}^{(1)}$ (4) is an ordered multichannel sample associated with minimal weighted angle distance $\beta_{(1)}$ according to

$$\beta_{(1)} \le \beta_{(2)} \le ... \le \beta_{(r)} \le ... \le \beta_{(N)} \tag{9}$$

To achieve an output of the proposed method, it is necessary to compare detection operator *Val* and threshold angle parameter *Tol*. This simple comparison forms the decision rule

$$\begin{aligned} &\text{IF } Val \ge Tol \quad \text{THEN } \mathbf{y} = \mathbf{y}_{BVDF} \\ &\qquad\qquad\qquad\quad\ \text{ELSE } \mathbf{y} = \mathbf{x}_{(N+1)/2} \end{aligned} \tag{10}$$

where Val can be expressed as

$$Val = \sum_{k=\lambda}^{\lambda+2} A(\mathbf{y}_k, \mathbf{x}_{(N+1)/2}) \tag{11}$$

Note that $\mathbf{x}_{(N+1)/2}$ is the central sample of the input set W and λ is the parameter that depends on a window size N. In the case of a 3×3 filter window, optimal values of parameter λ and threshold parameter Tol are followed $\lambda_{opt} = 2$ and $Tol_{opt} = 1.9$ (Figure 1).

Experimental Results

As the test image was used well-known color image Lena (Figure 2a). The noise corruption (Figure 2b) was simulated by the impulse noise that is defined by [3],[4]

(a) (b) (c)

(d) (e) (f)

Figure 2. *Achieved results (a) Original image (b) 10% impulse noise (c) Output of vector median (d) Output of marginal median (e) Output of BVDF (f) Output of proposed Method*

$$\mathbf{x}_{i,j} = \begin{cases} \boldsymbol{\upsilon} & \text{with probability } p_\upsilon \\ \mathbf{o}_{i,j} & \text{with probability } 1-p_\upsilon \end{cases} \quad (12)$$

where i,j characterize sample position, $\mathbf{o}_{i,j}$ is the sample from the original image, $\mathbf{x}_{i,j}$ represents the sample from the noisy image, p_υ is a corruption probability and $\boldsymbol{\upsilon}=(\upsilon_R,\upsilon_G,\upsilon_B)$ is a noise vector of intensity random values. Note that single components of $\boldsymbol{\upsilon}$ are generated independently and thus, the gray impulses can occur in the special case, only.

As a measure of the noise corruption and the filter performance, too, three objective criteria [9],[13], namely mean absolute error (MAE), mean square error (MSE) and color difference (CD), are used. In general, MAE is a mirror of the signal-details preservation, MSE evaluates the noise suppression well and CD is a measure of the color chromaticity preservation.

The performance of the proposed method was compared (Table 1-5, Figure 2) with marginal median, vector median and BVDF. These results show that the proposed method achieves the significant improvement in comparison with above-mentioned filters. Important property of the proposed method lies in the simultaneous noise suppression and the preservation of signal-details and color chromaticity. In addition, the proposed method can output the image with the color difference smaller than is the threshold value equal to 2.9 that characterizes the senselessness of human eyes to color distortion.

Table 1 Performance of methods ($p_\upsilon = 0.1$)

Method	MAE	MSE	CD
identity	7.312	832.0	32.717
marginal median	3.703	56.8	17.777
vector median	3.687	56.5	15.396
CWVDF ($k=3$)	1.632	62.5	5.617
CWVDF ($k=4$)	2.393	42.9	8.817
BVDF (CWVDF $k=5$)	4.099	67.6	15.343
proposed method	**0.800**	**28.7**	**2.513**

Conclusion

In this paper, a new adaptive approach for the impulse noise suppression with the simultaneous preservation of signal-details and color chromaticity in noisy color images was presented. The proposed method, especially for the impulse noise suppression in color images, was derived from vector directional filters. The significant improvement in comparison with well-known vector filters was achieved by the introducing the center weight to basic vector directional filter and consecutive adaptive selection between an identity filter and basic vector directional filter. As the base for adaptive control, three selected smoothing levels of the center weighted vector directional filter were used. Thus, the excellent approach for the multichannel image filtering was developed.

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Biography

Rastislav Lukac (Ing, Ph.D.) received the M.Sc. (Ing.) degree with honor at the Technical University of Kosice, the Slovak Republic, at the Department of Electronics and Multimedia Communications in 1998. In 2001 he finished his PhD. study. Currently, he is an assistant professor at the Department of Electronics and Multimedia Communications at the Technical University of Kosice. His research interest includes image filtering, impulse detection, neural networks and permutations.