Vector Median M-Type L Filter to Process Multichannel Images

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Abstract. The Vector Median M-type L (VMML) -filter to remove impulsive noise from color images and video color sequences is presented. This filter utilizes multichannel image processing by using the vector approach and the Median M-Type L (MML) algorithm. Simulation results indicate that the proposed filter consistently outperforms other color image filters by balancing the tradeoff between noise suppression, detail preservation, and color retention.

Keywords: Median M-Type L algorithm, Multichannel image processing, Impulsive noise suppression.

1 Introduction

Many useful techniques of multichannel signal processing based on vector processing have been investigated due to the inherent correlation that exists between the image channels compared to traditional component-wise approaches [1,2]. Many applications of this technique are color image processing, remote sensing, robot vision, biomedical image processing, and high-definition television (HDTV) [1]. Different filtering techniques have been proposed for color imaging. Particularly, nonlinear filters applied to color images have been designed to preserve edges and details, and remove impulsive noise [1-3].

In this paper, we introduce the Vector Median M-Type L (VMML) -filter. This filter utilizes multichannel image processing by using the vector approach [2,4], and the Median M-Type L (MML) algorithm [5,6]. The proposed filter uses the combined RM-estimator [7] into the L-filter [8] by following way. The redescending *M*-estimator with different influence functions is combined with the *R*- (median) estimator into the *L* filtering scheme to obtain sufficient impulsive noise suppression for each channel by using the vector approach. We also introduce the use of an impulsive noise detector [9] to improve the properties of noise suppression and detail preservation in the proposed filtering scheme.

Simulation results have demonstrated that the proposed VMML filter consistently outperforms other color image filters by balancing the tradeoff between noise suppression, detail preservation, and color retention.

J. Ruiz-Shulcloper and W.G. Kropatsch (Eds.): CIARP 2008, LNCS 5197, pp. 54–61, 2008.

2 Proposed Multichannel MM Filters

The proposed VMML filter employs the *L* algorithm [8]. The following representation of *L* filter is often used,

$$\theta_{\mathrm{L}} = \sum_{k=1}^{N} a_k \cdot X_{(k)} \tag{1}$$

where $X_{(k)}$ is the ordered data sample, $a_k = \int_{k-1/N}^{k/N} h(\lambda)d\lambda \Big/ \int_0^1 h(\lambda)d\lambda$ are the weighted coefficients, and $h(\lambda)$ is a probability density function [8].

For convenience the VL (Vector L) filter is written below as

$$\theta_{\mathrm{L}} = \sum_{m=1}^{N} a_m \cdot \psi(y_m) y_m \tag{2}$$

where y_m are the noisy image vectors in sliding filter window, which includes $m = 1,\ldots,N$ vectors $y_1, y_2, \ldots, y_N$ located at spatial coordinates in the filter window, and $\psi(y_m) = \begin{cases} 1 & m \le (2L+1)^2 \\ 0 & \text{otherwise} \end{cases}$ is the influence function.

To improve the robustness of the VL filter, we propose to use the Median M-type estimator [5-7],

$$\theta_{\mathrm{MM}} = \mathrm{MED}\{Y_k \tilde{\psi}(Y_k - \mathrm{MED}\{Y_N\}), k = 1,\ldots,N\} \tag{3}$$

where Y_k is data sample, $\tilde{\psi}$ is the normalized influence function ψ: $\psi(Y) = Y\tilde{\psi}(Y)$, and Y_N is the primary data sample. The Median estimator provides good properties of impulsive noise suppression and the M-estimator uses different influence functions to provide better robustness, for these reasons it can be expected that the properties of combined MM-estimator could be better in comparison with Median and M- estimators [7].

So, the Vector Median M-type L (VMML) -filter can be written as:

$$\theta_{\mathrm{VMML}} = \mathrm{MED}\{a_m \cdot [Y_m \psi(Y_m - \mathrm{MED}\{Y_N\})]\} / a_{\mathrm{MED}} \tag{4}$$

where $Y_m \psi(Y_m - \mathrm{MED}\{Y_N\})$ is set of values of vectors y_m which are weighted by value in accordance with the influence function $\tilde{\psi}(y_m)$ in a sliding filter window, y_m are the noisy image vectors in a sliding filter window, which includes vectors $y_1, y_2, \ldots, y_N$ located at spatial coordinates (i, j) in the filter window, a_m are the weighted coefficients used into the proposed filtering scheme, and a_{MED} is the median of coefficients a_m used as a scale constant. The simple cut and Andrew's sine influence functions are used in the filtering scheme [7],

$$\psi_{\mathrm{cut}(r)}(y_m) = y_m \cdot 1_{[-r,r]}(y_m) = \begin{cases} y_m, & |y_m| \le r \\ 0, & \text{otherwise} \end{cases} \tag{5}$$

$$\psi_{\sin(r)}(y_m) = \begin{cases} \sin(y_m/r), & |y_m| \le r\pi \\ 0, & \text{otherwise} \end{cases} \tag{6}$$

where the parameter r is connected with restrictions on the range of $\psi(y_m)$.

We also propose to enhance the removal ability of VMML filter to involve an impulsive noise detector. The impulsive detector used here is defined as [9]:

$$[(rank(y_c) \le T_1) \vee (rank(y_c) \ge N - T_1)] \wedge (|y_c - \mathrm{MED}(Y_N)| \ge T_2) \tag{7}$$

where y_c is the vector of interest (the central vector in the filtering window), $T_1>0$ and $T_2 \ge 0$ are thresholds, and N is the length of the data.

The parameters for VMML filter were found after numerous simulations in different test images degraded by impulsive noise. The idea was to find the parameters values when the values of criteria PSNR and MAE would be optimum. In our experiments, a 3x3 sliding window was applied. The parameter of the *Andrew's sine* influence function is $r \le 31$ and for the impulsive noise detector $T_1=3$ and $T_2=0.3 \cdot \mathrm{med}\{Y_N\}$. To compute the weighted coefficients we use the exponential, Laplacian and uniform distribution functions.

3 Simulation Results

The described VMML filter with *the simple cut* (S) and *Andrew's sine* (A) influence functions, the *exponential* (E), *Laplacian* (L), and *uniform* (U) distribution functions and, the *impulsive noise detector* (D) and without it (ND) has been evaluated, and its performance has been compared with *vector median* (VM), *α-trimmed mean* (α-TM), *basic vector directional* (BVD), *generalized vector directional* (GVD), *adaptive* GVD (AGVD), *double window* GVD (GVD_DW), *multiple non-parametric* (MAMNFE), *vector median M-type K-nearest neighbor* (VMMKNN), and *fast adaptive similarity* VM (FASVM) filters [4,10,11,12].

The criteria used to compare the restoration performance of various filters were the *peak signal-to-noise ratio* (PSNR) for evaluation of noise suppression, the *mean absolute error* (MAE) for quantification of edges and detail preservation, the *mean chromaticity error* (MCRE) for evaluation of chromaticity retention, and the *normalized color difference* (NCD) for quantification of color perceptual error [1-4]:

$$\mathrm{PSNR} = 10 \cdot \log\left[(255)^2 / \mathrm{MSE}\right] \text{, dB} \tag{8}$$

$$\mathrm{MAE} = 1/M_1 M_2 \sum_{i=1}^{M_1} \sum_{j=1}^{M_2} \left\| y(i,j) - y_0(i,j) \right\|_{L_1} \tag{9}$$

where $\mathrm{MSE} = 1/M_1 M_2 \sum_{i=1}^{M_1}\sum_{j=1}^{M_2} \left\| y(i,j) - y_0(i,j) \right\|_{L_2}^2$ is the *mean square error*, M_1, M_2 are the image dimensions, $y(i,j)$ is the 3D vector value of the pixel (i,j) of the filtered image, $y_0(i,j)$ is the corresponding pixel in the original uncorrupted image, and $\|\cdot\|_{L_1}$, $\|\cdot\|_{L_2}$ are the L_1- and L_2-vector norms, respectively;

$$\mathrm{MCRE} = \sum_{i=1}^{M_1}\sum_{j=1}^{M_2} \left\| p_{i,j} - \hat{p}_{i,j} \right\|_{L_2}^2 \Big/ M_1 M_2 \qquad (10)$$

where $p_{i,j}$ and $\hat{p}_{i,j}$ are the intersection points of $y(i,j)$ and $y_0(i,j)$ with the plane defined by the Maxwell triangle, respectively;

$$\mathrm{NCD} = \sum_{i=1}^{M_1}\sum_{j=1}^{M_2} \left\| \Delta E_{Luv}(i,j) \right\|_{L_2} \Big/ \sum_{i=1}^{M_1}\sum_{j=1}^{M_2} \left\| E_{Luv}^*(i,j) \right\|_{L_2} \qquad (11)$$

where $\left\|\Delta E_{Luv}(i,j)\right\|_{L_2} = \left[\left(\Delta L^*(i,j)\right)^2 + \left(\Delta u^*\right)^2 + \left(\Delta v^*\right)^2 \right]^{1/2}$ is the norm of color error; ΔL^*, Δu^*, and Δv^* are the difference in the L^*, u^*, and v^* components, respectively, between the two color vectors that present the filtered image and uncorrupted original one for each a pixel (i,j) of an image, and $\left\|E_{Luv}^*(i,j)\right\|_{L_2} = \left[\left(L^*\right)^2 + \left(u^*\right)^2 + \left(v^*\right)^2 \right]^{1/2}$ is the norm or magnitude of the uncorrupted original image pixel vector in the $L^* u^* v^*$ space.

The 320x320 “Lena” color image was corrupted by 20% of impulsive noise. Table 1 shows that the performance criteria are often better for the proposed VMML filter in comparison when other filters in the most of cases.

Figure 1 exhibits the processed images for test image “Lena” explaining the impulsive noise suppression, and presenting the original image “Lena”, image corrupted with noise probability occurrence of 20% for each color channel, and exhibiting the filtering results produced by the FASVM, VMMKNN, and the proposed VMML filter. From these results one can see that the proposed VMML filter has a better subjective quality in comparison with VMMKNN and FASVM filters.

We also use one frame of the 176x144 “Miss America” and “Flowers” video color sequences, which were corrupted by 15% and 10% of impulsive noise, respectively. Table 2 shows that the performance criteria in a frame of “Miss America” are often better for the proposed VMML filter in comparison when other filters in the most of cases.

Figure 2 exhibits the processed frames for test frame “Miss America” explaining the impulsive noise suppression according with Table 2. The restored frame with VMML filter has a better subjective quality in comparison with MAMNFE and VMMKNN filters. Figure 3 presents the subjective visual qualities of restored color frame “Flowers”. The restored frame with VMML filter appears to have a similar subjective quality in comparison with FASVM and VMMKNN filters that have the better performance among the known color filters.

Table 1. Comparative restoration results for 20% impulsive noise for color image "Lena"

Algorithm	PSNR	MAE	MCRE	NCD
VM	21.15	10.73	0.035	0.038
α-TM	20.86	14.97	0.046	0.049
BVD	20.41	12.72	0.043	0.045
GVD	20.67	11.18	0.038	0.040
AGVD	22.01	11.18	0.028	0.036
GVDF_DW	22.59	10.09	0.028	0.039
MAMNFE	22.67	9.64	0.027	0.035
VMMKNN (S)	23.15	10.00	0.033	0.034
VMMKNN (A)	23.07	10.01	0.033	0.035
FASVM	24.80	5.00	0.025	0.017
VMML (S,E,ND)	24.90	7.81	0.032	0.033
VMML (S,L,ND)	25.81	6.49	0.026	0.016
VMML (S,U,ND)	25.88	5.53	0.026	0.026
VMML (A,E,ND)	22.65	12.32	0.034	0.040
VMML (A,L,ND)	25.88	7.00	0.026	0.015
VMML (A,U,ND)	26.52	5.36	0.022	0.015
VMML (S,E,D)	26.13	3.36	0.024	0.027
VMML (S,L,D)	26.46	2.90	0.023	0.027
VMML (S,U,D)	26.47	2.79	0.023	0.025
VMML (A,E,D)	25.25	4.48	0.030	0.023
VMML (A,L,D)	26.59	3.00	0.022	0.029
VMML (A,U,D)	26.73	2.74	0.021	0.025

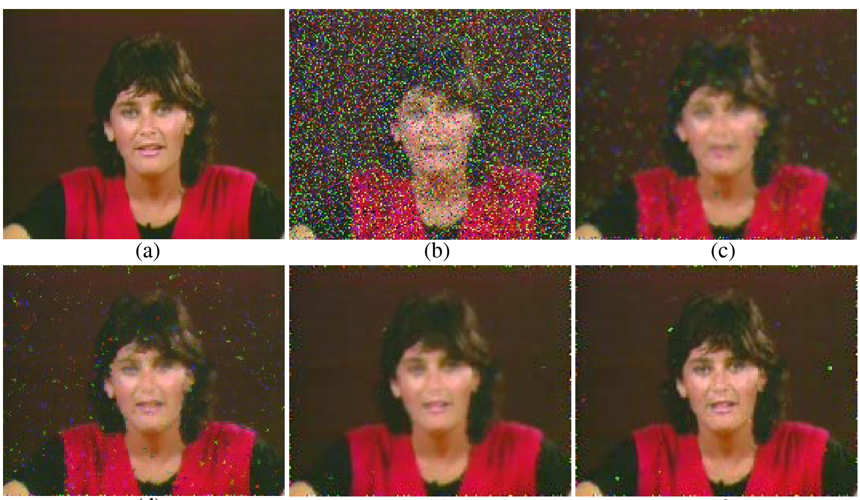
(a) (b) (c)

(d) (e) (f)

Fig. 1. Subjective visual qualities of restored color image "Lena", (a) Original test image "Lena", (b) Input noisy image (with 20% of impulsive noise), (c) VMMKNN filtering image, (d) FASVM filtered image (S), (e) Proposed VMML filtering image (S,E,ND), and (f) Proposed VMML filtering image (S,E,D)

Table 2. Restoration results for 15% impulsive noise for a color frame of "Miss America"

Algorithm	PSNR	MAE	MCRE	NCD
VM	25.54	5.38	0.0371	0.0332
α-TM	24.47	6.54	0.0589	0.0251
BVD	22.45	7.68	0.0379	0.0329
GVD	23.56	9.12	0.0362	0.0308
AGVD	26.97	5.24	0.0308	0.0302
GVDF_DW	26.88	5.95	0.0311	0.0249
MAMNFE	27.01	5.82	0.0390	0.0270
VMMKNN (S)	28.20	3.86	0.0312	0.0140
VMMKNN (A)	28.04	3.91	0.0317	0.0143
VMML (S,E,ND)	27.87	4.41	0.0221	0.0189
VMML (S,L,ND)	28.42	3.36	0.0218	0.0157
VMML (S,U,ND)	28.56	2.62	0.0218	0.0150
VMML (A,E,ND)	27.07	5.58	0.0225	0.0193
VMML (A,L,ND)	28.44	3.27	0.0218	0.0157
VMML (A,U,ND)	28.69	2.55	0.0217	0.0147
VMML (S,E,D)	28.42	1.52	0.0218	0.0143
VMML (S,L,D)	28.56	1.21	0.0218	0.0132
VMML (S,U,D)	28.57	1.13	0.0217	0.0129
VMML (A,E,D)	28.17	1.81	0.0219	0.0151
VMML (A,L,D)	28.59	1.20	0.0217	0.0131
VMML (A,U,D)	28.60	1.11	0.0217	0.0129



(a) (b) (c)

(d) (e) (f)

Fig. 2. Subjective visual qualities of restored color frame "Miss America", (a) Original test frame "Miss America", (b) Input noisy frame (with 15% of impulsive noise), (c) MAMNFE filtered frame, (d) VMMKNN filtered frame (A), (e) Proposed VMML filtered frame (A,U,ND), and (f) Proposed VMML filtered frame (A,U,D)

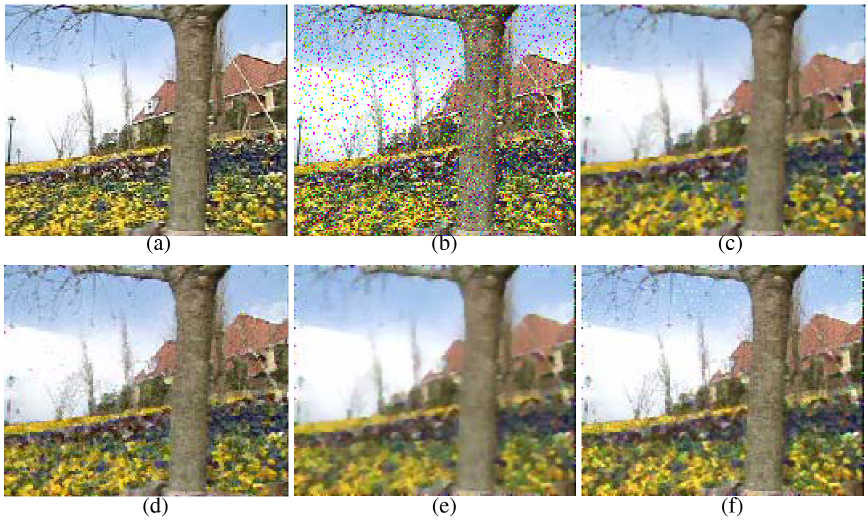


Fig. 3. Subjective visual qualities of restored color frame “Flowers”, (a) Original test frame “Flowers”, (b) Input noisy frame (with 10% of impulsive noise), (c) VMMKNN filtered frame (S), (d) FASVM filtered frame, (e) Proposed VMML filtered frame (A,U,ND), and (f) Proposed VMML filtered frame (A,U,D)

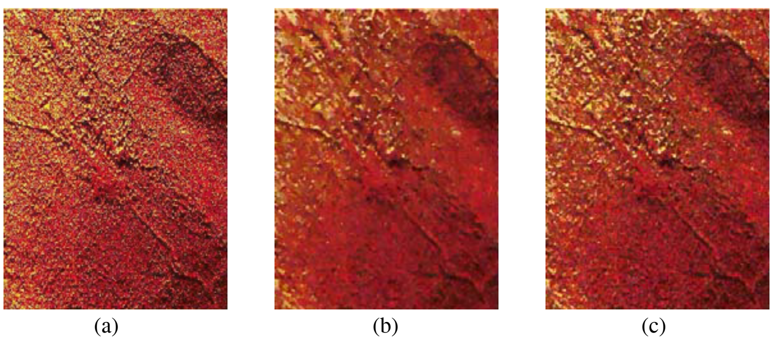


Fig. 4. Visual results of despeckled SAR image. a) Original image “Manzano”, resolution 2m, source Sandia National Lab., b) Despeckled image with the proposed VMML filter (S,U,ND), c) Despeckled image with the proposed VMML filter (S,U,D).

From Tables 1-2 and Figures 1-3, one can see that the proposed VMML filter provides better noise suppression, detail preservation, and color retention when we use the impulsive noise detector in the most of cases, otherwise the MAE increase but the PSNR decrease. By other hand, the VMML filter has better performance when the impulsive noise percentage is high.

To demonstrate the performance of the proposed filtering scheme we applied it for filtering of Ku Band SAR images, which naturally have speckle noise. The filtering results are presented in Figure 4 for the image “Manzano” (forest near Manzano State

Park, New Mexico). It is possible to see analyzing the filtering images that speckle noise can be efficiently suppressed, while the sharpness and fine feature are preserved using the proposed filter.

4 Conclusions

The proposed VMML filter is able to remove impulsive noise and preserve the edges and details in color imaging. The proposed filter uses the robust RM-estimator and utilizes an impulsive noise detector to provide better noise suppression, detail preservation, and color retention. The VMML filter has demonstrated better quality of image processing, both in visual and analytical sense in comparison with different known color image processing algorithms.

Acknowledgments. This work is supported by National Polytechnic Institute of Mexico.

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