A new adaptive vector median rational hybrid filter for impulsive noise suppression

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A New Adaptive Vector Median Rational Hybrid Filter for Impulsive Noise Suppression

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***Abstract*—In this article, multichannel image processing using an adaptive approach is the subject of our study. So we have Proposed a new Adaptive Vector Median Rational Hybrid Filter (PAVMRHF). This filter is formed by two-layered filters which combine three Adaptive Vector Median Filters in the first layer and a Rational Function in the second. Simulations'results illustrate that this new proposed filter outperforms the classic Vector Median Rational Hybrid Filter (VMRHF) when images are contaminated with impulsive noise.**

***Keywords*—Adaptive VMF; colour image; Fuzzy VMF; VMRHF; impulsive noise.**

I. INTRODUCTION

The need to filter images is a primary purpose for a variety of applications and in various fields such as photography, cinematography, surveillance, video conferencing … Noise suppressing, image restoration and image enhancement are the most important applications of filtering. A glance of the literature reveals that a good number of filters were introduced to get rid of the impulsive noise [1] [2] [3]. The Vector Median Filter (VMF), which minimizes vector space distance between image vectors as a criterion for the appropriate error, is one of the most commonly used filters. This filter is very efficient in suppressing the impulsive noise (salt and peppers). On the other hand, a new study on non-linear-vector filters shows that the adaptive approach is interesting and gives a better image quality [4][5][6]. Therefore, the use of structure Hybrid is more interesting compared to the simple and adaptive VMF [7]. In fact, the VMRHF filter (Vector Median Rational Hybrid Filter) is constituted by stages [7] [8]. The first one is a set of three VMF filters using each of the various pixels to the same filtering window. The second stage is a Rational Function (FR) which exploits the three outputs VMF filters to determine the filtered pixel according to a Rational function (as detailed on section II).

In [9], an adaptive class of nonlinear hybrid filters is presented. The hybrid filter is based on two stages. It is a combination of a fuzzy and a non-fuzzy component.

This article was organized as follows: we present in section 2 an overview of VMRHF filter. A description of the VMF and Adaptive VMF filter is the item of the next section. In section 4, we concentrate on the proposed Adaptive VMRHF. In section 5, our experimental results were introduced and discussed. The main conclusions of this research study were presented in section 6.

II. OVERVIEW OF VMRHF FILTER

Vector Median Rational Hybrid Filter (VMRHF) was introduced for the first time in [7]. Simulation results of the filtered image indicated that the VMRHF outperformed the Vector Median Filter (VMF). In [9], fuzzy techniques were being applied. The Fuzzy VMRHF (FVMRHF) showed better performance than the VMRHF for different types of noise. This new filter is founded on two stages. It is essentially a combination of a fuzzy and non-fuzzy component. The Principle architecture of the FVMRHF can be defined as follows: two bidirectional Fuzzy Vector Median sub-filters and one Fuzzy Center Weighted Vector Magnitude filter [9] are put in the first stage. In the second stage, the input set of the Vector Rational operation is constituted by the outputs of these three sub-filters in the first stage. Its structure is shown in figure 1.

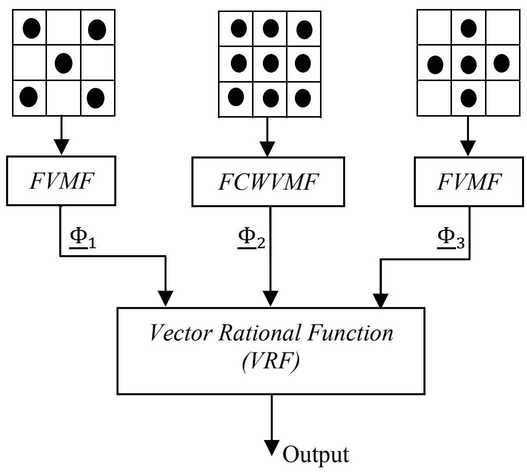

Figure 1.Structure of the adaptive FVMRHF using bidirectional sub-filters.

The result of the vector rational function constitute the output vector y_i of the FVMRHF, taking into Consideration the three input sub-functions which establish an input function Package $\{\Phi_1, \Phi_2, \Phi_3\}$. The central one ($\Phi_2$) is fixed as a fuzzy center weighted vector magnitude sub-filter. The equation of y_i will be explained in the following. In the newt

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section, we look closely the VMF filter as well as the Fuzzy VMF and Adaptive VMF.

III. VMF AND ADAPTIVE VMF FILTER

A. VMF Filter

The median Filter, used for gray scale images, is a nonlinear operator which consists in arranging pixels in a local window according to the intensity values. In the output image, it replaces the pixel value by the median value in this order. This idea is developed to include colour images [1]. This extension is based on the minimum Euclidean distance. The output is also the pixel value which reduces the distance between all pixels in a filtering window. This filter is named Vector median Filter. The figure 2 explains the difference between MF and VMF:

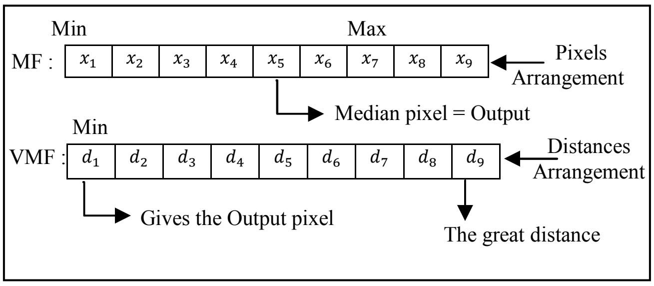

Figure 2. MF and VMF Filters

A median operation implements an odd size window (ex 3x3 window). At each position of the sample filtering window, distances calculated from the signal or image are sorted. Then, the median sample value is assumed as the sample that gave the minimum distance. This selected sample replaces the sample in the center of the window.

Let $x: Z^l \to Z^m$ denote a multichannel image, where l and m represent an image dimension and the number of colour channels, respectively. In the example of standard colour images, we get $l = 2$ and $m = 3$. Let $W = \{x_i \in Z^l; i = 1,$ *2, ..., N* define a filtering window of finite size *N*. *x1, x2, ...,* x_N are the noisy samples. The central sample $x_{(N+1)/2}$ defines the position of the filtering window.

We consider that each distance measure d_i is associated with the input multichannel sample x_i

$$d_i = \sum_{j=1}^{N} \left\|x_i - x_j\right\|_2 \ , i = 1 \dots N \qquad (1)$$

Where $\left\|x_i - x_j\right\|_2$ measures the distance between two channel samples x_i and x_j when using the Euclidean distance.

Supposing that the sums of the aggregated vector distances $d_1, d_2, \dots, d_N$, which imply the sums of the aggregated vector distances, satisfy the ordering criterion as

$$d_{(1)} \le d_{(2)} \le \cdots \le d_{(N)} \qquad (2)$$

and (2) denotes the same ordering proposition to the input Package $x_1, x_2, \dots, x_N$. The procedure results of colour vectors in the ordered sequence is written by

$$x_{(1)} \le x_{(2)} \le \cdots \le x_{(N)} \qquad (3)$$

The sample $x_{(1)} \in W$ which correspond to the minimum vector distance $d_{(1)} \in \{d_1, d_2, \dots, d_N\}$, form the output of the vector median filter that minimize the distance to different samples indoor this sliding filtering window W.

B. Adaptive Vector Median Filter

A new idea of Vector Median Filter is proposed in [6] named Adaptive Vector Median Filter (AVMF).

We consider ψ the approximation of the multivariate variance of the vectors comprised in the supporting window W of sufficiently large window size N, expressed by

$$\psi = \frac{d_{(1)}}{N-1} \qquad (4)$$

Where $d_{(1)}$ represent the measure of the distance calculated via (1) and (2). The quantity $d_{(1)}$ is the smallest aggregated distance associated that correspond to the VMF output $x_{(1)}$. It can be defined by:

$$d_{(1)} = \sum_{j=1}^{N} \left\|x_{(1)} - x_j\right\|_2 \qquad (5)$$

This approximation denoted in (4) defines the mean distance between the vector median and all different pixels contained in W. The division of $d_{(1)}$ by $(N-1)$ giving the number of distances from $x_{(1)}$ to all samples from W assures that the dispersion measure is independent on the filtering window size.

Therefore, the output of the Adaptive Vector Median Filter (AVMF) is described as below:

$$y_{AVMF} = \begin{cases} x_{(1)} & for\ d_{(N+1)/2} \ge \xi_1 \\ x_{(N+1)/2} & otherwise \end{cases} \qquad (6)$$

where y_{AVMF} denotes the proposed AVMF output, $d_{(N+1)/2}$ obtained via (1) indicates the distance measure of the center pixel $x_{(N+1)/2}$. The vector $x_{(1)}$ denotes the VMF output obtained in (3) and ξ_1 represents the threshold value defined as

$$\xi_1 = d_{(1)} + \lambda_1 \psi = \frac{N - 1 + \lambda_1}{N-1} d_{(1)} \qquad (7)$$

ψ was the approximated variance (4) and λ_1 denoted a tuning parameter which let the adjustment of the smoothing properties of the proposed method.

C. Fuzzy Vector Median Filter

In [9], fuzzy techniques were being applied. The general structure of the adaptive Fuzzy Vector Median Filter is donated as a fuzzy weighted average of the input vectors into the window W:

$$y_i = \frac{\sum_{j=1}^{N} W_j x_j}{\sum_{j=1}^{N} W_j} \quad (8)$$

These weighting coefficients W_j represent the transformations of the distances sum between the pixel in the in the filtering window center (the pixel under consideration) and the other input vectors in this filtering window. The value of the membership function can be considered as the comparison of the vector under consideration with the ideal vector that results in a distance, that can be expressed as

$$W_j = \frac{\beta}{1 + \exp\left(\tilde{d}_i^r\right)} \quad (9)$$

Where r is a parameter used to adjust the output's smoothness. Note that in this filter, the distance between pixels is calculated as follows:

$$\tilde{d}_i = \left(1/_N\right) \sum_{j=1}^{N} \|x_i - x_j\| \quad (10)$$

To compare these three filters, we calculated the Normalized Colour Difference (NCD) [9] of filtered images at the output of each filter. This parameter permits the measure of the colour distortion and can be defined as follows:

$$NCD = \frac{\sum_{i=1}^{N} \sum_{j=1}^{M} \sqrt{(L_{i,j}^o - L_{i,j}^f)^2 + (a_{i,j}^o - a_{i,j}^f)^2 + (b_{i,j}^o - b_{i,j}^f)^2}}{\sum_{i=1}^{N} \sum_{j=1}^{M} \sqrt{(L_{i,j}^o)^2 + (a_{i,j}^o)^2 + (b_{i,j}^o)^2}}$$

Where i, j represent the indices of the sample position, $M \times N$ is the size of the image, $L_{i,j}^o$,$a_{i,j}^o$,$b_{i,j}^o$ and $L_{i,j}^f$,$a_{i,j}^f$,$b_{i,j}^f$denote the values of the perceived lightness and chrominance related to the original image sample and the filtered image sample, respectively.

The obtained results indicate that the Adaptive VMF (AVMF) is obviously superior and outperform other filters. Therefore, in the next section, we focus on the incorporation of this filter in hybrid structure.

TABLE I. COMPARISON OF NCD OF THE PRESENTED FILTERS WHEN IMAGES ARE AFFECTED BY IMPULSIVE NOISE (30%)

	VMF	FVMF	AVMF
Flower	0.015514	0.017184	**0.005032**
Bird	0.050971	0.051489	**0.020313**
Fruit	0.022979	0.022881	**0.007707**
House	0.028317	0.026784	**0.006509**

As we can see, the AVMF filter gives clearly better results in term of NCD (as well as quality of images) than other filters.

IV. PROPOSED VMRHF

We propose in this work a new Adaptive Vector Median Rational Hybrid Filter (PAVMRHF). The new filter is a two-stage type hybrid filter. In the first stage, three adaptive sub-filters are the AVMF introduced in section III.*B*. It is shown in the previous section, that the AVMF [6] is more efficient for impulsive noise suppressing. In the second stage, the input Package of the Vector Rational operation is constituted by the outputs of the sub-filters in the first stage. Its structure is shown in figure 3.

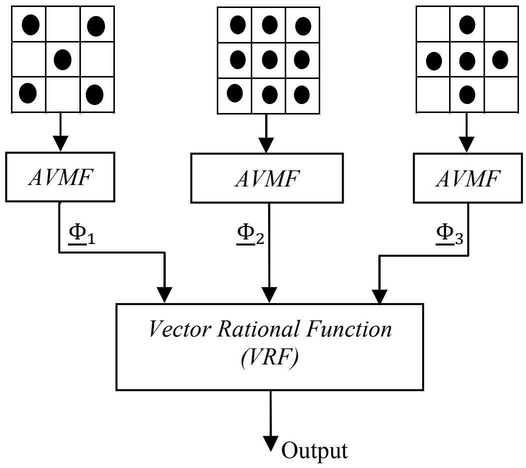

Figure 3. Structure of the PAVMRHF.

The output $y_i$of this filter can expressed as follow:

$$y_i = \Phi_2(x_i) + \frac{\sum_{j=1}^{3} \alpha_j \Phi_j(x_i)}{h + kD[\Phi_1(x_i), \Phi_3(x_i)]} \quad (11)$$

Where $D[.]$ represents the function of scalar output. This function plays a significant role in RF as the edge sensing term, $\alpha = [\alpha_1, \alpha_2, \alpha_3]$ characterizes the coefficient of the constant vector of the input sub-functions. In this study, we considered a simple prototype filter coefficients, that comply wih the condition: $\sum_{i=1}^{3} \alpha_i = 1$. In our paper, $\alpha = [1, -2, 1]^T$. h and k are positive constants. The parameter k is used to control the amount of the nonlinear effect.

V. EXPERIMENTAL RESULTS

In this section, the new filter PAVMRHF is compared to the FVMRHF mentioned in [9]. It was proved that the FVMRHF outperform the VMRHF classic in [9].

We note that all results of the filtering images presented in this study were obtained when a 3×3 square window is used (i.e. for $N = 9$). The noise attenuation properties of the different filters are explored by using the real colour images, Flower Fig. 4(a), bird Fig. 4(b), fruit Fig. 4(c), house Fig.4(d). The test images have been infected using impulsive noise ("salt and pepper" 20% in each image channel). By varying many value of λ_1, simulation results show that, $\lambda_1 = 4$ give the best quality of image.

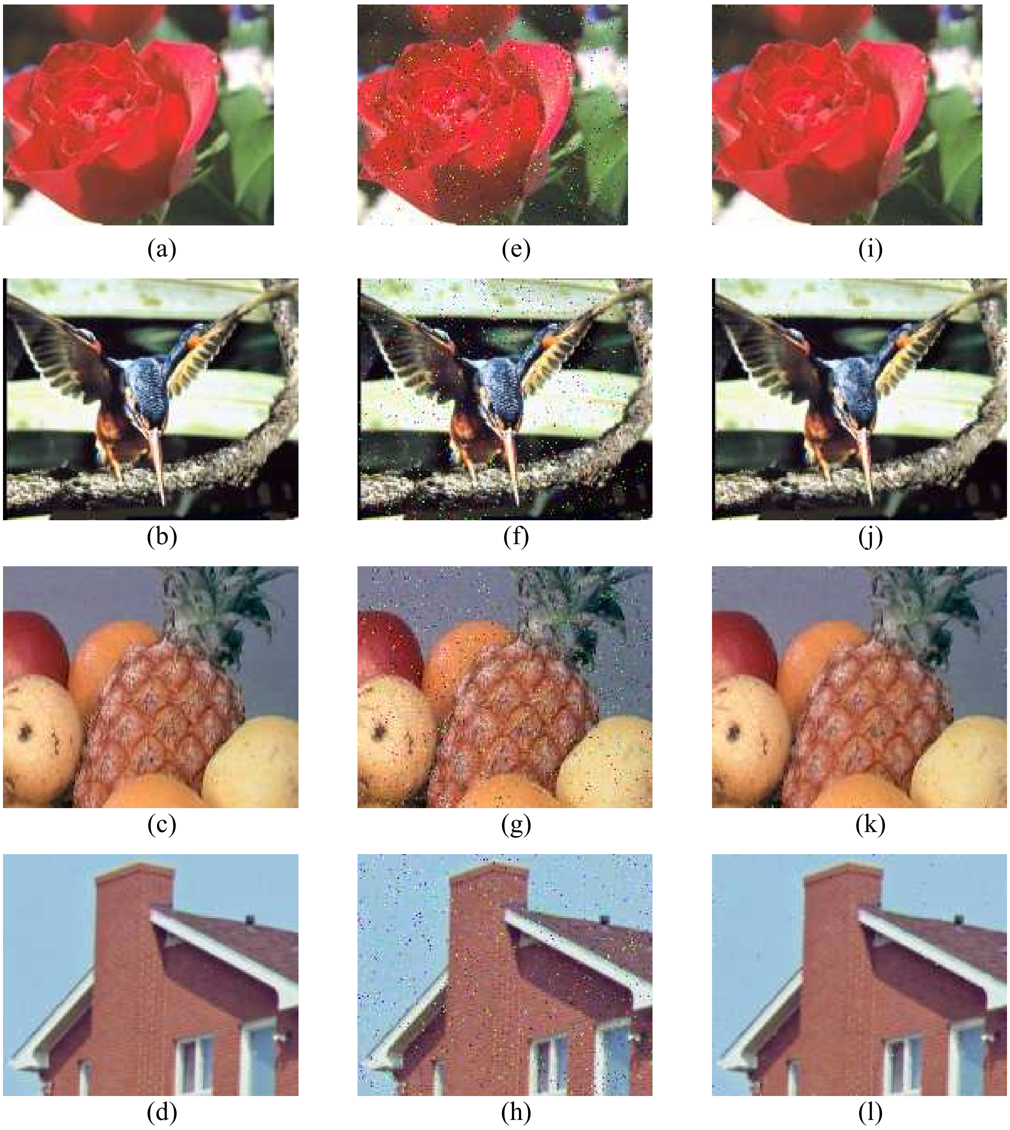

Figure 4. Original images: (a) Flower; (b) Bird; (c) Fruit; (d) House, (e-h) Noisy images affected by impulsive noise, (i-l) Filtered images by applying the PAVMRHF

The most broadly used measure is the Normalized Colour Difference (NCD). Therefore, we compare the NCD of different filtered images for different impulsive noise. In all simulations, the NCD of images on the output of the PAVMRHF is better than, those on the output of the FVMRHF.

From table II, we note the difference in term of NCD for these two filters. It is clear that this new Adaptive filter (PAVMRHF) outperform the Fuzzy VMRHF.

TABLE II. COMPARISON OF NCD OF THE PRESENTED FILTERS USING DIFFERENT IMPULSIVE NOISE RATES

	10%		**20%**		**30%**	
	FVMRHF	PAVMRHF	FVMRHF	PAVMRHF	FVMRHF	PAVMRHF
FLOWER	0.01572	**0.00279**	0.01595	**0.00558**	0.01643	**0.01116**
BIRD	0.04768	**0.01153**	0.04845	**0.01944**	0.04925	**0.02716**
FRUIT	0.02114	**0.00549**	0.02146	**0.00830**	0.0216	**0.01271**
HOUSE	0.02475	**0.00413**	0.02502	**0.00673**	0.02526	**0.01034**

VI. CONCLUSION

A new Adaptive Vector Median Rational Hybrid Filter has been suggested in this work. This filter is a two-stage filter which combines in an entirely novel way an adaptive Vector Median Filter in the first stage and a Rational Function in the second stage. Simulations results and subjective evaluation (NCD) of the filtered images show that this new filter outperforms the VMRHF classic when images are contaminated with impulsive noise. To further boost performance of the Adaptive VMRHF, we will focus in the future works, on the noise estimation. Our next aim is to implement this filter in Hardware or HW/SW design.

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