June. 2017. Vol. 10, No.1 ISSN 2305-1493
International Journal of Scientifc Knowledge

www.ijsk.org/ijsk

IMPULSIVE NOISE DIMINUTION USING NEW ADAPTIVE VECTOR MEDIAN RATIONAL HYBRID FILTER

[1]I. Abid, A. Boudabous, A. Ben Atitallah

Laboratory of Electronics and Information Technology (LETI), University of Sfax, Tunisia.
imen.abid.86@gmail.com, anis.boudabous@enis.rnu.tn,, ahmed.benatitallah@enetcom.rnu.tn

ABSTRACT

To ameliorate the quality of filtering, we studied in this paper, the adaptive approach applied in multichannel images. So, we have proposed an Adaptive Vector Median Rational Hybrid Filter (AVMRHF). This filter is based on Adaptive Vector Median Filters (AVMF) and a Vector Rational Function (VRF). The analysis and experimental results reported in this paper indicate that the proposed filter is able to remove impulsive noise in color images. Also, this new filter (AVMRHF) provides better performances comparing with the classic version VMRHF. Indeed, we note an average percentage of 70% of improvement with regard to the NCD parameter between the new filter and the classic one.

Keywords—*Vector approach; color image; adaptive Filter; VMRHF filter; impulsive noise.*

1. INTRODUCTION

The necessity of ameliorating quality of images is increasing on a daily basis. For that, the interest in perception and color processing has expanded rapidly. Thus, color image processing, like filtering [1][2], segmentation [3] and others domains, has been the subject of many studies recently. Indeed, filtering is one of the most important components of color image processing. Its most important applications are the suppression of noise, the restoration and the improvement of image quality. Another important factor is the difficulty in understanding and modeling the human perception of color because of the complexity of the human visual system. Therefore, linear filters used in image filtering applications cannot deal with the non-linearities of the transmission channels and cannot account for the non-linearity of human vision. That's why, the use of non-linear filters is suitable for digital color images. Indeed, they have good properties for image detail retention [4].

In non-linear filtering, the transformation of the pixel is the result of a non-linear combination of the values of pixels in the same window. The advantage of non-linear filtering is the possibility of removing noise without introducing an important distortion into the image. Moreover, color images can be presented or coded in color spaces according to the constraints of the application such as YUV space [5], RGB space...The latter space will be used in our research work. Two approaches are possible: the first one considers the image as three components RGB (Red Green Blue) and processes them each independently of the others. This approach is called the "Marginal approach" [6]. The drawback of this approach is that it ignores the correlation which may exist between the different components, and thus neglects all the information which may ameliorate the processing performance.

The second approach, known as the "Vector approach" [6] considers the pixels as a vector of three components RGB. This strategy is more satisfying since it takes into account the correlation between the three components, RGB, of the pixels in the color image. Also, it is more prevalent than the marginal approach, especially when using a non-linear filter.

Many non-linear filters based on the vector approach are proposed in the literature. The classic Vector Median Filter (VMF) and its variants represent the first non-linear approach which appeared for color image processing [7]. It minimizes the distance in a vector space between the image vector as an appropriate error criterion. It uses the channel's inner correlation and retains the scalar median desired properties, namely the zero impulse response and the edges of a signal. A second class of filters utilizes Rational Functions (RF) in its input/output relation, hence the name "Vector Rational Filters" (VRF) [8]. There are different interests to the use of such a function. Similarly, to a polynomial function, the RF is a universal approximate (which can approximate any continuous function arbitrarily well). But, it can reach a required level of accuracy with lower complexity, and improves better extrapolation capabilities. To benefit from the advantages of the VMF and the VRF, an hybrid structure was developed in [9]. The filter is named Vector Median-Rational Hybrid Filter (VMRHF). This VMRHF is a two-stage filter, which takes advantage in an effective way of the characteristics of the VMF and also those of the VRFs.

So, in this work, in order to upgrade the performance of the filtering quality without increasing the complexity of the algorithm, we are interested to look for improvements in the VMRHF to eliminate the impulsive noise. Our idea is to incorporate the adaptive method [13] in these filters to get a new adaptive VMRHF (AVMRHF). A comparison will be made between these two filters and the classic ones. The remainder of this paper is organized as follows: we begin in section 2 with a presentation of the classic VMRHF. Section 3 illustrates some related work. In section 4, we develop the adaptive approach for our filter. In section 5, we give an idea about the Impulsive

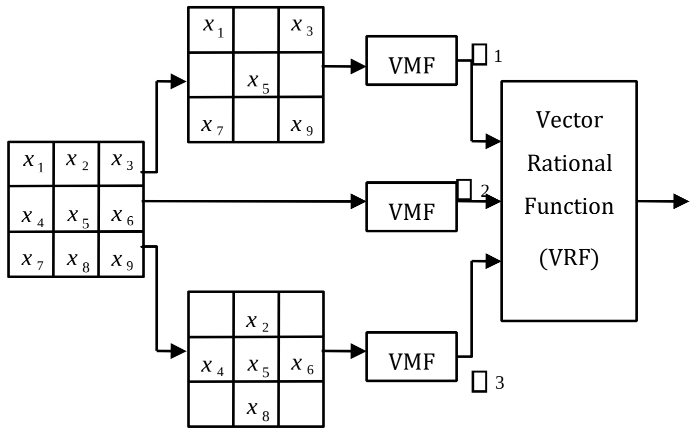
June. 2017. Vol. 10, No.1 ISSN 2305-1493
International Journal of Scientifc Knowledge

www.ijsk.org/ijsk

Noise and Quality Metric. In section 6, however, our simulation results are presented and discussed. Finally, the main conclusions of this research work are drawn in section 7.

2. PRESENTATION OF THE CLASSIC VMRHF

The Vector Median Rational Hybrid Filter (VMRHF) was presented initially in [9]. The VMRHF is formed by



three sub-filters (three VMFs) in the first stage and a vector rational operation in the second stage. VMRHFs are very effective in color (in general multichannel) image processing, because they receive the properties from their ancestors. They form very precise estimators in long-and-short-tailed noise distributions. Additionally, they preserve the chromaticity of image vectors at the same time. Moreover, they proceed in a small window with a small number of operations, resulting in fast and simple filter structures. Their structure is shown in figure 1.

Fig. 1.Structure of the classic VMRHF

The output vector y_i of the VMRHF is constituted using the result of the vector rational function, taking into consideration the three input sub-functions which establish an input function package $\{\Phi_1,\Phi_2,\Phi_3\}$. The output of y_i is defined as follows:

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

where D [.] is the function of scalar output. This function plays a significant role in RF as the edge sensing term and $\beta = [\beta_1,\beta_2,\beta_3]$ characterizes the coefficient of the constant vector of the input sub-functions. h and k are positive constants [9][11].

As we can see, we put in the first stage of the VMRHF three sub-filters VMF. The median filter, used for gray scale images, is a non-linear operator that consists in ranging pixels in a local window depending on the intensity values. Then, in the output image, this filter replaces the pixel value by the median value in this order. This idea is developed to include color images [7]. 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. Figure 2 presents the difference between MF and VMF.

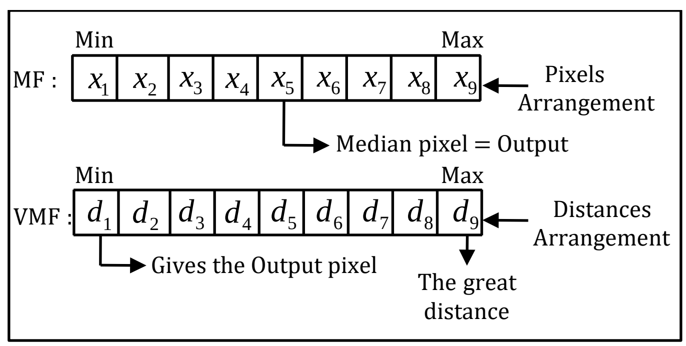


Fig. 2.MF and classic VMF filters

sample of the considered window is replaced by the selected sample. Output Let $x : Z^l \rightarrow Z^m$ represent a multichannel image, with y_i l and m denoting the image dimension and the number of color channels, respectively. When having the standard color

$$W = \{x_i \in Z^l; i = 1, 2, \ldots, N\}$$

images, we obtain l = 2 and m = 3. Also, we define by a finite size (N) filtering

window. $x_1,x_2,\ldots,x_N$ represent the noisy samples. $x_{(N+1)/2}$ is the central sample which defines the position of the filtering window. Let's consider that each input multichannel sample x is associated with a distance measured.

A median operation executes an odd size window (exp 3 × 3 window). So, at each position of the sample filtering window, the distances computed from the image or signal are sorted. Here, the value of the median sample is supposed to be the sample giving the minimum distance. Therefore, the central

June. 2017. Vol. 10, No.1 ISSN 2305-1493
International Journal of Scientifc Knowledge

www.ijsk.org/ijsk

$$d_i = \sum_{j=1}^{N} \| x_i - x_j \|_2 \,, i = 1,...,N \qquad (2)$$

where the term $\| x_i - x_j \|_2$ 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 $d_1,d_2,...,d_N$, which imply the sums of the aggregated vector distances, satisfy the ordering criterion as

$$d(1) \le d(2) \le ... \le d(N) \qquad (3)$$

then (3) denotes the same ordering proposition of the input package $x_1,x_2,...,x_N$. And so, the procedure results of color vectors in the ordered sequence correspond to

$$x(1) \le x(2) \le ... \le x(N) \qquad (4)$$

The sample $x_{(1)} \in W$ which corresponds to the minimum vector distance $d_{(1)} \in \{d_1,d_2,,d_N\}$, establishes the output of the vector median filter which minimizes the distance to all other samples inside this sliding filtering window W. In general, we can define the sample that corresponds to the minimum vector distance by

$$x_{(i)} = Argmin\,(d_{(i)}) \qquad (5)$$

3. RELATED WORK

Many approaches have been proposed in the literature to eliminate impulsive noise in color image based on classic vector filters. In [15], fuzzy techniques were presented. The architecture of the proposed filter is established in two stages. This filter combines essentially a fuzzy and nonfuzzy component. So, its structure can be depicted as follows: three adaptive sub filters are computed, in the first stage, using fuzzy membership functions based on two distance criteria: the first is the Euclidean distance ($L2$-norm), which is why the resulting sub filter is named fuzzy vector magnitude filters; and the second is the angular distance and thus, the name fuzzy VDFs. Therefore, the outputs of the three sub filters in stage one form, in the second stage, the input set of the vector rational operation.

In [16], another method is presented for reducing impulsive noise in color images. This method consists of three steps: In the first step, Laplacian operators and threshold values are used to identify pixels that are likely to have been corrupted by noise. In the second step, these noise candidates are judged by using the neighborhood of each pixel. After recognizing the noisy pixels, the vector median filter is used for replacing the noisy pixels, in the third step. The proposed algorithm is tested against different color images, and it gives a better peak signal-to-noise ratio and a lower normalized mean square error.

In [13], the author presented a new adaptive multichannel filter. The structure of the proposed filter takes advantage of robust order-statistic theory, switching schemes and approximation of the multivariate dispersion. So, the VMF was improved and a variable threshold was used in the equation. This filter does not necessarily replace pixels unlike the VMF filter and uses a threshold value to detect the probability of the pixel to be noisy.

This latter method is characterized by its low algorithm complexity, unlike the others methods proposed in [15] and [16] which prove their algorithmic complexity. In addition, this method is interesting since it ameliorates the classic filters without introducing complexity in their algorithms. Therefore, in the next section, this adaptive approach will be used to improve the filtering quality of the classic VMRHF filter, and so we propose the new adaptive filter AVMRHF for impulsive noise reduction.

4. ADAPTIVE METHOD USED IN THE VMRHF FILTER

In this section, a new Adaptive Vector Median Rational Hybrid Filter (AVMRHF) is proposed. We should mention that we have presented this filter in [17]. However, in this paper, we will give more details and more simulation results for this filter. So, the new filter is a two-stage-type hybrid filter. In fact, in the first stage, there are three adaptive sub-filters (AVMF) which are introduced. It was proved that this AVMF is more effective for impulsive noise reduction [13]. As to the second stage, there is one Vector Rational operation. So, its input package is constituted by the three outputs of the AVMF of the first stage. We show its structure in figure 3.

The expression of the output y_i of this filter is like the output of the VMRHF (equation (1)). In this research work, we chose simple prototype filter coefficients which comply with the condition: $\sum_{i=1}^{3} \beta_i = 0$. In our paper, we considered $\beta = [1,-2,1]^T$. And k is a parameter which is used to control the amount of the non-linear effect.
The difference in the expression of the two filters (VMRHF and AVMRHF) is the output of the three sub-filters Φ_i. So, to get the output of each filter, we take the following steps [13]: We consider Ψ_{AVMF} the approximation of the multivariate

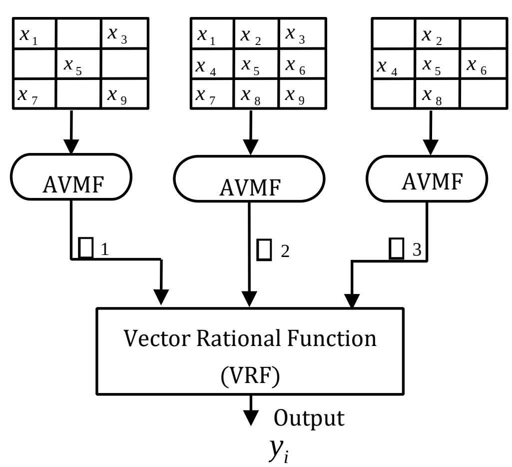


Fig. 3.Structure of the proposed AVMRHF

International Journal of Scientifc Knowledge

www.ijsk.org/ijsk

variance of the vectors comprised in the supporting window W of a sufficiently large window size N, expressed by:

$$\Psi_{AVMF} = \frac{d_{(1)}}{N-1} \tag{6}$$

where $d_{(1)}$ represents the measure of the distance computed via (2) and (3). We note that the quantity $d_{(1)}$is the smallest aggregated distance that corresponds to the VMF output $x_{(1)}$. It is defined by:

$$d_{(1)} = \sum_{j=1}^{N} \|x_{(1)} - x_j\|_2 \tag{7}$$

In fact, the approximation denoted in (6) defines the mean distance between the vector median with all different pixels held in W. This division of $d_{(1)}$ by (N −1) giving the number of distances from $x_{(1)}$ to all other samples from W assures that the dispersion measure is independent of the filtering window size.

Therefore, the output of the AVMF is described as given below:

$$y_{AVMF} = \begin{cases} x(1) & \text{for } d(N+1)/2 \geq \xi_{AVMF} \\ x(N+1)/2 & \text{otherwise} \end{cases} \tag{8}$$

In this equation, $y_{AV\,MF}$ denotes the output of the AVMF, $d_{(N+1)/2}$ which is obtained via (2) indicates the distance measure of the center pixel $x_{(N+1)/2}$. The vector $x_{(1)}$ denotes the VMF output obtained in (4) and $\xi_{AV\,MF}$ represents the threshold value defined as

$$\xi_{AVMF} = d_{(1)} + \lambda_{AVMF}\Psi_{AVMF} = \frac{N-1+\lambda_{AVMF}}{N-1} d_{(1)} \tag{9}$$

$\Psi_{AV\,MF}$ was the approximated variance (6) and $\lambda_{AV\,MF}$ denoted a tuning parameter which let the adjustment of the smoothing properties of the proposed method.

5. IMPULSIVE NOISE AND QUALITY METRIC

To evaluate the performances of the proposed filters (AVMRHF and AVDDF), we will compare them with the classic filters (VMRHF and VDDF). For this purpose, we will calculate some quality metrics like PSNR, MSE and NCD for images contaminated by impulsive noise.

A. Impulsive Noise

Even with the latest technology, there are many situations where the degradation of original images are too important for some applications. This may be due to, for example, the difficult conditions of acquisition encountered in medical imaging, astronomy or in the military. Any treatment can really cause the proper reappearance of the information that was lost during the image acquisition. Yet, it is possible to compensate for the degradation of the information. The techniques of image restoration and image enhancement aim to achieve a better image quality.

There are many types of degradation in digital images. In this work, we are interested in filtering images contaminated by noise. Indeed, the main causes of noise are errors produced during transmission, through means of recording, during electronic measurements, etc ... So, on each pixel, the noise is characterized by three components, often independent. Because of the complexity of the process, the noise of acquisition is usually modeled by a White Gaussian noise. In addition, the imperfections of the image resulting from impulsive noise are generated during transmission with a communication channel. Indeed, the methods of processing and filtering color images are distinguished by the degree of complexity with which the noise is modeled. So, in the case of color images, the noise will affect each component separately. In this paper we are interested in studying and eliminating impulsive noise. This noise appears especially by scanning an image or during its transmission. Let $X_{i,j}^k$,($k = R,GorB$) be a component of the vector representing a pixel at the position $(i,j) \in A \equiv 1,...,M \times 1,...,N$ the color level for an $M \times N$ image, and $[S_{min}S_{max}]$ is the range of values of X, i.e $S_{min} \leq X_{i,j}^k \leq S_{max}$ for each $(i,j) \in A$. Let $Y_{i,j}^k$ be the k component of the vector representing a pixel (i,j) on the noisy image. In the classic model of the impulsive noise, the color (R,G,orB) observed for a pixel at the position (i,j) for the component k is given by:

$$Y_{i,j}^k = \begin{cases} S_{min} & \text{, with probability } p \\ S_{max} & \text{with probability } q \\ X_{i,j}^k & \text{with probability } (1-p-q) \end{cases} \tag{10}$$

where (p + q) represent the noise parameter.

B. Quality Metric

- Objective Metric

To compare quantitatively the performance of different filters, some reconciliation measures between the two digital images will be used. The Mean Square Error “MSE” [18] is defined by:

$$MSE = \frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} \|O_{i,j} - f_{i,j}\|_2 \tag{11}$$

where $M \times N$ characterizes the size of the image, $O_{i,j}$ is a pixel of the original image and $f_{i,j}$ is the corresponding pixel of the filtered image.

We will also compute the Peak Signal to Noise Ratio “PSNR”. It is defined by the following equation:

$$PSNR = 10 \times log_{10}\left[\frac{max^2}{MSE}\right] \tag{12}$$

where max is the maximum value that a pixel can reach.

- Subjective Metric

June. 2017. Vol. 10, No.1 ISSN 2305-1493

International Journal of Scientifc Knowledge

www.ijsk.org/ijsk

Seeing the importance of taking into account the human color vision, in addition to the PSNR computation, the measurement of the Normalized Color Difference "NCD" [13][19] defined in the Lab space will also be considered. Let L be the clarity component, which ranges from 0 (black) to 100 (white). The component a represents the range of the red axis. The component b represents the range of the yellow axis. Let i and j be the sample position indices; $L^0_{i,j}$, $a^0_{i,j}$, $b^0_{i,j}$ and $L^f_{i,j}$, $a^f_{i,j}$, $b^f_{i,j}$ are the values of perception (lightness) representing the chrominance related to the sample of the original image, respectively. The difference between two colors in the CIELab space is:

$$\Delta E = \left[\left(L^0_{i,j} - L^f_{i,j}\right)^2 + \left(a^0_{i,j} - a^f_{i,j}\right)^2 + \left(b^0_{i,j} - b^f_{i,j}\right)^2\right]^{\frac{1}{2}} \tag{13}$$

The metric NCD is a measurement of information preservation in the color images. It is defined by:

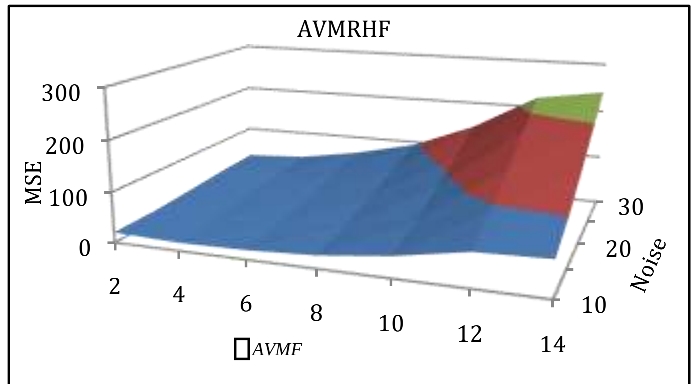
$$NCD = \frac{\sum_{i=1}^{N}\sum_{j=1}^{M}\sqrt{(L^o_{i,j} - L^f_{i,j})^2 + (a^o_{i,j} - a^f_{i,j})^2 + (b^o_{i,j} - b^f_{i,j})^2}}{\sum_{i=1}^{N}\sum_{j=1}^{M}\sqrt{(L^o_{i,j})^2 + (a^o_{i,j})^2 + (b^o_{i,j})^2}} \tag{14}$$

Therefore, the MSE, PSNR and NCD will be used in our work to make conclusions about the objective quality (MSE and PSNR) and the subjective one (NCD) of the image.

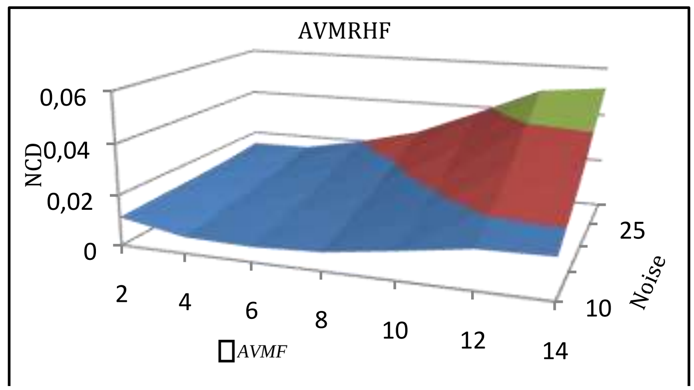
6. SIMULATION RESULT

In this section, we will compare the performances of the new filter AVMRHF. So, the proposed filter was implemented using C/C++ project software environment. All the images are represented in the RGB color space. The size of the test images is 255 × 255. It is worth noticing that all the image filtering results presented in this study were acquired with a 3 × 3 square window (N = 9). The test images have been infected using impulsive noise ("salt and pepper" [16]). The noise levels (noise intensity) have been varied from 10% to 30%. To efficiently choose the suitable values of λ_{AVMF}, we have drawn in figures 4 diagrams that show the NCD and the MSE in terms of impulsive noise and the λ_{AVMF} parameter for the AVMRHF filter. Note that these results were achieved using the test image Lena corrupted by impulsive noise with an intensity ranged from 10% to 30% and with a step size of 10%. A visual inspection of the results depicted in figures 4 reveals that the optimal value of λ slightly decreases with the degree of noise corruption. Therefore, the graphs shown in figures 4 denote that the NCD and MSE metrics are optimal when λ_{AVMF} = 4 for the proposed AVMRHF filter.

To evaluate the performances of our proposed filter, we have chosen some typical images. So, the test has been done with four standard color images of Flower figure 5(a), Lena figure 5(d), Watch figure 5(g), Peppers figure 5(j). The filtered images are presented in figure 5 for visual and qualitative comparison, since in all cases they are the best measure of performance. This is confirmed by the computation of the quality metric using the MSE, NCD and PSNR.



(a)



International Journal of Scientifc Knowledge

www.ijsk.org/ijsk

Filter		VMRHF		AVMRHF	
Image	Noise	PSNR	NCD	PSNR	NCD
Flower	10%	30,3101	0,028164	35,4024	0,007421
	20%	29,7753	0,029275	32,8694	0,012520
	30%	29,5459	0,030149	31,5257	0,018051
Lena	10%	31,9986	0,032464	36,1030	0,006464
	20%	31,5560	0,033547	34,0056	0,009781
	30%	31,1297	0,034597	32,0419	0,014789
Watch	10%	31,9693	0,024128	36,1164	0,004725
	20%	31,2683	0,025339	33,2288	0,009230
	30%	30,9367	0,026640	31,4336	0,013816
Peppers	10%	32,2941	0,044012	37,6692	0,00735
	20%	31,7807	0,044809	35,0620	0,010001
	30%	31,4449	0,045434	32,9549	0,014127

Table I. Comparison Of The Adaptive Filters With The Classic Ones For Different Percentage Of Noise For All Images Presented In Figure 5.

(b)

Fig. 4. Performance of the proposed AVMRHF depending on the adjustment of the parameter λ_{AVMF} and the impulsive noise intensity using the test image of Lena.

Figure 6 summarizes the results obtained using the MSE, NCD and PSNR error criteria for images contaminated by 10%, 20% and 30% impulsive noise. The comparisons of the filtering performance results with three distinct measures for impulsive noise are shown in the form of plots in figure 6. The results correspond to the use of the test images shown in figures 5(a)(e)(i)(m). In these schemes, the proposed filter is compared with the classic one. The obtained results indicate that the new Adaptive filter is clearly superior and outperform the classic filter. So, as shown in figure 6, we note an important decrease in the value of the NCD and MSE against a gain in the value of the PSNR, of course. These improvements are evident for Lena's image as well as for the peppers' image. For example, the reduction of the NCD for lena's image is approximately 78% between the VMRHF and the AVMRHF when the noise is 10% but this percentage is reduced when the noise increases up to approximately 57% in 30% of noise. In table I, we show the results obtained using the NCD and PSNR error criteria for all the images shown in figure 5 to give a better idea of the simulation values. Evermore the adaptive filters present a lower value of NCD compared with the classic ones. The proposed Adaptive filter can effectively remove impulses, smooth out nominal noise and preserve edges, details and color uniformity. For the images corrupted by high intensity of impulsive noise ($\succ 30\%$), re-optimization of the filter parameter may be recommended to obtain the robust smoothing capability.

It should be emphasized that the Adaptive scheme such as the considered AVMRHF are primarily geared to address to problem of impulsive noise removal in the images with a low or moderate amount of corrupted pixels. For such a task, the proposed solutions hold excellent performance.

International Journal of Scientifc Knowledge

www.ijsk.org/ijsk

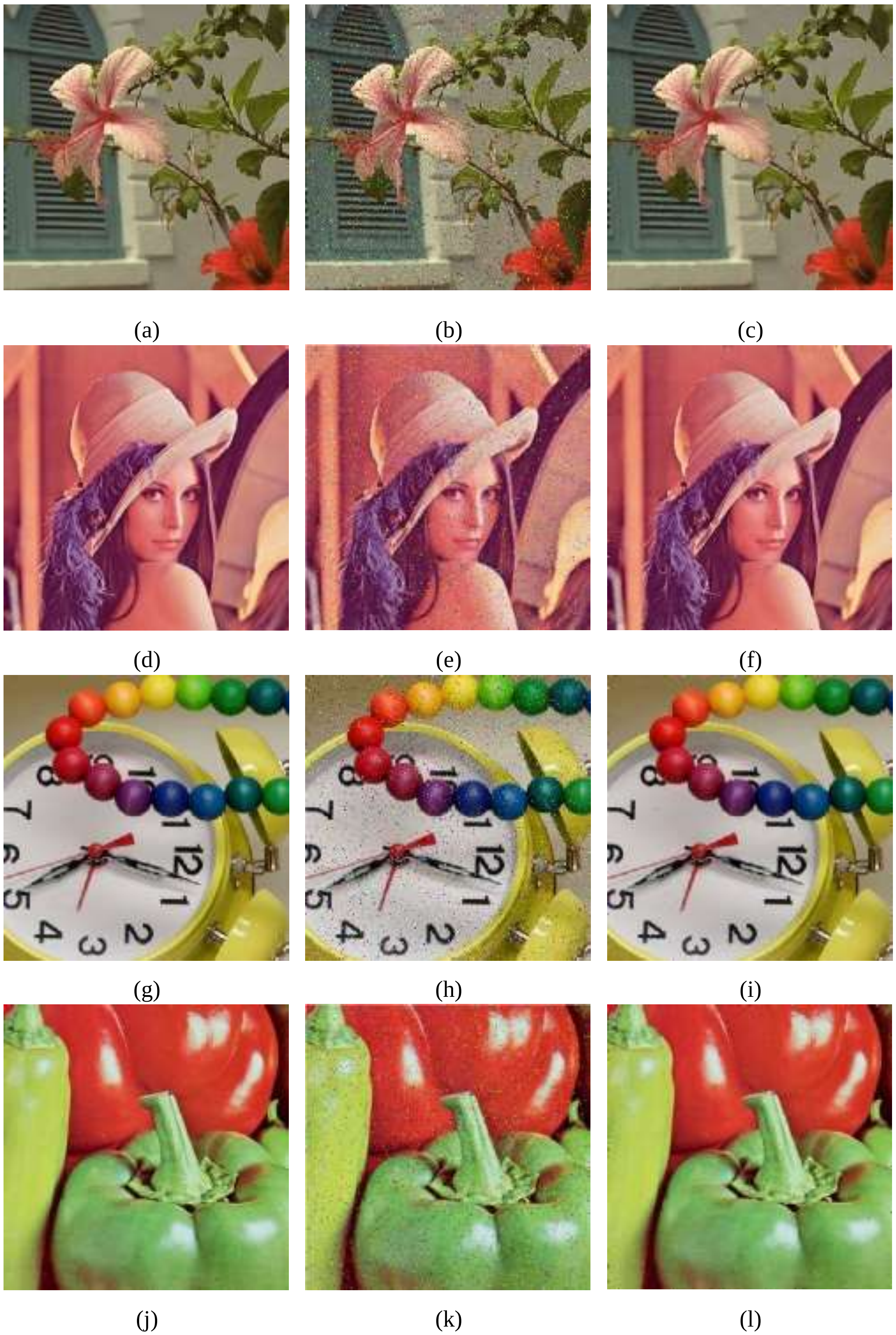


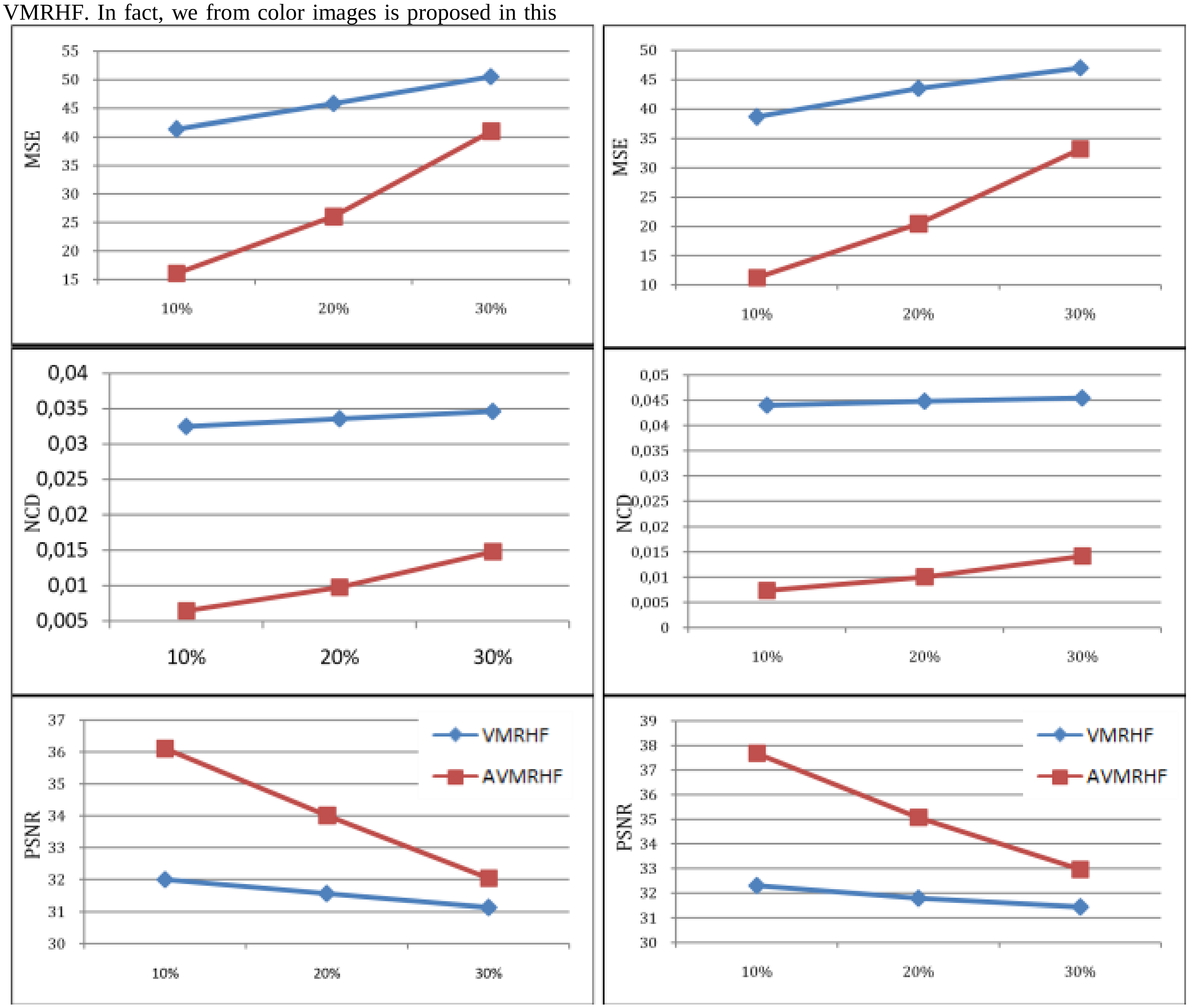
Fig. 5. Original images: (a) Flower; (d) Lena; (g) Watch; (j) Peppers; (b)(e)(h)(k) Noisy images by impulsive noise (30%), (c)(f)(i)(l) Filtered images using the proposed AVMRHF.

June. 2017. Vol. 10, No.1 ISSN 2305-1493
International Journal of Scientifc Knowledge

www.ijsk.org/ijsk

7. CONCLUSION

The experimental results show that this adaptive method is effective and more. Novel adaptive filter AVMRHF for salt and pepper removal efficient compared to the classic filter VMRHF. In fact, we from color images is proposed in this paper. A prominent get an average of improvement of 77% for the NCD value feature of the algorithm is to provide a proper approach to



(a) (b)

Fig. 6.Comparative results for the images contaminated by impulsive noise: (a) Lena's image; (b) Peppers' image.

when the noise is 10%. However, this percentage is reduced absolutely when the noise reaches 54%. The performance is obviously much better especially for images with lower density noise. To further boost the performance of these filters, we will endeavor in our future works to implement these filters in Hardware or HW/SW design to obtain the minimum run time.

ISSN 2305-1493
International Journal of Scientifc Knowledge

www.ijsk.org/ijsk

REFERENCES

1 S. Wang And C. Wu, “A New Impulse Detection And Filtering Method For Removal Of Wide Range Impulse Noises”, Pattern Recognition, 2009, Vol. 42, No 9, P. 2194-2202.

2 Z. Ramadan, “Monochromatic-Based Method For Impulse Noise Detection And Suppression In Color Images”, Circuits, Systems, And Signal Processing, 2013, Vol. 32, No 4, P. 1859-1874.

3 R. Cossu, L. Chiappini “A Color Image Segmentation Method As Used In The Study Of Ancient Monument Decay”, Journal Of Cultural Heritage, 2004, Vol. 5, No 4, P. 385-391.

4 M. E. Celebi, H. A. Kingravi And Y. A. Aslandogan, “Nonlinear Vector Filtering For Impulsive Noise Removal From Color Images”, Journal Of Electronic Imaging, 2007, Vol. 16, No 3, P. 033008-033008-21.

5 P. Denis, “Quaternions Et Algbres Gomtriques, De Nouveaux Outils Pour Les Images Numriques Couleur”, Thse De L’universit De Poitiers, December 2007.

6 P. Lambert, “Etudes Methodologiques Du Filtrage Et De La Segmentation´ Des Images Multi-Composantes”, Memoir Hdr, Savoie University, July 2002.

7 J. Astola, P. Haavisto and Y. Neuvo, “Vector Median Filters”, Proceedings of The Ieee, 1990, Vol. 78, No 4, P. 678-689.

8 L. Khriji, F. Alaya Cheikh, M. Gabbouj, “High Resolution Digital Resampling Using Vector Rational Filters”, Optical Engineering, 1999, Vol. 38, No 5, P. 893-901.

9 L. Khriji and M. Gabbouj, “Vector Median-Rational Hybrid Filters For Multichannel Image Processing”, Ieee Signal Processing Letters, 1999, Vol. 6, No 7, P. 186-190.

10 P.E. Trahanias, D. Karakos, A.N. Venetsanopoulos, “Directional Processing Of Color Images: Theory And Experimental Results”, Ieee Transactions On Image Processing, 1996, Vol. 5, No 6, P. 868-880.

11 L. Khriji, “Vector Directional Distance Rational Hybrid Filters For Color Image Restoration”, Computer Journal Of Engineering Research, 2005, Vol. 1, No 2, P. 1-11.

12 D. G. Karakos and P. E. Trahanias, “Combining Vector Median And Vector Directional Filters: The Directional-Distance Filters”, In Image Processing, 1995. Proceedings., International Conference On (Vol. 1, Pp. 171-174). Ieee.

13 R. Lukac, K. N. Plataniotis, A. N. Venetsanopoulos And

14 B. Smolka, “A Statistically-Switched Adaptive Vector Median Filter”, Journal Of Intelligent And Robotic Systems, 2005, Vol. 42, No 4, P. 361391.

15 Boudabous, A. Ben Atitallah, L. Khriji, And Al. “Fpga Implementation Of Vector Directional Distance Filter Based On Hw/Sw Environment Validation”, Aeu-International Journal Of Electronics And Communications, 2011, Vol. 65, No 3, P. 250-257.

16 Khriji, And M. Gabbouj, “Adaptive Fuzzy Order Statistics-Rational Hybrid Filters For Color Image Processing”, Fuzzy Sets And Systems, 2002, Vol. 128, No 1, P. 35-46.

17 Pilevar, S. Saien, M. Khandel, And Al. “A New Filter To Remove Salt And Pepper Noise In Color Images”. Signal, Image and Video Processing, 2015, Vol. 9, No 4, P. 779-786.

18 Abid, A. Boudabous, A. B. Atitallah, “A New Adaptive Vector Median Rational Hybrid Filter For Impulsive Noise Suppression”. In: Sciences And Techniques Of Automatic Control And Computer Engineering (Sta), 2015 16th International Conference On. Ieee, 2015. P. 417-421.

19 O. Rubel, V. Lukin, S. Abramov, And Al. “Efficiency of Texture Image Filtering and Its Prediction”, Signal, Image And Video Processing, 2016, Vol. 10, No 8, P. 1543-1550.

20 Ben Atitallah, A. Boudabous, L. Khriji, Lazhar, And Al.“Reconfigurable Architecture Of Vdf Filter For Multidimensional Data”, International Journal Of Circuit Theory And Applications, 2013, Vol. 41, No 10, P. 1047-1058.