MULTICHANNEL IMAGE PROCESSING USING FUZZY VECTOR MEDIAN-RATIONAL HYBRID FILTERS

Lazhar Khriji

Electrical Engineering Department
E.N.I.M., CP 5019, Monastir, Tunisia.
e-mail: lazhar.kheriji@enim.rnu.tn

Moncef Gabbouj

Signal Processing Laboratory, TUT
P.O. Box 553 FIN-33 101 Tampere, Finland,
e-mail: moncef@cs.tut.fi

ABSTRACT

A new multichannel filtering approach is introduced and analyzed in this paper. These filters are based on rational functions (RF) using fuzzy transformations of the Euclidean distances among the different vectors to adapt to local data in the image. The output is the result of vector rational operation taking into account three subfunctions, such as two Fuzzy Vector Median (FVM) subfilters and one Fuzzy Center Weighted Vector Median Filter (FCWVMF). Simulation studies indicate that the filters are computationally attractive and have excellent performance such as edge and details preservation and accurate chromaticity estimation.

1. INTRODUCTION

Recently, an increased attention was given to the filtering techniques to date for multichannel image processing. The nonlinear filters applied to images are required to remove noise (Gaussian and impulsive) and preserve the integrity of edge and detail information. To this end, vector processing is more appropriate to filter noise and detect edges on multichannel images, compared to traditional approaches that use instead componentwise operators. For instance, the vector median filter (VMF) [1] minimizes the distance in the vector space between the image vectors as an appropriate error criteria. A second class of filters the so-called "vector directional filters" (VDF) [10] uses the angle between the image vectors as an ordering criteria. Lately, the vector rational filter (VRF) was introduced in [5] operating on the input vectors using rational functions. Recently, a new nonlinear filter structure *the vector median-rational hybrid filters* (VMRHF) in an hybrid form was developed in [4]. The VMRHF is a two-stages filter, which exploits in an effective way the features of the vector median filter and those of the vector rational filters. Fuzzy techniques have been successfully applied to image processing field. The local correlation in the data is utilized by applying fuzzy rules directly on the pixels which lie within the operational window. The output value depends on the fuzzy rules and on the defuzzifying process, which combines the effects of these different rules [8],[11]. However, the increase of the local characteristics for such filter causes the increase the number of rules rapidly. There is no optimal way to optimize such filters constructed by a large number of fuzzy rules.

In this paper, a new class of fuzzy vector median-rational hybrid filters is introduced. The filter acts on two stages. It basically combines a fuzzy and a non- fuzzy components. Its basic structure can be described as follows: in the first stage, three subfilters should be used in which two fuzzy vector median filters [2], and one fuzzy center weighted vector median filter [9]. Fuzzy membership functions based on distance criterion are adopted to determine the weights of a weighted mean filter [7]. In the second stage, the outputs of the three subfilters in stage one constitute the input set of the vector rational operation.

2. FUZZY VECTOR MEDIAN- RATIONAL HYBRID FILTERS

The new filters are a two stage type hybrid filters. They combine in the first stage the L_p norm criteria with weighted mean filters and fuzzy transforms to produce three output vectors in which two fuzzy vector median outputs and one fuzzy center weighted vector median filter output. In the second stage a vector rational operation acts on the above three output vectors to produce the final output vector.

The weights of the filter are determined using fuzzy membership functions at each image location.

Let $\underline{\mathbf{f}}(x) : Z^l \rightarrow Z^m$, represent a multichannel signal and let $W \in Z^l$ be a window of finite size n (filter length). l represents the signal dimensions and m represents the number of signal channels. The pixels in W will be denoted as x_i, $i = 1, 2, \ldots, n$ and $\underline{\mathbf{f}}(x_i)$ will be denoted as $\underline{\mathbf{f}}_i$. $\underline{\mathbf{f}}_i$ are m-dimensional ($m \geq 2$) vectors in the vector space defined by the m signal channels. The FVMRHF is defined as follows:

<u>Definition</u> 2.1 *The output vector $\underline{y}(\underline{\mathbf{f}}_i)$ of the FVM-RHF, is the result of a vector rational function taking*

Contact Author: lazhar.kheriji@enim.rnu.tn

into account three input sub-functions which form an input functions set $\{\underline{\Phi}_1, \underline{\Phi}_2, \underline{\Phi}_3\}$*, where the "central one"* ($\underline{\Phi}_2$) *is fixed as a fuzzy center weighted vector median sub-filter*

$$\underline{y}(\underline{\mathbf{f}}_i) = \underline{\Phi}_2(\underline{\mathbf{f}}_i) + \frac{\sum_{j=1}^{3} \alpha_j \underline{\Phi}_j(\underline{\mathbf{f}}_i)}{h + k||\underline{\Phi}_1(\underline{\mathbf{f}}_i) - \underline{\Phi}_3(\underline{\mathbf{f}}_i)||_2} \quad (1)$$

where, $||.||_2$ *is an* L_2*-vector norm,* $\alpha = [\alpha_1, \alpha_2, \alpha_3]$ *characterizes the constant vector coefficient of the input subfunctions. In this approach, we have chosen a very simple prototype filter coefficients which satisfies the condition:* $\sum_{i=1}^{3} \alpha_i = 0$*. In our study,* $\alpha = [1, -2, 1]^T$*.* h *and* k *are some positive constants. The parameter* k *is used to control the amount of the nonlinear effect.*

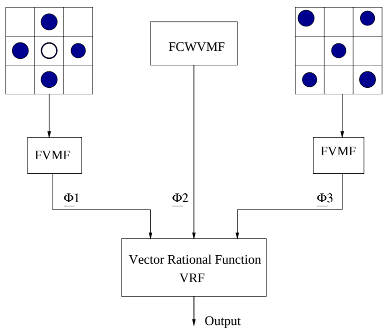


Figure 1: Structure of FVMRHF using bidirectional subfilters.

The sub-filters $\underline{\Phi}_1$ and $\underline{\Phi}_3$ are chosen so that an acceptable compromise between noise reduction, edge and chromaticity preservation. It is easy to observe that this FVMRHF differs from a linear low-pass filter mainly for the scaling, which is introduced on the $\underline{\Phi}_1$ and $\underline{\Phi}_3$ terms. Indeed, such terms are divided by a factor proportional to the output of an edge-sensing term characterized by l_2-vector norm of the vector difference between the two vectors $\underline{\Phi}_1$ and $\underline{\Phi}_3$. The weight of the fuzzy vector median-operation output term is accordingly modified, in order to keep the gain constant. The behavior of the proposed FVMRHF structure for different positive values of parameter k is the following:

1: $k \simeq 0$, the form of the filter is a linear lowpass combination of the three nonlinear sub-functions:

$$\underline{y}(\underline{\mathbf{f}}_i) = c_1\underline{\Phi}_1(\underline{\mathbf{f}}_i) + c_2\underline{\Phi}_2(\underline{\mathbf{f}}_i) + c_3\underline{\Phi}_3(\underline{\mathbf{f}}_i). \quad (2)$$

where, the coefficients c_1, c_2, and c_3 are constants.

2: $k \to \infty$, the output of the filter is identical to the central sub-filter output and the vector rational function has no effect:

$$\underline{y}(\underline{\mathbf{f}}_i) = \underline{\Phi}_2(\underline{\mathbf{f}}_i). \quad (3)$$

3: For intermediate values of k, the $||\underline{\Phi}_1(\underline{\mathbf{f}}_i) - \underline{\Phi}_3(\underline{\mathbf{f}}_i)||_2$ term perceives the presence of a detail and accordingly reduces the smoothing effect of the operator.

Therefore, the FVMRHF operates as a linear lowpass filter between three nonlinear suboperators, the coefficients of which are modulated by the edge-sensitive component. The proposed structure of the FVMRHF is shown by Fig. 1 using two bidirectional Fuzzy vector median sub-filters and one fuzzy center weighted vector median filter.

The output of each subfilter is given as a weighted average of all the vector valued signals inside the window:

$$y = \frac{\sum_{j=1}^{n} w_j x_j}{\sum_{j=1}^{n} w_j} \quad (4)$$

The relationship between the pixel under consideration (window center) and each pixel of the window should be reflected in the decision of each weight of the subfilter. It can be seen from the form of fuzzy filter that normalized weights are used to weight the input contributions.
The weight w_i is based on the distance criteria selected. The criteria adopted here is the minimum Euclidean distance criterion [1],[2]. It was pointed out in [1], that the VMF selects the vector most centrally located using as a criterion the minimization of the sum of Euclidean distance with the other vectors. The sum of the Euclidean distance with the other vectors in the window is the distance criterion used here as the input to the fuzzy transformation. Let a_i correspond to x_i defined as

$$a_i = \sum_{j=1}^{N} |x_i - x_j| \quad (5)$$

where $|.|$ denotes Euclidean distance. The weights on the new subfilter are determined using a fuzzy membership function on the above distance. Usually the fuzzy transformation depends on the distance measure used. Since in this paper the Euclidean distance criterion is used, the fuzzy weight adopted is sigmoid,

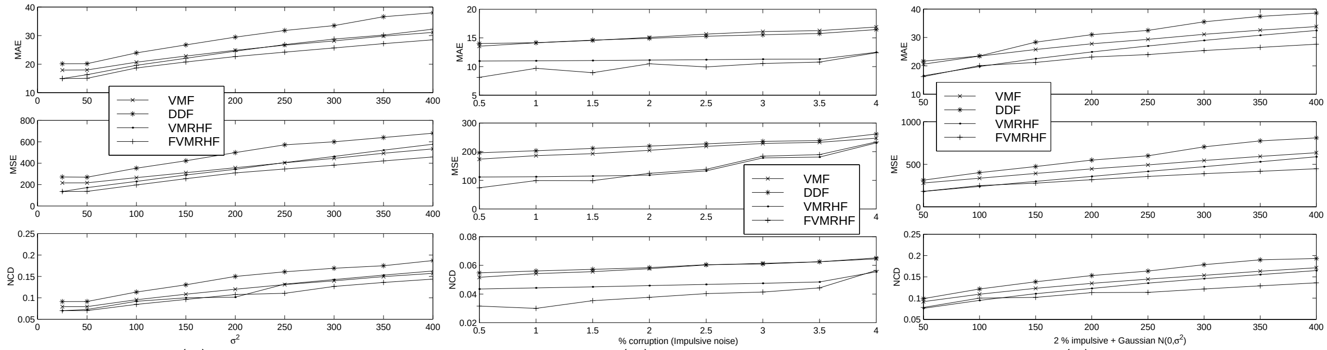
$$w_j = \frac{1}{1 + exp(a_j^r)} \quad (6)$$

where r is a smoothing parameter to be determined.

Depending on the problem under consideration, different values of r are selected. In this way, each subfilter can produce different output values, despite the fact that it retains the basic structure of (4). It is easy to observe:

1: Using the above subfilter formulation, there is no requirement for fuzzy rules. The fuzzy weight is determined through the distance and the fuzzy transformation. The fuzzy membership function selected here derives its output in the range $[0, 1]$ and is smooth over the entire input range.

2: The new fuzzy subfilters do not require any ordering. It is well known [6] that nonlinear filters based on order statistics are computationally expensive. The ranking process for multichannel images is computationally demanding, especially for large window.



(a) (b) (c)

Figure 2: Comparative results from the original Lena image contaminated by: (a) Gaussian, (b) Impulsive, and (c) mixed noise (salt and pepper 2% in each component).

3: Every subfilter output (4) provides a vector valued signal, which is not included in the original set of inputs. Thus, some problems for image restoration can be solved. Mainly when the desired output is not one of the observation samples.

3. EXPERIMENTAL RESULTS

The new filters are compared quantitatively with the widely known multidimensional nonlinear filters such as, the vector median filter (VMF), the vector distance directional filter (DDF), and the vector median-rational hybrid filter (VMRHF). The noise attenuation properties of the different filters are examined by utilizing the color image Lena. The test image has been contaminated using various noise source models in order to assess the performance of the filters under different scenarios:

- Gaussian noise implies corruption by zero mean additive noise with standard deviation σ, (σ is variable).
- Impulsive noise: each image channel is corrupted independently using salt and pepper noise. We assume that both salt and pepper are equally likely to occur.
- Mixed Gaussian-impulsive noise: the impulsive noise is fix (salt and pepper 2% in each channel). We varied the standard deviation of the Gaussian noise.

The original image, as well as its noisy versions, are represented in the RGB color space and shown in Fig. 3(a)-(b) respectively. This color coordinate system is considered to objective, since it is based on the physical measurements of the color attributes. The filters operate on the images in the RGB color space.

A number of different objective measures can be utilized for quantitative comparison of the performance of the different filters. All of them provide some measure of closeness between two digital images by exploiting the differences in the statistical distributions of the pixel values [3]. The most widely used measures are the mean absolute error (MAE), the mean square error (MSE), and the normalized color difference (NCD).

The results obtained are shown in the form of plots in Fig. 2(a)-2(c) for the three noise models: Gaussian, impulsive, and Gaussian mixed with impulsive, respectively. As can be verified from the plots, the performance of the new FVMRHF is superior to the performance of VMF, DDF, and VMRHF. Moreover, consistent results have been obtained when using a variety of other color images and the same evaluation procedure.

The filtered images are presented in Fig. 3 for visual and qualitative comparison, since in many cases they are the best qualitative measure of the performance of image processing techniques. Figs. 3(c)-3(f) are the filtered images of the corrupted Lena image by impulsive noise (4% in each channel), using DDF, VMF, VMRHF and FVMRHF respectively. All the filters considered operate using a square 3x3 processing window. A comparison of the images clearly favors our newly FVMRHF over their counterparts VMF and DDF, and slightly better than VMRHF. The FVMRHF do not suffer from VMF's inefficiency in a non impulsive noise scenario and small filtering window. As the VMRHF, the proposed FVMRHF can effectively remove impulses, smooth out nominal noise and keep edges, details and color uniformity unchanged.

Considering the number of computations needed for the implementation of the fuzzy FVMRHF, it should be noted that it does not require any ordering, which make it faster than those based on order statistics. In addition, the different subfilters can be run in parallel reducing the execution time and making the new Fuzzy filters suitable for real-time implementation with digital signal processors.

4. CONCLUSION

This paper has introduced a new class of fuzzy vector median-rational hybrid filters (FVMRHF) for filtering multichannel image. These filters are a two-stage filters which combine in a novel way, fuzzy memberships, av-

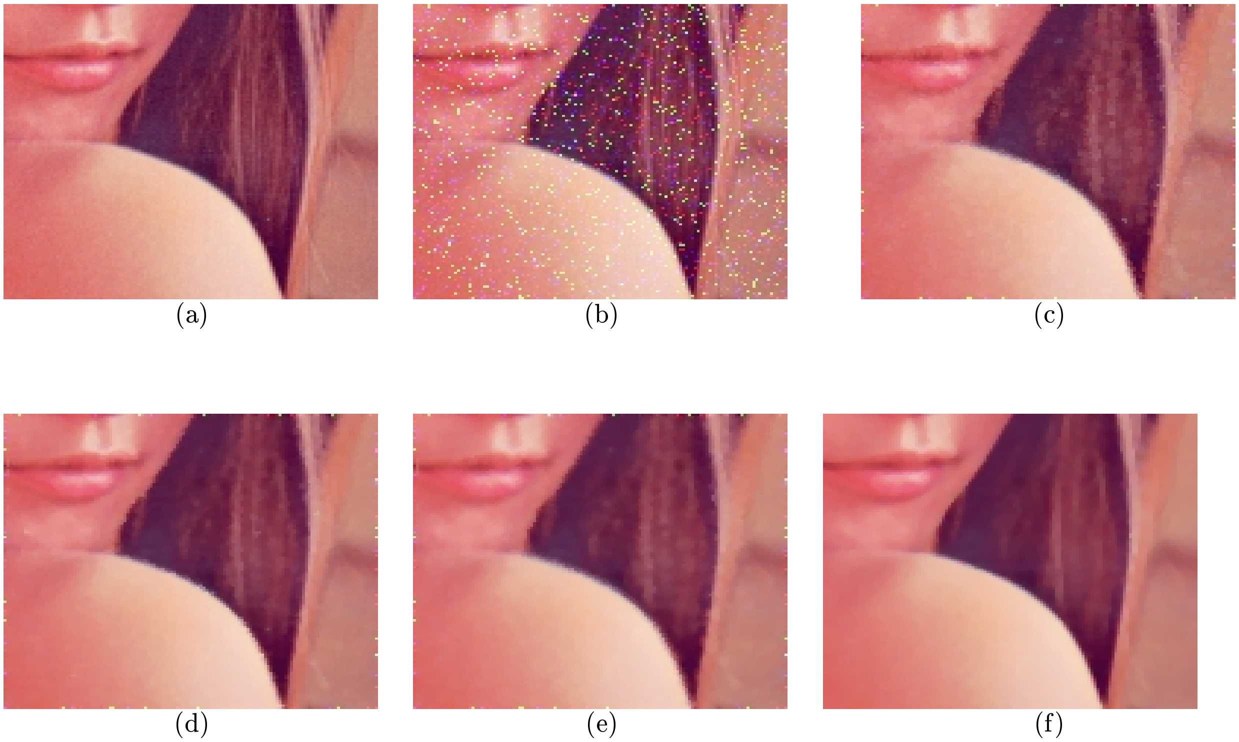


Figure 3: Images (a), (b) are respectively the noise free Lena image and the contaminated one by impulsive noise (4% in each component). Images (c), (d), (e) and (f) are the processed images by the DDF, VMF, VMRHF, and FVMRHF respectively.

erage filters and Euclidean based distances to provide the outputs of their first stage. They combine the good behavior of rational function and fuzzy vector median filters. Simulation results and subjective evaluation of the filtered images indicate that the new FVMRHF outperform all other filters used in the study. Moreover, as seen from the attached images, FVMRHF preserve the chromaticity component.

5. REFERENCES

[1] J. Astola, P. Haavisto and Y. Neuvo, "Vector Median Filter", *Proceedings of the IEEE*, vol.78, pp.678-689, April 1990.

[2] V. Chatzis, and I. Pitas, "Fuzzy scalar and vector median filters based on fuzzy distances",*IEEE Trans. on Image Processing*, vol. 8, no. 5, pp. 731-734, May 1999.

[3] A.M. Eskicioglo, P.S. Fisher, and S. Chen, "Image quality measures and their performance",*IEEE Trans. on Communication*, vol. 43, pp. 2959-2965, 1995.

[4] L. Khriji and M. Gabbouj, "Vector Median-Rational Hybrid Filters for multichannel image processing", *IEEE Signal Processing Letters*, vol.6, no.7, pp.186-190, July 1999.

[5] L. Khriji, F. A. Cheikh, and M. Gabbouj, "High Resolution digital resampling using Vector Rational Filters", *Journal of Optical Engineering, SPIE*, Vol. 38, Issue 5, pp.893-901, May 1999.

[6] I. Pitas, and A.N. Venetsanopoulos, "Order statistics in digital image processing", *Proceedings of the IEEE*, vol.80, no. 12, pp.1893-1923, December 1992.

[7] I. Pitas, and A.N. Venetsanopoulos, "Nonlinear Digital filters: principles and applications",*Kluwer Academic,* Norwell Ma., 1990.

[8] F. Russo, G. Ramponi, "Nonlinear fuzzy operators for image processing", *Signal Processing*, vol. 38, pp.429-440, April 1994.

[9] A. Taguchi, and N. Azawa, "Fuzzy center weighted median filters",*Eusipco-96*, vol. III, pp. 1721-1724, 10-13 September. Trieste, Italy, 1996.

[10] P.E. Trahanias, D. Karakos and A.N. Venetsanopoulos, "Directional Processing of Color Images: Theory and Experimental Results",*IEEE Trans. on Image Processing*, vol. 5, no. 6, pp. 868-880, June 1996.

[11] S. G. Tzafesta, and A.N. Venetsanopoulos, "Fuzzy reasoning information, decision and control systems",*Kluwer Academic,* 1994.