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ADAPTIVE GENERALIZED VECTOR MEDIAN

In this paper, a new adaptive filter intended for the attenuation of impulse noise in colour images is proposed. The new filtering design is based on the concept of a peer group of pixels sharing similar chromatic properties. The novel approach adaptively determines the size of the peer group which minimizes the aggregated distance to its members, utilizing the Fisher linear discriminant. The analysis of the obtained noise reduction results leads to the conclusion, that the new filter is capable of reducing even strong impulse noise, while preserving and even enhancing the edges of colour images. This unique property of the proposed filtering design is shown on examples of colour biomedical images.

1. INTRODUCTION

The *Vector Median Filter* (VMF) is the most popular *vectorial operator* used for the removal of impulses injected into the colour image by the noise process [1]. This filter is quite efficient at reducing the impulses, retains sharp edges and linear trends, however it does not preserve fine image structures, which are treated as noise and therefore generally the VMF tends to produce blurry images. This unwanted feature of the VMF is very important as much of the image information is contained in its edges, and sharp edges are pleasing to humans and are desirable for machine processing.

Many edge *enhancement techniques* that counteract blur without the knowledge about its model are based on linear filters which emphasize the high-frequency image components performing the high-pass filtering in the spatial or frequency domain. The drawback of these simple techniques is that they strongly amplify the image noise producing annoying overshoots and ringing effects at sharp edges. Also the deconvolution algorithms fail in the presence of noise and in the cases when the knowledge about the degradation model is not available.

One of the most popular technique intended for noise reduction, while preserving edges is the *anisotropic diffusion*, whose aim is to encourage intraregion smoothing and to inhibit blurring of edges [2]. This powerful method has been successfully applied to colour images contaminated by Gaussian noise, however its main drawback is its difficulty to cope with impulse noise, which is being retained, as it is treated like a strong edge, which should be preserved [3].

Another solution to the problem of image quality improvement with edge enhancing abilities is provided by the *shock filters*, which are based on the idea to apply locally either a dilation or an erosion process, depending on whether the pixel belongs to the in influence zone of a local maximum or a minimum [4]. This filter class creates a sharp discontinuity at image edges and produces piecewise constant segmentation of the image, however it is not able to enhance the image in the presence of impulse noise, as the impulses are treated as local extrema.

The described above filtering schemes exemplify the main difficulty when enhancing images polluted by impulses. The majority of the well known techniques which are able to suppress the impulse noise tend to blur the image and those with edge enhancing properties preserve or amplify the outliers introduced by noise process. As a result, much research has been devoted to the construction of filters which can cope with noise while simultaneously preserving image details and enhancing edges in the gray-scale [5] and colour images [6,7].

In this paper, a solution to the problem of image noise filtering with edge enhancing abilities is proposed. Extending the VMF using the *peer group* concept introduced in [8], the proposed *Adaptive Generalized Vector Median Filter* (AGVMF) is able to efficiently remove impulse noise while sharpening the colour image edges. The proposed filtering design is comparable in noise reduction with the VMF but preserves much better image details and produces images with sharp edges.

2. ADAPTIVE GENERALIZED VECTOR MEDIAN FILTER

Various filtering approaches based on the order statistics theory have been proposed to remove the impulse noise from colour images. The most popular filtering class operating on a sliding window is based on the *vector sample ordering* [6].

The *reduced* or *aggregated ordering* scheme assigns an aggregated dissimilarity measure to each colour pixel from the filtering window W. The aggregated dissimilarity measure assigned to pixel $\mathbf{x}_i$ is defined as $r_i = \sum_{j=1}^{n} \rho(\mathbf{x}_i, \mathbf{x}_j)$, $\mathbf{x}_i, \mathbf{x}_j \in W$, where $\rho(\cdot)$ denotes the distance between the colour pixels belonging to W containing n pixels. The scalar accumulated dissimilarity measures are then sorted and the associated vectors can be correspondingly ordered. The vector median of a set of vectors from W is defined as the vector $\mathbf{x}_{(1)}$ for which the sum of distances to all other vectors belonging to W is minimized:

$\mathbf{x}_{(1)} = \mathrm{argmin}_{\mathbf{x} \in W} \sum_{j=1}^{n} \rho(\mathbf{x}, \mathbf{x}_j)$.

The notion of the vector median can be generalized, so that the filter output will be the vector $x_{(1)}^{\alpha}$, for which the sum of α smallest distances to other vectors from W is minimized. Of course for α equal to the number of pixels n in the filtering

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window, the standard VMF is obtained. If the distance between the vector $\mathbf{x}_i$ and $\mathbf{x}_j$ is denoted as $\rho_{i,j}$, then we can order the set of distances $\rho_{i,j}$, $(j = 1,...,n)$ to obtain the sequence: $\rho_i^{(1)} \leq ... \leq \rho_i^{(\alpha)} \leq ... \leq \rho_i^{(n)}$, where $\rho_i^{(k)}$ is the k-th smallest distance from x_i. For each pixel in the filtering window the cumulated sum r_i^α is calculated as: $r_i^\alpha = \sum_{k=1}^{\alpha} \rho_i^{(k)}$ and the output of the *Generalized VMF* (GVMF) is that pixel, for which the trimmed sum of distances r^α is minimized.

In [9] the following criterion for determining the α parameter has been proposed

$$\alpha = \max \alpha^*, \quad \text{subject to} \quad \left[\sum_{j=1}^{\alpha^*} \rho_i^{(j)} \right] \leq \rho_i^{(n)}, \ \mathbf{x}_i \in W, \tag{1}$$

where $\rho_i^{(n)}$ is the largest distance between the central pixel $\mathbf{x}_i$ and its neighbours from W. This definition, although yields acceptable results, is quite heuristic and therefore a new rule for the choice of α has been devised.

For the task of determining the value of α, which can be treated as the cardinality of a cluster of pixels which were not disturbed by noise, we can make use of the Fisher's linear discriminant. Fisher's linear discriminant is a classification method that generally projects high-dimensional data onto a line and performs classification in this one-dimensional space. In our case, the dimensionality reduction of the colour vectors is performed by the calculation of the aggregated distances.
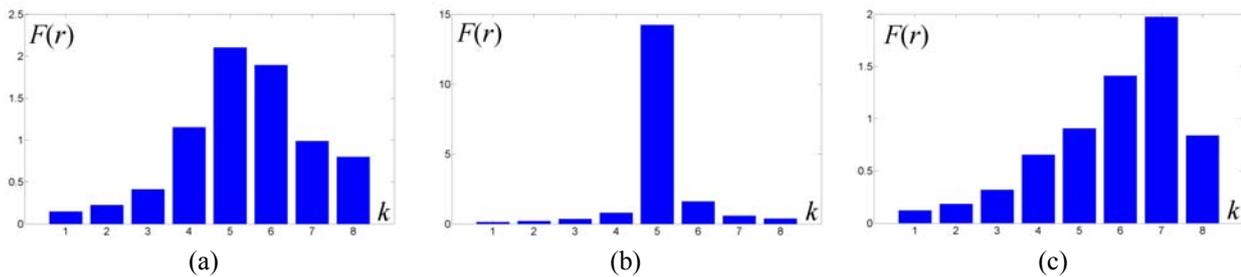

Fig.1 Plots of the sorted aggregated distances r of pixels from a 3×3 window of the original (a-b) and noisy colour test image (c).

The goal of the discriminant is to maximize the distance between the means of two classes, while minimizing the variance within each class. This defines the Fisher criterion function $F_{(k)}$, where k denotes the rank of the sorted sequence of the sorted $r_{(k)}$ values

$$F_{(k)} = \frac{\left[\mu_1(k) - \mu_2(k) \right]^2}{\sigma_1^2(k) + \sigma_2^2(k)}, \qquad \mu_1(k) = \frac{1}{k} \sum_{i=1}^{k} r_{(i)}, \quad \mu_2(k) = \frac{1}{n-k} \sum_{i=k+1}^{n} r_{(i)}, \ \ k = 1,...,n-1, \tag{2}$$

where μ_1 and μ_2 denote the mean values of the two classes of pixels and σ_1^2 and σ_2^2 stand for the variances of the aggregated distances in each of the two classes.

Figure 1 shows examples of plots of the dependence of the Fisher's linear discrimination function on the sorted values of aggregated distances of pixels in a 3×3 filtering mask. As can be observed the set of pixels in the filtering window is divided into two clusters. In Figs. 1 (a-b) the cluster, which contains the VMF consists of five pixels and in Fig. 1 (c) the first cluster consists of seven pixels and two remaining pixels are with high probability contaminated by the noise process.

The α value is determined by the maximum of the Fisher's function. The division into two clusters is always performed, as shown in Fig. 1, and as a result even in the absence of impulses a reasonable value of α is delivered by the Fisher's criterion, which guarantees the edge enhancing effect as shown in [9].

3. EXPERIMENTS

For the evaluation of the efficiency of the proposed filter, a series of experiments has been performed utilizing natural and artificial colour images contaminated by impulse noise. The applied noise model is defined as:

$$\mathbf{x}_i = \begin{cases} o_i, \ \text{with probability } 1 - p, \\ \{\rho_{i1}, \rho_{i2}, \rho_{i3}\} \ \text{with probability } p, \end{cases} \tag{3}$$

where **x** and **o** denotes the noisy and original colour test image, p is the sample corruption probability and the variables ρ_{ik}, $k = 1,...,3$ take the value 0 or 255 with equal probability.
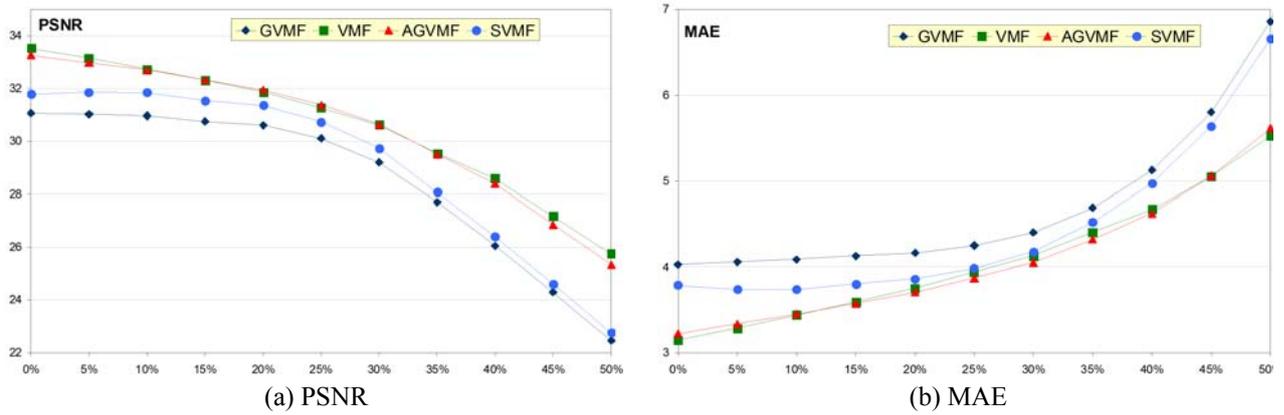

(a) PSNR

(b) MAE

Fig.2 Dependence of the restoration quality measures on the noise intensity of the proposed AGVMF as compared with VMF, SVMF [9] and GVMF with fixed parameter $\alpha = 5$

For the measurement of the restoration quality, the *Root Mean Squared Error* (RMSE) expressed through the *Peak Signal to Noise Ratio* (PSNR) was used. For the evaluation of the detail preservation capabilities of the proposed filtering design the *Mean Absolute Error* (MAE) has been utilized.

The overall good noise reduction abilities of the proposed filtering design are presented in Fig. 2, which show the dependence of the PSNR and MAE on the noise intensity p when restoring the *LENA* noisy image. As can be observed the efficiency of the proposed AGVMF is superior to that of the *Sharpening VMF* (SVMF) proposed in [9] and the *Generalized VMF* (GVMF) with fixed parameter α. The noise reducing properties evaluated by means of PSNR and MAE are comparable with VMF, however the proposed AGVMF has the unique ability to sharpen the edges present in the colour images. This feature is visible in Fig. 3 which depicts the filtering results delivered by the new filter as compared with the VMF, GVMF and SVMF.

(a)LENA

(b)NOISY

(c) VMF

(d) AGVMF

(e) GVMFα=5

(f) SVMF

Fig.3 Efficiency of the proposed Adaptive Generalized VMF as compared with the VMF, GVMF and SVMF

The novel filtering technique can be applied for various tasks in which the noise reduction capabilities combined with the strong edge enhancing properties are beneficial. One of such applications is the analysis of the cDNA microarrays, which quantify the genes expression levels [10]. As can be observed in Fig. 4, the impulse noise is efficiently removed and the spots

have sharp edges, which enable their reliable detection and estimation of the mean expression level calculated as an average intensity over the spot area.
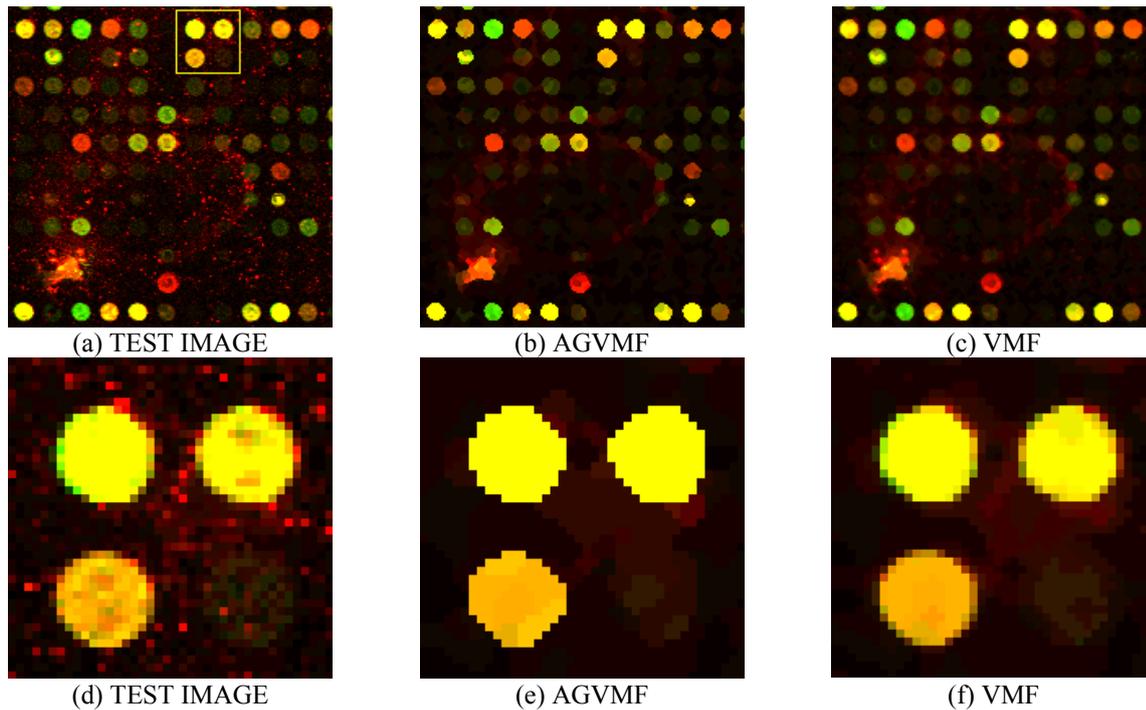

Fig.4 Illustration of the edge enhancing capabilities of the new filter (a) cDNA test image, (b) image restored with the proposed AGVMF, (c) VMF output. Below, (d-f) cropped and zoomed image parts are shown

The good efficiency of the proposed switching scheme can be observed in Fig. 5, which reveals the edge enhancing properties of the proposed noise reduction filter. The edge sharpening property can be utilized also for the enhancement of images which were not exposed to impulse noise. An example is provided by Fig. 6, in which the improvement of the sharpness of edges can be evaluated when observing the output of the *Vector Range* (VR) edge detector defined as the distance between the vectors $\mathbf{x}_{(1)}$ and $\mathbf{x}_{(n)}$ from the filtering window [6]. As can be seen the quality of the edge maps is increased when the pre-filtering with the described PGVMF filter is performed.
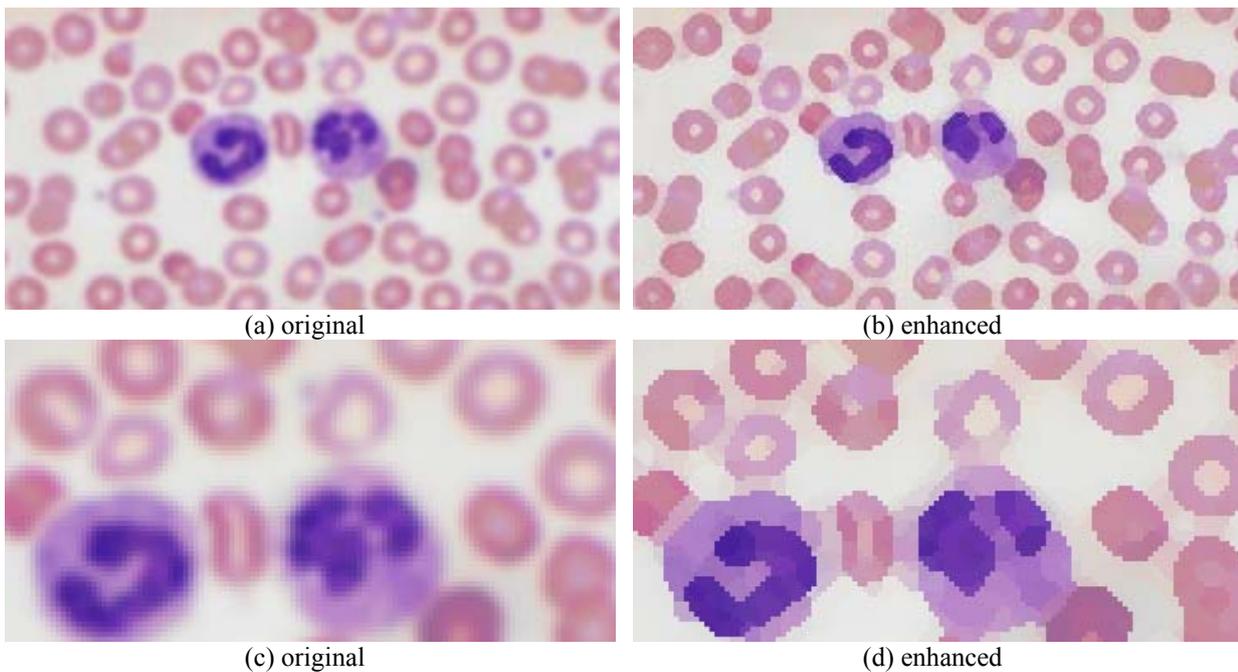

Fig.5 Illustration of the edge enhancing properties of the proposed filtering design: (a) microscopic histology image, (b) output of the proposed adaptive filter after three iterations, (c-d) cropped and zoomed image parts

(a) Test Image

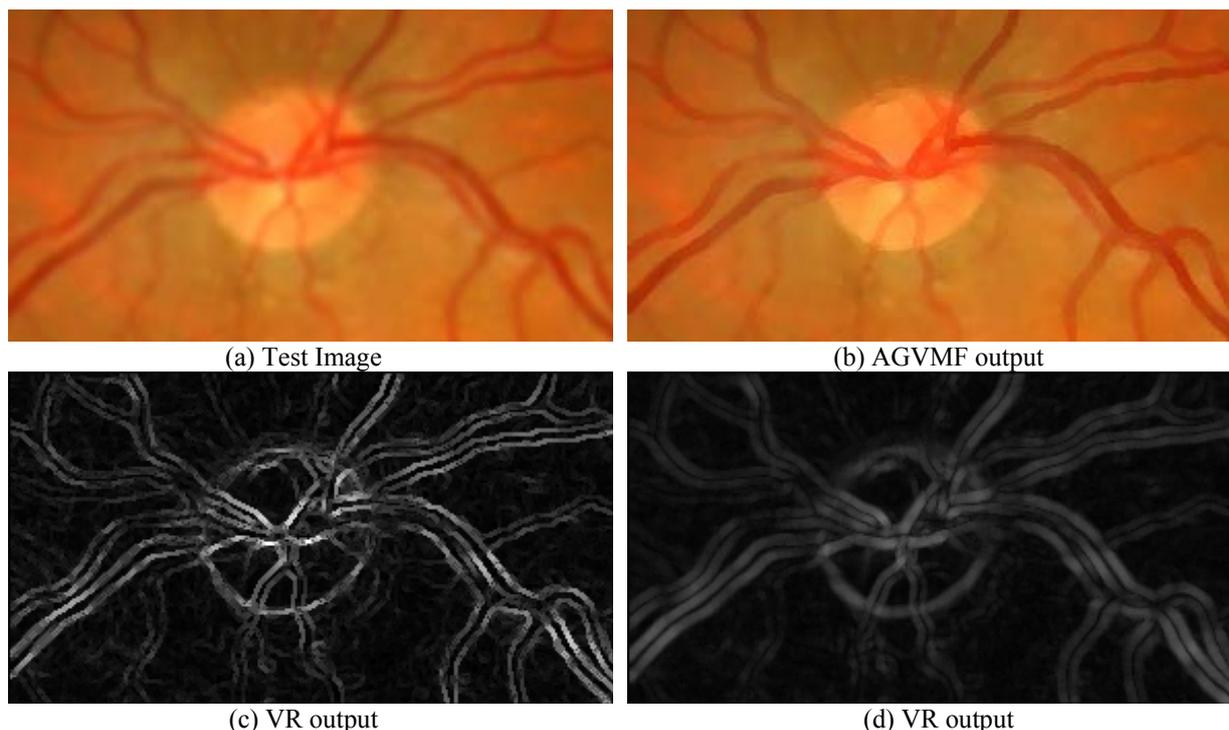(b) AGVMF output

(c) VR output

(d) VR output

Fig.6 Edge enhancing property of the proposed AGVMF scheme: (a) test image, (b) enhancement result, (c-d) edge intensities evaluated using the Vector Range (VR) edge detector.

4. CONCLUSIONS

In this paper, the properties of a novel adaptive filtering design has been examined. The proposed filter can be regarded as an adaptive generalization of the standard *Vector Median Filter*. Besides its excellent impulsive noise reducing capabilities, its unique feature is its ability to enhance colour image edges by sharpening their edges. This effect is really beneficial as in many applications sharp image edges are desired to enable the success of further image processing steps.

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