UDK 519.7: 004.8

Ye.V. Bodyanskiy, N.Ye. Kulishova

NONCONVENTIONAL MEMBERSHIP FUNCTIONS FOR IMAGES FILTERING USING FUZZY PEER GROUP APPROACH

Annotation: The paper presents the architecture of a filter for digital color images, which is based on fuzzy peer groups and uses a membership functions ensemble. This allows to filter more flexible under the action of different types of distortions in images with different structure.

Keywords: color image, fuzzy peer group, the ensemble membership functions.

Introduction

Digital images are often exposed to noise during their registration or transfer and therefore the filtering problem is still not lost its relevance. In digital cameras, there are three types of noise: random, structural and line. Random noise is characterized by variations of brightness and color above and below the actual value. A part of random noises is always present at any exposure time and more depends on the ISO (sensitivity). Structural noise usually occurs at slow shutter speeds and increases at higher temperatures. Structural noise is unique because it shows almost identical distribution of “hot” pixels when shooting goes under identical conditions (temperature, exposure time, the ISO value).

The line noise depends mainly of the camera and is a disturbance that camera makes itself in the process of reading data from a digital sensor. The line noise is most noticeable at high ISO settings and in the shadows, or when the image is too lighten.

Solution of the filtering problem is complicated by the variety of types of images, the necessity of suppressing noise components without smoothing contours, textures and small details. To carry out this treatment a number of methods were suggested, including adaptive, which differ in speed, degree of smoothing noise and other criterions.

The vast majority of these methods are built on the required presence of a “clean” learning signal that in practice of the image processing is uncommon. In addition, the images can vary in color, structural, frequency characteristics, so the applicability of filters trained on disparate images is significantly limited.

In such circumstances, an effective approach using the concept of the so-called fuzzy peer group is represented in [1].

Fuzzy approach to image filtering

The image is processed by sliding window W, which pixels form the set $F_{(i)}, i = 1, 2, \ldots, n^2$ ($n \times n$ – window size), F_0 – the central pixel. Each pixel is represented by a three-component vector, consisting of its R, G, B values: $F_{(k)} = \left[F^R_{(k)}, F^G_{(k)}, F^B_{(k)}\right]^T$.

Peer group for image pixel F_0 is defined as the set of neighboring pixels that in some sense are similar to it. There are several ways to determine this set [2]. One of them is based on a threshold distance to decide whether the current pixel is belong to the group or not. Thus, the peer group of pixel labeled as $C^{F_0}\left(F_{(i)}\right)$ – is the set $\left\{F_{(k)} \in W : \left\|F_0 - F_{(k)}\right\| \leqslant T\right\}$ where $\|\bullet\|$ denotes the Euclidean norm and $T > 0$. It is evident, that $F_0 \in C^{F_0}\left(F_{(i)}\right)$. According to this approach, when the cardinality is $Cd\left(C^{F_0}\left(F_{(i)}\right)\right) = m$, $m \in \left\{1, \ldots, n^2\right\}$, $C^{F_0}\left(F_{(i)}\right)$ is called the group of m equal members. This cardinality is used in [2] for deciding whether a pixel F_0 is free from impulsive noise, or not. Due to the use of the threshold T, peer group is specified crispy.

In the article [1] fuzzy membership function is proposed as a measure of similarity, resulting in a fuzzy peer group. As has been shown in several studies [1, 3–5], this class of metrics proved its suitability for fuzzy image processing procedures.

On a set of pixels $F_{(i)}, i = 1, 2, \ldots, n^2$, it may be formed the fuzzy set $C^{F_0}\left(F_{(i)}\right)$ whose elements $F_{(i)}$ are similar to F_0, and the degree of similarity $\rho\left(F_0, F_{(i)}\right)$ is determined by the membership function $\mu\left(C^{F_0}\left(F_{(i)}\right)\right)$. Fuzzy similarity measure is a monotonically decreasing function of $\left\{\mathbf{F}_{(0)}, \mathbf{F}_{(1)}, \ldots, \mathbf{F}_{\left(n^2-1\right)}\right\}$. If the membership function value would be restricted by certain threshold, then the fuzzy peer group of pixels that are similar in some ways to the central is formed within the window. For this group fuzzy averaging is performed by some filter whose coefficients can be adjusted. Thus, the filtration transforms to membership levels estimation.

The choice of membership functions significantly affects the adaptive filtering quality. Particularly, the function width determines dimensions of the peer group, and from the function steepness the filter's response to the contours and textures is depend.

In some works, such as [1, 3, 6] for this purpose such kernel functions as splines, quadratic, Gaussian, polynomial were used. However, they have many adjustable parameters that make such filters computationally cumbersome. This circumstance complicates the action of such filters in conditions when the image details, structure, color content, etc are different.

In this paper, several types of membership functions to use for a single filter are proposed:

$$\mu_1(x) = 1 - \left(0.75x^2\right), \tag{1}$$

$$\mu_2(x) = e^{-\frac{\|x\|}{0.2}}, \tag{2}$$

$$\mu_3(x) = \frac{1}{1+\left(\frac{x}{\alpha}\right)^2}, \quad \text{where } \alpha = \text{const}. \tag{3}$$

A set of such functions can be defined as $\mu_4(x) = \{\mu_{4\_1}(x), \mu_{4\_2}(x), \ldots, \mu_{4\_n}(x)\}$. These functions are shown in Fig. 1.

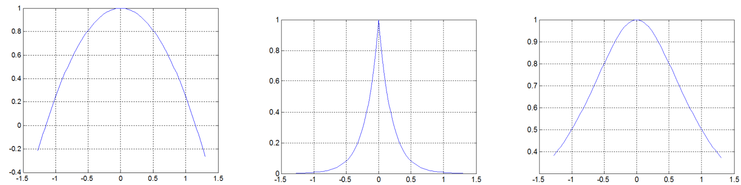

Figure 1 – Graphs of functions: a)$\mu_1(x) = 1-(0.75x^2)$; b) $\mu_2(x) = e^{-\frac{\|x\|}{0.2}}$; c) $\mu_3(x) = \frac{1}{1+\left(\frac{x}{\alpha}\right)^2}$

For the approach under consideration the same filter uses a set of different membership functions $\mu\left(C_k^{F_0}(F_i)\right)$ to form several fuzzy peer groups $C_k^{F_0}(F_i)$, $k = 1, \ldots, M$, (M – quantity of functions in the set) within a selected window W.

The scheme of filter action is shown in Fig. 2.

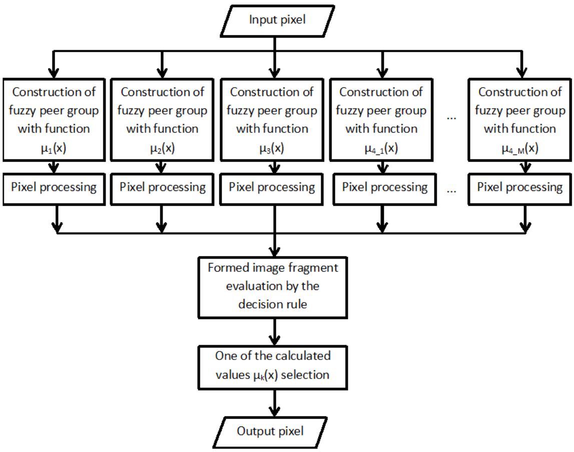

Figure 2 – Scheme of the filter action with indistinct equal groups with different membership functions

This scheme includes a pixel processing operation, which also consists of several actions. They are shown in Fig. 3.

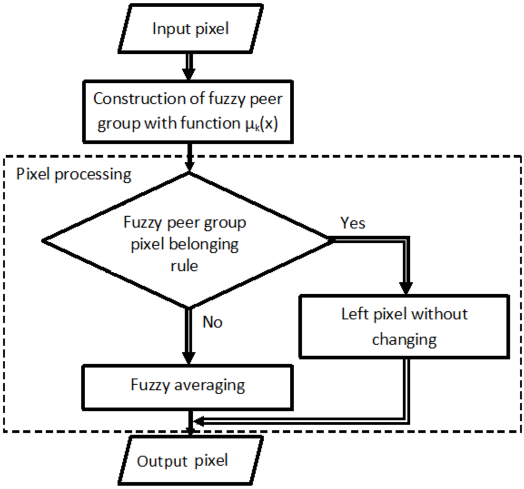

Figure 3 – Pixel processing in a fuzzy peer group

Experiments

The action of fuzzy peer group filter using the proposed membership functions has been tested experimentally without merging into the ensemble. As the test, two images with different degrees of detail and color content were chosen (Fig. 4).

Figure 4 – Test images: a) Parrot, b) Lena

Images were corrupted by Poisson, impulse, Gaussian and multiplicative noise of different intensity and processed using the proposed filter (window size of 7×7 pixels). Filtering quality estimates based on the mean square error values and visual. The experimental results are shown in Table. 1.

Table 1 – Results of filtering

Membership function	Type of noise and its parameters	Mean square error	
		Parrot	Lena
$\mu_1(x) = 1 - 0.75x^2$	Salt and pepper, σ=0.1	1.9277e-005	0.0024
	Gauss, m=0, σ=0.01	8.4018e-006	0.0025
	Speckle, σ=0.05	5.2251e-005	0.0026
	Poisson	6.7396e-005	0.0025
$\mu_2(x) = e^{-\frac{\|x\|}{0.2}}$	Salt and pepper, σ=0.1	0.3902	0.1970
	Gauss, m=0, σ=0.01	4.2051e-006	0.0029
	Speckle, σ=0.05	4.1529e-005	0.0030
	Poisson	1.0311e-004	0.0028
$\mu_3(x) = \frac{1}{1+\left(\frac{x}{\alpha}\right)^2}$	Salt and pepper, σ=0.1	2.7867e-005	0.0024
	Gauss, m=0,σ=0.01	3.7320e-005	0.0025
	Speckle, σ=0.05	5.1022e-005	0.0025
	Poisson	5.5341e-005	0.0025

Conclusions

The experimental results show that the examined nonconventional membership functions are responsive to the color image content structure change. For the same image, but in the case of various noises these functions provide a close, but different filtering results. Consequently, they can be aggregated into an ensemble in which a set of functions will provide a variation of filters working on the same principle, but with a more flexible adjustment to the conditions of specific images and noise. Thus, the proposed filter based on fuzzy peer groups effectively can suppress the noise inherent to the majority of images taken with digital still cameras.

References

1. Morillas S. Fuzzy peer groups for reducing mixed gaussian-impulse noise from color images/ S. Morillas, V. Gregori, A. Hervas/ IEEE Trans. on Image Processing. – V. 18, No. 7, 2009. – P.1452 – 1466.
2. B. Smolka, A. Chydzinski. Fast detection and impulsive noise removal in color images./ Real-Time Imag., vol.11, no. 5-6, pp. 389-402. Nov.-Dec. 2005.
3. S. Morillas, V. Gregori, G. Peris-Fajarnes. P. Latorre. A fast impulsive noise color image filter using fuzzy metrics./ Real-Time Imag., vol. 11, no. 5-6, pp. 417-428. Nov.-Dec. 2005.

4. S. Morillas, V. Gregori, G. Peris-Fajarnes. A. Sapena. New adaptive vector filter using fuzzy metrics / J. Electron. Imag., vol. 16, no. 3, Jul.-Sep. 2007, paper no.033007.

5. S. Morillas, V. Gregori, G. Peris-Fajarnes. A. Sapena. Local self-adaptive fuzzy filter for impulsive noise removal in color images / Signal Process., vol. 88, no. 2, pp. 390-398, Feb. 2008.

6. Barner K.E. Polynomial weighted median filtering/ K.E.Barner, T.C. Aysal/ IEEE Trans. on Signal Processing. – V. 54, No. 2, 2006. – P.636 – 650.

Отримано 07.04.2015 р.

ISSN 1560-8956