Using fuzzy fractal features of digital images for the material surface analysis

Privezentsev D.G., Zhiznyakov A.L., Astafiev A.V., Pugin E.V.
Vladimir State University named after Alexander and Nikolay Stoletovs Vladimir, Russia
E-mail: dprivezencev@mail.ru

Abstract. Edge detection is an important task in image processing. There are a lot of approaches in this area: Sobel, Canny operators and others. One of the perspective techniques in image processing is the use of fuzzy logic and fuzzy sets theory. They allow us to increase processing quality by representing information in its fuzzy form. Most of the existing fuzzy image processing methods switch to fuzzy sets on very late stages, so this leads to some useful information loss. In this paper, a novel method of edge detection based on fuzzy image representation and fuzzy pixels is proposed. With this approach, we convert the image to fuzzy form on the first step. Different approaches to this conversion are described. Several membership functions for fuzzy pixel description and requirements for their form and view are given. A novel approach to edge detection based on Sobel operator and fuzzy image representation is proposed. Experimental testing of developed method was performed on remote sensing images.

1. Introduction
To extract information from remote sensing image different methods of image processing are used. Edge detection is one of these methods. It can be used to further extraction of interesting objects. There are a lot of algorithms developed in this area. The most popular are Canny, Sobel, Prewitt, Roberts operators and some others [1]. One of the perspective techniques in image processing is the use of fuzzy logic and fuzzy sets theory [2]. Different algorithms and methods use different approaches to fuzzy processing. Linguistic variables are useful when the results are well distinguishable [3], but this is not very common situation. On the other hand it is better to process the results using analytical methods. Most papers suggest to switch to fuzzy sets on very late stages of processing when the source image is enhanced, converted or somehow preprocessed. Papers that extract fuzzy properties based on existing crisp features can be taken to this category [4]. Early defuzzification of the results has also negative influence on fuzzy processing [5]. All these things lower flexibility of fuzzy approach.

Other drawback is the use of fuzzy sets of first type (Type-1 Fuzzy Sets or T1FS), that have very little amount of uncertainty. To solve this issue type-2 fuzzy sets (T2FS) and other more high-type fuzzy sets were introduced [6]. Also other types of sets based on fuzzy sets are evolving: rough sets, soft sets, soft rough sets, blurry sets and others [7].

In this paper we propose a novel approach to image processing based on fuzzy sets, that suggest a transition to fuzzy image representation with fuzzy pixels on the earliest stages of processing. With this approach all extracted features are fuzzy by definition and defuzzification process at best should be done only when retrieving information from the computer system.
Figure 1: Membership function of image fuzzy pixel. Real intensity level at $\mu(F(x, y)) = 1$: a) greater, b) less than current.

2. Fuzzy image representation

Continuous image can be described as two-dimensional signal $f(x, y)$, where $x$ and $y$ – coordinates. During formation of digital image transition to discrete coordinates and values of intensities are performed:

$$F(x, y) = D[f(x, y)],$$

where $D[\cdot]$ – transformation operator from continuous signal to discrete, that is implemented on hardware, $F(x, y)$ – the discrete image. Obviously that with insufficient level of quantization, signal levels are rounded to integers. Then real intensity level of point $R(x, y)$ could be computed as

$$R(x, y) = F(x, y) + d(x, y),$$

where $d(x, y)$ – round error. More noticeable distortion is brought by different noises $\nu(x, y)$, that could be greater than 1. We will use the simplest noise model – additive noise. More complex models of noise could be investigated accordingly. Then the real intensity level could be calculated as

$$R(x, y) = F(x, y) + d(x, y) + \nu(x, y).$$

Computations that does not take into account these details, soon could accumulate big error related to source continuous image. Methods of fuzzy sets theory allow us to save the uncertainty till the latest stages of image processing and analysis. To do it we should switch to fuzzy image representation. $U(F, x, y)$

$$U(F, x, y) = \mu(F(x, y)),$$

where $\mu(F(x, y))$ – membership function of a pixel with coordinates $(x, y)$ to intensity level $F(x, y)$. Graphically this can be represented as shown on Fig. 1.

There are a lot of membership functions known. One must select those which satisfy the following conditions

$$\lim_{l \to \infty} \mu(F(x, y)) = 0,$$

$$\int_0^{L-1} \mu(F(x, y))dl > 0, \quad l \in [0; L - 1].$$
3. Edge detection
Most of the edge detection operators use gradient operator that has modulo $|\nabla G|$ and direction $\theta$

$$|\nabla G| = \sqrt{G_x^2 + G_y^2},$$

$$\theta = \arctan \frac{G_y}{G_x},$$

where $G_x = M_x \ast G$, $G_y = M_y \ast G$ – the result of convolution operator with horizontal and vertical matrices.

Let us consider the possibility of using fuzzy pixels in Sobel and Prewitt edge detection operator. To do this we must process the membership function values $\pi(F(x,y))$ in addition to normal intensity levels. Calculations of $G_{x\mu}$ and $G_{y\mu}$ can be done analogously. The difference here is in gradient computations of $\pi$-function.

$$|\nabla \pi| = 1 - \sqrt{G_{x\mu}^2 + G_{y\mu}^2}.$$  

We take complementary value because after squaring, sum and square root operations from values on interval $[0; 1]$, the result is near to 0. The final value of gradient will be

$$|\nabla G_\pi| = |\nabla G||\nabla \pi|.$$  

Threshold value of gradient can be selected manually or with different binarization techniques (e.g. with Otsu method [8]).

4. Testing
One of the most important application domains of nondestructive testing methods is the evaluation of defects. This problem is generally solved by recognizing visual patterns of defects on defectoscopy images and by determining their geometric characteristics (length, width, and area). To detect flat steel defects of arbitrary forms and sizes (for example, dents and blisters), we use the algorithm for detecting uncharacteristic image segments, with the maximum error being the average error of the rank block approximation. [9, 10].

We found that the developed algorithms for identifying uncharacteristic segments detect most defects, including dents, blisters, and shears. Further analysis of the found defects shows that the number and geometric characteristics of defects are almost identical to the corresponding values that were obtained by a nondestructive testing inspector. This supports the usability of the proposed algorithms in practical problems of nondestructive testing. The detection of groups of defects that consist of a set of single defects is an important defectoscopy problem because, according to certain standards, such defects may be unacceptable.

5. Conclusion
Proposed algorithm showed their applicability in edge detection task during image processing. Main feature is the use of fuzzy image representation based on fuzzy pixels. This approach is very perspective because it saves the uncertainty much better rather other existing algorithms. In the future this model could be extended to type-2 and higher fuzzy sets and also to other kinds of fuzzy sets. The results of comparing the developed algorithm for finding flat steel defects on the image with well known algorithms allow us to make the following conclusions. The proposed algorithm enables the automatic detection of objects without preprocessing the source image; given a preprocessed image, this algorithm is inferior to the wellknown ones. Further analysis of the defects that were found showed that the numbers and geometric characteristics of defects are almost identical to the corresponding values that were obtained by a nondestructive
testing inspector. This supports the usability of the proposed algorithms in practical problems of nondestructive testing.

This work was supported by the project number 2.1950.2017/ in the framework of the basic tasks of the state of the Russian Ministry of Education.

The reported study was funded by RFBR according to the research project 17-47-330073

[1] Canny, J. A computational approach to edge detection / John Canny // Pattern Analysis and Machine Intelligence, IEEE Transactions on. 1986. 11. Vol. PAMI-8, no. 6. P. 679698.

[2] Kuo, Y.-H. A new fuzzy edge detection method for image enhancement / Yau-Hwang Kuo, Chang-Shing Lee, Chao-Chin Liu // Proceedings of 6th International Fuzzy Systems Conference. [S. l.] : Institute of Electrical and Electronics Engineers (IEEE), 1997.

[3] Becerikli, Y. A new fuzzy approach for edge detection / Yasar Becerikli, Tayfun M. Karan // Computational Intelligence and Bioinspired Systems. [S. l.] : Springer Nature, 2005. P. 943951.

[4] Interval type-2 fuzzy sets constructed from several membership functions: Application to the fuzzy thresholding algorithm / Miguel Pagola, Carlos Lopez-Molina, Javier Fernandez [et al.] // IEEE Transactions
on Fuzzy Systems. 2013. apr. Vol. 21, no. 2. P. 230244.

[5] Fuzzy Techniques in Image Processing / Ed. by Etienne E. Kerre, Mike Nachtegael. [S. l.] : Physica-Verlag HD, 2000.

[6] Edge-detection method for image processing based on generalized type-2 fuzzy logic / Patricia Melin, Claudia I. Gonzalez, Juan R. Castro [et al.] // IEEE Transactions on Fuzzy Systems. 2014. dec. Vol. 22, no. 6. P. 15151525.

[7] Molodtsov, D. Soft set theoryfirst results / D. Molodtsov // Computers & Mathematics with Applications. 1999. Vol. 37, no. 4. P. 19 31. URL: http://www.sciencedirect.com/science/article/pii/S0898122199000565.

[8] Otsu, N. A threshold selection method from gray-level histograms / N Otsu // IEEE Trans. Sys., Man., Cyber. 1979. Vol. 9. P. 6266.

[9] Privezentsev, D. G. Use of characteristic image segments in tasks of digital image processing / Denis G. Privezentsev, Arkady L. Zhiznyakov // 2015 International Conference Stability and Control Processes in Memory of V.I. Zubov (SCP). [S. l.] : Institute of Electrical and Electronics Engineers (IEEE), 2015. oct.

[10] Zhiznyakov, A. L. Using fractal features of digital images for the detection of surface defects / A. L. Zhiznyakov, D. G. Privezentsev, A. A. Zakharov // Pattern Recognition and Image Analysis. 2015. jan. Vol. 25, no. 1. P. 122131.