ADAPTIVE PROCEDURE FOR BOUNDARY DETECTION IN SATELLITE IMAGES

Borislav Marinov, Veselina Gospodinova

ABSTRACT

The appropriate modification of adaptive procedure for generation of boundaries in multi-band images is proposed. It is based on the comparison of Sobel, Hueckel and Canny edge detector algorithms. The algorithm is modified in such manner to be suitable for analyses of images using the larger window of the edge detector. It is possible to be applied to multi-band and texture images. The accuracy and quality of contours generated from images with different resolution are estimated. Different modes of edge detector are tested and compared. The properties of these procedures are encountered and the criteria for choice of the appropriate procedure are formulated.

The suggested approaches and procedures are suitable for implementation in the software packages for digital processing of remote sensing images. The procedures are tested on the Landsat, SPOT and IKONOS images. The accuracy and reliability of detector are estimated. The results of contour description after applying the detector are presented. The recommendations are formulated for appropriate usage of suggested procedures for medium and high resolution images.

Assoc. Prof. Dr. Borislav Marinov - University of Architecture, Civil Engineering and Geodesy, Bulgaria, Sofia 1046, 1 boul. Hristo Smirnenski, GSM: +359896088084, FAX: +35928666670, E-mail: dimitrovbm_bg@yahoo.com

Eng. Veselina Gospodinova - University of Architecture, Civil Engineering and Geodesy, Bulgaria, Sofia 1046, 1 boul. Hristo Smirnenski, GSM: +359899830236, E-mail: veselina_gospodinova80@abv.bg

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1. INTRODUCTION

Procedures for edge detection and boundary estimation are main part of reduction process in digital image processing. Classical procedures are intended to grey level images. Classical procedures are based on local gradient operators and estimation the probability for edge existing. Operators of such types are these of Roberts, Previt and Sobel. The single parameter in such types of operators is threshold for edge finding. More sophisticated procedures are based on transformation in space of orthogonal functions which are optimal in statistical sense. The operators of such types are Hueckel [Hueckel M.H., 1972] and Humel operators. Another approach for edge finding is based on the estimation of statistical characteristics of image. Detectors of such type are LoG (Laplacian of Gaussian) and Canny detector [Canny, J., 1986].

The Canny edge detector is typical example of statistically optimized procedure. It is separated in several main steps: applying the Gaussian smoothing, 2-D differentiating, and the tracking procedure. The tracking process exhibits hysteresis between two thresholds – low and high. It ensures that leaves only the pixels at the top of the ridges that ensures thinning of the edge contour. The usage of hysteresis between two threshold levels ensures that noisy edges are not broken up into multiple edge fragments.

The one dimensional model of edge in different angle position is suggested by [Nalwa, V.S., T.O. Binford, 1986]. This method is robust to noise and ensures good subpixel position localization and angle localization. Its implementation shows that detector's design makes it insensitive to smooth shading.

The comparison of several types of edge detectors with different parameters is provided by [Heath, M., S. Sarkar, T. Sanocki, K. Bowyer, 1998]. The obtained boundaries are compared for test grey level images by applying different sets of parameters.

The application of classic detector has some speciality in finding edges due to the properties of multiband images. There are a lot of experiments which are applied to color or texture images. Five of the most widely used edge detectors are compared in [Wang S., F. Ge, T. Liu, 2006]. Four criteria are applied for estimation the good edge detection method: well quantified measure, objective evaluation measure, testing on real images, statistical analyses over the large data set.

There are proposed algorithms that combine the image segmentation and boundary detection. The boundary finding procedure named "edge flow" is proposed by [Ma W.Y., B.S. Manjunath, 1997]. This scheme utilizes a predictive coding model to identify the direction of change in color and texture at each image location and constructs an edge flow vector. This procedure is suitable for color and texture images.

Different methods are applied for edge detection in multi band and color images. The usage of color dipole moment is suggested and tested in [Sparavigna A., 2009]. The formulation of color dipole moment is made in analogues form corresponding to the dipole moment of electrical charges. The obtained edge maps for small window sizes show the similar result as Sobel edge detector and better than other gradient detectors. The simultaneous usage of multi-scale images in boundary detection procedure gives better results within 20 to 50% range than single scale image [Ren X., 2008]. The binary classification scheme is applied over the contour images obtained by detector set with different size of area.

The Fuzzy logic technique is used to find edges by [Mathur, S., A. Ahlawat, 2008]. It applies the exhaustive scanning of an image which is subjected to a set of fuzzy conditions for the comparison of pixel values of adjacent pixels.

The methods of Pattern Recognition could be applied for finding the boundary edges. Several techniques for image clustering and neural network algorithms are combined by [Abrantes, A.J., J.S. Marques, 1992]. The methods of c-mean, fuzzy c-mean, Kohoen maps, elastic maps are enhanced with dynamic data segmentation by using of noise model. The application of noise model allows to widespread the clustering algorithms to the context of shape analysis.

The formulation of edge detection technique is made by [Abdou I.E., W.K. Pratt, 1979]. The theoretical foundations of edge detection techniques are discussed from theoretical and psychophysical points of view in [Marr, D., E. Hildreth, 1980]. The theory of Gaussian filtration and Laplacian are investigated at the preliminary stages. It is formulated the optimal operator for image filtering. The zero-crossing procedure is investigated too. The computational model for boundary detection which calculates cell parameters at the adjacent part of image edge is proposed by [Joshi, G.D.; J. Sivashwamy, 2006]. The formulation of proposed edge detector is based on main principals of human vision. The comparison between human perception and mathematical model of edge detection techniques is provided. The results obtained by two methods are analysed.

2.EDGE DETECTORS THEORY

The three types of detectors are compared. The simplest one is Sobel edge detector. Hueckel operator is optimal from statistical point of view. The third one is Canny detector, which combines Gaussian filtering, differentiation and topological procedures to ensure boundary thinning and connection of edge segments by line following procedure.

2.1.Sobel edge detector

Sobel edge detector is classic differentiating operator. Usually it uses mask with size 3x3. The presentations of edge masks have the form:

$$H_x^S = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \qquad H_y^S = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} \tag{1}$$

The elements for x and y directions are calculated by convolution operator. The amplitude and direction of edge element are calculated by relations:

$$A_S = \sqrt{a_x^2 + a_y^2} \text{ - amplitude} \qquad \theta = \arctan\frac{a_y}{a_x} \text{ - angle} \tag{2}$$

Operator has small window size that makes it insensitive to change of edge direction near to boundary vertexes. The only parameter under control is threshold level for selection of edge segments.

2.2. Hueckel operator

Hueckel operator is of regional type. It is based on the transformation into feature space of stair-case edges and lines [Hueckel M.H., 1974]. Pixel values in the operator window are transformed to components of vector in feature space. The set of basic functions has the form:

$$H_k(r,\theta) = \varphi_k(\theta).\varphi_k(r) \tag{3}$$

where $\varphi_K(\theta)$ и $\varphi_k(r)$ are orthogonal functions, for angle and displacement of the theoretical edge.

For the estimation of error is used mean square error between experimental a_k end theoretical values s_k of edge. For ideal edge S(x,y,***P***)

$$N^2 = \sum_{k=1}^{n} (a_k - s_k)^2 \tag{4}$$

where s_k and a_K are calculated by relations:

$$a_k = \sum_D \sum \mathrm{H_k}(x,y).I_0(x,y).dx.dy \qquad k = 1,2,...n$$
$$\mathrm{s_k} = \iint_D \mathrm{H_k}(x,y).S(x,y,\mathbf{P}).dx.dy \tag{5}$$

Minimization of N from expression (4) as function of edge parameters allows determining the optimal edge parameters ***P***$(x_1,\ldots x_m)$. The decision for edge presence is taken from the relation:

$$\frac{\|N\|^2}{\|S\|^2} < \mathrm{t}$$
$$where\ \mathbf{N}^2 = \mathbf{I}^2 - 2.\mathbf{I}.\mathbf{S}_p + \mathbf{S}_p^2 \tag{6}$$

I=(a1,…,an) – vector of experimental coefficients,

Sp=(s1,…sn) – vector of discrete edge model that is defined from minimizing of (4).

This method gives good results but requires complex calculations.

2.3. Canny detector

Canny detector is implemented in four steps as formulated in [Heath, M., S. Sarkar, T. Sanocki, K. Bowyer, 1998]:

First step: Application of orthogonal Gaussian filtering is made by usage of relations:

$$H_x^C = \frac{1}{\sigma_x\sqrt{2.\pi}} e^{-\frac{1}{2}\frac{x^2}{\sigma_x^2}}, \quad H_y^C = \frac{1}{\sigma_y\sqrt{2.\pi}} e^{-\frac{1}{2}\frac{y^2}{\sigma_y^2}} \tag{7}$$

Second step: Differentiations in x-direction and y-direction are made by simple differentiating scheme:

$$d_x = v_{k+1} - v_{k-1}, \quad d_y = v_{j+1} - v_{j-1} \tag{8}$$

Third step: The suppression of edge pixels is made in direction orthogonal to edge direction.

Fourth step: The hysteresis between high and low thresholds (*thigh* and *tlow*) is used in line following algorithm for connection of neighbouring edge segments.

3. ADJUSTABLE PARAMETERS OF TESTED DETECTORS

The three types of images are included in experiments. These images include Landsat-7 image with resolution of terrain element 15m, SPOT-5 image with resolution of 5m and IKONOS-2 image with terrain element resolution of 1.0m. The image detectors which are applied include Sobel detector, Hueckel type detector and Canny detector. There are tested different parameters of detectors but in final results are presented only the best one. The parameters which are adjusted are threshold for Sobel detector are size of the detector and the threshold for converting the edge image to binary image.

The parameters for Hueckel operator are *window size*, *conf*, *diff* parameters and *Width-threshold*. They are presented in figure 1.

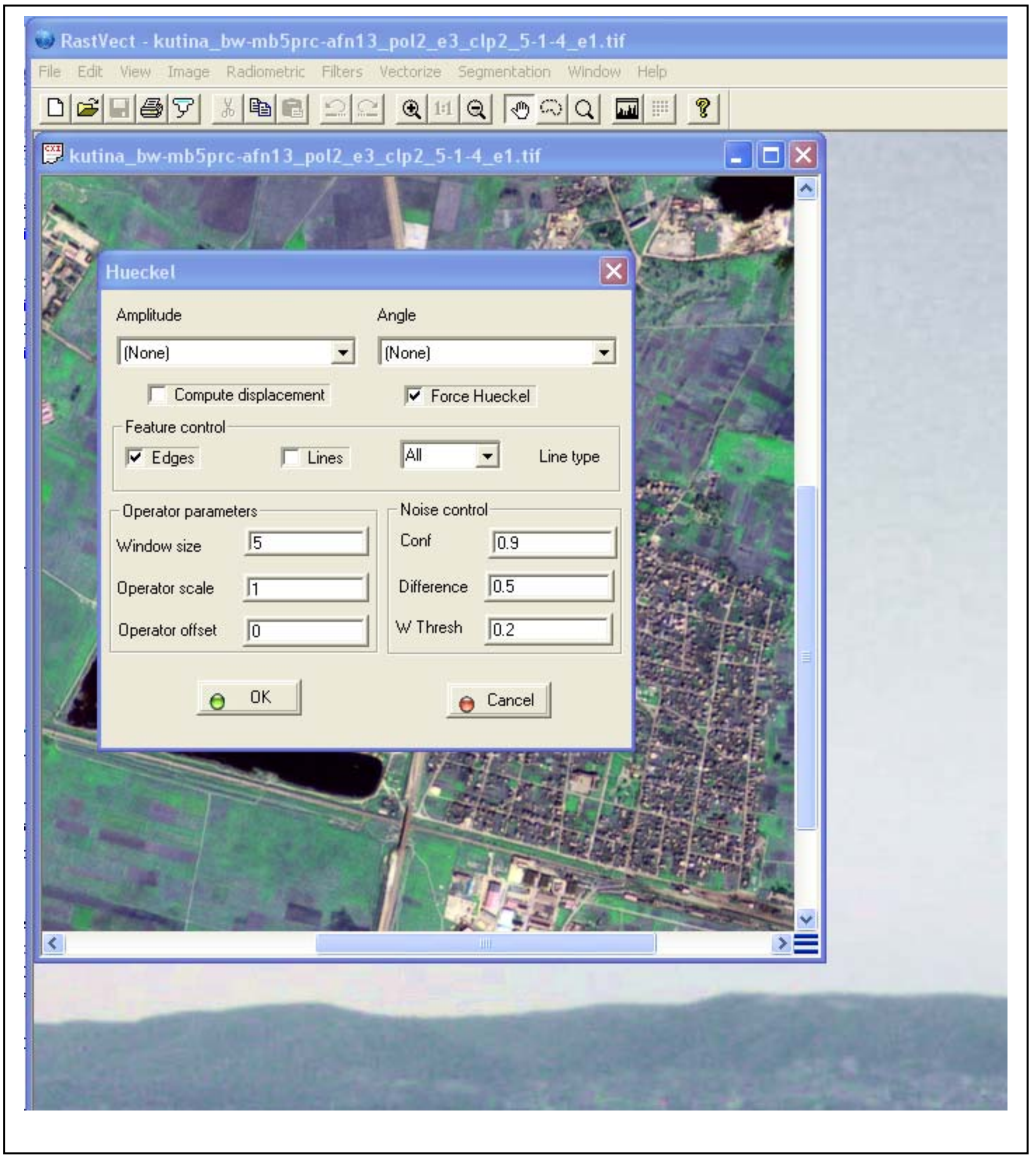

Figure 1.Adjustable parameters of Hueckel Operator

For Canny detector the main parameters for adjustment include window size, sigma parameters of Gaussian filter and threshold levels for boundary scanning – low threshold and high threshold. The image fragment with parameters of detector is presented in figure 2.

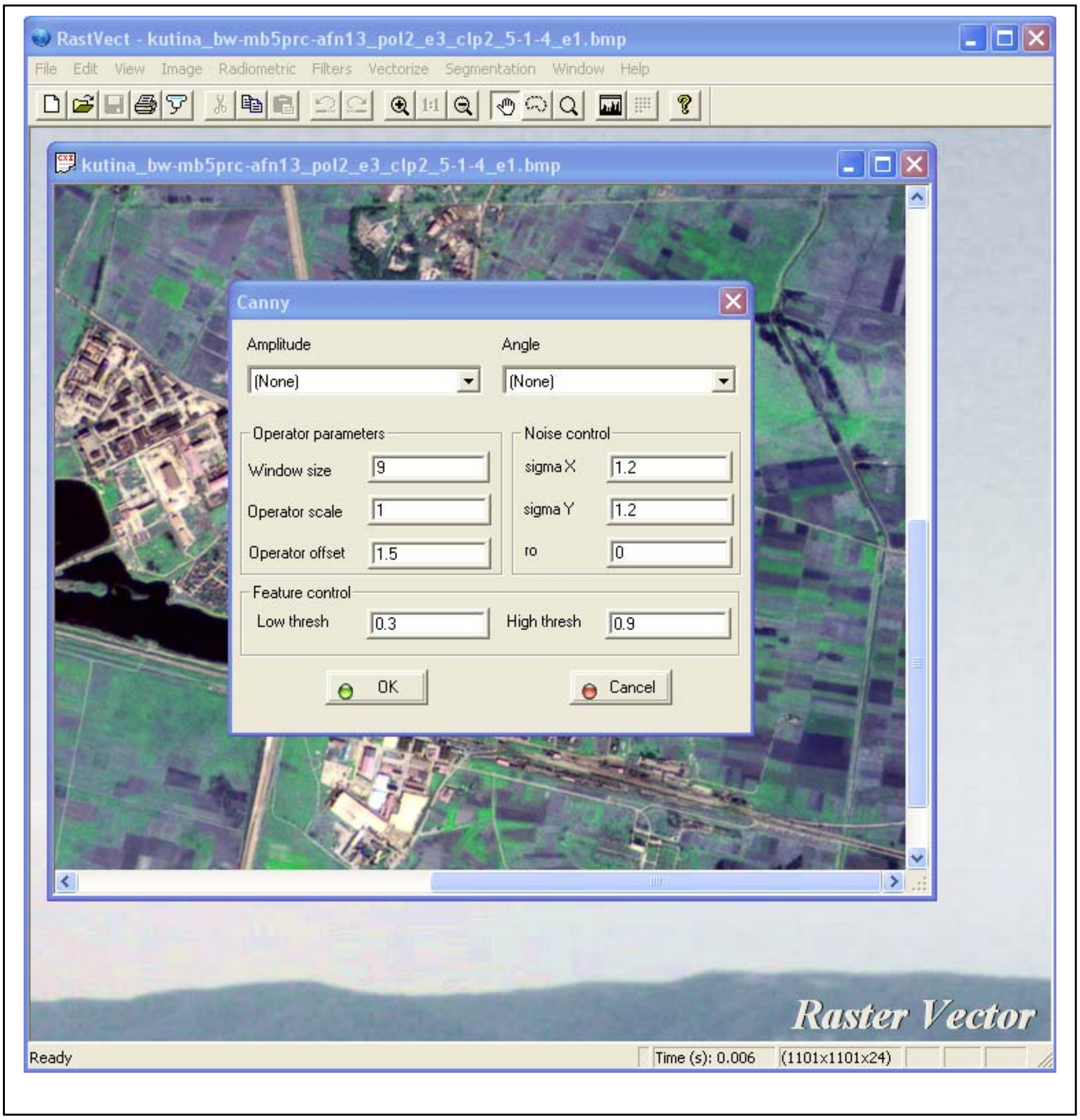

Figure 2. Parameters for Canny detector.

There are tested two approaches for finding the edges in multiband images. One of them is based on the transformation the color image from RGB (red-green-blue) space to BHS (brightness-hue-saturation). It has the advantage that the first component is more significant but its application is limited to color images. Second approach uses the computation of boundary maps in different spectral channels. Final estimation is calculated by superposition of these maps after applying of threshold level.

4. EXPERIMENTS WITH MULTIBAND IMAGES

The experiments with low resolution images are presented in following figures. The initial images cover part of Sofia field at the eastern side of Sofia. Fragment of test image is presented in figure 3.

The results obtained after applying Sobel edge detector are presented in figure 4.

The results obtained with Hueckel detector are created by usage the window size 5x5. The fragment of processed image is shown in figure 5.

The Canny edge detector creates contour image with more connected segments. The result boundary image is presented at figure 6.

Figure 3. Fragment of Landasat7 image.

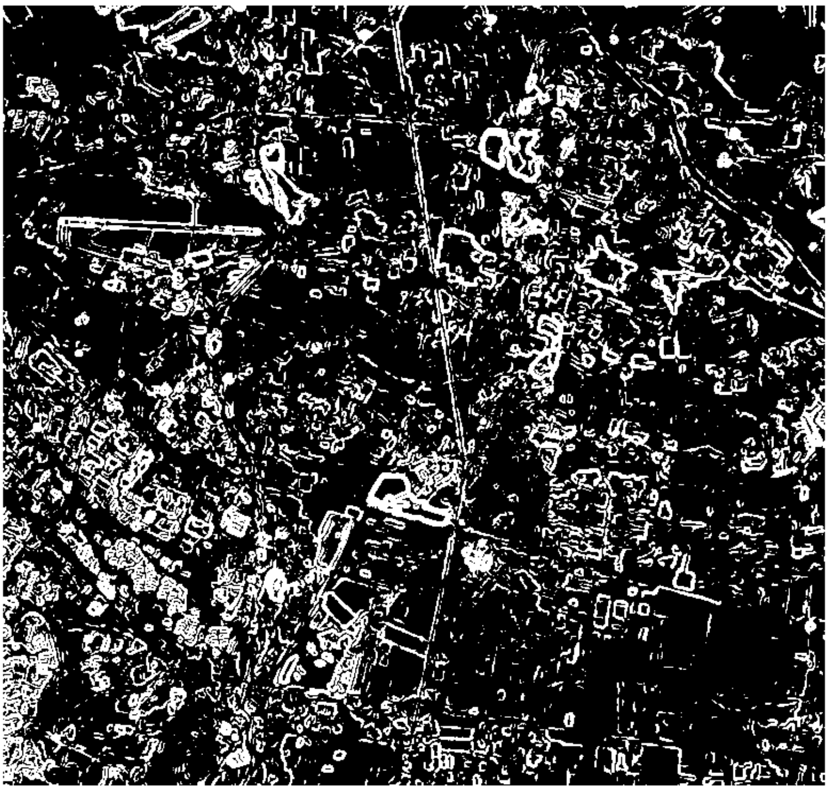

Figure 4. Contour elements after Sobel with window size 3x3 and threshold 9.

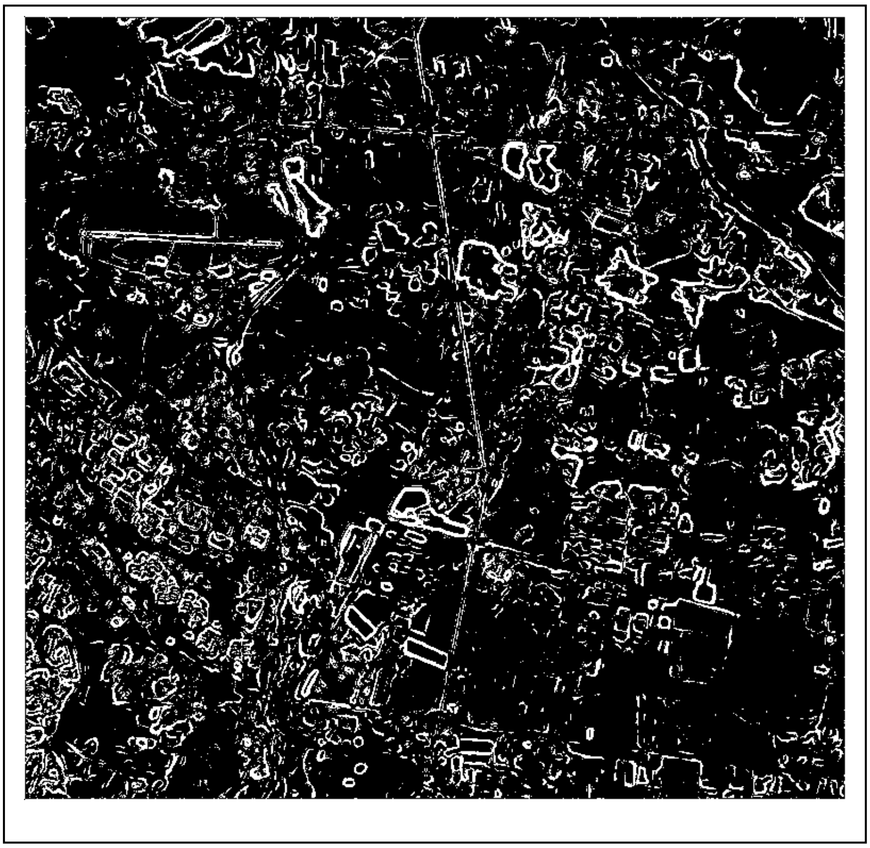

Figure 5. Fragment of image boundaries by Hueckel operator with window 5x5, conf=0.8 and diff=0.4.

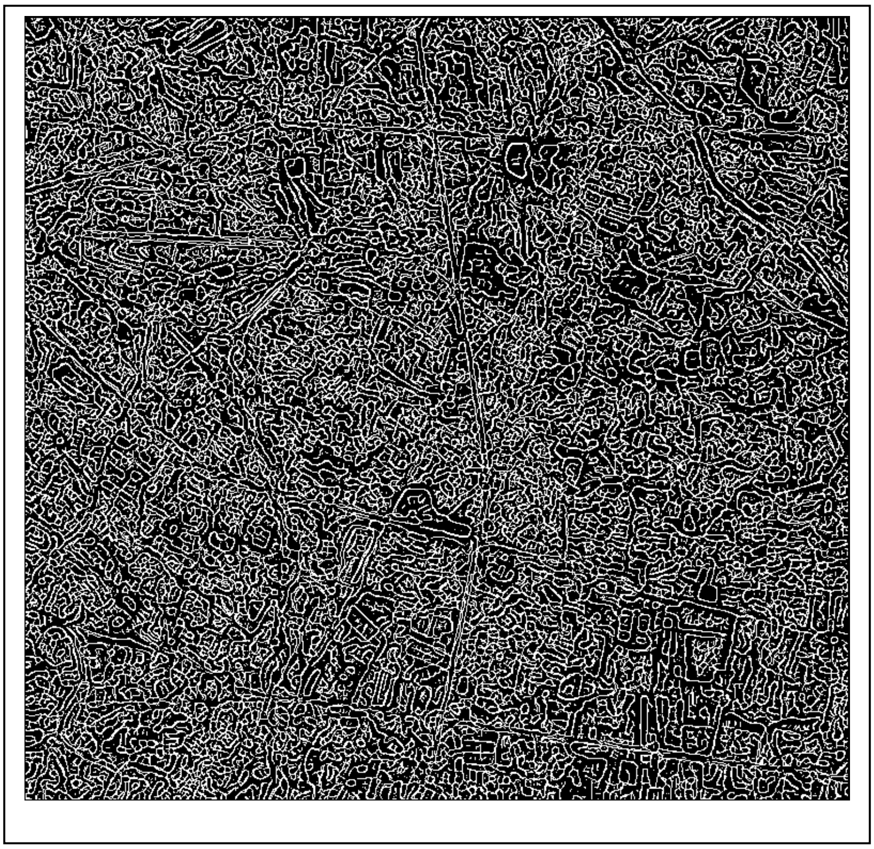

Figure 6. Fragment of contour image after applying of Canny detector with σ=0.9, thigh=0.9 and tlow=0.3.

The similar results are obtained from images of SPOT 5. The resolution of this images is higher than for Landsat7 images. The size of terrain element for pan-sharpened multiband image is 5x5m. The image of boundaries obtained by Sobel operator is shown in figure 7.

Figure 7. Fragment of boundary map after applying the Sobel operator with threshold level t=42.

The results obtained by Hueckel operator are calculated for window size 5x5 and presented in figure 8.

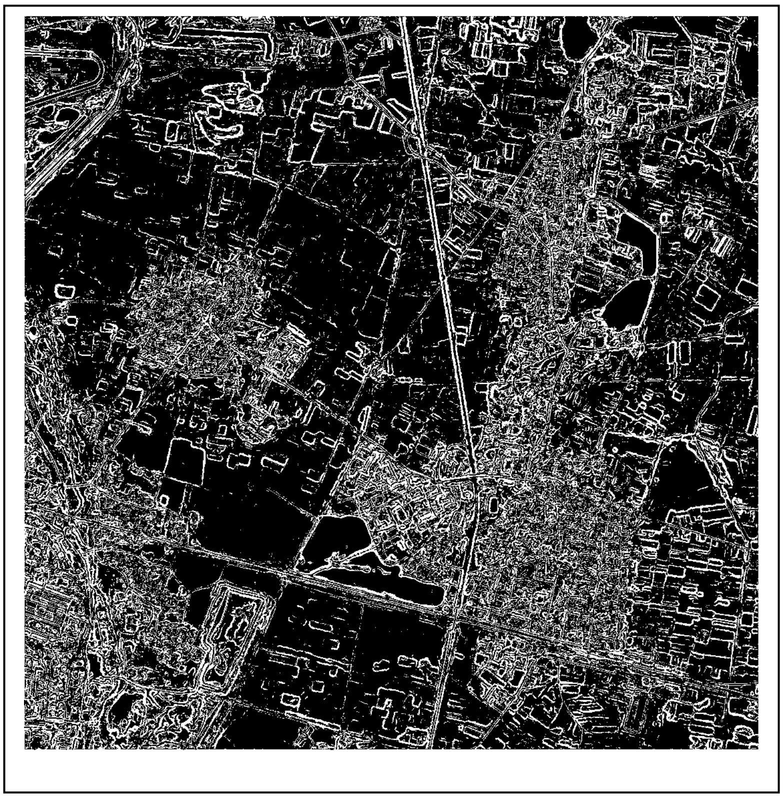

Figure 8. Fragment of contour elements after applying of Hueckel operator with conf=0.9, diff=0.3 and Wthresh=0.2.

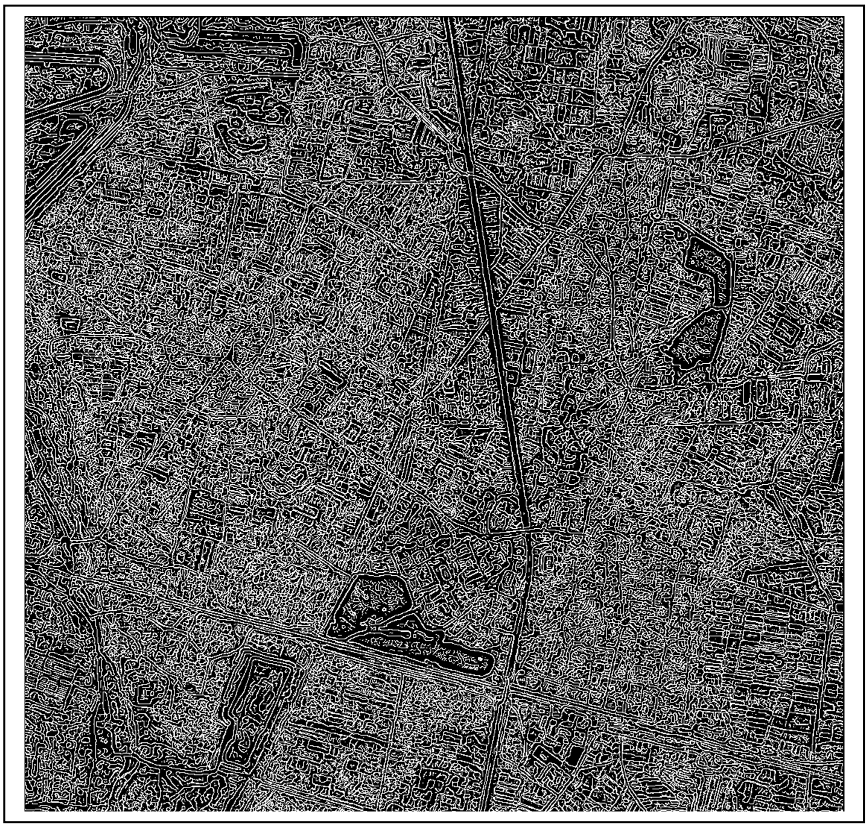

Figure 9. Fragment of Contour after Canny operator with σ=1.2.

The test image for high resolution image is part of IKONOS-2 image of north part of Sofia. High resolution image contain very much small objects. This produces very complex boundary image. The results obtained by Sobel operator with threshold level t=32.

Figure 10. Contour map obtained by Sobel operator with t=32.

Hueckel operator creates more sophisticated contour map. It requires usage of larger window which tends to more simplified contours. The results are shown at figure 11.

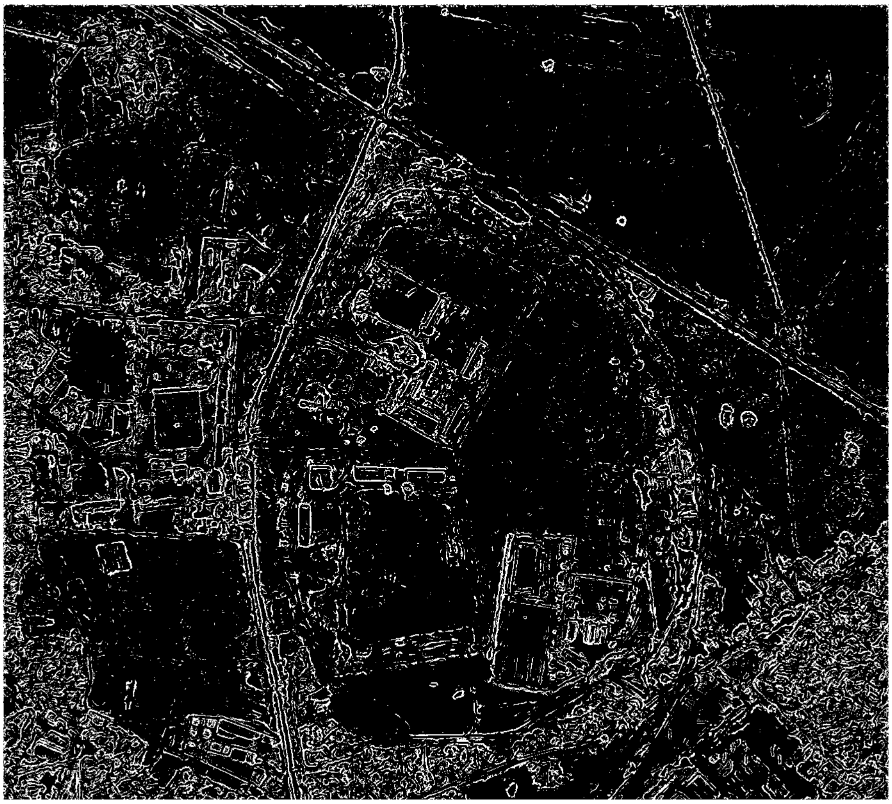

Figure 11. Contour map obtained by Hueckel operator with window size 5x5 and threshold t=16.

The usage of Canny detector produces a lot of contour elements. The result is shown in figure 12.

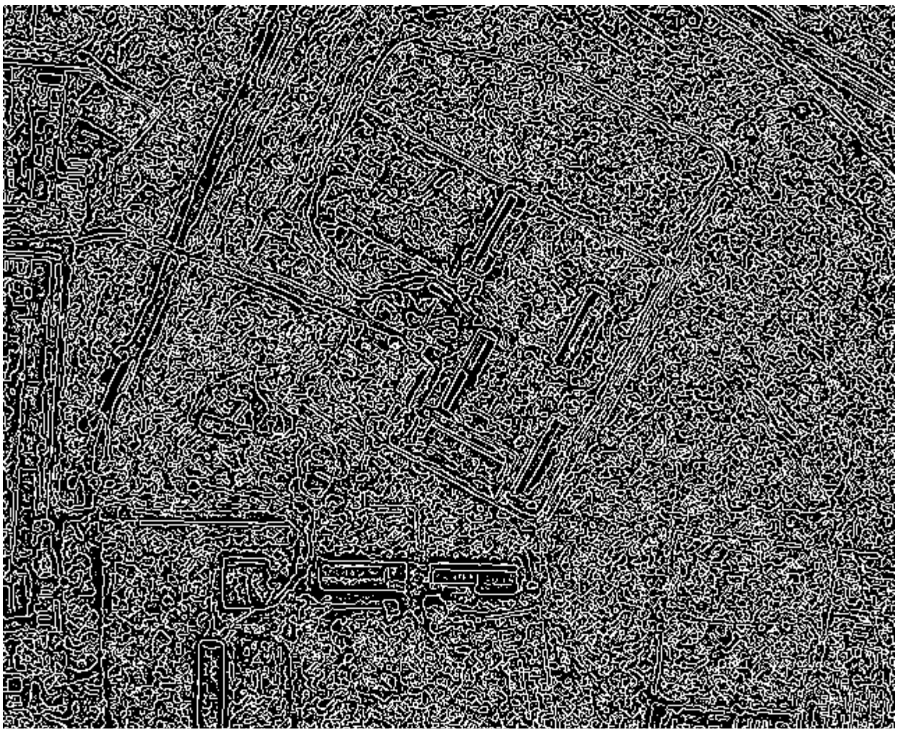

Figure 12. Object boundaries obtained by Canny detector with σ=0.9, thigh=0.9 ant tlow=0.3.

5. DISCUSIONS AND CONCLUSIONS

The comparison of edge detector shows that for medium resolution images Canny detector gives better results. Hueckel operator allows obtaining more precise contours but it requires more intensive calculations. For high resolution images with a lot of objects Canny detector produces too much contours and the contour map is very intense. For such types of images Hueckel and Sobel operators are more appropriate. The usage of Hueckel operator allows controlling of more parameters but large size of window makes it not very suitable convenient for contours of objects with right angles between sides.

There is a possibility to combine the tested edge detector in common program and to select the preferable one depending on the resolution of image and intensity of contour elements.

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Authors:

Borislav Dimitrov Marinov was born in Sofia, Bulgaria at 1951. He has graduated as Electro Engineer in Electronics at Technical University - Sofia. He received his Ms.Sc. degree in Geodesy, Photogrammetry and Cartography at the University of Architecture, Civil Engineering and Geodesy. He has received his PhD degree at 1999. The topic of his doctoral research thesis is on the "Application of Digital Image processing for automation of technology processes in Photogrammetry". He is Associate professor on Photogrammetry and Remote Sensing since 2001 year. He is lecturer on Digital Image Processing, Signal Theory, Photogrammetry and Remote Sensing, Remote Sensing and GIS, Image Analyses, Object Oriented Programming for processing of Geo-images. The field of his professional interests are Digital Image Processing in Photogrammetry, Image Analyses and Interpretation of Multi band Space Images, Close-Range Photogrammetry, E-learning in Photogrammetry.

Veselina Dimova Gospodinova was born in Stara Zagora, Bulgaria at 1980. She received her master degree on Geodesy , specialization: in photogrametry and cartography from University of Architecture, Civil Engineering and Geodesy in 2004. She has experience in working with digital photogrammetric systems. Since 2008 to now she is PhD student in Photogramerty and Remote Sensing at the same University. Her research interests include photogrammetry, remote sensing, image analysis and interpretation.