Object Description and Finding of Geometric Structures on the Base of Extracted Straight Edge Segments in Digital Images

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Abstract – *We present a novel method of grouping straight line segments to describe objects in digital images after straight edges extraction by oriented filtering edge-based algorithm. This method uses crossings in the ordered segments as the main property and it also takes into consideration some specific properties of grouped lines such as anti-parallelism, proximity and adjacency. Structures obtained by this method present an intermediate-level description of interesting objects which have polygonal view (buildings, parts of roads, bridges and some natural places of landscape). At the first step simple structures are obtained by lines grouping taking into consideration all crossing lines or only part of them. At the second step simple structures are joined allowing for restrictions. Application with real aerial and satellite images shows a good ability to separate and extract specific objects like buildings and other line-segment-rich structures.*

Keywords: object recognition, local descriptors, geometric primitives, edge-based feature detector, feature-based image matching, perceptual grouping, building and road extraction.

1 Introduction

Object recognition is one of the fundamental and most studied problems of image processing and computer vision. It has important applications for object extraction and visual tracking, image matching, image indexing and image retrieval [1-9,13,15,24-27]. The key moment of object recognition is describing the category for a recognized object. This is usually done through a set of reliable and repeatable features which may be obtained from an object model or given from a reference image by a universal method. Local features and descriptors are very successful in providing a compact representation for image matching, with applications to registration, wide baseline matching, image retrieval, object recognition and categorization.

There are several levels of feature description. Low-level descriptors may be broadly classified into three main types: point-based, edge-based or linear, and region-based [2,20,26]. Corners and edges are two of the most important geometrical primitives in image processing. Intermediate-level or mid-level descriptors can be obtained by perceptual grouping of the geometrical primitives to get simple structures. High-level descriptors result from comparative analysis of obtained structures and can get enough information for image interpretation, understanding and matching with other image or template.

Detecting and matching specific features across different images typically involves three distinct steps [2,19,20,27]. First a 'feature detector' identifies a set of image locations presenting rich visual information and whose spatial location is well defined. The second step is 'description': a vector characterizing local visual appearance is computed from the image near the nominal location of the feature. 'Matching' is the third step: a given feature is associated with one or more features in other images.

There are intensity-based and geometrically-based methods of feature extraction. If images are obtained from different sources or one image is a sketch, it results in problems in the use of intensity-based methods.

A very important property of every recognition approach is scale invariance. This allows recognition for an object viewed from a different distance or with different camera settings. Other problem is occlusion and background clutter which can significantly change the appearance of features localized on object boundaries.

There are two main approaches to performance assessment of feature detection and extraction algorithms [25]. The first approach deals with stability and localization accuracy of obtained features. The second approach uses the final effect of solving the problem [26].

The performance of the different combinations of detectors and descriptors was evaluated for a feature matching problem [2,11,25-27].

2 Related work

Our study relates to construction of structures for intermediate-level local description of objects in an image. It includes perceptual grouping of geometric primitives taking into account their intrinsic and relative properties [2,5,9,11-18,20,22,30].

There are many objects whose distinctive features are edges and geometrical relations between them. There are very important problems such as land use detection and classification, automatic building and road extraction, river and stream localization, landscape changes and change of object detection, image fusion and multi-image feature-based matching, which require the development and investigation of specific object models and feature descriptions with the use of straight line segments [1,4,5,7-13,21,29,31].

Straight line segments play an important role in features description because almost all contours are locally straight [8,12,15,16,28,31]. In addition many real objects of interest in air imagery have locally straight edges. They are buildings, bridges, roads, rivers, landscape boundaries and so on. There are many approaches of getting straight edge segments from an image. Most of them there interpreted in [12,19,31]. Recent publication [21] presents another interesting algorithm based on aligned points and *a contrario* approach with a false detection control.

A new method proposed in [12,19] uses oriented filtering (slope line filter) and forming a gradient profile in the chosen direction. It has a very important advantage over other methods. It allows getting crossing points between extracted line segments. The second important property of this method is ordering of line segments with respect to the output of the slope line filter. These properties are essential here for grouping lines to simple structures which relate to the intermediate-level description of an image.

Matching images using linear features was discussed in [9]. The authors used the term *anti-parallel* lines, which was defined by Nevatia and Babu, and anti-parallel pairs (APARS). Such parallel segments were represented by a single line through the middle of two segments whose orientations differ by approximately 180^0, the tolerance being inversely proportional to their length, and separated by a width lower than a given threshold. The anti-parallel properties along with crossings present correspondences between line segments.

Idea of straight line grouping for features description seems was first theoretically developed in [18]. An image was interpreted as a collection of objects and relationships between these objects. They used a hierarchy of line segments and relations between these segments to describe geometric structures. The proposed Intermediate-level relational graph describes image structure and contains points (pixels) at the lower level. At the first level points combines to get segments which can form ribbons, junctions and curves at higher levels. Grouping at each level is based on some geometric constraints such as continuity, parallelism, symmetry, overlapping, coincidence and others. The information embedded in the graph is useful for a variety of tasks. Object recognition is often mapped into a graph matching problem.

In [15] authors develop new structural features called *consistent line clusters* that are useful in recognizing and locating man-made objects in images. An important question for content-based image retrieval is how to use the extracted segments to form more advanced features that can be used to recognize various objects.

Coordinates of straight line segments together with angles and magnitudes form the first description level for object description [19]. We can find points of cross-section to detect corners and junctions on the basis of extracted lines. The simplest features are represented by collections of lines which have some relations.

Better extraction of straight line segments allows detection of corners and junctions of edges. We can further develop the known matching algorithms of [8,18] through the use of additional features. Some new ideas were discussed in [14], though without considering the sign of edge gradient.

Searching for related line pairs was implemented by comparing the relation of angles. In [8] a weighed matching measure model of straight lines which simultaneously use various linear features has been constructed and the values of weights of different features have been discussed. The method adopts a hierarchical straight line matching strategy, which uses the matching result of the first step as a restriction to reduce the searching range, and thus to finish the complete matching of the whole imagery. However, it has not overcome the incorrect matching caused by parallel straight lines.

Other descriptors, which are based on active contours, snakes, graph/trees, also including evaluation of the convex hull and the minimum bounding rectangle, have been proposed in [6,11,14,24,30].

Adjacent fields for this research are extracting shapes and meaningful curves from images [16], SIFT local descriptors and interest point extraction [1,20,25-29], detection of multi-part objects [17], region-based features and shape representation [2,11,20,22-24,30].

3 Problem statement and method of solution

3.1 The problem statement and tasks

Our goal is to develop a method for straight line segments grouping to describe specific objects in real imagery.

We propose a new method for straight line segments grouping to make structures which represent intermediate-level object description. We use our method for straight edge segments extraction [12,19] because well-known detectors do not obtain surely localized edges and their intersections. Straight line segments are ordered with respect to the mean gradient magnitudes of edges. Additional features are the orientation and intensity.

The problem is how to construct the object description on the basis of straight line segments and a set of low-level additional features. A novel method uses crossings in the ordered segments as the main property.

The next problem is a practical application and evaluation of this method to real aerial and satellite images for object extraction and recognition, and for image matching tasks.

3.2 Image processing structure description

Image processing structure under investigation is shown in Fig.1. Pre-filtering and straight line segments extraction form a low-level description of an image content. A grey-level image X is obtained from registered initial image after some pre-filtering to smooth the initial image. Straight edge segment extraction algorithm was described in detail in [12,19]. Together with coordinates of end points of each line segment the algorithm gives its angle and the maximal output of a directional filter. All segments are ordered with respect to this output.

The main operation for the next level of feature description is a detection of lines crossings. Every line may be crossed be several lines, and a final table Z contains rows with ordered numbers of lines which cross (or adjoin) the chosen line. Corners and junctions are also included in this table. Algorithm gives up to first 17 ordered crossings for every line. Crossing points coordinates P are estimated and may be also used for final structure description.

Grouping of straight line segments allows getting simple structures which may be obtained by the use of some set of constraints. Here we will use crossings of ordered lines. Structures S obtained after grouping represents the intermediate-level description of an image.

High-level description is obtained after evaluation of geometrical relations between these structures. The results are used for scene interpretation and image understanding.

3.3 Lines grouping algorithms for feature description

The problem is to construct feature descriptors on the base of extracted ordered straight segments for object recognition and image matching. A hierarchical set of features was developed in [19] on the base of the proposed straight line segment detector.

Here we will give slightly different approch to lines grouping on the base of their crossings and analize simple structures which can be obtained by this approach.

At the intermediate level of description straight edge segments are grouped getting a simple structure for a given segment.

Simple structure $C_k = \{L_k, L_m, L_n, L_p ...\}$ may include all crossing lines for a given line L_k or only part of them.

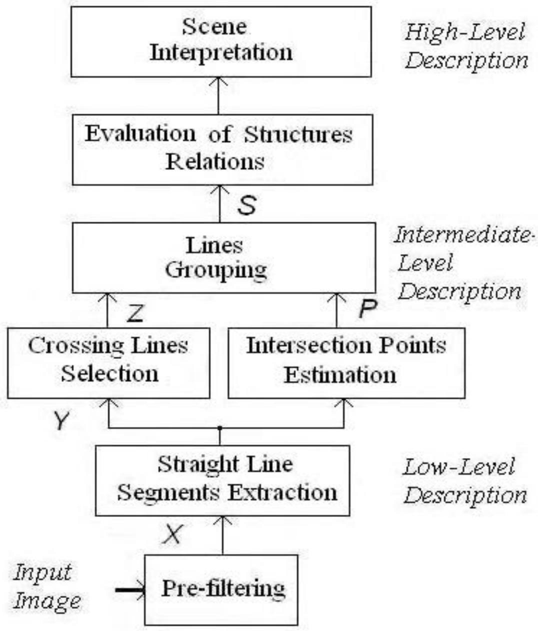

Fig 1. Image processing structure for object description on the base of extracted straight line segments

If we take only one crossing line we can get simple structures of X and L-types. Taking into grouping two crossing lines structures of Π-type and closed triangular structures may be obtained. Some of segment pairs have anti-parallel property and satisfy conditions of proximity (small distance relative to the mean length) and a little shift of one line with respect to another (this means that the projection of one of parallel segment to the direction of another occupies enough part of the second segment). Taking into account more than two first crossing lines may result in appearance of surplus segments in simple structures which leads to rising structure noise level. Application of these restrictions results in selection of simple structures with desired properties among all possible structures.

Complex structure $S_k = \{C_k, C_m, C_n, C_p ...\}$ represents a collection of simple structures for a given line and for their crossing lines allows for mentioned restrictions. Some of simple structures may also be excluded from S_k if corresponding lines have small magnitude M_m with respect to the magnitude M_k of the main line. Resulting complex structure is used for object description along with properties of segments contained in this complex structure.

At this step compound objects with closed parallelogram structures are of primary interest. They may be considered as salient regions. This method can be generalized to form more complex sets of straight segments with corresponding descriptors.

4 Experimental results for Aerial and Satellite Images

4.1 Straight Edge Segments Extraction and Crossing Lines Selection

Original satellite and aerial images are shown at the top of Fig.2 and Fig.3. They contain buildings which have straight edges. The aerial image (right-hand picture) has a better resolution than the satellite one (left-hand picture).

These pictures show the same region of land and have similar scales. We can visually recognize some objects of interest which are the same in both images. They differ in many details and their intensity histograms are not similar, so intensity-based features are not useful.

Pictures in the middle of both figures show good results for detection and localization of straight edge segments. We have achieved a good detection and localization of interest regions. There are two kinds of lines crossings in digital images. First kind means that two crossing binary lines give the value two in the crossing point after summation. In other cases crossing lines move through one another and do not obtain an evident crossing point. Instead we have a small crossing region. The same problem in detection of crossing points appears for relatively small angles between crossing lines.

Image in the middle in Fig.2 contains 490 lines which have 456 crossing points of the fist kind and 44 crossing regions of the second kind; the middle image in Fig.3 contains 400 lines with 387 crossing points of the first kind and 29 crossing regions of the second kind.

Images in the bottom of Fig.2 and Fig.3 indicate first 100 line segments which allow extraction of objects. The problem is how to group corresponding lines for each object and to separate one object from another.

4.2 Lines Grouping and Structures Extraction

The proposed method for line grouping is based on crossings. At the first step simple structures were obtained by lines grouping. Only two first crossing points were taken into account for every line segment so that a simple structure $C_k = \{L_k, L_m, L_n\}$ contains up to 2 crossing lines for a given line L_k. First 50 simple structures were obtained from both images and they are shown in the top of Fig.4 and Fig.5. It is evident that they are partially merged. Together with the main structure C_k we took into account all structures $C_i = \{L_i, L_j, L_p\}$, $i = m, n, ...$ for all crossing lines for a given line. Anti-parallel property, proximity and adjacency were examined for structures selection.

At the second step simple structures obtained were joined for allowing for restrictions. Complex structure S_k may contain the simple structure C_k or may not so that we have a hierarchy of complex structures. Pictures in the middle of Fig.4 and Fig.5 present only closed structures which are of primary interest. The former picture contains six closed structures and five of them (S_0, S_1, S_{12}, S_{23}, S_{32}) relates to the same objects as in the later picture (S_6, S_{38}, S_7, S_0, S_{20}). These objects may be considered as salient regions in both images. Other complex structures for remaining lines are shown in the bottom pictures. Nine structures again relate to the same objects so that 14 objects are correctly separated on both images.

The next stage of processing is the estimation of the centers of objects locations and calculating the geometrical relations between objects extracted, to form an overall set of features for describing the scene.

5 Conclusions

The problem of feature construction for object description and extraction has been discussed. This problem includes feature detection and feature description tasks.

A new method for finding of geometric structures includes two steps. At the first step simple structures are obtained by lines grouping. The method uses crossings in ordered segments as the main property. At the second step anti-parallel property and restrictions in proximity and adjacency are examined to exclude segments due to structural noise.

Applications to real aerial and satellite images show a good ability to separate and extract specific objects like buildings and other line-segment-rich structures.

6 References

[1] J. Shao, R. Mohr, C. Fraser. “Multi-image matching using segment features”; Int. Arch. of Photogrammetry and Remote Sensing. Vol. XXXIII, Part B3. Amsterdam, 2000.

[2] K Mikolajczyk, A. Zisserman, C. Schmid. “Shape recognition with edge-based features”; Proc. Brit. Mach. Vision Conf., Sept. 9-11, Norwich UK, 779—788, 2003.

[3] G. Sohn, I.J. Dowman. “Extraction of buildings from high resolution satellite data”; In: Autom. Extract. of Man-Made Objects from Aerial and Space Images (III), Sweets&Zeitlinger, The Netherlands, 345—355, 2001.

[4] D.A. Lavigne, P. Saeedi, A. Dlugan, N. Goldstein, H. Zwick. “Automatic building detection and 3D shape recovery from single monocular electro-optic imagery”; SPIE Defence&Security Symp., Florida USA, 2007.

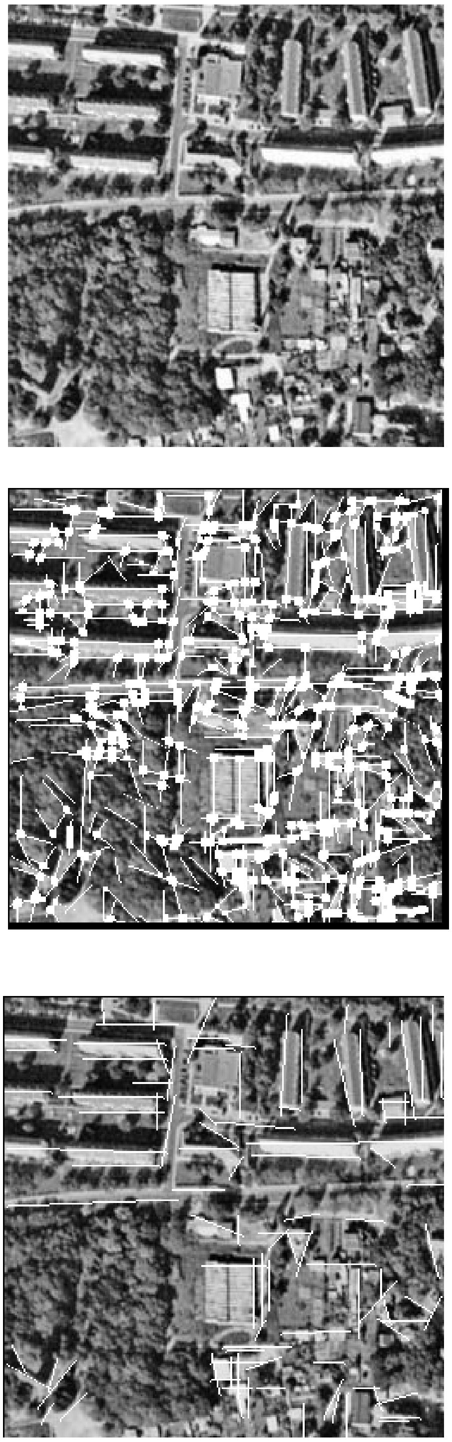

Fig. 2. Straight line segments extraction from the satellite image.

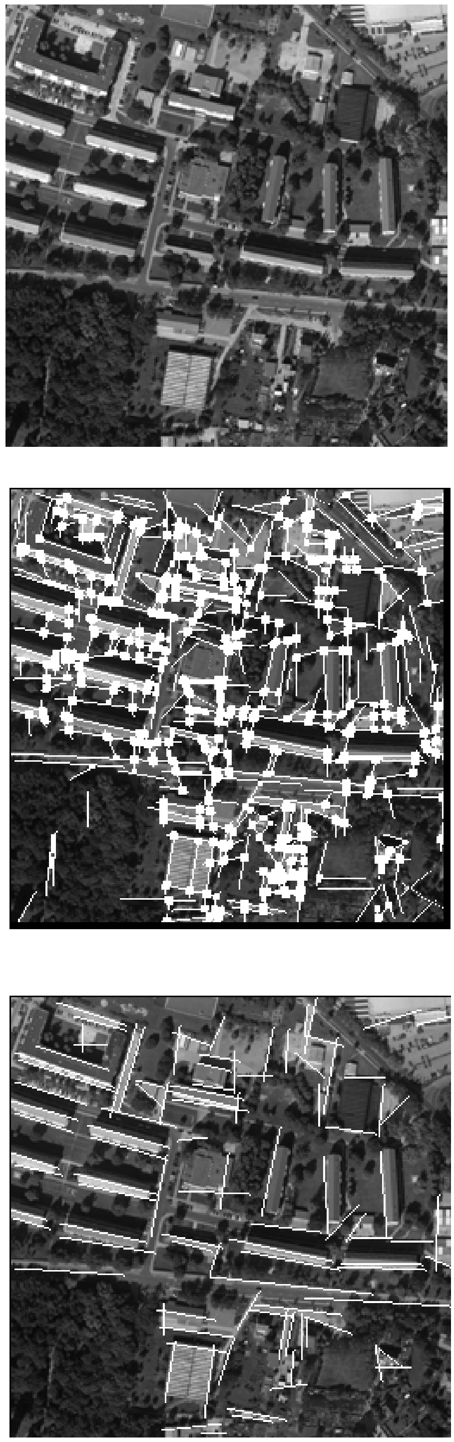

Fig. 3. Straight line segments extraction from the aerial image.

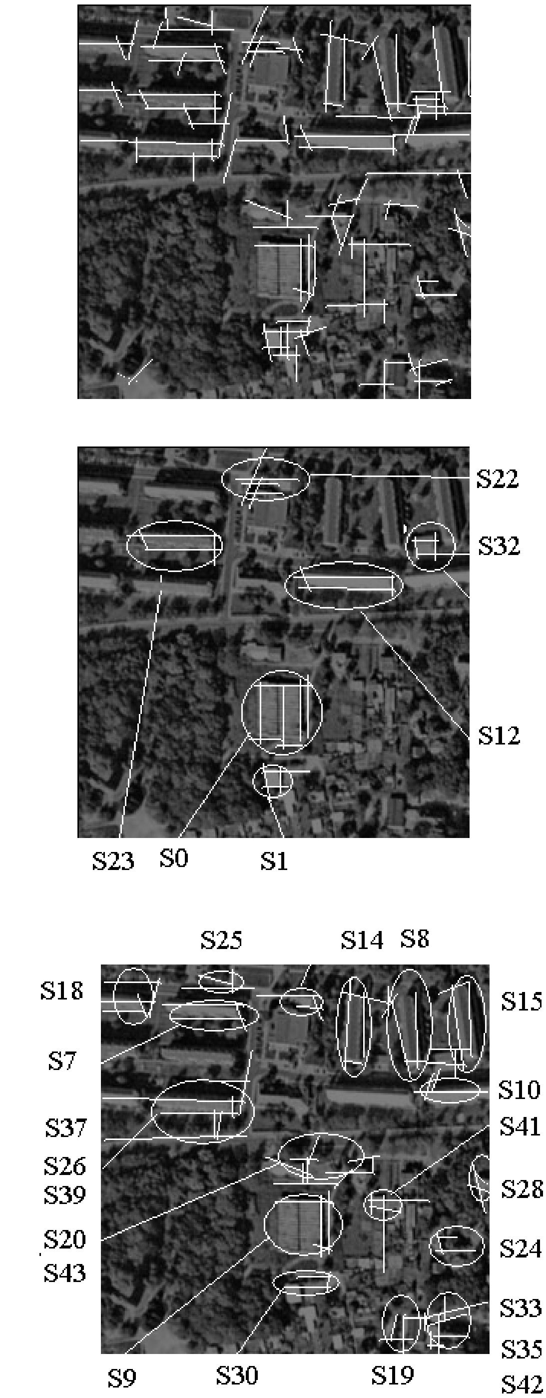

Fig. 4. First 50 simple structures after lines grouping for satellite image and resulting complex structures allowing for restrictions.

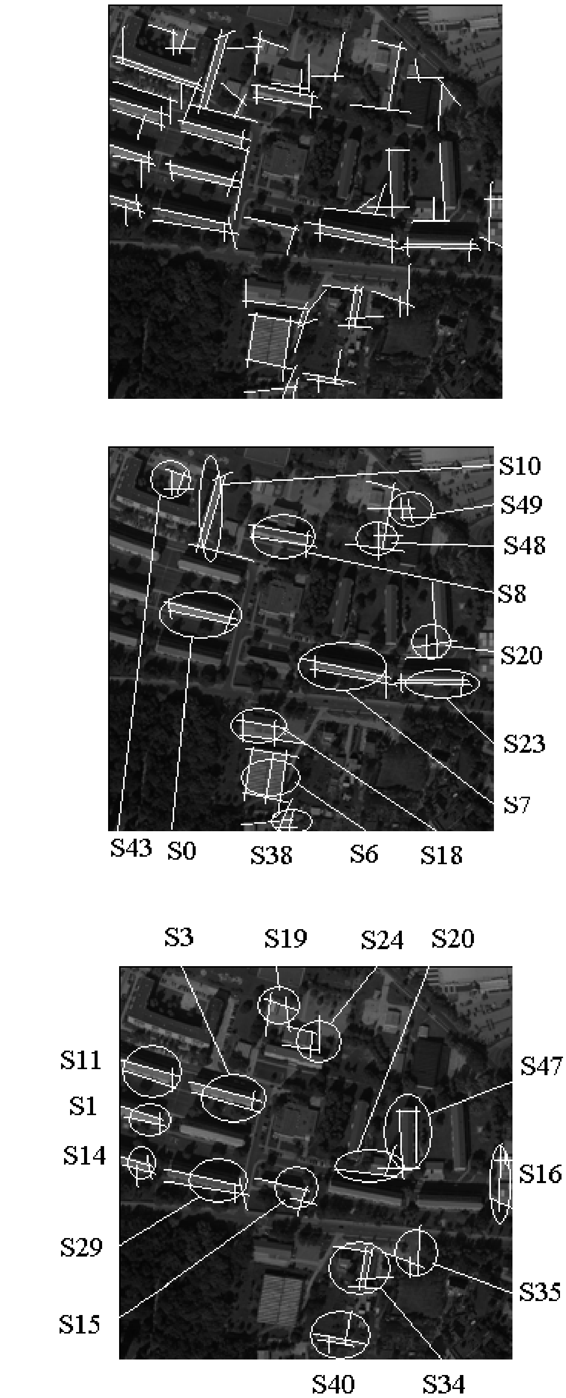

Fig. 5. First 50 simple structures after lines grouping for aerial image and resulting complex structures allowing for restrictions.

[5] E. Tretyak, O. Barinova, P. Kohli, V. Lempitsky. "Geometric image parsing in man-made environment"; Int. J. Comp. Vision, V. 67, 1—17, 2011.

[6] L.B. Theng. "Automatic building extraction from satellite imagery"; Engineering Letters, 13:3, Nov 2006.

[7] X. Jin, C.H. Davis. "Automated building extraction from high-resolution satellite imagery in urban areas using structural, contextual, and spectral information"; EURASIP J. on Applied Signal Processing, V. 14, 2196—2206, 2005.

[8] Z. Fu, Z. Sun. "An algorithm of straight line features matching on aerial imagery"; The Int. Arch. Photogrammetry, Remote Sensing and Spatial Inf. Sciences, V. XXXVII, Part B3b, Beijing, 97—102, 2008.

[9] G. Medioni, R. Nevatia. "Matching images using linear features"; IEEE Tr., V. PAMI-6, 675—685, 1984.

[10] Y. Song, X. Yuan, H. Xu. "A multi-temporal image registration method based on edge matching and maximum likelihood estimation sample consensus"; The Int. Arch. PRSSI Sci., V. XXXVII, Part B3b, Beijing, 61—66, 2008.

[11] M. Brown, G. Hua, S. Winder. "Discriminative learning of local image descriptors"; IEEE Trans., V. PAMI-33, No 1, 1—14, 2011.

[12] V. Volkov, R. Germer. "Straight edge segments localization on noisy images"; Proc. of the IPCV'10, V. II, Las Vegas, Nevada, USA, 512—518, 2010.

[13] M. Ettarid, M. Rouchdi, L. Labouab. "Automatic extraction of buildings from high resolution satellite images"; ISPRS 2008, V. XXXVII, VIII, 61—65, 2008.

[14] S.K. Kim, H.S. Ranganah. "Efficient algorithms to extract geometric features of edge images"; Proc. IPCV'10, V. II, Las Vegas, Nevada, USA, 519—525, 2010.

[15] Yi Li, L.G. Shapiro. "Consistent Line Clusters for Building Recognition in CBIR"; IPCR 2002.

[16] F. Cao, P. Mus.e, F. Sur. "Extracting Meaningful Curves from Images"; Journal of Mathematical Imaging and Vision 22: 159—181, 2005.

[17] R. Bergevin, J.-F. Bernier. "Detection of unexpected multi-part objects from segmented contour maps"; Pattern Recognition, V. 42, Issue 11, November 2009, 2403—2420.

[18] R. Horaud, F. Veillon, T. Skordas. "Finding geometric and relational structures in an image"; First European Conf. Computer Vision, France April 23-27, 1990.

[19] V. Volkov, R. Germer, A. Oneshko, D. Oralov. "Object description and extraction by the use of straight line segments in digital images"; Proc. of the IPCV'11, V. II, Las Vegas, Nevada, USA, 588—594, 2011.

[20] T. Kadir, M. Brady. "Saliency, Scale and Image Description"; International Journal of Computer Vision 45(2), 83—105, 2001.

[21] R. Grompone von Gioi, J. Jakubovich, J-M. Morel, G. Randall. "LSD: A Line Segment Detector"; IEEE Trans., V. PAMI-32, N4, 722—732, 2010.

[22] P. Srinivasan, L. Wang, J. Shi. "Grouping Contours via a Related Image"; IEEE Conf. Computer Vision and Pattern Recognition (CVPR), 2010.

[23] E.J. Bernstein, Y. Amit. "Part-Based Statistical Models for Object Classification and Detection"; IEEE Proc. of CVPR, 2005.

[24] V. Ferrari, L. Fevrier, C. Schmid. "Groups of Adjacent Contour Segments for Object Detection"; IEEE Trans. V.PAMI-30, 36—51, 2008.

[25] K. Mikolajczyk, C. Schmid. "A Performance Evaluation of Local Descriptors"; IEEE Trans., V. PAMI-27, No 10, 1615—1630, 2005.

[26] T. Tuytelaars, K. Mikolajczyk. "Local Invariant Feature Detectors: A Survey"; Computer Graphics and Vision, Vol. 3, No. 3, 177—280, 2007.

[27] P. Moreels, P. Perona. "Evaluation of features detectors and descriptors based on 3D Objects"; Int. J. of Computer Vision, V. 73, No. 3, 263—284, July 2007.

[28] Y. Zhao, Y.Q. Chen. "Connected Equi-Length Line Segments for Curve and Structure Matching"; J. Pattern Rec. and Artificial Intel. V. 18, 1019—1037, 2004.

[29] V. Hedau, H. Arora, N. Ahuja. "Matching images under unstable segmentations"; Proc. 6th Euro Conf. on Comp. Vision, 551—563, 2008.

[30] S. Belongie, J. Malik, J. Puzicha. "Shape matching and object recognition using shape contexts. IEEE Trans., V. 24, N 2, 509—521, 2002.

[31] E. Magli, G. Olmo, L.L. Presti. "On-board selection of relevant images: an application to linear feature recognition"; IP(10), No. 4, 543—553, 2001.