Object Selection by Grouping of Straight Edge Segments in Digital Images

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Abstract – A new method for finding geometric structures in digital images is proposed. An adaptive algorithm of straight line segments extraction is developed for manmade objects description in digital images. It uses an adjustment of oriented filter angle for precise extraction of line corresponding to real edge. Perceptual grouping approach is applied to these segments to obtain simple and complex structures of lines on the base of their crossings. Initial image is presented as a collection of closed structures with their locations and orientations. Applications to real aerial, satellite and radar images show a good ability to separate and select specific objects like buildings and other line-segment-rich structures.

Keywords: object recognition, feature-based image matching, perceptual grouping, content-based image retrieval, building and road extraction

1 Introduction

Object extraction, selection and classification are most studied problems of image processing and computer vision. They have important applications for segmentation, visual tracking, image matching, image indexing and image retrieval [1-8].

Model-based approaches instead of view-based are generally used for manmade object recognition. Techniques of this kind analyze semantic information which is contained in object shape. The usual method is to extract contours and investigate their properties. Perceptual grouping is defined as the problem of aggregating primitive image features that project from a common structure in the visual scene [2]. Grouping of contours is a natural way to get these structures [4-6].

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 [1,2,4,5,9-12].

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 [11-24].

Though plenty of works were devoted to theoretical aspects of grouping problems there are not so much practically effective algorithms for manmade object selection in real images [3,15,17,19,20,23-27]. In addition it is often difficult to obtain performance characteristics for such algorithms, choose criteria and make comparative analysis.

2 Related work

Straight line segments play an important role in features description because almost all contours of real objects are locally straight [3,11-24].

These objects 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 [10-14].

A new method proposed in [11,12] 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.

Idea of straight line grouping for features description seems was first theoretically developed in [9]. An image was interpreted as a collection of objects and relationships between these objects. 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 [1,9,10]. The information embedded in the graph is useful for a variety of tasks. Object recognition is often mapped into a graph matching problem.

In [23] 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 level for object description [11,12]. Better extraction of straight line segments allows detection of corners and junctions of edges. We can further develop the known matching algorithms of [3,9] through the use of additional features. Some new ideas were discussed in [10], though without considering the sign of edge gradient.

Searching for related line pairs was implemented by comparing the relation of angles. In [3] 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 [10,17,20] (also see [12] for more citations).

### 3 Problem statement and method of solution

#### 3.1 The problem statement and tasks

Our goal is to develop a practical algorithm for straight line segments grouping to select manmade objects in real imagery. These objects may have polygonal configuration, in most cases they are rectangular in shape.

We present a detailed description of the new method for straight line segments grouping to make structures which represent intermediate-level object description. We develop our method for straight edge segments extraction [11,12] because well-known detectors do not obtain surely localized edges and their intersections. New algorithm includes line angle adaptation loop to get precise estimate of edge orientation.

Straight line segments are ordered with respect to the mean gradient magnitudes of edges. Additional features are the orientation, intensity and width of the edge. The problem is how to construct the object description based on straight line segments and a set of low-level additional features. A novel method uses crossings in the ordered segments as the main property for grouping.

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 and algorithm modifications

Image processing structure 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 [11,12]. In comparison with previous algorithm several improvements have been made to get better edge locations and to decrease the calculation time. Instead of rotating gradient images oriented filtering was obtained by the use of a bank of rectangular filter masks. Every mask has small width (about 3-5 pixels) and a length $l_{mask}$. This length is a filter parameter which affected on the resulting lines ordering. It is also related to image sizes and determined edges which were extracted at the first steps.

Eight local gradients are calculated by the use of Sobel masks in corresponding sectors. Directional filter masks have different angles of orientation in these sectors with spacing of 6 degrees. The first extracted point has maximum value among all oriented filter outputs. Direction of this filter defines rough estimation of the first line orientation angle.

To obtain end points coordinates of the segment gradient profile along the obtained rough direction is formed which has to be averaged among several adjacent lines. In the top of Fig.2 gradient ridge is represented which has a small positive angle of orientation. Dashed line relates to the oriented filter mask which got maximum output filter value. It has horizontal direction which is a rough direction of the line. The corresponding gradient profile is described below. There is an angle error $a$ between rough direction and the ridge slope. This error results in bad end points estimation which was a drawback of the previous algorithm.

In contrast to early version in the modified algorithm orientation angle of the line is adapted by maximizing the estimated length of the segment at this point. Oriented mask is rotated within the bounds of 6 degrees with the step of 0.5 degrees.

At every step a length of segment is calculated through the threshold circuit and the precise angle $\phi$ is set which corresponds to the maximum of the segment length. This procedure prevents fragmentation of lengthy lines in the image. The resulting profile is presented in the bottom of the Fig.2.

Threshold value $length\_thresh$ is the other parameter of the algorithm which determines the resulting line lengths. All gradients inside the segment have to exceed the $length\_thresh$. So high values of $length\_thresh$ may cause line fragmentation. Too small values may result in connection of different lines in the same direction.

Number of lines $n\_lines$ is the last parameter which has to be chosen. It determines maximal number of extracted segments in the image.

In practice we may set additional threshold $grad\_thresh$ which restricts minimal gradient values for lines extraction. In this case exact number of lines may be less than $n\_lines$. The task of setting the value of $grad\_thresh$ relates to the problem of noisy lines cancellation.
At the beginning of processing the number $n_{lines}$ of extracted lines should be restricted by the use of some a priori information about number of objects in the image. Together with coordinates of end points $s_{coordinate}$ and the length of each line segment $length$ the algorithm gives its angle $\phi$, the maximal output of a directional filter $m_{filter}$ and width of the ridge $width$. To calculate this width the second threshold value $h_{widththres}$ is needed. Algorithm forms several cross-sections of the ridge gradients and makes estimates of width which are averaged to form the resulting width.

All segments obtained are ordered with respect to the value $m_{filter}$ of filter output.

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

### 3.3 Lines grouping algorithms for object description and selection

The problem is to construct feature descriptors on the base of extracted ordered straight line segments for object recognition and image matching. A hierarchical set of features was developed in [11,12]. Here we present the detailed description and evaluation the performance of the method.

At the intermediate level of description straight edge segments are grouped getting a simple structure for a given segment line. Here we define simple structure $C_k = \{L_k, L_m, L_n\}$ as a set of lines which may include up to two crossing lines for a given main line $L_k$, $k = 1, \ldots, n_{lines}$, $k < m < n$.

At the first step of grouping lines several restrictions may be applied to select the most interesting simple structures:

- Contiguity describes touching or bordering of two lines; here a crossing of lines is a kind of contiguity;
- Anti-parallelism of two lines which cross the main line means that they have absolute difference in orientations near 180 degrees; in practice we may define some angle $\gamma$ in degrees (the half of possible error) as a measure of anti-parallelism; anti-parallel lines are called APARS [14];
- Proximity is being to or near; it can be evaluated by the distance $d$ between lines;
- Adjacency is being enough so as to touch; adjacent line results from road borderers extraction; it characterizes by the shift $\delta$ of one of anti-parallel line with respect to another.

These parameters are illustrated in Fig.3. It needs to normalized values $d$ and $\delta$ with respect to minimal length of anti-parallel lines. Application of these restrictions results in selection of simple structures with desired properties among all possible structures.

Complex structure $S_k = \{C_k, C_m, C_n, C_p, \ldots\}$ 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 the corresponding line has small magnitude \( M_w \) 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.

In this study compound objects with closed parallelogram structures are of primary interest. They may be considered as salient regions. Then a complex structure consists of two simple structures with mutual lines. This method can be generalized to form more complex collections of straight segments with corresponding descriptors.

4 Modelling of object detection, selection and localization

Consider a model of a noisy image which contains ten equal horizontal stripes, every stripe contain ten square objects of size 16x16 with Gaussian noise background (Fig.4, left top image). Signal-to-Noise ratio (SNR) is different in stripes. Its values vary from the top stripe to the bottom: 0.58; 1.16; 2.32; 3.49; 4.65; 5.81; 6.98; 8.14; 9.3; 11.6. The task is to detect and select square objects in the image.

Well-known Canny detector gives excellent extracted edge presentation (top right image in Fig.4) for object localization but it is difficult to test square shapes of the objects. It needs getting straight segments for solving the selection problem. The Hough transform can get straight line segments on the base of Canny edges. They are represented in the left bottom image in Fig.4. Few square objects may be extracted here even at high SNR.

One of modern algorithms is the Line Segment Detector [13] which obtains the presumed false alarms of noisy lines in the image. The result of lines extraction is shown in the right bottom image in Fig.5. The drawback of the LSD is the lack of crossing points but it is possible to construct closed objects by the use of lines fusion. By this way algorithm can detect and localize closed square objects but with low quality even at high SNR.

The proposed algorithm gives closed square objects as complex structures. Results of detection and localization are represented in the top of Fig.5.
Comparative analysis with Harris detector (right top picture) shows that the proposed algorithm can better detect crossing points. This is shown on the detection characteristic where curve 1 represents the proposed algorithm and curve 2 relates to Harris corner detector.

Consider another model of a noisy image which contains four stripes and different rectangular objects in each stripe (Fig.6).

Objects have different sizes in each stripe and SNR has increasing values 0.58, 1.16, 2.33 and 4.65 from top stripe to the bottom. The task is to select rectangular objects with different shapes, estimate their location and orientation parameters.

It is possible to control the selection process by varying the parameters $\gamma$, $d$, and $\delta$. When we do not restrict the shape of objects algorithm extracts every rectangular object for SNR more than 1.16.

This is presented in Fig.6, where bottom images show location and orientation of the first two objects.

If minimal $\delta$ equals to 0.5 algorithm gives 6 objects in the centre. Reducing angle $\gamma$ to 1 with $\delta=0.1-10$, we get only well-shaped four objects (Fig.6).

5 Experimental results for aerial, satellite and radar images

Original aerial and satellite images are shown at the top of Fig.7. They contain buildings which have straight edges. The aerial image (left-hand picture) has a better resolution than the satellite one (right-hand picture).

These pictures were investigated in [12] but closed structures have not been selected and localized. Here the processing was made more precisely. At the output we get 154 different closed structures in the left image and 107 structures in the right image. These structures represent whole objects and also different fragments of them and all have localization and orientation. We can initially distinguish ten objects which are the same in both images. Six of them can be extracted as a whole or partly.

Locations and orientations of the main object are shown on the bottom of Fig.7.

Another pair of images is represented in Fig.8. Aerial image on the left contains 187 closed structures and SAR radar image on the right side contains 190 structures for objects and their parts. Despite a poor quality of both images about a half of objects can be selected correctly.

The perspective investigations may relate to application of region-based methods of object extraction and recognition after previous segmentation is made by the use of lines grouping.
Consider aerial image on the top of Fig. 9 which is taken from [20] where active contour (snake) procedure was performed and the result is repeated in the second picture. Such a procedure needs initial points for successive object selection. The proposed algorithm works without initial setting and gives closed structures which are shown in the third picture. It selects almost all rectangular objects but gives several surplus structures. These structures do not relate to false or noisy objects but selection of useful objects needs additional analysis. Fourth picture in Fig. 9 shows triangular structures on the image and fifth picture gets extracted roads.

6 Conclusions

The problem of object selection by the use of straight line segments extraction and grouping has been discussed. The method proposed includes several stages. At the first stage low-level description is obtained by the use of ordered list of straight line segments. Algorithm is improved by adaptation to decrease the errors of angle and length estimates. At the second stage crossing points of lines are calculated and lines are grouped on the base of their crossings to get simple structures. At the third stage selection is made subject to geometrical restrictions, and simple structures are joined to get closed complex structures. Only rectangular (or sometimes triangular) objects and parts of them were selected and localized here but algorithm permits to extract other types of objects (roads, polygonal structures) with little effort.

Analysis on noisy models shows the dependence of processing characteristics on the main parameters which can control the object selection process. Applications to real aerial, satellite and radar images show a good ability to separate and extract rectangular objects like buildings and other line-segment-rich structures. Most of objects are selected somehow or other and the following problem is how to improve grouping process.

7 References


Fig. 9. Selection of different objects in aerial image