Automatic Extraction of Road Network on the Satellite Image

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ABSTRACT

Road selection on satellite images is one of the stages of topographic map updating. In this paper the scheme of automatic map updating is described, the problem of road network elements localization on the satellite image is formulated, researches in this area are analyzed. Proposed by author modified algorithm for road network elements detection is described. The results of the experiments showed that ٧٣٪ of road network are selected.

Index Terms— extraction of road network, satellite image, scanning algorithm, segmentation of satellite image, updating of topographic maps.

I. INTRODUCTION

Extraction of road network on satellite imagery is one of the most important stages in topographic maps updating. Even partial automatization of this stage could speed up the updating process and cut down its cost. Topographic map updating task has some difficulties due to constant changing of terrain infrastructure. Now several researches try to realize automatic updating of digital topographic maps using satellite images. In this article author described one approach to solve this task.

II. FORMULATION OF THE PROBLEM IN GENERAL TERMS, ITS CONNECTION WITH IMPORTANT SCIENTIFIC AND PRACTICAL TASKS

Extraction of road network elements on satellite images should be performed in accordance with their geometric and brightness features. Author selects two steps: (١) localization of the road network elements on a raster satellite image and (٢) creating of vector data model of the target layer. Second step can be formulated as a task of forming a set of linear fragments for approximation of the road network. Image binarization and vectorization are sub-tasks of this one.

Methods and techniques from various fields should be used to solve the problem of road network extraction. These fields include: digital images processing (including filtration, segmentation or clustering methods), image discrimination theory, linear algebra, mathematical statistic. Statistical techniques, as well as methods of cluster analysis and methods of images binarization are used for classification of the points (i.e. extraction of road points from the others) (Gonzalez, Woods, ٢٠٠٨).

The result of extraction is a set of metric and attribute data described the road fragments.

Topographic map updating according to satellite images is performed as follows. There are raster map and raster image, taken later than map was formed, and there are procedures for extraction of map/ image elements. Task of map updating according to satellite imagery can be solved through finding of two sets of elements. The first set contains the elements shown on image but absent on map (i.e. newer objects that appeared on terrain after map creation); these elements should be mapped. The second contains the elements that are shown on map but absent on image (i.e. old objects that disappeared after map creation); these elements must be deleted from a map.

So, the process of automated map updating according to the satellite imagery can be described schematically as shown on Fig. ١ (Rang Abdallah, ٢٠١٥).

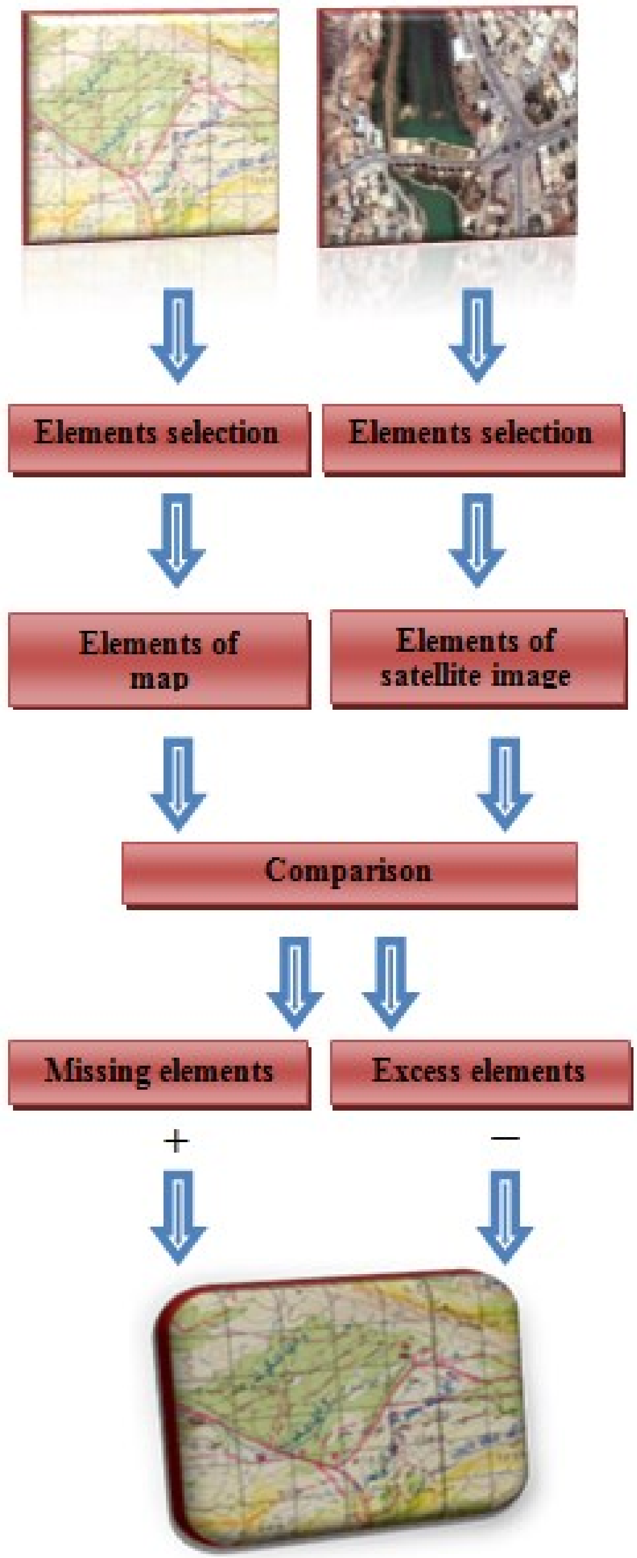


Fig. ١. General scheme of map updating according to satellite image.

The process of road network elements extraction on satellite imagery is shown on Fig. ٢.

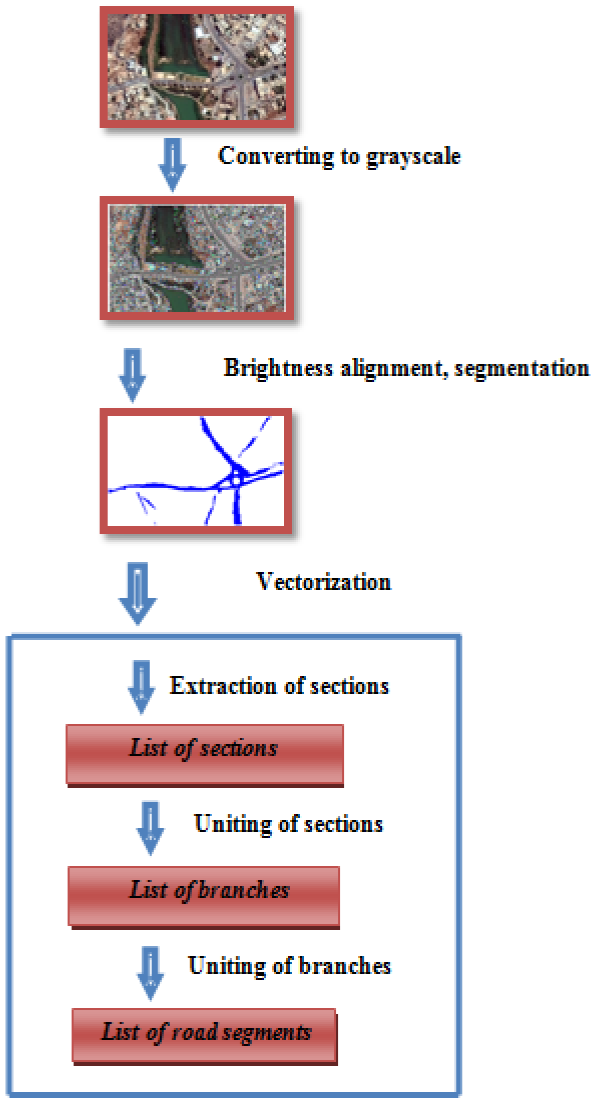


Fig. ٢. Stages of road network extraction on satellite image

III. RECENT RESEARCH ANALYSIS, EMPHASIZING THE UNRESOLVED ISSUES

Road network extraction on raster satellite images is a topic of some researches in different countries.

Thus, in A. Grote's work (Grote, ٢٠١١), the aerial images of suburban scenes in Grangemouth (Scotland) and Vaihingen (Germany) was used. For segmentation author presents the image as a graph and uses a method of normalized cuts. Road fragments are extracted from segmented images and merged for creation of road network. P.N. Anil et al. (Anil, Natarajan, ٢٠١٠) offered the statistical area merging for imagery segmentation. Road network is extracted due to the skeleton pruning method based on contour partitioning.

In the work (Dal Poz, ٢٠٠٥), the methods of road extraction are offered based on dynamic programming algorithm. Moreover, various methods are discussed in the works (Qiaoping Zhang, ٢٠٠٦; Ziems, ٢٠١٢; Ziems, ٢٠١٠). All approaches are characterized by one common feature – semiautomatic image segmentation. It means that initial points for road extraction are selected by human operator. None of the works describe an approach that enables to extract road network absolutely right. Thus, in the work (Qiaoping Zhang, ٢٠٠٦) ٧٣ % of roads are extracted at most. Approach described in the work (Ziems, ٢٠١٠) enables to extract almost ٥٨ % of roads. In the work (Yashenko, ٢٠١٤), the automated method of road network extraction on aerospace imagery is offered and reasoned.

Problem of road extraction is solved after imagery binarization. Two approaches are used here: tracking and scanning. Tracking algorithms (Shapiro, Stockman, ٢٠٠١) assume that one point of object is detected whereupon contour is determined. Simplicity is advantage of these algorithms, while disadvantages contain slow realization of sequential execution and a certain difficulty of internal contour searching and processing.

Scanning algorithms (Forsyth, Ponce, ٢٠٠٣; Zheltov, Vizilter, ٢٠٠٤; Oneshko, ٢٠١٠) are based on image scanning in general and extraction of boundary points without contour tracking.

Binarization of satellite imagery is performed by its segmentation, as the result of which all pixels are divided into ٢ segments: “road” and “non-road”. The main problem is insufficient accuracy. So, elements that do not belong to the road network are selected, as well as some points of roads are missed. Methods applied for segmentation of random images are described in (Gonzalez, Woods, ٢٠٠٨); methods of contour extraction and cluster building are the most popular among them (Gonzalez, Woods, ٢٠٠٨.). However, as shown in (Yashenko, ٢٠١٤), these methods are of insufficient accuracy with regard to the satellite imagery.

IV. ARTICLE’S OBJECTIVE, SETTING THE TASKS THAT ARE SOLVED IN IT

The article’s objective is describing the modified method of extracting the road network elements as suggested by authors, as well as analysis of obtained results from the perspective of their accuracy.

V. BASIC MATERIAL, SUBSTANTIATION OF THE OBTAINED RESULTS

Several researches deal with road network extraction. For topographic map color is the key feature of identification (Rang Abdallah, ٢٠١٥). But in case of satellite images, as shown in (Grote, ٢٠١١), color can't be used, brightness of points is the main identifying parameter.

In other work, elements of road network are the objective layer of extraction; they exhibit the following properties (Yashenko, ٢٠١٤): measurable elongation on straight-line section; the same width of section; balanced distribution of brightness within the bounds of object; sharp contours of road platform. Finite Impulse Response Filter (FIR-filter) (Yashenko, ٢٠١٤) was employed as a basic method for localization of road network. This approach is used as basic by author. There are some modifications in basic method. First modification is made at the stage of finding the brightness values of points that belong to the filter window. In the basic algorithm filter points coordinates calculated through line equation. This line is formed by filter window in the chosen coordinate system, as well as equation of a circle, described by filter window in rotation of the relatively testing point. However, it is shown (Rogers, ١٩٩٧) that this approach has insufficient accuracy. In order to increase accuracy, author used the Bresenham's raster algorithm (Rogers, ١٩٩٧) for generating of points in filter window.

Thus, the process of extracting the target layer (elements of road network) includes the following stages:

١. Image reading. The basic data for this step is a raster file with image; the output is a bit map of image, ٢٤ bits per pixel.

٢. Image converting into grayscale according to the formula (Gonzalez, Woods, ٢٠٠٨):

$$Y = ٠.٢٩٩R + ٠.٥٨٧G + ٠.١١٤B,$$

where R,G,B are the color components of original point of image, Y – brightness component.

٣. Extraction of linear fragments with balanced brightness and sharp contour, in which their length is much greater than width (wave segmentation). In the result of executing the following stage, the matrix of binary image is formed; the matrix size is equal to the size of original image, each element stores the value ١ for the points belonging to linear fragments, and ٠ – for the rest.

٤. Image vectorization for describing the geometric parameters of road network elements.

Consider in detail the stage of wave segmentation. The first step is extraction of points in the R-area of current point. Work's authors (Yashenko, ٢٠١٤) use the equation of a circle $x^٢ + y^٢ = R^٢$ for defining the coordinates of points of such area. Whereas, author of this work offers to generate points of the region with help of the Bresenham's raster algorithm, as using of the equation of a circle in raster image does not give the balanced distribution of points and therefore reduces accuracy of results.

The second step of this stage is defining the coordinates of points of linear filter. The equation of a line in the form $y = kx + b$ is used in basic algorithm. Author here uses the Bresenham's raster algorithm on this stage also for generation of points of line section: this algorithm has better time and accuracy characteristics, as in case of generating the points of a circle.

The third step is checking the belonging of points in window filter to the object, possessing the qualities of road network element as listed above. To achieve this, a mean square deviation of point brightness in window filter is calculated.

The fourth step is analysis of mean square deviation and making a decision concerning the belonging of point to road network element (Yashenko, ٢٠١٤).

Let's consider in detail the algorithm for line segments selecting with author's modification. As in the basic algorithm (Yashenko, ٢٠١٤), we select line segments with small width and equal brightness. The algorithm processes grayscale image with height *imHeight* and width *imWidth*. The algorithm analyzes the R - area of each point of the image and considers all possible line segments passing through this point. If we found a segment that consists of points with the same brightness (the criterion is the standard deviation of points brightness) and has a small width, we add it to the list of selected segments.

A flowchart illustrated the algorithm for line segments selecting is shown on fig. ٣.

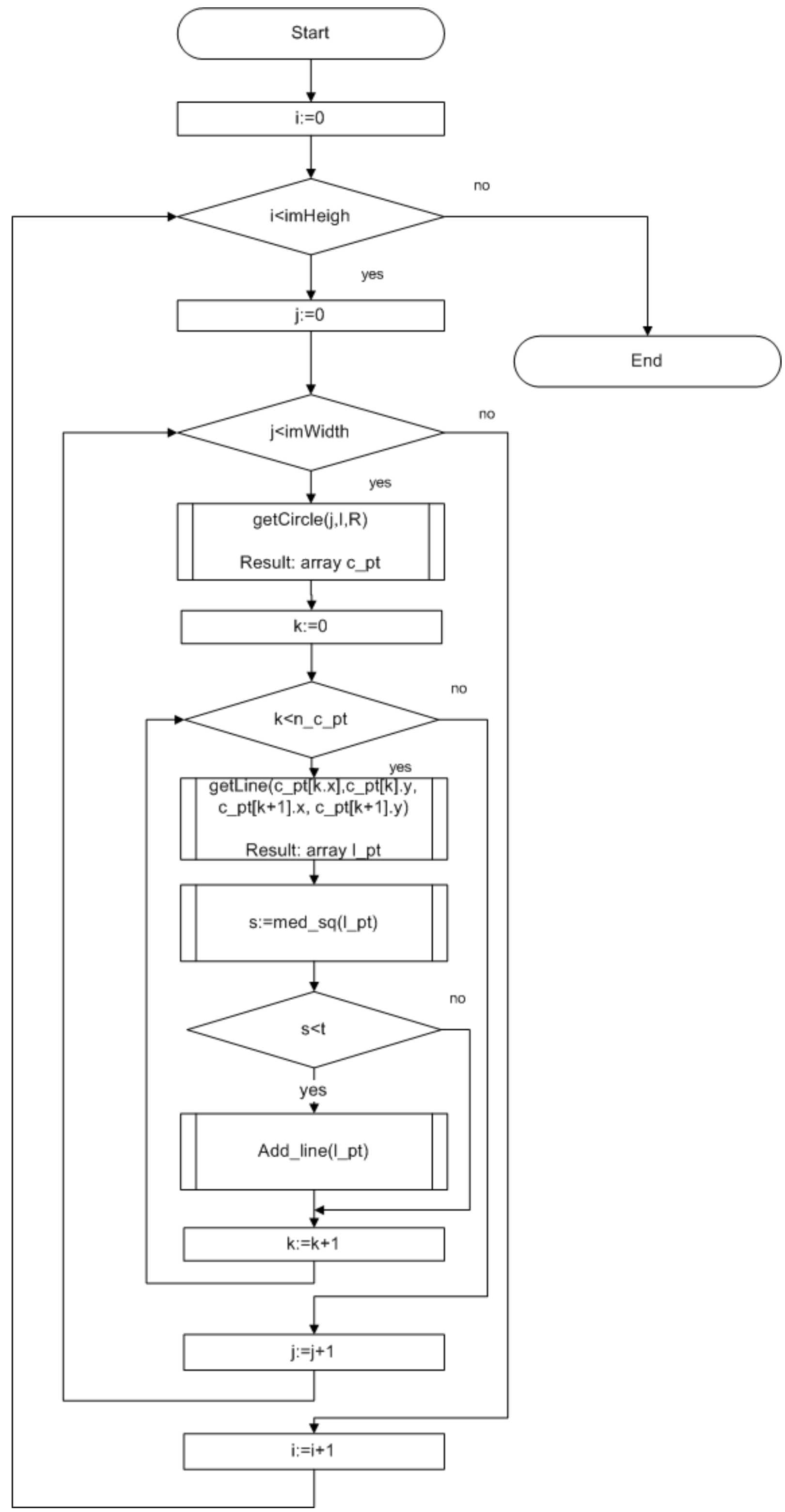


Fig. ٣. The algorithm for line segments selecting

The algorithm uses two arrays: *c_pt[٠.. n_c_pt]* and *l_pt[٠..n_l_pt]*. Array *c_pt* contains a set of circle R-area points, and array *l_pt* contains a set of line filter points; both of sets are generated by Bresenham's raster algorithms, n_c_pt and n_l_pt are numbers of each array elements respectively. Each element of these arrays is packed record of two "longint" fields X and Y. We use two values found empirically: R – radius of area and t - threshold for the standard deviation of points brightness. The algorithm contains subroutines *getCircle* and *getLine* for generation points of circle and line by Bresenham's raster algorithms and subroutine *Add_line* for adding selected line to set of line segments.

A fragment of satellite image in the suburban area of Khanaqin was used for experiments, as shown on fig. ٤.

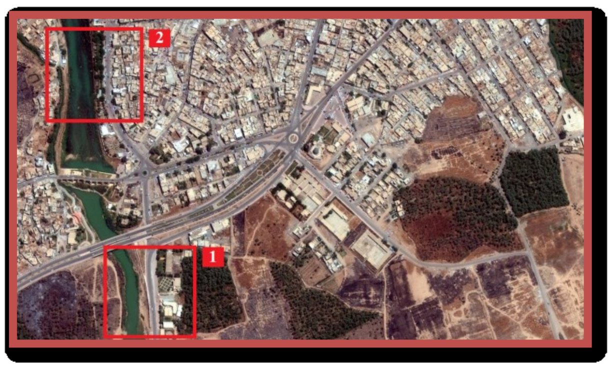
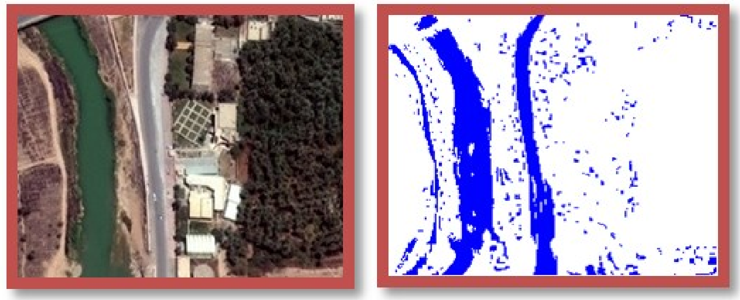


Fig. ٤. Satellite image fragment of the suburban area in Khanaqin, Iraq.

Satellite image was received by the satellite imaging system GeoEye-١ in ٢٠١٥ and its space resolution is ٢.٨ m, radiometric resolution is ١١ bits, reduced to ٨ bits. Size of the satellite image fragment is ٢٠٠٠*١٢٠٠ pixels. There is a river, elements of low-rise building, and road network consisting of urban and suburban roads located on the territory that is shown on this image.

Fig. ٥, a shows a fragment, for which an effectiveness of the described approach was analyzed (this fragment is marked on fig. ٤ with a rectangular frame ١), fig. ٥, b –result of this image segmentation using the method elaborated by authors.

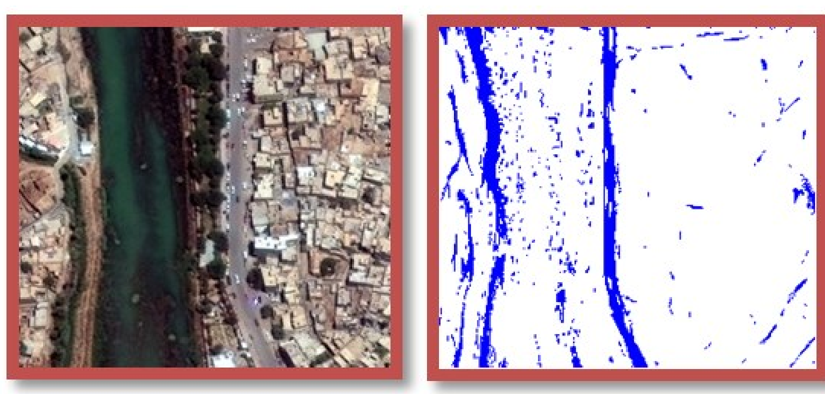


a) b)

Fig. ٥. Segmentation results of satellite image fragment.

The original image fragment contains two layers that can be described as linear extended objects: fragments of road network (light object) and a river (dark object). The river shown in the image is extracted as a road too. This situation is quite natural, since in terms of geometric and brightness characteristics a river and a road look almost identical in the image. A river, as well as a road, is line extended object, whose length is much greater than width and brightness of points is balanced. In order to distinguish them, we need additional information about the area or manual adjustment of extraction results.

Fig. ٦, a , b show segmentation results of the second image fragment (marked on fig. ٤ with a rectangular frame ٢), where a river and a road network segment are presented too. In this case, for several reasons (considerable river width compared to a width of road platform) through filtration a riverbed is not extracted completely, but only its borders. A human expert can be also involved to correct this defect.



a) b)

Fig. ٦. Segmentation results of satellite image fragment.

Image segmentation can be performed with different parameters. Changing of these parameters allows to select different kinds of area presented on images. Results of segmentation with different parameters are shown on fig. ٧. These results demonstrate that better segmentation is achieved for those areas, where all passing roads have nearly equal width and roadside territory is homogeneous. Fig. ٨ shows examples of wrong segmentation, due to terrain characteristics. Segmentation parameter values are specified, for which the results were received: R – radius of segmentation in pixels, K – minimal correlation of brightness between points of interest and terrain. Extraction of excess elements and problems in extraction of roads with narrow width refer to a need of adjustment of results by human operator.

Various fragments of satellite imagery of Khanaqin city and its suburban area were processed for analysis of algorithm efficiency.

As a result of imagery data segmentation, road network fragments were extracted (fig. ٧). Results of extraction were assesed by a human expert and are presented in Table ١. Segmentation process becomes complicated due to the following terrain characteristics: road goes near extended building of rectangular form; trees and shadow cover the road in places; road is too narrow.

Experimental results show that there is a need for additional processing of segmented image by an operator. The reason is similarity of brightness characteristics of road network and some other elements. It may cause errors such as excess or insufficient extraction.

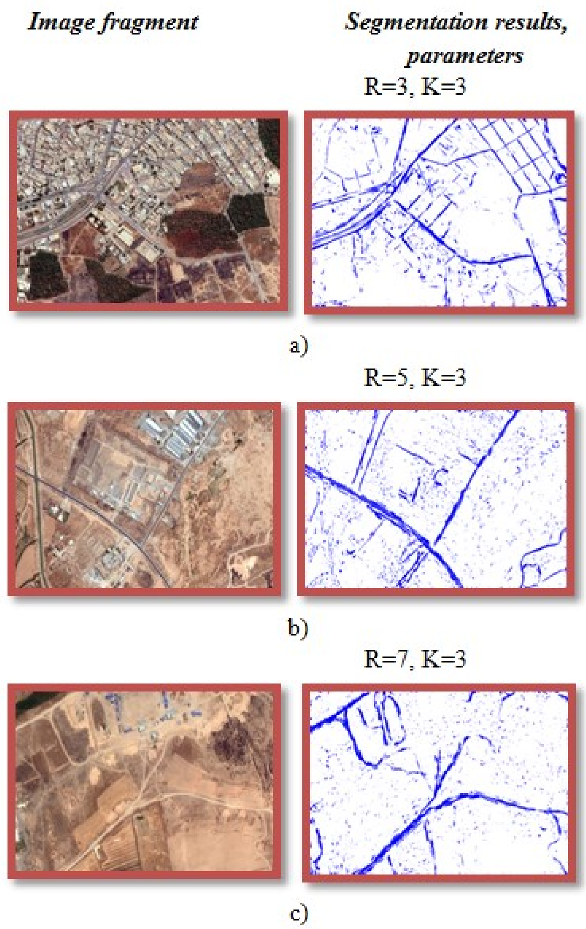


Fig. ٧. Fragments, for which the consistent results of segmentation were received.

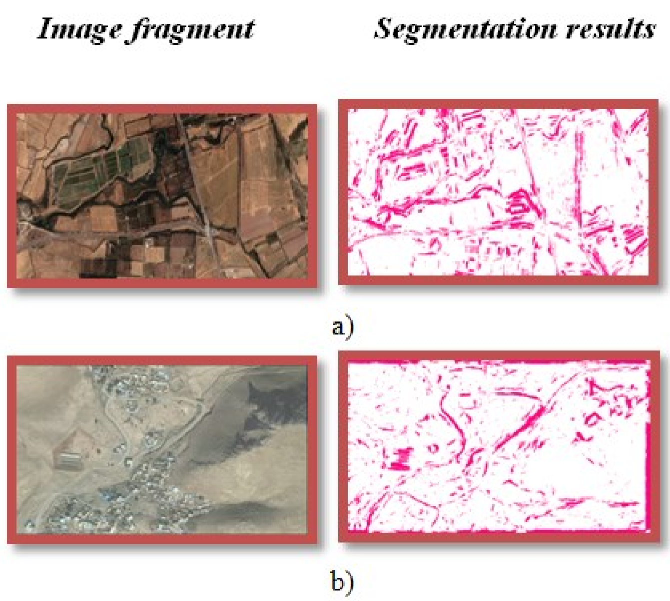


Fig. ٨. Unsatisfactory results of segmentation

TABLE I

SATELLITE IMAGERY SEGMENTATION RESULTS

Kinds of roads	Total length of roads (km)	Length of roads extracted as a result of segmentation (km)	Extraction efficiency, %
Urban	١٥.٦	١٠.٥	٦٧
Suburban	١٠.٣	٨.١	٧٩
Rural	٩.٤	٦.٩	٧٣

To identify geometric parameters of road network elements the scanning algorithm is applied, which earlier enabled to receive consistent results for topographic maps (Rang Abdallah, ٢٠١٥).

Scanning algorithm (Forsyth, Ponce, ٢٠٠٣) is based on scheme of image band storage in computer memory and on extraction of contour points in the process of band moving across the whole image. Two cases are distinguished for data processing in a band: situation detecting in image band and its resolution. Two image rows are kept in band simultaneously (current and previous). X-coordinates of black series of both lines are analyzed in ascending order (from left to right) and five situations are detected that can emerge. While analyzing, the following situations are processed separately: “start”, “extension”, “branching”, “merging” and “end”.

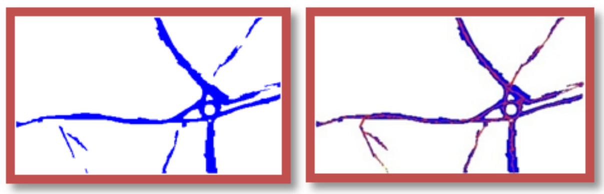
List of sections and list of branches formed by sections are results of sections separation procedure. Both of lists are the arrays and their elements describe the selected sections and branches formed by them. In the course of procedure work, X and Y coordinates of starting and ending points are calculated, as well as thickness of section, quantity of forming points, number of branch, to which a section belongs to.

List of branches is an array and each its element contains number of branch, quantity of forming points, number of starting and ending sections of branch.

Amount of extracted sections is sufficiently large at this stage. Received list can include short isolated sections that are not the road network fragments, as well as fragments of one line, that’s why the formed list of sections is subject to further processing.

The first step of such processing is unifying pairs of sections, the starting and ending point of which is located sufficiently close to each other. The next step is unifying branches. Short isolated sections are deleted too.

Fig. ٩ shows image, received in the result of image fragment segmentation (see fig. ٥) and manual processing by operator; fig. ٩, b – processing result of its scanning algorithm (center lines of extracted road network elements are shown in light red color).



a) b)

Fig. ٩. Scanning algorithm working results

Efficiency analysis of applying the scanning algorithm enables to say that in case of segmented image preparation of an adequate quality level, the geometric parameters of road network are determined precisely enough.

VI. CONCLUSION

In this work, author presented approach to extraction of road network elements on satellite imagery. This approach uses the modified method of wave segmentation and clustering; the scanning algorithms are applied to form descriptions of road network. Experiments showed consistent results of extraction.

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