Road Extraction from High Resolution Satellite Images by Morphological Direction Filtering and Length Filtering

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Abstract — **This paper proposes a modified method for road extraction from high resolution images acquired by satellites such as the IKONOS which has 1 m resolution, the QuickBird which has 1 m resolution and the SPOT-5 which has 2.5 m resolution. This method combines global segmentation, morphological direction filtering, and length filtering. Direction filtering is carried two times by a structuring element and its inverse, separately. The results obtained from these two operations are anded together to allow the detection of roads in all directions. After the direction filtering step, a length filtering step based on the major axis length of each extracted object is performed to remove small objects which are not classified as roads.**

Index Terms — **Direction filter, high resolution satellite images, length filter, morphology, road extraction.**

I. Introduction

Satellite images are used in different applications such as agriculture, water resources detection, civilization planning, geology, and weather forecasting. High spatial resolution satellites such as the IKONOS, the QuickBird, and the SPOT-5 produce high resolution images that are required by the different applications. So, segmentation and feature extraction has become heavily needed to extract specified objects from the satellite images related to specific applications for analysis, construction, and updating of the geographical information systems (GIS) [1,2]. Unfortunately, the conventional multi-spectral color based segmentation is not satisfactory for land or GIS use.

The proposed method for feature extraction in this paper combines global segmentation, direction morphological filtering and length filtering to extract roads from the obtained high resolution images. Morphological direction filtering and length filtering are used for local analysis after the global segmentation.

It is known that roads have a lot of shape properties. The proposed method uses two of these properties in the extraction process; the direction and the length. This method enables us to extract road information from satellite images faster and with a higher degree of accuracy compared to the conventional methods.

The conventional methods of road extraction consist of two major steps:

1- Global segmentation which consists of color and texture feature classification.
2- Local analysis which consists of smoothing, thinning and labeling.

In the global segmentation step, color and texture features are used for classification by trained systems such as neural networks. In this step, regions such as roads with the same color and texture features are classified to the same class [3,4].

One of the methods that can be used for the extraction of texture features is the principle component analysis (PCA) template matching method. In this method, all the templates are obtained by learning the principal components of image patches to a neural network, and then the image is transformed to a feature image. The texture features are then extracted from this feature image [3, 4].

In the local analysis step, the extraction of shape information is carried out in three steps. First, a smoothing filter (median filter) is used to remove salt and pepper noise like objects that still exist after the global segmentation step. Next, a thinning step is performed on the existing objects to eliminate the excess parts of image objects. The final step is the extraction of shape information after the application of the thinning step.

The traditional road extraction methods have some disadvantages such as the long computational time, the existence of some residual objects in the image which are not classified as roads and the inability to detect roads in all directions. So, the proposed method in this paper try to avoid these disadvantages by performing the morphological direction filtering in two steps and merging the results of these steps to detect roads in different directions.

II. DIRECTION AND LENGTH FILTERS

The direction and length filters are used for local analysis. The global segmentation stage is performed first, and then a local analysis is performed using a direction filter and a length filter [5,6]. The objects resulting from the global segmentation step have specific directions. So, the direction filter is needed to extract objects in these specific directions. The direction filter opens four direction windows for each pixel of an object and examines the strength of the object length in each window. After that, the length is determined as the value which satisfies a certain threshold.

The mathematical model that is used for the calculation of the direction label is as follows [6]:

$$d_{\max}(x,y) = \max(d^{k}_{1\le k\le 4}(i,j)) \qquad 0 \le i \le m,\ 0 \le j \le n \tag{1}$$

where $d_{\max}$ is a direction label which is the maximum of d^k, m and n are the dimensions of the object of interest.

Then direction that satisfies a threshold is defined by[6]:

$$I_d(x,y) = \begin{cases} 1 & d^k > f_q \\ 0 & otherwise \end{cases} \tag{2}$$

where f_q is a predetermined threshold value.

The length filter is performed using morphology theory by dilation of the direction filtered image with two structuring elements (one in x direction and the other in y direction) as follows [6,7]:

$$(I \oplus g_1)(y) = \max_{z\in G, y-z\in I} I(y-z) + g_1(z) \tag{3}$$

$$(I \oplus g_2)(x) = \max_{z\in G, x-z\in I} I(x-z) + g_2(z) \tag{4}$$

where I is the image resulting from direction filtering step and g_1 and g_2 represents the structuring elements in vertical and horizontal directions, respectively.

Then, the diagonal length of the object can be obtained by the root square summation of vertical and horizontal lengths as follows [6]:

$$\sqrt{(I_x(x,y)-1)^2 + (I_y(x,y)-1)^2} \tag{5}$$

III. THE PROPOSED ROAD EXTRACTION METHOD

The proposed method for road extraction includes global segmentation, morphological direction filtering, and length filtering. The general scheme of this method is the same as that in the previous section but the methodology of applying the direction and length filters is different.

A. Morphological Direction Filter

There are two basic morphological operations; dilation and erosion. These two operations involve an interaction between an image (A) and a structuring element (B). The structuring element can be square, rectangular, circular disc and any other shape.

Dilation:

$$A \oplus B = \{z \mid [(\hat{B})_z \cap A] \subseteq A\} \tag{6}$$

Erosion:

$$A \ominus B = \{z \mid (B)_z \subseteq A\} \tag{7}$$

where z is a displacement of the structuring element.

These two basic morphological operations can be combined in various ways to obtain other morphological operations like opening, closing, and hit-or-miss transformation. Opening means smoothing the contour of an object, breaking narrow isthmuses, eliminating noises such as salt and pepper noise, and eliminating thin protrusions while closing means fusing narrow breaks and long thin gulfs, eliminating small holes, filling gaps in the contour, and also smoothing sections of contours. Opening and closing can be implemented using the following equations.

Opening:

$$A \circ B = (A \ominus B) \oplus B \tag{8}$$

Thus, opening of A by B is the erosion of A by B, followed by the dilation of the result by B (the same structuring element).

Closing:

$$A \bullet B = (A \oplus B) \ominus B \tag{9}$$

Thus, closing of A by B is the dilation of A by B, followed by the erosion of the result by B (the same structuring element).

To apply the direction filtering to the image after the global segmentation step, morphological opening is used mainly with a structuring element and its inverse.

First, the obtained image A from the global segmentation step is opened by the structuring element B_1.

$$OP_1 = A \circ B_1 \tag{10}$$

Second, the image A is opened by the structuring element B_2 (the inverse of B_1).

$$OP_2 = A \circ B_2 \tag{11}$$

B_1 and B_2 are shown in Fig. 1.

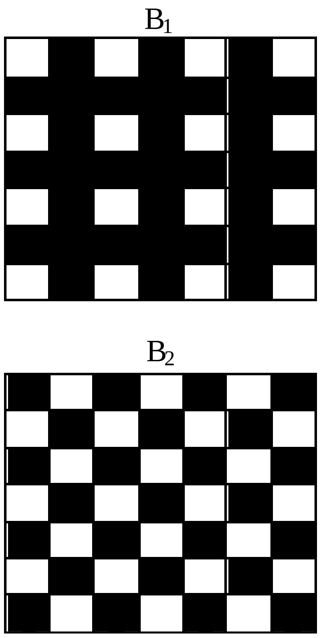


Fig. 1 Structuring elements B_1 and B_2.. *Black* indicates 0 and *white* indicates 1.

After opening of the image by the two structuring elements, the results are merged. ANDing of the two results is used for merging in the proposed algorithm The resultant image as will be seen eliminates a lot of noise and small objects from the image obtained from the global segmentation step.

B. Length Filter

This filter uses the length feature of objects as the main criterion to extract roads. The length feature can be represented as [8]:

$$L = \sum_i \sqrt{(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2} \tag{12}$$

where, x_i and y_i represent the coordinates of the *ith* pixel forming the object curve. The above criterion is applied after labeling the objects in the image. Labeling means assigning a unique number to each object to be easily dealt with and after that the evaluation of a specific property or criterion for each assigned object. Extraction of a specific object (road) is done by defining a threshold for length of that object [9].

IV. EXPERIMENTAL RESULTS

This section is devoted to the experimental study of the proposed algorithm. Two experiments are carried out to test this algorithm. The results of the three main steps for the proposed algorithm are illustrated in Figs. 2 and 3 for the extraction of intersected or branched and multiple roads. As shown in these figures the results obtained are very good for the extraction of roads as salt and pepper noise and other objects are eliminated effectively.

In the first example, the source image is for intersected roads. The steps of the proposed algorithm have succeeded in the extraction of the two intersected roads and the removal of small objects which are not classified as roads.

In the second example, the proposed algorithm is used for the extraction of intersected and branched roads. As shown in 3 (d), the multiple, the intersected and the branched roads are extracted, efficiently.

V. CONCLUSIONS

A modified method for road extraction from high resolution satellite images is presented. This method is performed in three steps; global segmentation, morphological direction filtering using a structuring element and its inverse and length filtering. The two results obtained from the morphological direction filtering are anded together to allow the detection of roads in all directions. The length filtering step is used to determine whether the detected object is a road or not based on a certain length threshold. The proposed method has succeeded in the detection of single, multiple, intersected and branched roads, efficiently.

(a) SPOT image for part of Cairo.

(b) Threshold segmentation and closing.

(c) Morphological direction filter

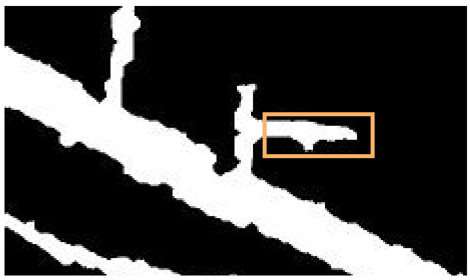
(d) Length filter.

Fig. 2 Extraction of intersected roads by the proposed algorithm using a SPOT-5 image for a part of Cairo.

(a) IKONOS image for a part of Cairo.

(b) Threshold based segmentation.

(c) Morphological direction filter.



(d) Length filter with the horizontal road labeled.

Fig. 3 Branched and multiple roads detection by the proposed algorithm using an IKONOS image for a part of Cairo.

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