A NEW ALGORITHM FOR AUTOMATIC ROAD NETWORK EXTRACTION IN MULTISPECTRAL SATELLITE IMAGES

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ABSTRACT:

The aim of this study is to develop automatic road extraction algorithm in satellite images. As roads have different width and surface material characteristics in urban and rural areas, a modular approach for road extraction algorithm is desired. In this study, edge detection, segmentation, clustering and vegetation and land cover analyses are used. In order to combine the results of different methods, a score map based on segmentation analysis is constructed. Quantitative and visual results show that this method is successful in road extraction from satellite images.

1. INTRODUCTION

The importance of satellite systems has constantly been rising in response to the increasing demand on military decision making, urban planning, traffic regulation, emergency management, crop estimation and so on. Roads are important components for these applications. The purpose of this study is to use multi-spectral high resolution satellite images for automatic road extraction to get accurate and detailed road map.

A large number of automatic and semi-automatic approaches have been developed for the analysis of transportation infrastructure in satellite images. Canny edge detection, Hough transform, morphological operations are some of the techniques used in road detection studies (Zhao et. al, 2002; Wang et. al, 2005; Vandana et. al.,2002; Zhang et. al., 1999). In the study by Zhao et. al, 2002, the road mask is extracted by using commercial remote sensing software. This binary mask shows possible road pixels. Then, Canny filter is applied on the image for detection of road edges. By tracing edge pixels, sudden and fast change points are determined and edge map is broken. In addition, edge lines which have similar direction and small gaps are merged. Some assumptions about the consistency of road features have been made. These are: road width, road direction and local average gray vary slowly, the contrast between road and background pixels is likely to be large, and roads are often long. This study uses 4-band (red, green, blue, and NIR) and 1 meter resolution satellite images obtained from IKONOS. In the study conducted by Wang et. al, 2005, in addition to Canny filter, some morphological operations and Hough transform have been used to enhance road extraction results. The employed road characteristics are that the width of a road and its curvature varies slowly; the texture enclosed by the road edges is rather homogeneous and roads create a connected network. IKONOS panchromatic 1 m resolution image was used in the study. Multi-resolution approach has been used to extract road sides and the centerline. Then, results obtained from different resolutions are combined. It is reported that this method is more suitable for main road detection. Moreover, there is manual post-processing to handle incomplete road segments.

In another semi-automatic approach (Vandana et. al.,2002), edge detection is used at pre-processing step, then seed points provided by the user are used to complete the roads by using path following considering the variance from the mean of the segment, potential directions, length and width on 1-m resolution IKONOS and aerial images.In the study by (Zhang et. al., 1999), mathematical morphology was applied on 1-m resolution satellite images to find roads. It is assumed that roads are areas rather than lines because of high resolution, and road networks forms elongated areas. After classification (gray level analysis), segmentation and size distribution analysis, trivial opening, hole filling, removing small paths and closing methods have been applied respectively for road extraction. It is reported in the study that this method cannot handle occluded road areas by tree shadows, cars and other objects, and cannot remove houses connected to the roads and shorter road parts because of image frames.

Landsat images with 25 m spatial resolution and 7 spectral channels have been used to extract the road network. Red band has been used to find the roads, and then watershed transform has been applied. In addition, curve adjacency graph has been constructed on watershed result. Lastly, Markov random fields have been used for road network extraction from this graph (Géraud & Mouret, 2004).

On the other hand, knowledge base methods have been used to extract roads from satellite images. In the study of (Lee et. al., 2000), 1 meter, IKONOS images have been used. The method consists of two steps. Firstly, road primitives were extracted using an intensity based segmentation approach called hierarchical gradient watershed algorithm. This algorithm was modified to avoid over segmentation problem. With the assumption that roads are elongated and large objects with constant intensity and have high contrast with their surroundings, road segments obtained by intensity based segmentation were expected to be elongated and large. So, road segments can be selected by analysis of mean gray value, size (number of pixels in segment) and shape information (major/minor axis).

Other studies generally focused on supervised techniques (Amini et. al., 2002), frequency based techniques (Hu et. al, 2007), and segmentation based methods (Géraud & Mouret, 2004; Lee et. al., 2000). Moreover, K-means clustering [Zhang et. al., 19990), Fuzzy c-means (Kim et. al., 2004), genetic algorithms, Markov Random Fields (MRF) (Lee et. al, 2000), Template Matching (Kim et. al., 2004) are some other techniques used in road extraction from satellite images studies.

2. METHODOLOGY

2.1 Data

IKONOS images are used in this study to extract roads automatically and analyze the contribution of spectral bands. The image provide panchromatic and multispectral (Blue, Green, Red, NIR) bands which has 1m and 4m resolution respectively. Images have been pan-sharpened. Sample image used in this study is shown in Figure1.

Figure 1Original Image

2.2 Algorithm

Roads have different characteristic in urban and rural regions. They may be also composed of different surface materials. Proposed methods have high performance for specific region and area. In order to have high road extraction performance for both rural and urban area, it is required to develop a modular approach for road extraction algorithm.
The technique used in our study consists of five main modules (Figure 2); edge detection, structural analysis, vegetation analysis, clustering and probability (score) map construction.

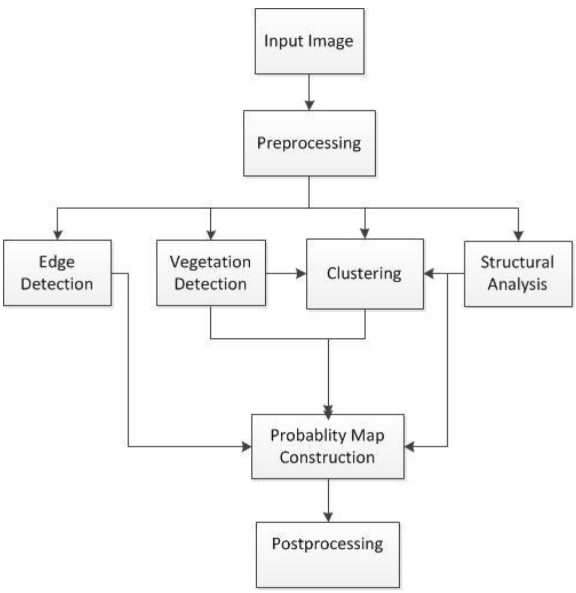

Figure 2 Flow chart of the algorithm

2.2.1 Edge Detection

Canny edge detection algorithm is applied on R, G, B and NIR band separately and the union of the edges on these four edge maps is obtained. Then parallel line pairs are found.

In order to find parallel line pairs, each edge pixel is visited and a pair point within a pre-defined range is searched. This procedure is applied for both horizontal and vertical directions. If a pair pixel is found in the range, their midpoint set to true. At the end of this process, vertical and horizontal midpoint masks are retained. Then, union of these two masks is obtained. Some midpoints are found both from vertical and horizontal procedure as shown in Figure 3.

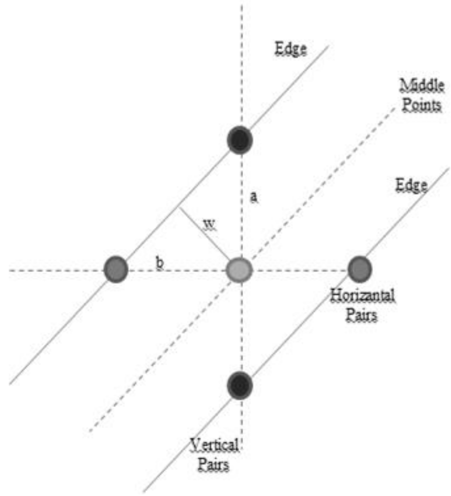

Figure 3 Midpoint's Width Calculation

Lastly, midpoints are dilated with the disk-structural element with radius equals to the "w" value of the related point. These midpoints form middle lines of parallel pairs. In order to fill small gaps morphological dilation operation is applied. Then, small lines are removed to get road-like lines and to avoid small parallel edges of those obtained from building. In Figure 4, selected midpoints and sample result of this module is shown.

Figure 4 Edge based result

2.2.2 Structural Analysis

In this module, data is segmented by using Mean-Shift algorithm (Comanicu & Meer, 2002; Christoudias, et.al., 2002) and these segments are analyzed to detect road-like and non-road segments.

Each segment is analyzed to see whether they satisfy the elongatedness assumption: its eccentricity is greater than 0.99 and its area is large enough. Sample result of this module is shown in Figure 5.

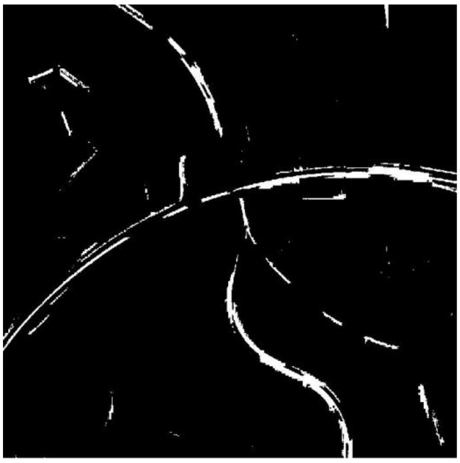

Figure 5 Segmentation analysis result

On the other hand, non-road segments are also detected in this module. It is assumed that non-road regions are large and compact. For this aim, each segment is examined to see whether its "thickness" (t) value its area (A) are greater than 50 and 600, respectively. The thickness value is computed by using the equation 1.

$$t = \frac{\text{A}}{(\text{Major Axis} * (2 - \text{Extent})} \qquad (1)$$

In this equation, "extent" represents the ratio of the bounding box and segment area. This gives information about the segments' flatness.

2.2.3 Vegetation Analysis

For vegetation detection, commonly used vegetation measures; NDVI (Normalized Difference Vegetation Index) and SAVI (Soil-Adjusted Vegetation Index) (Huete, A.R. , 1988) are used.

$$SAVI = \frac{NIR - Red}{\text{NIR+Red+L}} * (1 + L) \qquad (2)$$

In the equation "L" represents soil adjustment factor. When "L" is set to "0", SAVI reduces to the NDVI index. NDVI and SAVI results are thresholded by the predefined value (0.2). Sample vegetation masks are shown in Figure 6.

Figure 6 Vegetation Mask

2.2.4 Clustering

In this module, the vegetation and non-road mask obtained in the structural analysis stage are excluded from the image by reducing the total number of pixels. The K-means clustering algorithm is applied on the remaining data to obtain road cluster. Even though in (Zhang et. al., 1999), the value for K is suggested to be "six", in our study "K" value set to "four" since vegetation and large segments assumed to be bare soil are already removed from the image to be clustered. As in the "structural analysis" module, each cluster result is labeled and each connected component is analyzed to determine whether it belongs to the road region. A sample result of clustering module is given in Figure 7

Figure 7 Clustering Mask

2.2.5 Score Map Construction

Presently, we have five result masks; Edge-based road mask, Segment base road mask and non-road mask, Vegetation Mask and Road Clustering result. In order to fuse this information, a score map is constructed. The segments which were obtained by mean shift algorithm are re-evaluated in accordance with the results of modules including edge based, structural analysis and clustering. Firstly, the segments corresponding to road regions are selected. Next, each selected segment in the mask is scored according to elongatedness property. Then scores of the each mask are added together to obtain the initial score map. Moreover, the contribution of the pixels in the non-road masks to the score map is negative. A sample score map is show in Figure 8.

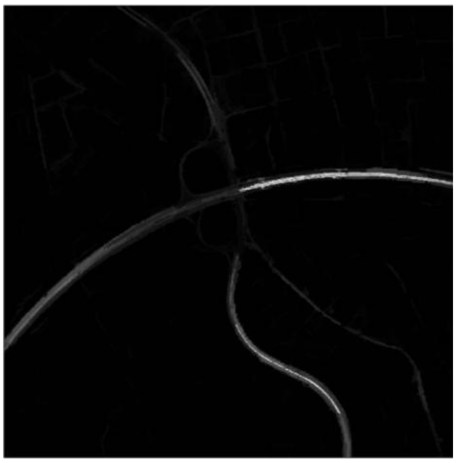

Figure 8 Score Map

When this score map is threshold with the predefined value, final road mask is obtained. In order to make this mask clear, small parts are removed. Then morphological closing and opening operations are applied to obtain final result (Figure 10).

Figure 9 Final Result

3. EXPERIMENTS AND DISCUSSION

This approach has been tested 20 different IKONOS satellite images including different land covers. Ground Truth are prepared for all images to evaluate the algorithm performance. In order to measure the result of the study, precision and recall values will be calculated based on Ground-Truth (GT). Performance measures are stated below;

$$\text{Precision} = TP / (TP+FP) \quad (3),$$

$$\text{Recall} = TP / (TP+FN) \quad (4),$$

where TP (True Positive) corresponds to the number of pixels that belong to the roads in both GT and extracted road mask, FP (False Positive) corresponds to the number of pixels that are in the extracted road mask but does not belong to GT, and FN (False Positive) correspond to the number of pixels that belong to GT but are not extracted by the algorithm. For all images, quantitative results are summarized in Table1.

Table 1Performance of the algorithm

Precision	Recall
% 50	% 70

In addition to these quantitative results, algorithm outputs are stated in Figure 10.

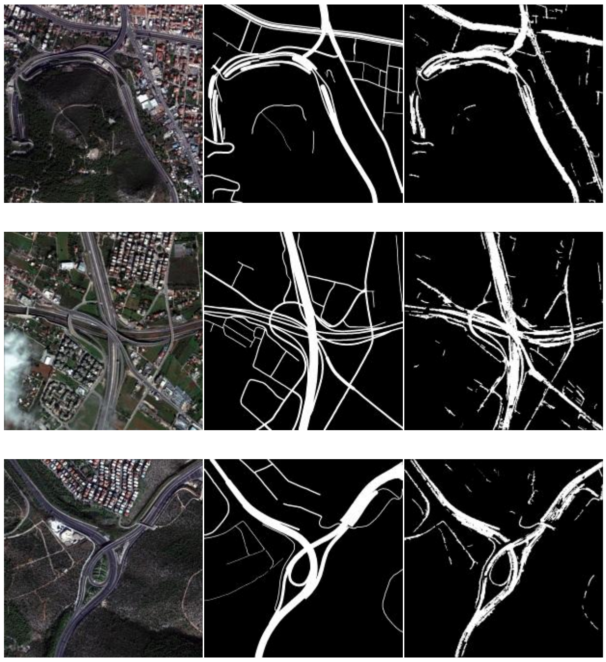

Figure 10 Original image, Ground-Truth and Result of the Proposed Algorithm.

4. CONCLUSION AND FUTURE WORK

In this study, an automatic road extraction algorithm is proposed. Both spatial and spectral features are used to improve extraction results. Results show that this approach is promising for extracting roads from satellite images covering both rural and urban regions. On the other hand, new modules may be developed in order to extract narrow roads. In addition, effective post-processing module may provide higher performance.

5. ACKNOWLEDGEMENTS

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