A Modified and Cost Effective Approach to Extractions of Intersections from High Resolution Satellite Imagery in Different Road Areas

Boshir Ahmed and Md. Fayzur Rahman

Abstract—Satellite images are rich in information, yet complex to analyze. For Geographic Information System (GIS), many features require fast and reliable extraction of roads and intersections. Satellite images provide useful data that is extracted from images of urban areas. Automatic extraction of road intersections in urban areas remains a challenging task. This is due to the fact that high resolution satellite images contain multiple layers representing roads, buildings and other high density objects. Our goal is to automatically separate the road layer from other layers and then to extract the road intersections. Traditional image processing methods fail to achieve satisfactory performance in cases of high resolution satellite images. This paper proposes a modified and cost effective method for road extraction from high resolution satellites images. In order to find the precise road intersection of urban areas, we divided the whole process into two sequential modules. Firstly, the extraction of road lines using different morphological direction filtering automatically eliminates the other layers. Secondly, the extraction of road intersections determines road orientation and interconnectivity. The accuracy of road network extraction reaches 96.12%, which is significantly higher than existing road extraction methods.

Keywords—Automatic road extraction, High resolution satellite image, Intersection detection, Remote sensing, Geographic Information System (GIS), Urban area, Semi urban area, Morphology

1 INTRODUCTION

GEOGRAPHIC Information System (GIS) is becoming increasingly popular, thanks to the attractiveness of the internet and satellite images. Google, Yahoo and Virtual Earth are examples of exhibiting high resolution satellite images [9]. For Geographic Information System (GIS), many features require fast and reliable extraction of roads and intersections. Information about urban and rural road areas is useful for resource management, security monitoring, urban development. With the availability of high resolution satellite data and processing technologies, the integration of digital image analyzing systems with advanced GIS systems permit compositing data sources and foster a partnership between human and machine[7]. Satellite images offer opportunities in many areas, such as security monitoring, communication industry, rural microclimate and transportation navigation, landscape planning and visualization. Road extraction from remotely sensed images remains a challenging issue for image processing [2].

- *F.A. Author, Department of Computer Science & Engineering, Rajshahi University of Engineering & Technology (RUET), Bangladesh. E-mail:boshir_bd@yahoo.com.*
- *S.B. Author, Department of Electrical & Electronic Engineering, Rajshahi University of Engineering & Technology (RUET), Bangladesh. E-mail:mfrahman3@yahoo.com*

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An early road extraction approach focuses on low-resolution aerial images. A road detector considering local and global criteria has been proposed (Fischler et al 1980). Road tracing step exploits local criteria calculated by low level processing. The method of line extraction is based on differential geometry is presented (Steger 1996). For each pixel in the image convoluted with the Gaussian kernel, the image profile along the principal direction is examined. Line points that are the first and second derivations of the profile have a vanishing and minimum respectively, and are detected and connected [4].

Automation is considered the most effective means of removing obstacles to labour intensive manual processes and reducing the cost and turnaround of spatial database updates [5]. Road layers are usually presented in single or double line format, depending on the image sources [1]. Our scheme considers a road as a group of "similar" pixels [6]. Traditional road extraction methods have certain disadvantages, such as long computational times, the existence of residual objects in the image that are not classified as roads and an inability to detect roads in every directions [3]. Most existing extraction methods for high resolution images rely on road boundaries as key hints for road extraction [6]. Our proposed methods avoid such disadvantages by performing automatic segmentation and various morphological operations in first steps. Various intersections aligned with non regular intervals in second steps are detected in the road's intersection points.

2 RELATED WORKS

Existing approaches to road extraction cover a wide variety of strategies, using different resolution aerial or satellite images. An extensive overview of the approaches is provided [11, 12]. Overall, schemes are divided into two groups: semi-automatic and automatic. Semi-automatic schemes require human interaction to utilise prior knowledge during the process of extraction, such as identifying road areas. Based on information provided by users, roads are extracted using methods such as profile matching [13], cooperative algorithms [14], and dynamic programming [15]. For automatic methods, we frequently extract hypotheses for road segments through edge and line detection, before establishing connections between road segments to form road networks. When data from multiple sources is combined [16] reliability improves. Depending on the type of image, some schemes deploy contextual information to guide the extraction of roads [17]. For uncluttered images, reducing the resolution helps to identify roads as lines [18]. However many proposed methods share the common assumption of relatively simplistic road models. The methods also require roads that are easily identifiable in images, such as constant intensity or straight and smooth road edges. As a result, sensitivity to interferences such as cars, shadows or occlusions is high and therefore consistent and reliable results often cannot be provided [10].

3 PROPOSED APPROACH

To determine the precise road intersection in urban areas, the entire process was divided into two sequential modules. The first is the extraction of road lines using different Morphological direction filtering, which automatically eliminates non-road layers. The second involves the extraction of road intersections to determine road orientation and interconnectivity.

The inputs of the method are high resolution satellite images. The proposed method is based on two steps. The first is to utilize an automatic segmentation algorithm to remove background pixels based on the difference in the luminosity level. We then obtain foreground pixels, which contain the entire information layer of the satellite image. The smoothing filter (median filter) is then used to remove salt and pepper noise, such as small objects that remain in the automatic segmentation step. Next, different morphological operation, dilation and boundary extraction are performed on existing objects to eliminate excess parts of image objects [9]. In the second part, various intersections are detected in the models, which are classified as three types of cross-roads; T-junctions and Y-junctions [4]. Finally, roads are extracted by connecting road intersections using the road tracking method.

Figure 1 illustrates the general process of extracting the road intersection from satellite images in rural areas.

3.1 Automatic Road Extraction

Applying the automatic road extraction algorithm to disconnected road segments is difficult, due to the poor visibility of roads in the original image. Roads are often divided into several short segments, or are completely missing from the image. To overcome this problem, we fit Gaussian models to image points, which represent the likelihood of being road points. These models are evaluated recursively to determine the correlation between neighboring points. The iterative process consists of finding the connected road points, fusing them with the previous image, passing them through the directional line filter set and computing new magnitudes and orientations. The road segments are updated, and the process continues until there are no further changes to the roads extracted. We combine the following steps for automatic road extraction processes.

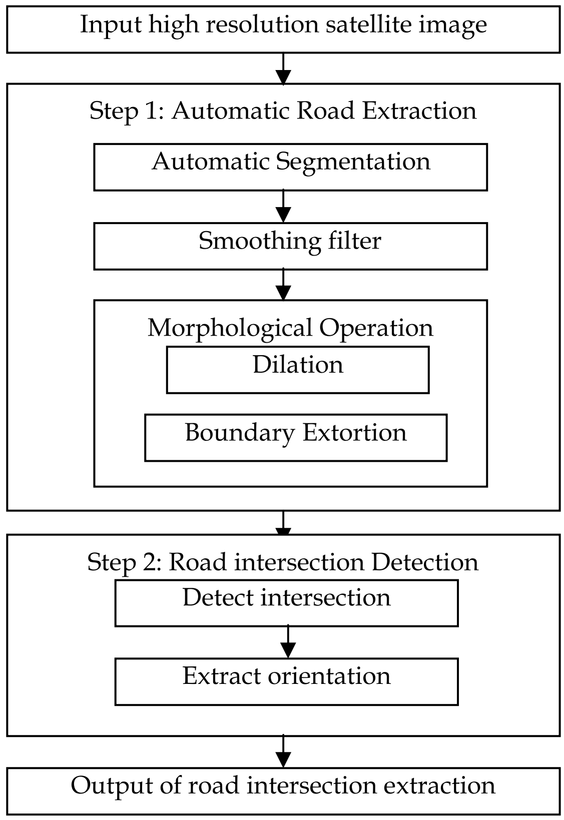

Figure 1: Overall approach to extract road intersections

3.1.1 Automatic segmentation

Segmentation is the process of grouping an image into units that are homogeneous in terms of one or more characteristics [20]. The common technique, segmentation, is used to automatically separate the foreground from background pixels. The color information from RGB values is first discarded by converting the original input image to an 8 bit grayscale with 256 color levels. We then use a threshold value to convert the grayscale image into a binary image. Segmentation uses the threshold to segment the foreground pixels from background pixels. Threshold assumes that images are composed of regions with different gray level ranges; the histogram of an image can be separated by a certain number of peaks, where each corresponds to one region with a seed value that separates two adjacent peaks [21]. The gray scale and binary images are shown in Figure 3 and 4.

Figure 2: Input high resolution satellite image [8]

Figure 3: Gray scale image

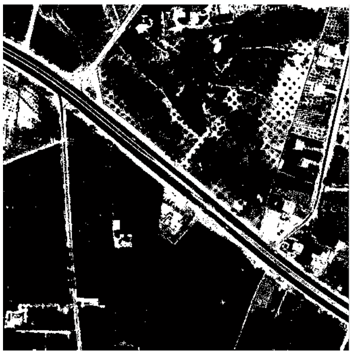

Figure 4: Binary image

3.1.2 Smoothing filter

Median filters are particularly effective in the presence of both bipolar and unipolar impulse noise. A median filter is a nonlinear digital filtering technique, which is often used to remove random and salt-and-paper noise. Noise reduction is a common preprocessing step that improves subsequent processing results [9]. The replacement of a pixel by the median filter of the gray level in the neighborhood of that pixel is given by:

$$\hat{f}(x, y) = \underset{(s,t) \in S_{xy}}{median}\{g(s,t)\}$$

The original value of the pixel is included in the computation of the median filter.

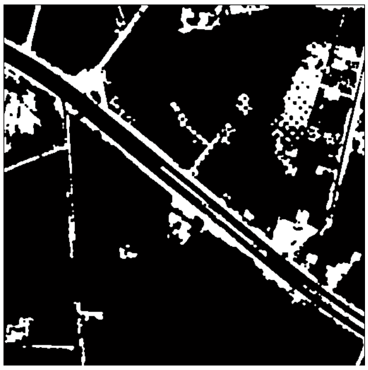

Figure 5: Median filtered image

3.1.3 Morphological operation

There are two Morphological operations: Dilation and Boundary extortion. Dilation operations are used for filling small holes and connecting disjoint object. The dilation processes are performed by laying the structuring element B on the image A. The structuring element can be square, rectangular, a circular disc, or any other shape [3].

Dilation:

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

Erosion:

$$A \Theta B = \{z \mid (B)_z \subseteq A\}$$

Where z is a displacement of the structuring element.

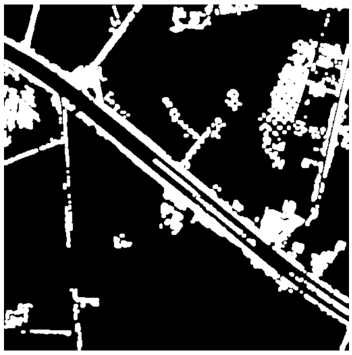

Figure 6: Image after dilation

The dilation operation is followed by the Morphological thinning operation. The binary thinning operation automatically extracts road intersections. Thinning operations are performed using hit-and-miss transform. The thinning of set A by structuring element B is denoted by $A \otimes B$ and can be defined by the terms of hit-and-miss transform [9].

$$\begin{aligned} A \otimes B &= A - (A \circledast B) \\ &= A \cap (A \circledast B)^c. \end{aligned}$$

The hit-and-miss transform is a general binary morphological operation used to identify particular patterns of foreground and background pixels within an image. Binary masks are used to scan over the input binary images. If the masks match with the pixels, it is a "hit"[9]. If the mask does not match, it is a "miss."

Figure 7: Image after boundary extraction

3.2 Road intersection Detection

To discover a road intersection, we first detect the intersection candidate before extracting road orientation. The road seed is a high density pixel denoting the road object. We now consider the steps described below.

3.2.1 Detecting intersection

A road seed is a binary image, with a white pixel denoting a high probability of a road-like object. As extraction errors arising from certain pixels on roof buildings or soil have a similar spectral response to roads and general morphological operator, the combination with closing, thinning and 8-neighbour pattern matching does not work particularly well. This is due to the high sensitivity to noise. Therefore, stronger constraints and further knowledge about intersections are required. We consider three types of intersections. The Crossroads represents the intersection of two road portions, while the Three-forked road has three road segments. Each branch has a different direction. The third is the T-Intersection, consisting of one straight road and a connected branch [4].

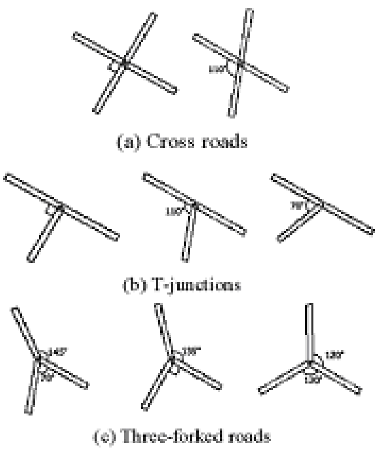

Figure 8: Types of road intersections [4].

Consider matching the above models to road seed and calculating matching value between the models and road seed. The model is rotated and positioned over the binary image. The matching measure is defined as follows,

$$M\theta_{(x,y)} \equiv \begin{cases} \mu(s)-\mu(B), if & \min\limits_{n=1,2,\ldots\ldots.N} \mu(S_n) > k_1 \\ 0 \quad , & otherwise \end{cases}$$

3.2.2 Extracting Road orientation

Road layers are connected by constricting branches of each intersection. Road tracking methods are available for the hypothesis. A structure of road curve-linear is modeled as ternary tree [4]. The directions of the tracking are given by center point and the direction at each branch of the intersection. The road orientation is extracted in the following equation,

$$E(a) = \mu(A_{in}) - \mu(A_{out}), \qquad a \in A$$

Where A is the set of edge of the road tree. A_{in} and A_{out} are respectively inside and outside regions around road edges.

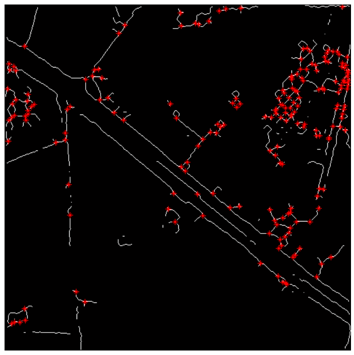

Figure 9: Cross points denote road intersections

4 Experimental Result and Performance Analysis

Our proposed method was tested on three sources of high resolution satellite images in urban, semi urban and rural areas. The road layers are a mixture of different small roads, buildings, grounds, and trees with many driveways connected to the road network. The distribution of buildings ranges from sparse to very close. The area contains many trees, with a number of large trees that are close to roads. The other layers, excluding the road layer, are difficult to remove using existing techniques. However the proposed approach demonstrates an ability to overcome these problems. Almost all roads in the network were successfully extracted and intersection points detected. The resulting images from our experiment are shown in Figure 9. In the figure, the red cross (X) represents the road intersection point extracted by the proposed method. On the other hand, our approach can extract intersections accurately and does not extract buildings as roads, even in suburban areas. The results indicate that we can construct road networks with a high degree of accuracy. The experimental achieved precisions with elapsed time comparisons are shown in Table 1. The accuracy of our proposed method is fairly similar to the existing road intersection model, but our elapsed time is much shorter than every other method.

TABLE 1: ACCURACY OF DIFFERENT ROAD AREA FOR PROPOSED METHOD

Source information	MS (Multi Scale Snake) Method	Existing Road Intersection Model	Proposed Road Intersection Model
Accuracy Developed Suburban Area	57.9%	95.5%	96.12%
Accuracy Developed Urban Area	69.7%	95.7%	95.5%
Accuracy Developed Rural Area	98.4%	90.9%	92.82%
Elapsed Time Developed Suburban Area	40.5	15.2	1.0624 sec
Elapsed Time Developed Urban Area	46.6	16.5	1.2256 sec
Elapsed Time Developed Rural Area	20.2	14.4	4.1114 sec

Extracting the road intersections from various high resolution satellite images on an Intel Core2Duo 1.83 GHZ Dual Processors with 2 GB memory took less than one minute.

5 CONCLUSION AND OBSERVATIONS

The above results show that mathematical morphology is of significant interest to Very High Resolution Spatial image interpretation. The neighborhood relations are a significant advantage. The experiments indicate that the proposed methodology is particularly worthwhile. Thus a modified and cost effective method for road intersection from high resolution satellite images is presented in this paper. This modified method is performed in two steps; firstly, global segmentation and morphological direction filtering using a structuring element [3]. The second step detects various intersections aligned with non regular intervals, such as the cross-road, T-junction and Y-junction [4]. Our proposed method assumes that background pixels are separable, as the luminosity level of the background and foreground pixels vary. Foreground pixels contain larger values than background pixels [9]. The paper's main contribution to the field is a modified and cost effective method that automatically and efficiently extracts road intersections from high resolution satellite images. Our approach does not require former information of the input satellite image. We applied the proposed approach to three different satellite images: urban, semi-urban and rural. The images were obtained online from Google Map and we successfully extracted road intersection points to identify geographical information. The approach achieved maximum accuracy with a time lapse lower than other existing methods. The proposed method efficiently detected single, multiple, intersected and branched roads.

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Boshir Ahmed, Head, Department of Computer Science & Engineering, Rajshahi University of Engineering & Technology. Research interests include Digital Image Processing, Microprocessor based system design, Digital Logic Design, Digital Signal Processing, Computer Networking and Digital Communication. Total number of published publications: 26 in which the number of journals: 05, number of conference papers: 18, number of published books: 03.

Md. Fayzur Rahman received the B.Sc. Engineering degree in Electrical & Electronic Engineering from Rajshahi University of Engineering & Technology in 1984 and M. Tech. degree in Industrial Electronics from S. J. College of Engineering, Mysore, India in 1992. He received his Ph.D. in energy and environment electromagnetic field from Yeungnam Unversity, Taegu, South Korea, in 2000. He serves as a Professor in Electrical & Electronic Engineering. His research interests include high voltage discharge application covering the control of non termal plasma, Ozone generation system, Image processing, dc drive and machine control. He is a fellow of IEB, Bangladesh and member of Korean Institute of Illuminating and Electrical Installation (KIIEE) and Korean Institute of Electrical Engineers (KIEE), Korea.