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Automatic Road Extractions from High Resolution Satellite Imagery Using Road Intersection Model in Urban Areas

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Abstract

This paper proposes intersection model and strategy for road extraction from high resolution satellite images. Satellite images are rich in information. For Geographic Information System (GIS), many features require fast and reliable extraction of roads and intersections. They are also complex to analyze. Satellite image provides useful data that is extracted from satellite image of the urban area. Automatic extraction of the road intersections from the urban areas has been a challenging topic because the high resolution satellite images contain multiple layers that represent roads, buildings, and other high density objects. Our goals is to automatically separate the road layer from the other layers then extract the road intersections. Usually traditional image processing methods don't achieve satisfied performance in case of satellite images. This paper proposes a modified and a cost effective method for road extraction from high resolution satellites images. In order to find the precise road intersection of urban areas we have divided whole process into two sequential modules: first, extraction of road line using different Morphological direction filtering to automatically eliminate the other layers from road layer and finally, extraction of road intersections to determine the road orientation and interconnectivity. We applied this method to a set of randomly selected high resolution satellite image from urban and semi urban areas and the correctness of road network extraction reaches 95.71%, significantly higher than those of other existing road extraction methods.

Keywords: Automatic road extraction, High resolution satellite image, Intersection detection, imagery, Remote sensing, Geographic Information System (GIS), Urban area, Morphology.

1. Introduction

Geographic Information System (GIS) aggressively being popular day by day due to attractiveness of internet as well as satellite image. Google, Yahoo, Virtual Earth and other maps are examples of exhibit of those high resolution satellite images (Ahmed *et al* 2010). Information of the urban and rural road areas for resource management, security monitoring, urban development and GIS is changing with the growing world. With the availability of high resolution satellite data and its processing technologies, integration of digital image analyzing systems with advance GIS systems permit compositing data sources as well as promoting a partnership between man and machine (Erick 2009). Satellite images provide opportunity in many areas like security monitoring, communication industry, rural microclimate and transportation navigation, landscape planning and visualization etc. Road extraction from remotely sensed images has been the purpose of many works in the image processing field and because of its complexity is still a challenging topic (Renaud *et al* 2009).

An early road extraction approach is focused in low-resolution aerial images. The road detector considering local and global criteria is proposed (Fischler *et al* 1980). Road tracing step exploits local criteria calculated by low level processing. The method of line extraction based on a 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 i. e. the first and second derivations of the profile have respectively a vanishing and minimum are detected and connected (Koutaki *et al*).

Above works have concentrated on open urban and rural areas. Multi-resolution approach mainly depends on the result of line detection in low-resolution. Most roads are distinct from background objects (mostly field and vegetation) and have road sides clearly presented. Therefore, because the line detector or ribbon snakes extract a lot of salient roads very successfully, the construction step of road network works well even if some gaps derived from shadows or tree exists (Koutaki *et al*). However, road sides in suburban areas are absent because of house, shadow or bush. Additionally, some house roofs that have parallel edges will be extracted as road sides and they will cause false connection for the road network generation.

Automation has been considering the most effective way to remove the obstacles of labour intensive manual processes and reduce the cost and shorten the turnaround time of spatial database updating [Xiangyun *et al* 2003). Road layers are usually presented in single line or double line format depending on image sources (Yao-Yi *et al* 2009). In our scheme, we considered a road as a group of “similar” pixels (Yan *et al* 2009). 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 (Talal *et al*). Our proposed methods try to avoid these disadvantages by performing the automatic segmentation and various morphological operations in first steps and detect various intersections aligned with non regular intervals in second steps to detect road intersections.

2. Previous Work

The existing approaches for road extraction cover a wide variety of strategies, using different resolution aerial or satellite images. A quite extensive overview of such approaches is given in (Mena 2003, Auclair-Fortier *et al* 1999). Overall, schemes can be divided into two groups: semi-automatic and automatic. Semi-automatic schemes require human interaction to provide some prior knowledge during the process of extraction, such as identifying the areas of roads. Based on the information provided by users, roads are then extracted by methods such as profile matching (Vosselman *et al* 1995), cooperative algorithms (Mckeown *et* al 1988), and dynamic programming (Gruen *et al* 1997). Automatic methods usually try to extract some hypotheses for road segments through edge and line detection and then establish connections between road segments to form road networks. Data from multiple sources may be combined (Hinz *et al* 2001) to improve the reliability. Depending on the type of images, in some schemes, contextual information is used to guide the extraction of roads (Ohlhof *et al* 2000). For images that are not cluttered, reducing the resolution may help identify roads as lines (Baumgartner *et* al 1996). However, most of the proposed methods share the common assumptions of relatively simplistic road models and require roads to be easily identified in images, such as constant intensity or straight and smooth road edges. As a result, they are very sensitive to interferences such as cars, shadows or occlusions and do not always provide consistent and reliable results (Yan *et al* 2009).

3. The Proposed Approach

In order to find the precise road intersection of urban areas we have divided the whole process into two sequential modules: first, extraction of road line using different Morphological direction filtering to automatically eliminate the other layers from road layer and finally, extraction of road intersections to determine the road orientation and interconnectivity.

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

The inputs of the method are high resolution satellite images. The proposed method mainly based on two steps. Firstly it utilizes an automatic segmentation algorithm to remove background pixels based on the difference in the luminosity level and then the foreground pixels, which contain the entire information layer of the satellite images are obtained. after that the smoothing filter (median filter) is used to remove salt and pepper noise like small objects that still exist in automatic segmentation step. Next, different morphological operation, dilation and boundary extraction are performed on the existing objects to eliminate the excess parts of image objects (Ahmed *et al* 2010). In second part, we detect various intersections the models are classified to three types of cross-roads, T-junctions and Y-junctions (Koutaki *et al*) After then Roads are extracted by connecting road intersections using the road tracking method.

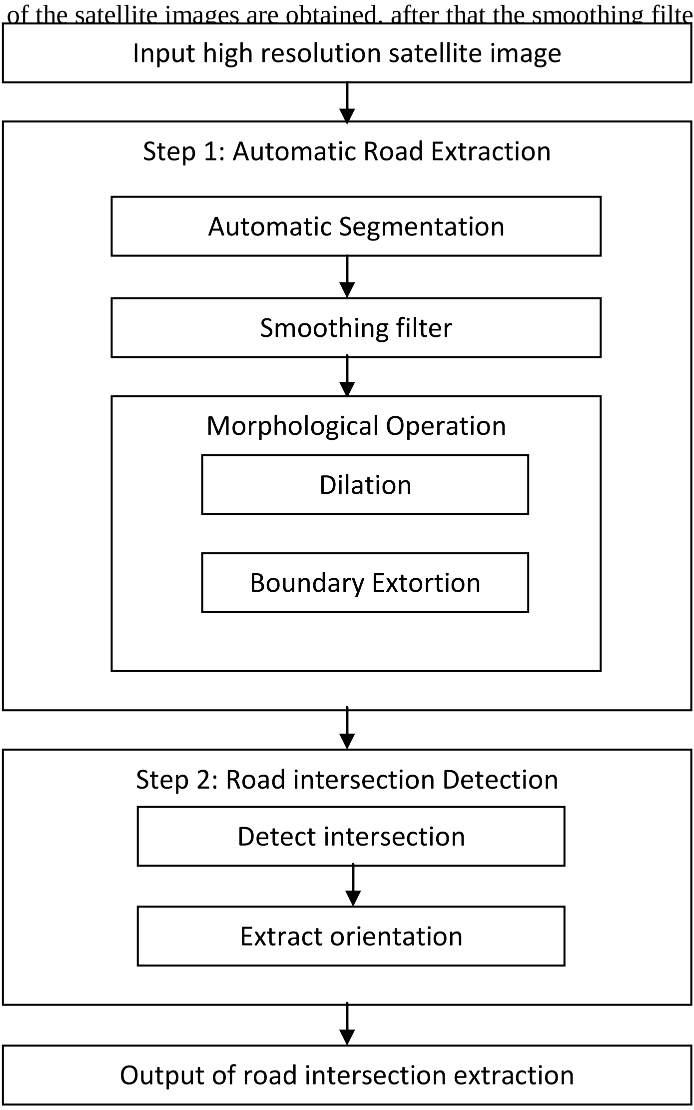


Figure 1: Overall approach to extract road

3.1 Automatic Road Extraction

Automatic road extraction algorithm is disconnected road segments due to the poor visibility of the roads in the original image. Often roads are divided into several short segments, or completely missing from the image. To solve 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 the 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 in the roads extracted. We have combined the following general steps for automatically road extraction processes.

3.1.1 Automatic Segmentation

Segmentation is the process of grouping an image into units that are homogeneous with respect to one or more characteristics (Gonzalez *et al* 1993). A widespread technique called segmentation is used to automatically separate the foreground and background pixels. At first we discard color information from RGB values by converting the original input image to 8 bit grayscale with 256 color levels. Then we use a threshold value to convert the grayscale image to binary image. The segmentation uses the threshold to segment the foreground pixels and background pixels. Threshold assumes that images are composed of regions with different ranges of gray level; the histogram of an image can be separate in a certain number of peaks, where each one corresponds to one region and there is a seed value, which separates two adjacent peaks (Marion 1987). The grays scale and binary images are shown in Figure 3, 4.

Figure 2: Input high resolution satellite images [8]

Figure 3: Gray scale images

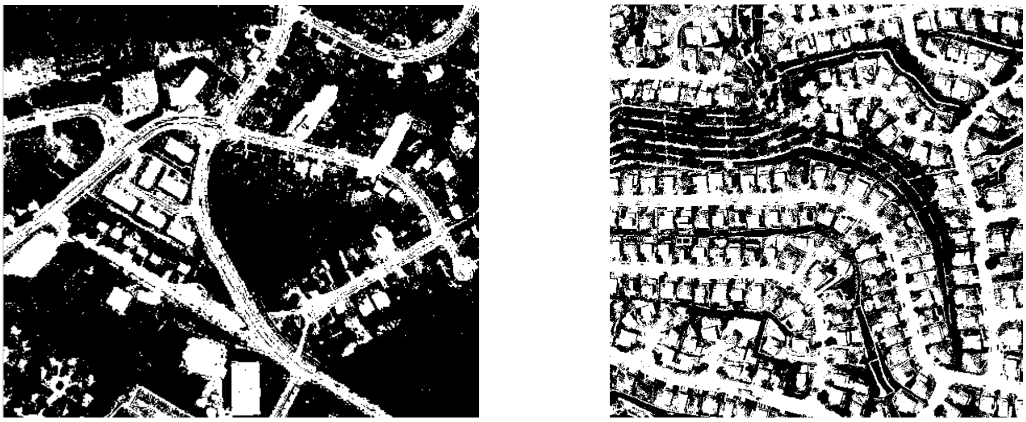


Figure 4: Binary images

3.1.2 Smoothing Filter

Median filters are particularly effective in the presence of both bipolar and unipolar impulse noise. Median filter is a nonlinear digital filtering technique, often used to remove random and salt-and-paper noise. Such noise reduction is a typical preprocessing step to improve the results of later processing (Ahmed *et al* 2010). The replaces value of a pixel by the median filter of the gray level in the neighborhood of that pixel:

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

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

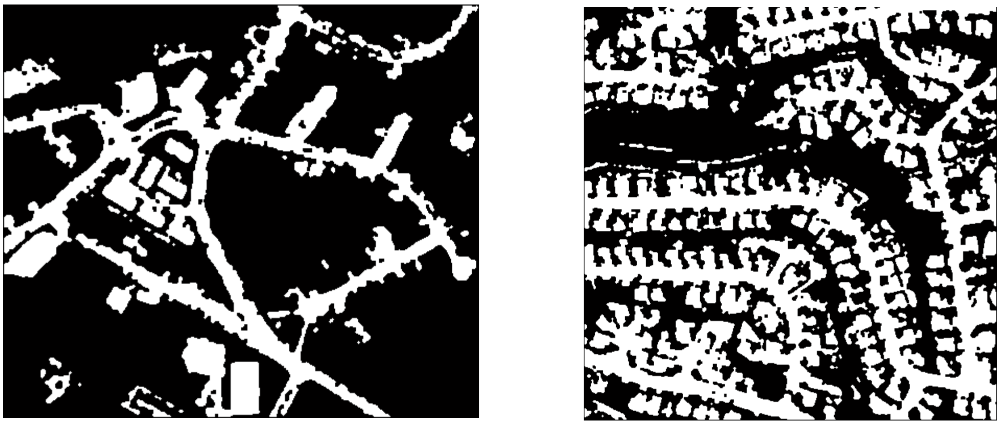


Figure 5: Median Filter Images

3.1.3 Morphological Operation

The proposed segmentation approach using the morphological operation will be applied in the graph (G) to get the desired regions and the structuring element will be the neighborhood VA (p). In the image I(x,y), if the nodes (pi) of the decimal graph constitute the digital grid and its neighbors the polygons ei, then the process will compare and will affect the radiometric value of ei on the decimal graph constructed using the morphological operations. These morphological operations will be the core of the segmentation (Erick).

There are two Morphological operations Dilation and Boundary extortion are performed in this step. The Dilation operations potentially filling in small holes and connecting disjoint object. The dilation processes performed by laying the strutting element B on the mage A. The structuring element can be square, rectangular, circular disc and any other shape (Talal *et al*).

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.

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 (Talal *et al*).

Opening:

$$A \circ B = (A \Theta B) \oplus B$$

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:

$$A \bullet B = (A \oplus B) \Theta B$$

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).

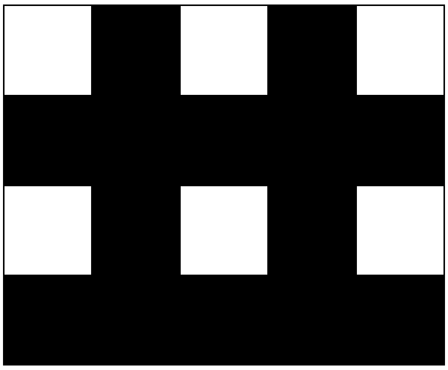
To apply the direction filtering to the image after the global segmentation step, morphological opening is used mainly with a structuring element and its inverse. First, the obtained image A from the global segmentation step is opened by the structuring element B1.

$$OP_1 = A \circ B_1$$

Second, the image A is opened by the structuring element B2 (the inverse of B1).

$OP_2 = A \circ B_2$. B1 and B2 are shown in Fig. 6.

B_1



B_2

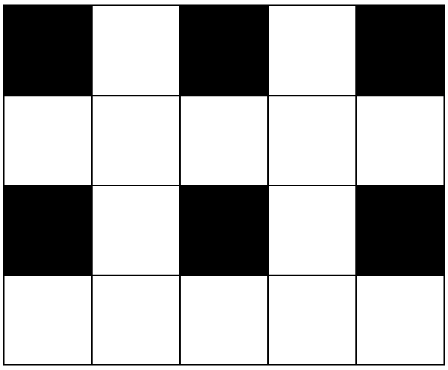


Figure 6: Structuring elements B_1 and B_2. Black indicates 0 and white indicates 1 [3]

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.

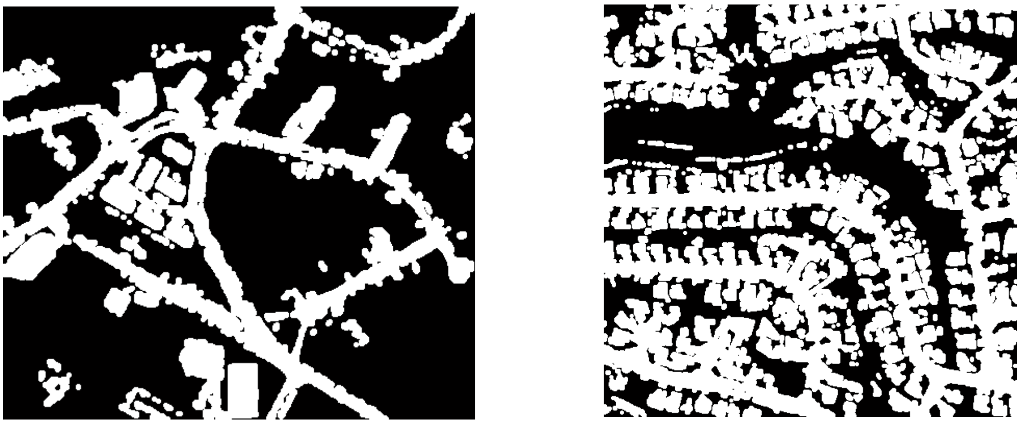


Figure 7: Median Filter Images

After dilation operation eration is used to automatically extract the road intersections. The thinning operations are performed by using hit-and-miss transform. The thinning of set A by strutting element B denoted by $A \otimes B$ can be defined by terms of hit-and-miss transform (Ahmed *et al* 2010).

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

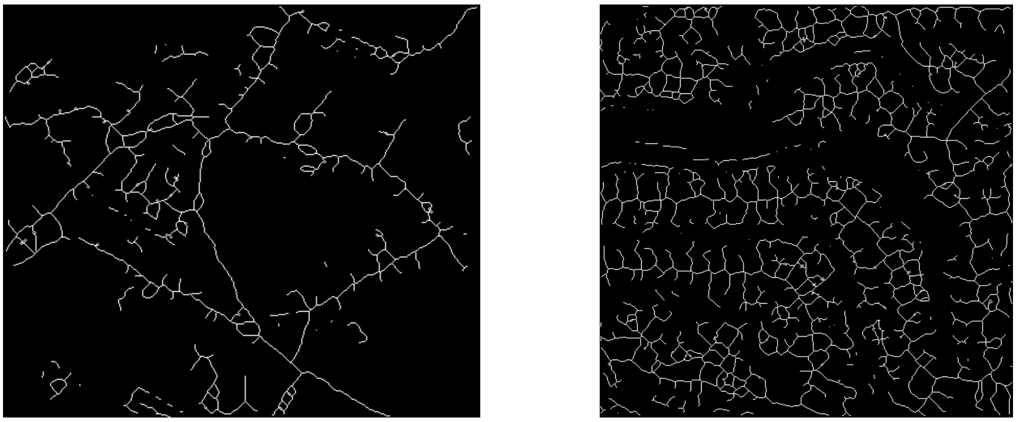


Figure 8: Median Filter Images

3.1 Discover Road Intersection

To discover road intersection first we detect intersection candidate then extract road orientation. The road seed is a high density pixels denoted the road object. Then we consider the following steps.

3.2.1 Morphological Operation

A road seed is binary image that white pixel denotes high probably road like object. Since an extraction error arises from some pixels on building roofs or soil have similar spectral response to roads, general morphological operator, for example the combination with closing, thinning and 8-neighbour pattern matching, will not work well because of very sensitive for noise. Therefore stronger constraint and knowledge about intersection are required. We consider intersection to following three types; first, the Crossroads represent the intersection of two road portions. Second, the Three-forked road has three road segments. Each branch has different direction. Last one, the T-Intersection consists of one straight road and connected branch (Koutaki *et al*).

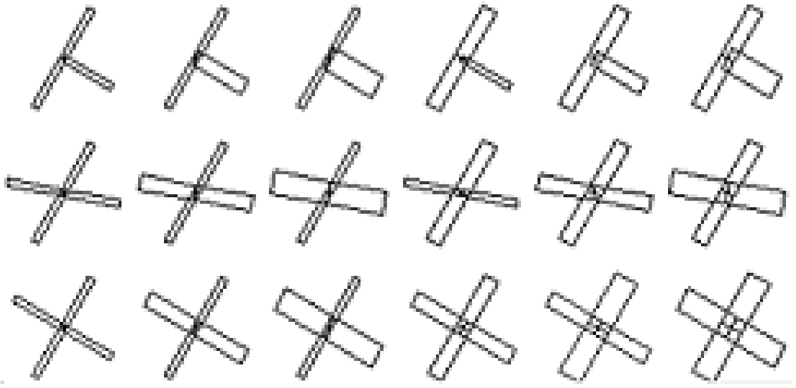
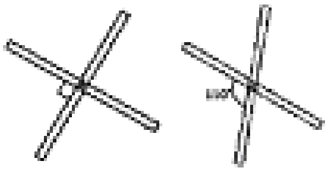
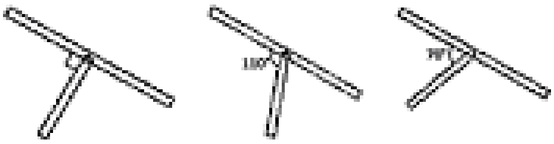


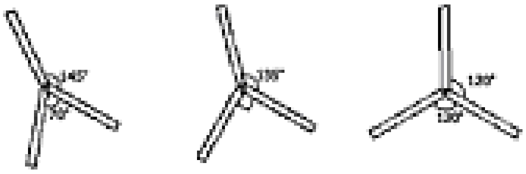
Figure 9: Combination of various road widths (Koutaki *et ai*).



(a) Cross roads



(b) T-junctions



(c) Three-forked roads

Figure 10: Types of road intersections (Koutaki *et ai*).

Consider matching 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 following,

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

Here **S** and **B** is a region of inner and outer model. $\mathbf{S_n}$ denotes region inside nth branch of intersection and $S = S_1 \cup S_2 \cup \ldots\ldots\ldots\ldots\ldots\ldots \cup S_n$.

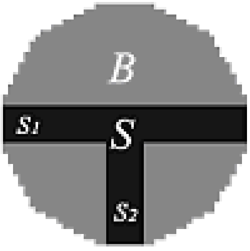


Figure 11: Inner and outer region of intersection model

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]. Directions of the tracking are given by center point and direction at each branch of the intersection. The road orientation are extracted as follow 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 inside and outside regions respectively around the road edges.

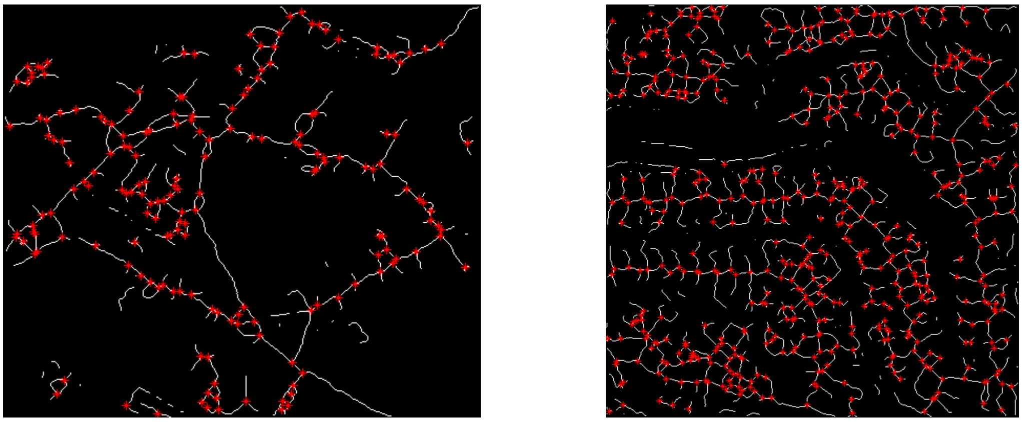


Figure12: Red cross points denote the intersection of road

4. Experimental Result and Performance Analysis

Our proposed method has been experienced with five different sources of high resolution satellite image in urban, semi urban and rural areas. The road layers are mixture different small roads, buildings, grounds, add tree with many driveways connecting to the road network. The distribution of buildings ranges from sparse to very close and the area contains a lot of trees, some trees very close to road. The other layers except the road layer are difficult to remove using existing techniques. However, the proposed approach aided demonstrates the ability to handle these problems. Almost all roads in the network are successfully extracted and intersection points are detected. The resulting images from our experiments are shown in Figure 12. In the figure the red colored cross (X) means road intersection point extracted by our proposed method. On the other hand, our approach could extract intersections correctly and not extract buildings as roads even if in suburban areas. As the results, we could construct road network with high correctness. The experimental achieved precisions are shown in Table 1. The precision is defined as the number of correctly extracted road intersection points divided by the number of road intersection points. The precisions of highway road was more higher than any other types of road because highway roads have less intersection points and the overall correctness was 95.91%

Table 1: Correctness of different road area for proposed method

Source information	**Intersection points**	**Extracted intersection points**	**Elapsed time**	**Correctness**
Developed Suburban Area	94	89	1.0624 sec	94.67%
Developed Urban Area	185	178	1.2256 sec	96.22%
Developed Rural Area	195	181	4.1114 sec	92.82%
Highway road	25	25	0.9382 sec	100%
Heavy traffic road	545	517	3.2923 sec	94.86%
			Overall Correctness	95.71%

In our experiment we use MatLab7.5.0.42 (R2007b) and image processing tool kit for processing the experiment. It took less than one minute to extract the road intersections from different high resolution satellite image on an Intel Core2Duo 1.83 GHZ Dual Processors with 2 GB memory.

5. Conclusion and Observation

A modified and cost effective method for road intersection from high resolution satellite images has been presented. This modified method was performed mainly in two steps; firstly, global segmentation, and morphological direction filtering using a structuring element (Talal *et al*). Second, various intersections aligned with non regular intervals such as cross-road, T-junction and Y-junction was detected (Koutaki *et ai*). We have made some general assumptions from our proposed method i.e., the background pixels are separable because the background and foreground pixels luminosity level are different. The foreground pixels contain larger value then the background pixels (Ahmed *et al* 2010). The main contribution of this paper is to provide a modified method to automatically and efficiently extract road intersections from high resolution satellite images. We applied our proposed approach on five different satellite images on urban, semi-urban and rural area taken from internet (Google Map) and successfully extracted the road intersection points to identify the geographical information. We achieved 95.71% correctness accurate to automatically extracting road intersection points. This proposed method has been successfully applied in the detection of single, multiple, intersected and branched roads, efficiently.

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