Extraction of Road Network from Aerial and Satellite Images using Mathematical Morphology

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Abstract— Aerial and satellite images are information rich and also complex to analyse. For GIS systems, many features such as cartographic, infrastructure planning and traffic routing software development requires fast and reliable extraction of roads and intersections. Due to noise present in the atmosphere and different road characteristics, the extraction of road network is scientifically challenging. In this paper, some efficient and reliable automatic extraction algorithms are used to address some difficult issues that are commonly seen in high resolution aerial and satellite images nonetheless not well addressed in existing solutions, such as blurring, broken road boundaries, lack of road profiles, heavy shadows, and interference from surrounding objects. The proposed scheme is able to extract roads reliably from images and the extracted road network fit the image as well.

Key words: Extraction, Reference Circle, Boundary Detection, Morphology, Skeletonization

I. INTRODUCTION

Extraction of road network from raster images is a very important part of many GIS activities such as GIS updating, geo-referencing, and geospatial data integration. However, high resolution images pose great challenges for automatic feature extraction due to the inherent complexities. First, a typical aerial photo captures everything in the area such as buildings, cars, trees, etc. Second, different objects are not isolated, but mixed and interfere with each other, e.g., the shadows of trees on the road, building tops with similar materials. Third, roads may even look quite differently within the same image, due to their respective physical properties. Assuming all roads have the same characteristics will fail to extract all the roads. In addition, the light and weather conditions have big impact over images. Therefore, it is impossible to predict what and where objects are, and how they look like in a raster image. All these uncertainties and complexities make the automatic extraction very difficult.

Most of the existing extraction methods for high resolution images rely on the road boundaries as key hints for road extraction. For roads with straight and clean edges, these edges can be detected using edge detection algorithms. Then certain navigation algorithm is used to follow the edges and extract the roads. There are numerous factors that can distort the edges, including but not limited to blocking objects such as trees and shadows, surrounding objects in similar colours such as roof tops. As a matter of fact, the result of edge detection is as complicated as the image itself. Edges of roads are either missing or broken and straight edges correspond to buildings instead of roads. Therefore, edge-based extraction schemes will all fail to produce reliable results under such circumstances. In this paper, we develop an integrated scheme for automatic extraction that exploits the inherent nature of roads.

II. LITERATURE REVIEW

The existing approaches for road extraction cover a wide variety of strategies, using different resolution aerial or satellite images. A new method proposed for road extraction which involves two key concepts: reference circle and central pixel explained in [1]. A general classification of Road Extraction methods based on different categories and goals are discussed in [2]. A new approach based on probabilistic contour tracking where the initialization strategy was based on the Hough transform and on some topological considerations, and the merging step was based on a new introduced quality measure, based on colour and gradient information [3]. The possibility of using artificial neural networks for road detection from high-resolution satellite images on a part of RGB Ikonos and Quick-Bird images from Kish Island and Bushehr Harbor respectively. Attempts were also made to verify the Impacts of different input parameters on network's ability to find out optimum input vector for the problem [4]. A variety of network structures with different iteration times were used to determine the best network structure and termination condition in training stage and also an improved Unsharp Mask (USM) sharpening algorithm to enhance the image and to strengthen the road feature with surrounding environment colour gradient [5].

III. PROPOSED METHOD

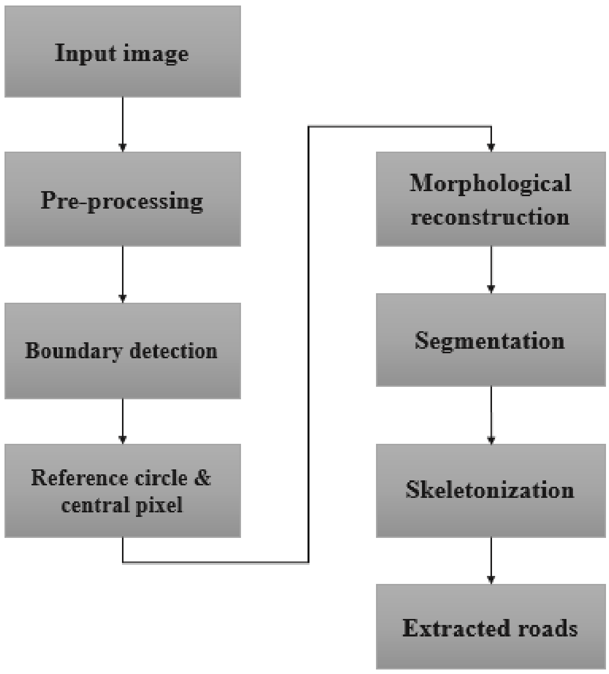


Fig. 1: Block diagram of proposed scheme

A. Pre-Processing

The proposed scheme has pre-processing step which includes the filtering of input image using a non-linear filter. The median filter replaces the value of a pixel by the median of the intensity values of neighbourhood pixels. It effectively reduces impulse noise and also the variation in intensity values.

B. Boundary detection

The detection and localization of edges works based on detecting discontinuities in brightness. Usually the edge pixels will have high frequency components and it help us to find the road network edges which are slightly varies with the intensity values. Either sobel or canny operator can be used to find the edges of the image.

In order to fully identify and separate road regions from the rest of image, we propose a new method which involves two key concepts: reference circle and central pixel. For a pixel p, its reference circle C(p) is the largest circle centered at p that does not contain edge points. Visually, the radius of the reference circle is the maximum distance from the pixel to the closet edge point. A pixel is a central pixel if it has the maximum reference circle among its neighboring pixels, which is a 3x3 area. Both concepts are illustrated in Figure 2 which shows the reference circles of three points P, Q, and S. Among them, Q and S are central pixels. The motivation of these two concepts is, under ideal situation, all the central pixels form the center line of a road. The incomplete and inaccurate edges will affect the location of central pixels to some degree. But central pixels have high tolerance over such error, especially when they are grouped together statistically, as illustrated in Figure 4. Therefore, all the central pixels can be considered as anchoring points for the road. For each central pixel, the set of all central pixels inside its reference circle is defined as its central pixel group, namely G(p). Again, ideally, the G(p) is the part of central line within the reference circle. In general case, we fit a line L(p) to the G(p) using the least squares method. L(p) is named as the axis for central pixel p and the direction of L(p) is called the direction of p. Figure 2 also shows the axis and direction for Q and S. To summarize, each central pixel has a local maximum reference circle, an axis, and a direction.

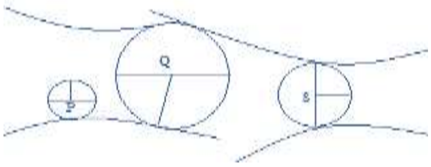


Fig. 2: Reference circle & Central pixel

C. Morphological Reconstruction

Morphological opening of an image is basically Erosion followed by a Dilation, using a structuring element. If A is the image and B is the structuring element then, opening of A by B is given to be

OPEN (A, B) =D (E (A))

Opening generally smoothens the contour of an object, breaks the narrow isthmuses and eliminates the thin protrusions.

Similarly the morphological closing of an image is basically Dilation followed by Erosion, using the same structuring element. That is

CLOSE (A, B) =E (D (A))

Closing also tends to smooth the sections of contours but, as opposite to opening, it generally fuses narrow breaks and long thin gulfs, eliminates small holes and fills gaps in the contour according to the size of structuring element.

D. Segmentation

The segmentation step refers to the extraction of region of interest. The segmentation is done based on the central pixels. Central pixels contain not only the centerline information of a region, but also the information of its overall geometric shape. For example, a perfect square will only have one central pixel at its center. A long narrow strip region will have large number of central pixels. Therefore the following ratio will be considered as threshold for finding the valid road regions. Regions only above threshold will considered as valid candidate regions.

$$T = \frac{\text{total number of central pixels}}{\text{average radius of reference circles}}$$

E. Skeletonization

Skeleton of an object is a unique geometrical description that requires far fever pixels than the original image. The skeleton of the road extracted road segment can be defined by placing a circular disc within an object and tracing its center. For every point within the object, there exist a set of maximum sized discs that just fit inside the object. The resultant of a skeleton operation consists of a set of lines corresponding to complete thinning of the region without losing the shape of the region.

IV. EXPERIMENTAL RESULTS

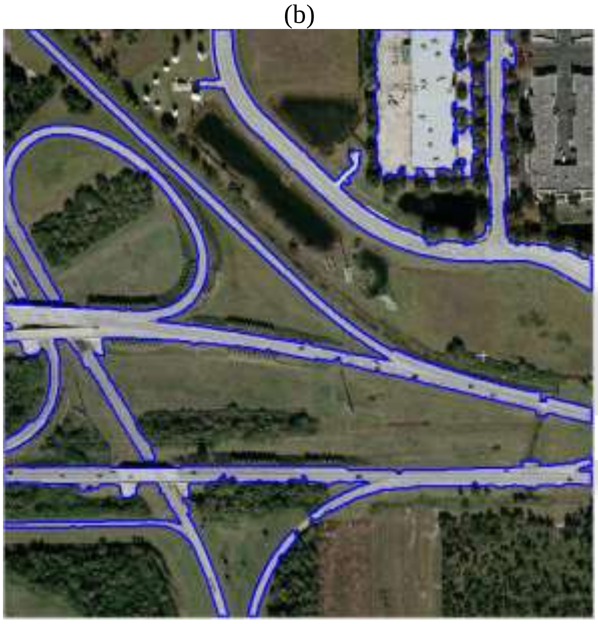
The results obtained for the input image shown in fig.3 (a) are shown in fig.3 (b) to (i).The quality of extraction is measured using Hausdorff fraction which is defined from a point set A={a_1, a_2 , , , a_p} to a point set B={b_1, b_2, , ,b_p} as follows

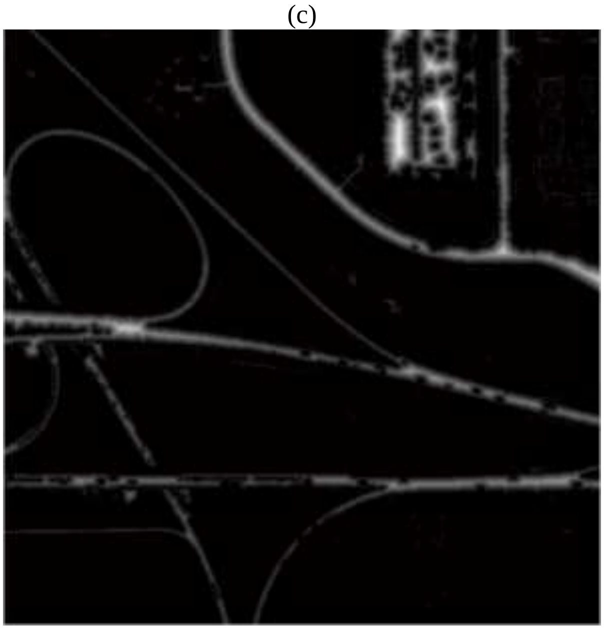
$$HF^t(A,B) = \frac{|a\epsilon A| \min_{b\epsilon B} \|a-b\| < t}{|A|}$$

This represents the faction of points in A, which are close to a point in B, within a threshold distance t(here the road width was set to be 10 pixels). The A and B are the sets of extracted roads central points and real central points respectively.

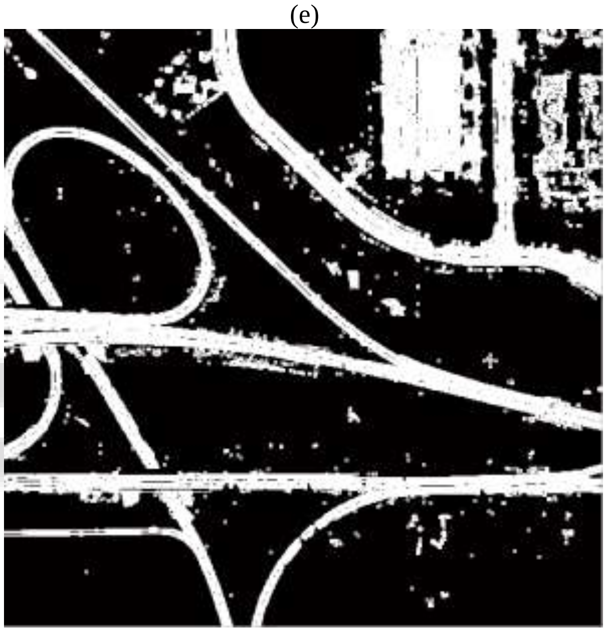
(a)

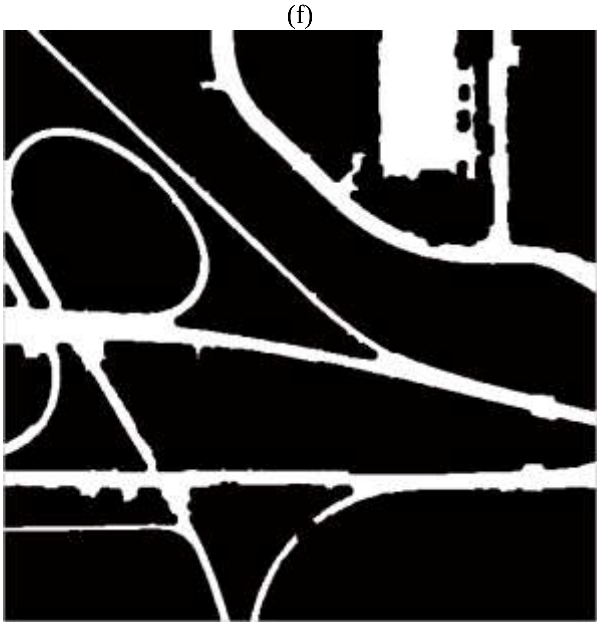

(b)

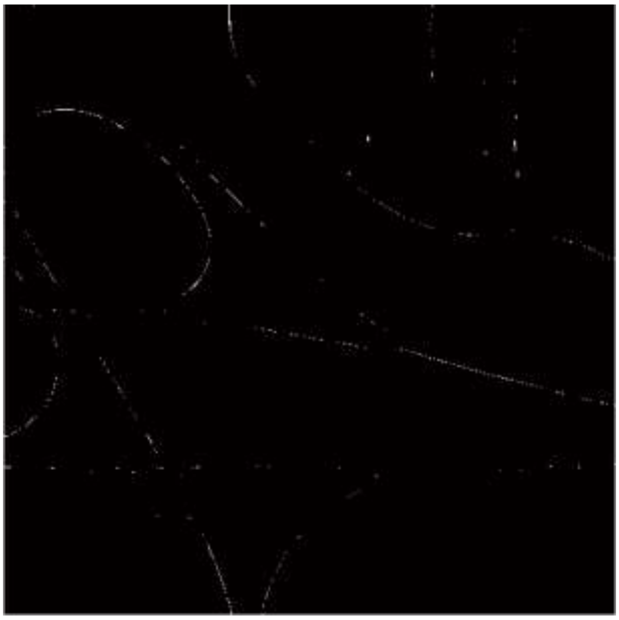

(c)


(d)


(e)


(f)


(g)



(h)

(i)

Fig. 3: (a) Input Aerial image (b) Median filter output (c) Boundary detected Image (d) Reference circles (e) Central pixels (f) Regions corresponding to the central pixels (g) Morphological reconstructed image (h) Segmentation output (i) Extracted skeleton of the road network

Input image size(512×512)	**No of 1's belongs to road**	**No of 0's not belongs to road**	**Hausdorff fraction (A,B)**
Road image	3484	258660	0.98
Road image	1320	260824	0.99
River image	1224	260920	0.95

Table 1: Quality measurement using HF

V. CONCLUSION

In this paper, we proposed some basic algorithms for extracting road network from aerial and satellite images downloaded from Google maps. The main aim of the proposed method is to address the issues with the current extraction schemes such as blurring effects, missing boundaries, discontinuity in the edges etc.,. The algorithm has been tested over 40+ aerial images of road network and the extracted skeleton of road network fits the original image very well. The proposed method can also be applied to extract rivers as well as structures like canals, and bridges. The proposed approach is efficient, reliable, and assumes no prior knowledge about the road conditions and surrounding objects. With extraction of road, the algorithm is also extracting the big objects like building tops which look similar to the road spectrum.

Additionally, further improvements can be done for extracting the road network of an urban area under higher traffic conditions, high intensity variations, big objects like building tops and heavy shadows.

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