A Multi-stage Method to Extract Road from High Resolution Satellite Image

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A Multi-stage Method to Extract Road from High Resolution Satellite Image

Huang Zhijian [1,2], Jinfang Zhang [2], Fanjiang Xu[2]

[1]School of Electronic Science and Engineering, National University of Defense Technology
[2]Science and Technology on Integrated Information System Laboratory, Institute of Software, Chinese Academy of Sciences

E-mail: zhijian07@iscas.ac.cn

Abstract. Extracting road information from high-resolution satellite images is complex and hardly achieves by exploiting only one or two modules. This paper presents a multi-stage method, consisting of automatic information extraction and semi-automatic post-processing. The Multi-scale Enhancement algorithm enlarges the contrast of human-made structures with the background. The Statistical Region Merging segments images into regions, whose skeletons are extracted and pruned according to geometry shape information. Setting the start and the end skeleton points, the shortest skeleton path is constructed as a road centre line. The Bidirectional Adaptive Smoothing technique smoothens the road centre line and adjusts it to right position. With the smoothed line and its average width, a Buffer algorithm reconstructs the road region easily. Seen from the last results, the proposed method eliminates redundant non-road regions, repairs incomplete occlusions, jumps over complete occlusions, and reserves accurate road centre lines and neat road regions. During the whole process, only a few interactions are needed.

1. Introduction

Road information not only plays a central role in the vehicle navigation, but also provides many other supports for human civilization. Extracting road from digital imagery is a fundamental operation for geographic information system (GIS) update. During last decades, many researchers have made great efforts on automatic road extraction [1-4]. The roads in high-resolution satellite images are complex, with a variety of spectrum characteristics, width and sinuosity. There are non-road regions (e.g. houses and bare lands) having similar characteristics with road, causing under-segmentation. Roads are always occluded incompletely or completely by trees, high buildings or large vehicles. Hence, the automatic road extraction is still a hard problem which has not been solved with a reasonable degree of success over a large set of images of different categories of urban and suburban areas[5]. For extracting road quickly and accurately, studying semi-automatic methods is a more practical choice [6].

There are usually two semi-automatic methods: road-tracking and snakes (active contours). The former tracks roads by utilizing road profile matching. Certain measurement (e.g. cross-correlation) is defined according to the similarity between the reference profile and current profile. Various filters are exploited to predict next road point, including Bayesian filter[7], Kalman filter, Particle filter and combined filters[8]. Snakes is a model which combines spectral characteristic and geometry-constrained[9]. A family of cooperating snakes[10], which are able to split, merge, and disappear as

necessary, are used to extract disconnected road networks and enclosed regions. Both road-tracking and snakes require manual identification of seed points.

Different from aforementioned semi-automatic methods, the method presented in this paper only needs human interference at the road verification stage. Hence, only a few interactions are needed, and the correctness and the position accuracy are satisfactory.

Most of the published works have exploited only one or two modules for processing. Just as stated in literature [5, only a multi-stage, well-formulated, and planned strategy is suitable for a wide variety of road in complex high-resolution satellite images. This paper proposes a multi-stage method, which consists of automatic information extraction (Stage I) and semi-automatic post-processing (Stage II). The Stage I includes three modules: namely the multi-scale enhancement (MsE), the Statistical Region Merging (SRM) and the Skeletonization. The MsE enlarges the contrast of human-made structure with respect to the background. The SRM segments image into regions, whose skeletons are extracted and pruned according to shape geometry information. The skeletons are candidates of road center lines, waiting to be verified manually. The Stage II constructs shortest paths according to the points set by operator. Then, the Bidirectional Adaptive Smoothing (BAS) [11] smoothens the road centre line and adjusts it to right position. At last, with the smoothened centre line and its average width, a buffer algorithm reconstructs the road region.
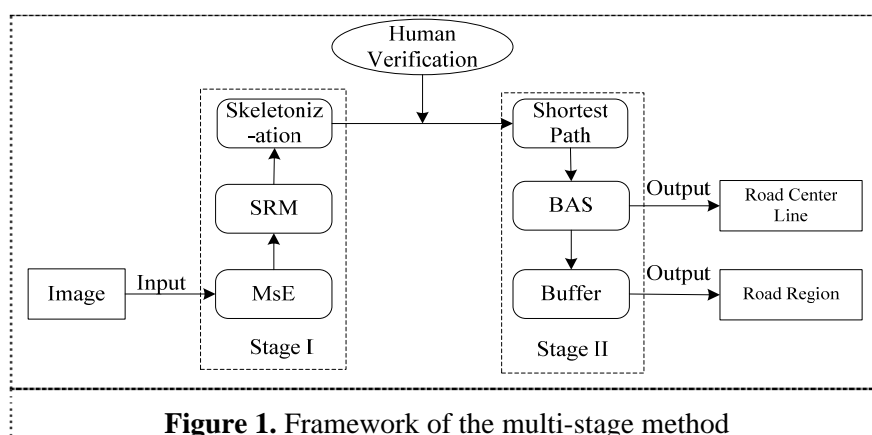

Figure 1. Framework of the multi-stage method

The framework of our method is shown in Figure1, and the corresponding intermediate results are shown in Figure 2. In the sub-image (d), the red lines are the skeletons, while the green points are set by operator. The road centerline is shown in the sub-image(e) with red line, and the road region is in the (f) with black region. Seen from the results, we obtain a smooth road center line with high position accuracy, and a neat road region without any redundant region.

2. The Multi-stage Method
The proposed multi-stage method contains two stages and six modules. This section will present the MsE and the BAS in detail, and other modules in brief.

2.1. Multi-scale Enhancement
In remote sensing image, there are often two troublesome problems for road extraction. On one hand, road regions inner are always not homogeneous, caused by noise, inhomogeneous illumination and material. So it is easy to segment a road region into many parts, i.e. over-segmentation. On the other hand, the difference between road and background is not obvious which causes under-segmentation easily. This letter presents a MsE to alleviate inhomogeneity of the road region and enlarge its contrast.

The MsE models the process of observation values changing with scales. At first, multi-scale observation images are obtained by recursive Gaussian filtering for efficiency. Then, the observation values of each pixel are compared with its initial observed value (not the original pixel value, but the observation value of the initial scale). If the initial value is higher than the observed value of a certain

scale, it means that this pixel is salient on this scale. Lastly, the comparison results are integrated with weights to form an enhanced image. The whole process is shown in Fig.3.
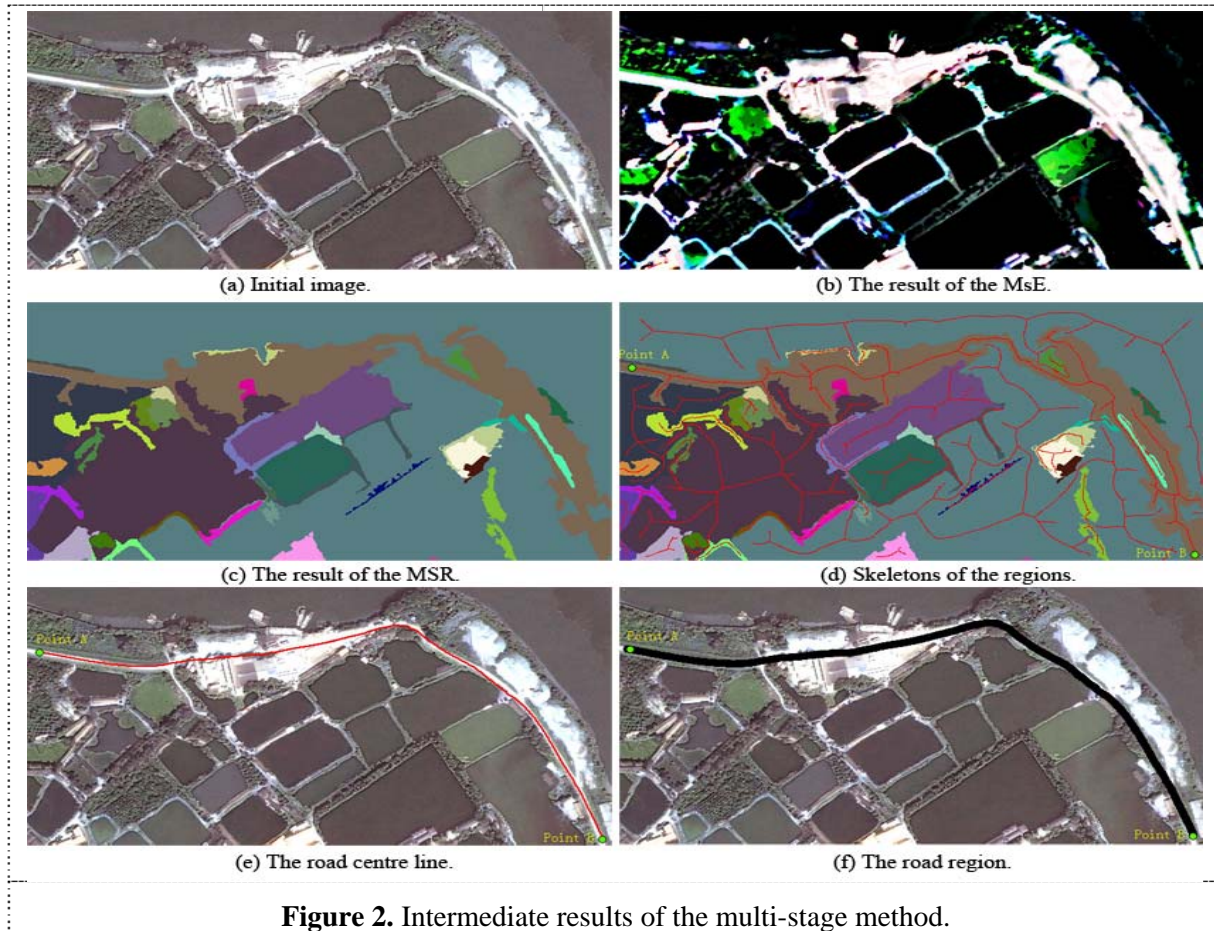

(a) Initial image.

(b) The result of the MsE.

(c) The result of the MSR.

(d) Skeletons of the regions.

(e) The road centre line.

(f) The road region.

Figure 2. Intermediate results of the multi-stage method.

Experiments show that inner of object becomes more homogeneous, and the contrast between object and background is enlarged. The MsE can be used as preprocessing step of segmentation. It brings improvement obviously. The results are more consistent with human perception.

2.2. Bidirectional Adaptive Smoothing

An ideal road region is a strip with locally constant width. Theoretically, its skeleton is just the road center line, with constant width. Unfortunately, the actual situation is more complex. On the one hand, noise of object contour causes some small branches though the skeletons are pruned. On the other hand, road region is mixed with some redundant regions (usually house, bare land and so on), which have similar spectrum and texture characteristics with road region. At the position where road region connected with a large redundant, its width increases abruptly, forming a bend, seen in Figure 2(d).

To solving these problems, an bidirectional adaptive smoothing algorithm is proposed in literature[11]. The shortest path can be represented as an ordered collection of skeleton points $P = \{p_i \mid p_i = (x_i, y_i, w_i), i = 1, 2, ..., N\}$, where N is the number of the path skeleton points and w_i is the radius of road region at p_i, which is the least distance from p_i to the contour. The coordinates can be represented as a sequence $x(i) = \{x_i \mid i = 1, 2, ..., N\}$ and $y(i) = \{y_i \mid i = 1, 2, ..., N\}$. A Gaussian kernel $g(u, \sigma) = \exp\{-|u - u_0| / 2\sigma^2\}$ is used to smooth the path, where variance σ^2 called smooth scale. The scale is not a constant, but proportional to radius w_i. So the adaptive scale Gaussian Kernel is:

$$g(u,w,i)=\frac{1}{Z}\exp\{-|u-u_0|^2/2(\sigma_0 w_i)^2\} \tag{1}$$

where $Z=\int\exp\{-|u-u_0|^2/2(\sigma_0 w_i)^2\}du$ is the normalization factor. The initial scale σ_0 usually takes

1. The Gaussian Kernel can be discretized as a sequence $g(i,j)$. To a skeleton point p_n, it adjusts to

$\overline{p_n}=(\overline{x},\overline{y})$. The $\overline{x}$ and $\overline{y}$ are calculated according to $\overline{x}=\sum\limits_{k=-m}^{m}x(n-k)g(k,n)$, and

$\overline{y}=\sum\limits_{k=-m}^{m}y(n-k)g(k,n)$ where m is the length of the Gaussian Kernel.

The result of adaptive scale smoothing depends on the processing sequence. So this smoothing should go from head to tail, and then from tail to head. This process called bidirectional adaptive smoothing. Results show that its performance is satisfactory.
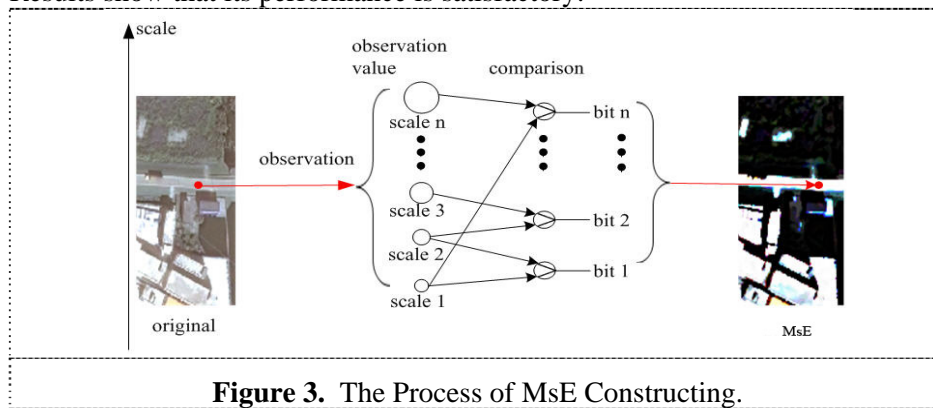

Figure 3. The Process of MsE Constructing.

2.3. Other modules

The SRM is a state-of-art segmentation technique proposed by Nock and Nielsen [12]. It is able to capture the main structural components of image using a simple but effective statistical analysis, and has the ability to cope with significant noise corruption and handle occlusions. Hence, the SRM algorithm is exploited in this paper.

Skeleton is an important representation of object. It is useful in many areas, such as image retrieval, shape classification, object detection and recognition. The state-of-art methods on skeleton extraction and pruning were presented in literatures [13-15]. Here, skeleton extraction and pruning exploits the algorithm proposed in[15].

The buffer module is applied to reconstruct road region. Once the road center line is fixed, the average width of the path can be calculated. By integrating a buffer algorithm into the business software ArcGis, we can reconstruct the road region.

Figure 4. The Results of Suburban Region.

3 Results and Discussion

In this paper, images of 0.61m resolution and three-band (RGB channels) are taken for experiments. Figure 4 shows a region of suburban, where a house roof has similar characteristics as the road region. Hence, after the SRM, the house roof still combines with the road (seen the back region of the left sub-image). With our method, the house roof and other redundancy regions are eliminated. In this situation, it is necessary to set only two points by operator.

In high resolution image, road is often shadowed by adjacent high buildings, trees, large vehicles and so on. There are two situations: incomplete and complete occlusion. For the first situation, the width is not locally constant. With the proposed method, the incomplete occlusion can be repaired. When the road is occluded completely, our method can also jump over the occlusion, by adding two interactions at the end point of the gap. The interaction points are shown in the middle sub-image of Figure 5.

Figure 5. Completely Occlusion.

More examples are shown in Figure 6 and 7, which present the results of suburban regions and urban regions respectively. The results accord with human visual perception. Most of the road center lines are extracted, and the center lines are smooth and their positions are accurate. The road regions are neat and without any redundant regions.

4 Conclusion

This paper proposes a multi-stage method to extract road from high-resolution satellite image. This method is composed of two stages: automatic information extraction (Stage I) and semi-automatic post-processing (Stage II). The Stage I consists of three modules: the MsE, the SRG and the Skeletonization. The Stage II makes full use of geometry shape information. It constructs shortest paths according to the points set by operator. The BAS smoothens the road centre line and adjusts it to right position. With the smoothed centre line and its average width, a buffer algorithm reconstructs the road region.

Seen from final results, the proposed method eliminates redundant non-road regions, repairs incomplete occlusions, jumps over complete occlusions, and reserves accurate road centre lines and neat road regions. During the whole process, only a few interactions are needed.

Figure 6. The Results of Suburban Region.

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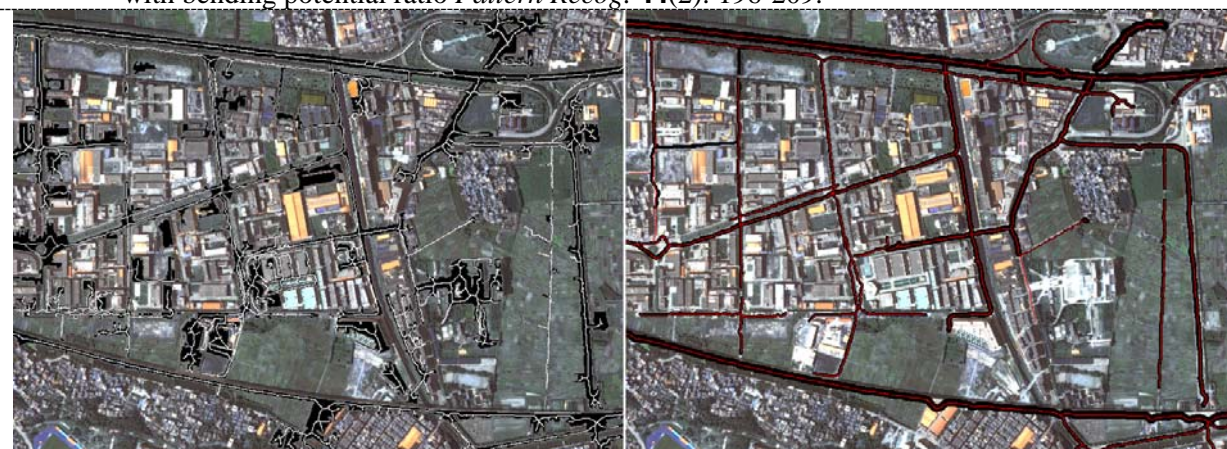
Figure 7. The Results of Urban Region.