OBJECT DECOMPOSITION BASED-ON SKELETON ANALYSIS FOR ROAD EXTRACTION

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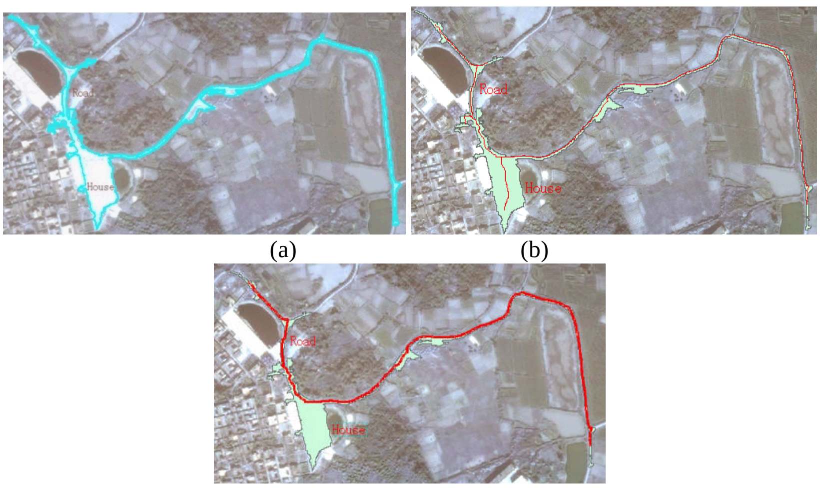
ABSTRACT:

The phenomenon of "different objects with similar spectrum" exists widely in remote sensing images, which often causes combined objects. In order to alleviate its effect in the process of object-based image analysis, a object decomposition based skeleton analysis method is proposed in this paper. At first, the shape characteristics of roads in remote sensing image are analyzed. For skeletons, these characteristics present as smoothness, stability, homogeneity and narrowness, based-on which road objects are decomposed and road centre lines are extracted. Results of experiments show that combined objects can be decomposed correctly, laying a solid foundation for future works. In fact, the proposed method of road extraction not only exploit the spectrum, texture and shape information, but also shape characteristic. As a consequence, both the correctness and completeness of the road extraction results are satisfying and attractive.

1. Introduction

One of the common challenges of information extraction from remote sensing image is the "different objects with similar spectrum" phenomenon, which often causes combined objects. For instance, the results of most of spectrum-based segmentation algorithms[1, 2], different ground true objects are combineed into one image object, shown in the Figure 1(a). In this image, a road and a house roof have similar spectrum and texture characteristic, which are segmented as a combined object. These combined objects may affect the future work, such as road extraction, building extraction and classification based on object. So it is necessary to decompose true objects from combined ones.

Since the different parts of a combined object have similar spectrum and texture information, the decomposition can make full use of shape information. Skeletons concentrate on shape information of object, which is important for object representation and recognition in different areas, such as image retrieval[3], shape classification[4-6] and object detection[7]. Recently, many researchers have devoted to object skeleton extraction and pruning[8-10]. With the shape information carried by object skeletons, the shape characteristic of object can be further used for higher level of image analysis, such as road extration.



(c)

Figure 1. An example of combined object composition. (a) An object combining a road and a house; (b) the skeletons of combined

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object; (c) road (red) decomposed from combined object.

Seen from remote sensing images, roads are long, smooth, with constant width and strip-like. The skeleton of road objects also has significant shape characteristics, such as no sharp angle, constant road radius, and narrow. At first, this paper analyses the shape characteristics of road objects, and introduces four terms (smoothness, stability, homogeneity and narrowness) to represent the characteristics. According to the shape characteristics, the road skeltons are separated from the other, and can be treated as road centre line. With road centre lines and their average radius (carried by every skeleton points), road object can be reconstructed conveniently with the buffer algorithm which is well-known in GIS. Seen from the final result, it is just like road objects are decomposed from the combined objects. Figure 1(b) shows the skeletons of the combined object, which is decomposed to be road object (red region) and non-road object (blue region).

In this paper, initial objects are often the results of image segmentation based on spectrum and texture characteristic, so the method proposed in this paper is actually a method fusing spectrum, texture and shape information. As a consequence, both the correctness and the completeness of the road extraction results are satisfying and attractive, which can also be demonstrated by the experiments in Section 3.

2. Methodology

2.1 Data Preparation and Concept Definition

Given a image object, its skeletons can be extracted with the algorithm mentioned in[11], and pruned with bending potential ratio[10]. However, these skeletons are raster, which are not convenient for post processing and further analysis. So, an automatic vectorization algorithm [12] is necessary to convert raster skeletons. For information completeness, the vectorized skeleton should be resampled with a constant step length, and every sample point (vertex of vector skeleton) carries radius, which means its nearest distance to corresponding object contour.

In this paper, all the vertexes of vector skeleton are named as **Skeleton Point**. The skeleton point having only one adjacent point is called as an **Endpoint**; the skeleton point which has more than two adjacent points is called **Junction Point**. The skeleton segment between two skeleton points is defined as **Skeleton Branch**. The definition of **Branch angle** is shown in Figure 2, where the branch angle of the current branch to branch A is •, while the angle to Branch B is •. **Path** is the skeleton segment between an endpoint to another endpoint or junction point. **Skeleton point radius** is the length of the shortest distance from skeleton point to the bound of corresponding object.

2.2 Road Skeleton Model

Taking account of the characteristics of road in remote sensing image, just as mentioned above, its skeletons should also present some characteristics called as smoothness, stability, homogeneity and narrowness.

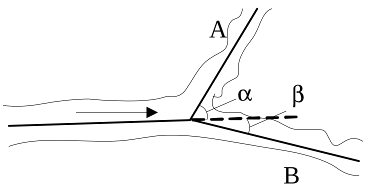


Figure 2. Branch angles at a Junction Point

2.2.1 Smoothness: It not only means that the road centre line should not be sinuous, but also that its direction should not change sharply, especially at a junction point. Seen as the Figure 2, since the branch angle • is less than •, branch B is more appropriate than A to be a part of road path. With this criterion, the path will be constructed to be a smoothest way. With a greedy algorithm, paths of a object can be constructed easily. An example is shown in Figure 4(a), where red one is the road centre path.

2.2.2 Stability: It means that the width of road should not change sharply, otherwise its centre line should be segmented. Let the s_i be the i-th skeleton point of a path, so the path can be presented as a sequence $S = \{s_i \mid 1 \le i \le N\}$, where N is the total number of the path skeleton points. All the skeleton points of a path constitute serially a 1D radius sequence $r(s_i)$, as shown in Figure 3. Let the extrema of $r(s_i)$ be $E = \{e_i \mid r'(e_i) = 0, e_i \in S\}$, where $r'(\cdot)$ is the derivative of radius function. Since $r(s_i)$ is discrete, the derivative can be calculated with $r'(\cdot,\sigma) = r(\cdot) \otimes g'(\cdot,\sigma)$, where $\otimes$ is the convolution symbol, $g(\cdot,\sigma)$ is the Gaussian kernel function with width σ, $g'(\cdot,\sigma)$ are the first order derivative.

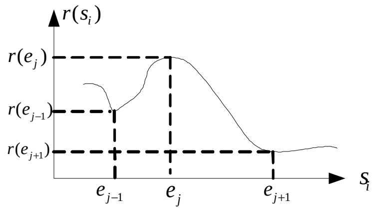


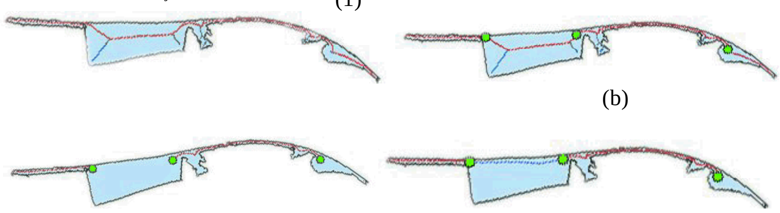
Figure 3. Radius sequence of a Path

Let $r = \max\{|r(e_{j-1}) - r(e_j)|, |r(e_j) - r(e_{j+1})|\}$, means the max change of the path radius of the adjacent extrema. If $|r(e_{j-1}) - r(e_j)| \le |r(e_j) - r(e_{j+1})|$, let $rr = r(e_{j+1})$ else $rr = r(e_{j-1})$. So the stability index can be defined as:

$$c = \nabla r / \min\{rr, r(e_j)\} \quad (1)$$

According to the definite, stability index c means the max change rate in a region of support (ROC, the region between the last extremum and next extremum). So it can represent the width change situation of a path. If $c \ge T$, the path should be segment at this position.,where T is a threshold set by user. All the experiments have shown that it is not sensetive, and we often let it to be 1.5.

With the red path in Figure 4(a) , an example is shown in Figure 5. The radius sequence and its first order are shown in Figure 4 (a) and (b) respectively, where hollow circles denote the extrema of the radius sequence. The segmentation points caculated with the criterion mentioned above are shown in Figure 5(c) with red hollow circle, and the corresponding points are denoted with green circle, shown in Figure 4(b).



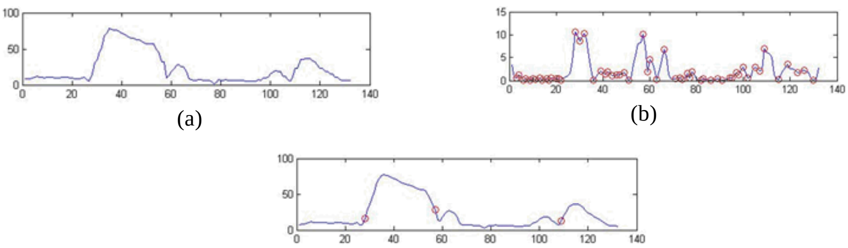
(b)

(c) (d)

Figure 4. An example of path segmentation.

2.2.3 Homogeneity: It is another characteristic to reflect the stability of road skeleton. The variance of radius sequence of skeleton segment can represent homogeneity well. Divided by the length of the skeleton segment, this index is invariable with object scale. With this criterion, two skeleton segments are selected as road line, as shown in Figure 5(c).

2.2.4 Narrowness: Seen from all kinds of remote sensing images, there are many strip objects, such as rivers and cultivated lands. These objects have similar shape characteristics and skeletons with road objects. But the width of road is limited, always no more than 100m. So we can calculated the average radius of radius sequence. With this criterion, some non-road skeleton segments will be filtered out.



(a) (b)

(c)

Figure 5. Radius sequence of the red Path in Figure 4(a)

3. Results and Analysis

3.1 Experiment with Simple Objects

Four simple objects are used in the experiment, and results are shown in Figure 6. All of them are the results of segmention[1]. The shape of these combined objects are relatively simple, with no hole, and only contain two or three different ground true objects. The red lines denote the skeleton of the strip-like parts extracted with the method introduced above. These lines may be parts of the potential road centre lines which are useful for road extraction in next step. Seen from the results, combined objects caused by the phenomenon of “different objects with similar spectrum" are decomposed correctly with the method proposed in this paper.

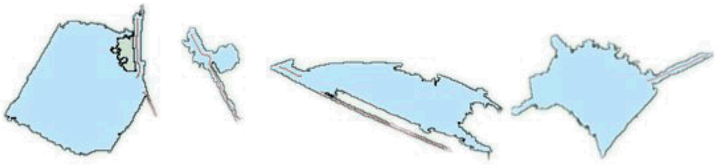


Figure 6. Results of Simple Objects

3.2 Experiment with Complex Objects

To validate the effectiveness of the proposed method, a complex object is taken in our experiment. It has more than ten holes and consists of roads, houses and some grass lands. The skeletons are also complex, shown in the left sub-figure of Figure 7. The result of skeleton decomposition with the method mentioned in section 2 is shown in the middle sub-figure, where road parts are marked with red line. With the road parts of skeletons and their average width, the buffer algorithm which is well-known in GIS reconstructs the road regions, is shown in the right sub-figure. Though there are still some missing road segments and some non-road segments, the objects are refined, which reduces the difficulty of next steps and improves the correctness and the completeness of road extraction. It is also demonstrated by the experiment of section 3.3.

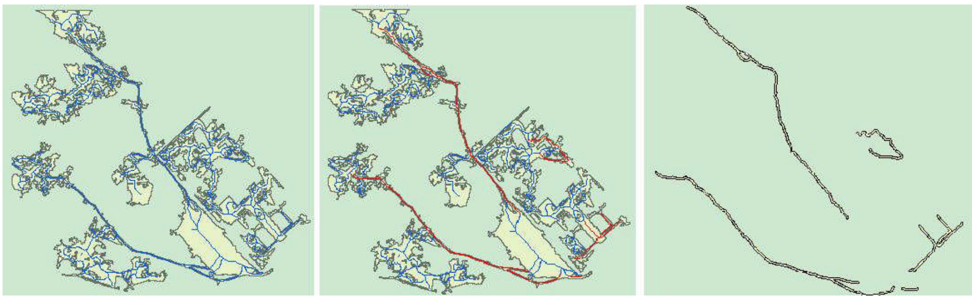


Fig. 7. Result of complex object. Left: Initial skeletons extracted with Method in[10]. Middle: Result of skeleton decomposition, where road parts are marked with red lines. Right: road regions reconstructed with the average width of skeleton segments.

3.3 Examples of Road Extraction with Objects Decomposition

In order to carry out quantitative evaluation of the quality of road extraction algorithm based on the method above, we used the method proposed in literate[13]. It calculates the completeness, the correctness and the quality in the formula (1):

$$\begin{cases} Com = L_{mr} / L_r \\ Corr = L_{me} / L_e \\ Q = L_{me} / (L_e + L_{ur}) \end{cases} \quad (2)$$

Where L_{mr} denote the length of matched reference, L_r the length of reference, L_{me} length of matched extraction, L_e length of extraction, L_{ur} length of unmatched reference. In the experiments, reference road lines are obtained with human visual interpretation.

The performance of our algorithm are given in Table 1, where two different regions (rural and suburban respectively) are taken into experiment. All of the images are Quich Bird, 0.6m resolution, 3000×3000 pixels. Table 1 shows the average performance. For intuitively, two examples of this road extraction algorithm are also shown in Figure 8 and Figure 9.

	Completeness	Correctness	Quality
rural	84.0%	91.2%	77.7%
suburban	81.6%	90.8%	75.4%

Table 1 Quality of Road Extraction

4. Conclusion and Future Work

A method of object decomposition based skeleton analysis for road extraction is proposed in this paper.

With the characteristics of road skeleton, namely smoothness, stability, homogeneity and narrowness, road can be composited from combined image object. Since image objects are always produced by image segmentation based on spectrum and texture characteristic, it is actually a method incorporating shape information with the spectrum characteristic and the texture characteristic. As a consequence, the performance of road extraction is improved. The results of experiments with simple and complex objects show the correctness of this method. In order to prove its effectiveness further, examples of road extraction based on this object composition are also presented. The results of the examples with village and suburb images present high quality, as shown in Table 1, Figure 8 and Figure 9. The result are satisfying and attractive. We also believe that it is promising for road extraction from high resolution remote sensing image.

Future work will focus on two aspects: (1) inference method to decompose true ground objects from combined objects more completely and correctly; (2) road centre line smoothness and perceptual organization. The first one means to infer a potential road segment as the blue segment in Figure 4(d) based on its context shape information. The second is to get more smooth and complete road centre lines.

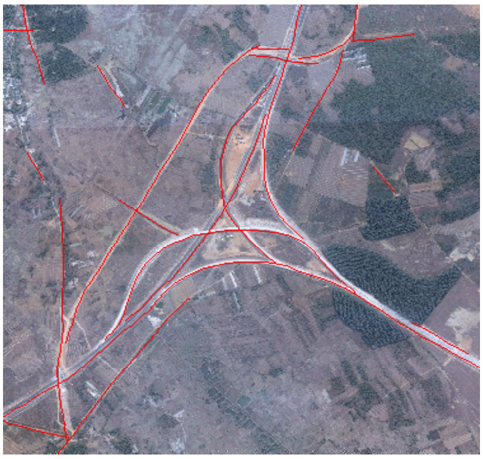


Figure 8. An example of rural

Figure 9. An example of suburban

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