Sequential Edge Linking Method for Segmentation of Remotely Sensed Imagery Based on Heuristic Search

Xiaomin Ji[1]*, Xueliang Zhang[1], Lifeng Zhang[1]
[1]School of Geographic and Oceanic Science, Nanjing University, Nanjing, China
* Corresponding author, Email: xiaominji@nju.edu.cn

Abstract—**An improved edge linking method for segmentation of remotely sensed imagery is proposed in this paper. Firstly, the gradient strength and the gradient direction are calculated. Secondly, the initial edge points are generated by the proposed locally maximal gradient strength strategy. Finally, edges are generated by the heuristic search method (A*) which links all the initial edge points based on the gradient strength, gradient direction and edge direction. Most of the existing edge-based segmentation methods would produce discontinuous edges, while the proposed method can produce the segmentation result with precise, continuous, and one-pixel-wide edges. In the experiment, the method is tested successfully on the QuickBird image and performs well.**

Keywords-remotely sensed imagery; image segmentation; edge linking; heuristic search

I. INTRODUCTION

The edge-based segmentation methods for remotely sensed imagery aims at obtaining the continuous, precise, and one-pixel-wide edges, mainly including two stages: the edge enhancing and edge linking. The existed edge detection methods, such as Laplacian operator [1], Canny operator [2], edge detection with embedded confidence [3], or generalized edge detection method [4], can produce precise and one-pixel-wide edges quickly, but the edges are always broken.

In order to produce continuous edges, the sequential edge linking (SEL) method was proposed by Eichel and Delp [5], which was tested successfully on medical and industrial images. Later on, Farag and Delp further improved the SEL method [6]. They constructed the path matrix based on the linear model, and took the space near the Laplacian zero-crossing point as the search range. Then the heap based graph search technology was adopted to generate the edge map. The result was better than before, but it still had many broken edges, which was mainly owing to the limitation of the search range. In this paper, we also make use of the SEL method to perform the edge linking task for remotely sensed imagery. But we focus on improving the searching condition, and we would not set the searching range to make sure that the edges are continuous.

The following sections of the paper are organized as follows. Section 2 presents the proposed method. Section 3 describes the experiment and show the analysis. Section 4 concludes the paper.

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II. METHODOLOGY

The overall segmentation method is shown as Figure 1. Firstly, the gradient strength and the corresponding direction of the remotely sensed imagery are calculated. Then, the initial edge points are obtained by the locally maximal gradient strength strategy. Finally, generating the edge map by searching each edge successively using the A* method until reaching the stopping rule.

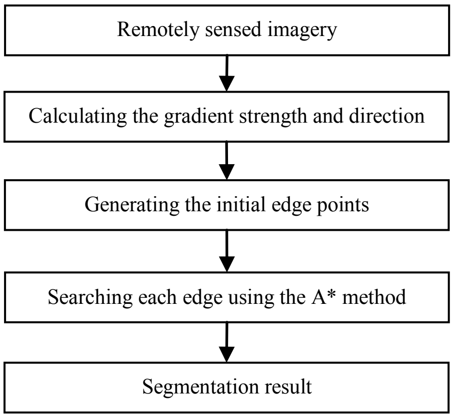


Figure1. The flow diagram of the proposed segmentation method.

A. Generating the initial edge points

The initial edge points are the starting points when searching each edge. They are obtained based on the gradient. The Sobel operator is used to calculate the gradient, including the gradient strength and gradient direction.

In the proposed edge linking method, an edge can be viewed as the set of edge points between the initial edge point and the other ending point. Then the search task for an edge would aim at obtaining the set of points in the edge. The search task for an edge starts from one initial edge point, and stops at another ending point. When all the initial edge points are included in edges, the segmentation is over, producing the edge map. Hence, the precision and number of the initial edge points would influence the segmentation result significantly. The thresholding method [7] is a classical method to generate the initial edge points. Setting a threshold for the gradient strength, the points with gradient strength larger than the threshold are viewed as the initial edge points. The method is simple and fast, but it is easily affected by subjectivity and can lead to the "overlay" effect, which would influence to produce the one-pixel-wide edge negatively.

In this paper, we propose the locally maximal gradient strength strategy to obtain the initial edge points. Given the size of a window, the point with the maximal gradient strength in the window is viewed as the initial edge point. Then we move to the next window to find the corresponding initial edge point until the windows totally cover the image. The windows are spatially adjacent and continuous, as shown in Figure 2.

However, some windows would be located within large homogeneous regions, then this leads to some false initial edge points. In order to avoid such false initial edge points, the locally maximal gradient strength points are sorted from small to large, and those which belong to the top 20% are excluded from the initial edge points.

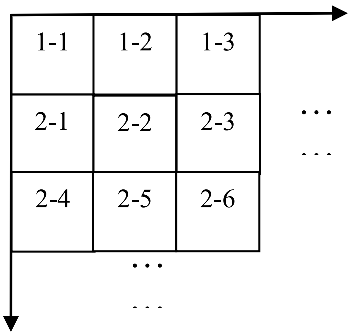


Figure2. The arrangement of the windows when searching the initial edge points.

B. Searching edges by sequential linking

The sequential search process is analogous to the graph search method. Firstly, calculate the edge strength of each pixel and view the map of edge strength as a graph. Then, the edge strength is viewed as the search condition. Taking the initial edge point and its gradient direction as the starting point and starting direction, respectively, search the path with the largest edge strength as an edge. The search task of an edge stops when reaching the other ending point. When all the initial edge points have been involved, the search process is completed.

Supposing that the forward direction is within 45° of the former direction, then there are only 3 possible forward directions when searching the next edge point during the search process in the 3*3 search window, as shown in Figure 3. Combining the forward direction, the gradient direction and the gradient strength, the edge strength is defined as below:

$$EdgeStrength = Gradient * \cos |D_g - D_e|, \quad (1)$$

where *EdgeStrength* represents the edge strength, *Gradient* is the Sobel gradient strength, D_g and D_e represent the gradient direction and the forward direction, respectively. According to Eq. (1), if the forward direction is perpendicular to the gradient direction, the edge strength would be large. On the contrary, if the forward direction is parallel to the gradient direction, the edge strength would be small.

Taking the edge strength as the search condition, the A* method is adopted to search each edge [8], which is capable of searching the best edge globally. The stopping rule for the search task of each edge is that it reaches the other ending point, which includes three cases: a) Reaching the border of the image; b) Returning to the starting point; c) Meeting other edges. The stopping rule for the whole search task is that all of the initial edge points are involved and included in the edges.

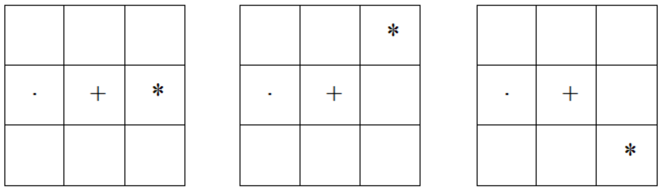


Figure3. The possible search directions, "*" represents the forward direction, "+" represents the current edge point, and "·" represents the former edge point.

III. RESULTS AND ANALYSIS

A. Data

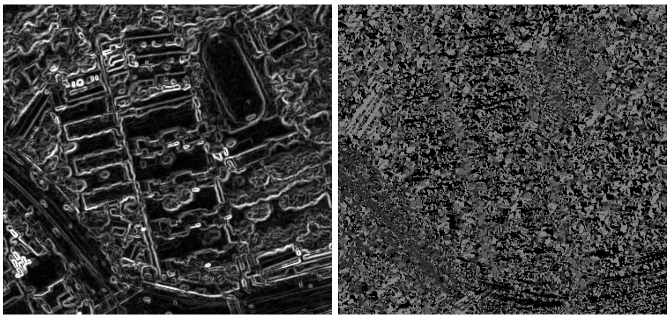
The test image is a subset of the QuickBird scene in Nanjing City, China. The spatial resolution is 0.6m after pan-sharping fusion [9]. The width of the test image is 373 pixel, and the height is 354 pixel, as shown in Figure 4. The test image represents the urban landscape with buildings, roads, trees and a playground.

Figure4. The original test image shown with band combination of the NIR, red, and green bands.

B. The initial edge points

The NIR band of the test image is used to calculate the gradient. Figure 5 (a) is the map of gradient strength, and (b) is the map of gradient direction. The gradient direction is normalized into 4 directions, including 0°, 45°, 90°, and 135°.

When applying the locally maximal gradient strength strategy on the gradient strength map, we need to set the proper window size to generate the initial edge points. The initial edge points produced by setting different window sizes are shown in Figure 6. Combined with the original test image in Figure 3, the initial edge points are mostly located on the boundary of ground objects. In other words, the initial edge points have high spatial accuracy. From visual analysis, it is easy to know that the number of initial edge points is decreased along with the increase of the window size. From Figure 6 (a) to Figure 6 (e), as the window size is increased from 3×3 to 11×11, the number of initial edge points is obviously getting smaller.



(a) (b)

Figure5. The map of gradient strength (a) and gradient direction (b).

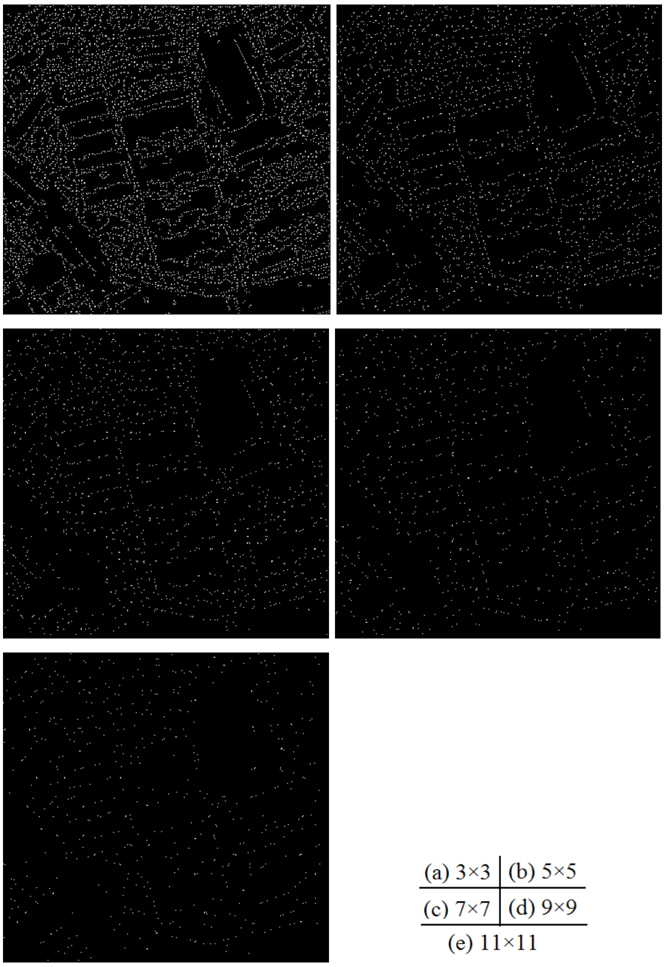


Figure6. The initial edge points produced by setting different window sizes.

When the window size is too small, such as in Figure 6 (a) or (b), there are too many initial edge points astride the true edge, leading to the overlapping effect, which would negatively affect the generation of the one-pixel-wide edge. Moreover, there are many fake initial edge points in Figure 6 (a) and (b) within the tree or building regions. On the other hand, if the window size is set too large, the number of initial edge points would not be large enough, which leads to the missing of some edges. Then, the precision of the edge is negatively affected. In the extreme case, when the window size is equal to the test image size, there is only one initial edge point. In this case, it is difficult to generate the precise edge map.

C. Segmentation results

Based on the initial edge points in Figure 6, the segmentation results produced by sequential search are presented in Figure 7. From visual assessment, the proposed method can produce edges separating different objects with high spatial accuracy. Since the search range is not limited during the search process, the edges are continuous.

The segmentation results in Figure 7 (a) and (b) are apparently over-segmented. Within the buildings and tree regions, there are some meaningless tiny segments. Moreover, there are multiple edges near the true edge, especially the edges around the playground. This is because there are too many initial edge points and the overlapping effect of the initial edge points. In Figure 7 (c) and (d), since the window size for generating initial edge points is larger than that of Figure 7 (a) and (b), the segmentation results are not over-segmented. Furthermore, the different objects are distinguished very well. This is because the number of initial edge points is proper, without overlapping effect but large enough. In Figure 7 (e), some edges are not searched out, leading to the under-segmented result. This is because the window size is a bit large, resulting in that the number of initial edge points is not large enough. Figure 7 (f) is the result produced by the method of edge detection with embedded confidence [3]. From visual analysis, the edges are spatially accurate, but they are broken, which cannot be applied for the successive analysis directly.

According to the analysis above, even though the proposed edge linking method can produce continuous one-pixel-wide edges, it is affected by the initial edge points significantly. When there are too many initial edge points, the segmentation would be over-segmented, and there are some multiple edges. However, when the number of the initial edge points is too small, some edges would be missed in the segmentation results, resulting in the under-segmentation. Hence, in order to produce the edge map with high quality, the window size should be set carefully to generate the proper initial edge points.

D. Segmentation time

The experiments are performed on the notebook PC with the CPU of 1.73 GHz. The average segmentation time to generate the results in Figure 7 is shown in TABLE I. The segmentation time is also affected by the number of the initial edge points. When the window size is set large, there are fewer initial edge points, then, the segmentation time is less. On the contrary, if the window size is set small, the segmentation is increased accordingly.

TABLE I. THE SEGMENTATION TIME AVERAGED ON 10 RUNS.

Window size	3×3	5×5	7×7	9×9	11×11
Time (s)	41	23.5	16.3	11.8	9.3

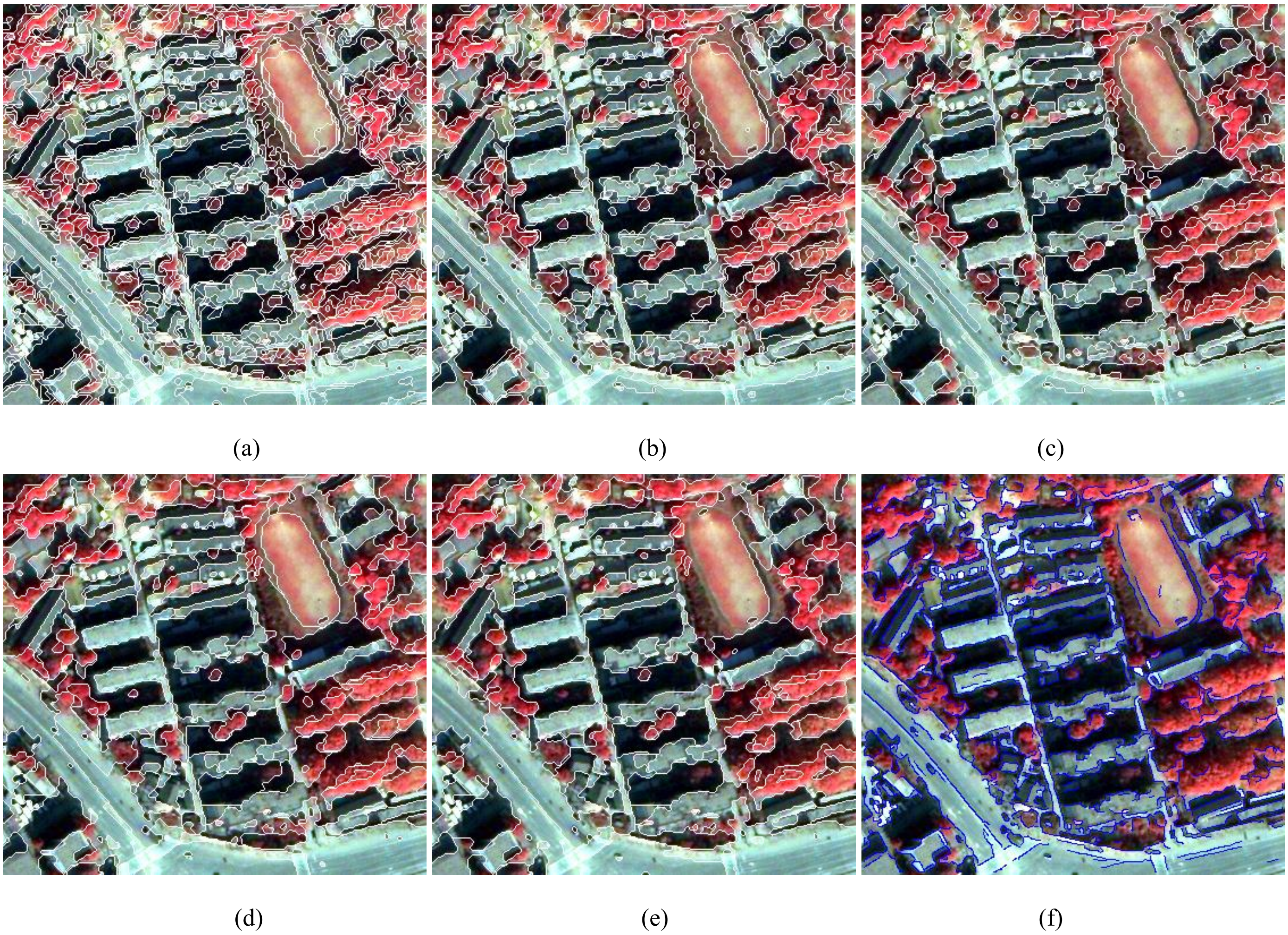


Figure7. The segmentation results based on different initial edge points, the window size of generating the initial edge points for (a)~(e) is 3×3, 5×5, 7×7, 9×9, and 11×11, respectively. The result produced by the method of edge detection with embedded confidence [3] is shown in (f) for comparison.

IV. CONCLUSIONS

The proposed sequential edge linking method can produce the segmentation result with precise, continuous, and one-pixel-wide edges. The edges are generated by searching each edge one-by-one using the A* method. Since the search range is not limited, the edges in the segmentation result are continuous. Moreover, the search condition is improved, including the gradient strength, the gradient direction and the forward direction. The experiments prove that the search condition is effective. The locally maximal gradient strength strategy is proposed to generate the initial edge points. The experiments show that the strategy can find the edge points with high spatial accuracy, but the segmentation result is sensitive to the window size when generating the initial edge points. The small window size would lead to over-segmentation, while the large window size could result in under-segmentation. Now, the window size is set according to the trial-and-error strategy. In the future, we would further research how to set the proper window size automatically. Moreover, the segmentation time is also affected by the window size. When the window size is set larger, the segmentation time would be less. However, the segmentation time is still endurable according to Table 1.

The A* method is adopted to search the edges. But the heuristic condition is neglected in this paper. In the future, we should also research how to add the heuristic condition in the search method to make the method perform better. Moreover, since the edge linking method is sensitive to the initial edge points, besides researching the strategy of setting the window size, we can also try other methods to generate the proper initial edge points, such as the filtering strategy.

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