Improved Gradient Direction Assisted Linking Algorithm for Linear Feature Extraction in High Resolution Satellite Images, an Iterative Dynamic Programming Approach

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Abstract: In this paper, an improved gradient direction assisted linking algorithm is proposed. This algorithm begins with initial seeds satisfying some local criteria. Then it will search along the direction provided by the initial point. A window will be generated in the gradient direction of the current point. Instead of the conventional method which only considers the value of the local salient structure, an improved mathematical model is proposed to describe the desired linear features. This model not only considers the value of the salient structure but also the direction of it. Furthermore, the linking problem under this model can be efficiently solved by dynamic programming method. This algorithm is tested for linear features detection in IKONOS images. The result demonstrates this algorithm is quite promising.

Keywords: linear feature extraction, IKONOS image, linking algorithm, dynamic programming.

1. Introduction

Ridge and edge detections are very important low level operations which have many applications for the object detection in aerial images, such as the road detection in high resolution images. The usual approach consists of two steps. In the first step, the original image will be convolved with some spatial filter to generate local candidates. Then, some linking algorithms will be done to link the local candidates and therefore form the desired linear features. Powerful linking algorithms can efficiently suppress the noise in the image and overcome the gaps. Conventional gradient direction assisted linking algorithm only consider the limited neighbor of the current point. It will stop when there are some gaps or very intense noise factors. Consequently, it only can give broken segments of the desired linear features. In this paper, an improved gradient assisted linking algorithm is proposed. This method is based on the dynamic programming method which can fill in the gaps in the desired linear feature as well as suppress the noise factors in the image. The other parts of this paper are organized as follows. In the second section, the general linking problems for the ridge structure with gradient information is presented. The gradient assisted linking algorithms based on the dynamic programming methods are presented. A simple stopping scheme is also presented for the automatic stopping of the linking. Section 3 presents the experiment result. We conclude this paper in the final section.

2. Methodology

In the following sections, we use the notations for the discussion as follows:

M,N: The number of rows and columns of the input image matrix.

K: The maximum distance of the neighbors. For example, if *K* is equal to 1 only the three pixels on the right side nearest to the current pixel will be considered as the neighbor.

$\bar{g}(i,j), 1 \le i \le M, 1 \le j \le N$: The salient value of the pixel (*i ,j*). For example, in the edge detection, it is the absolute value of local gradient [1]. In the scale-space filtering, it is the maximum absolute value of the eigenvalues of the Hessian matrix [2].

$$g(i,j) = \max_{i,j}(\bar{g}(i,j)) - \bar{g}(i,j), \quad 1 \le i \le M, 1 \le j \le N$$

$a(i,j), 1 \le i \le M, 1 \le j \le N$: The direction of the local salient structure, such as the direction of edge or the ridge. This direction belongs to the interval $-\pi \sim \pi$, anti-clockwise.

1) Improved mathematical model for ridge extraction

In this paper, the original image is regarded as an acyclic layered graph, such as the model presented in [3]. Alternatively, similar shortest path approach as in [3] can be applied here. This can be represented as the following model:

$$\begin{aligned} & Min \sum_{j=1}^{N} g(i(j), j) \\ & |\, i(j) - i(j+1)\,| \le K \\ & S.T. 1 \le i(j) \le M \\ & i, j \quad integer \end{aligned} \tag{1}$$

However, since it only considers the absolute value of the local salient structure the extracted object may be different from the desired one. One possible method is to add some smoothness constraint in the object function, such as the method presented in [4]. But this will lead to significant increase of the computational complexities. In this paper, a new approach is proposed. It not only takes advantage of the absolute value of the local salient structure but also the direction of it. When proper weight factors are applied, proposed algorithm can extract desired smooth salient structure with similar computational complexities to the method described in (1). The details of this model are described as follows:

$$
\begin{aligned}
& Min \quad \sum_{j=1}^{N} g(i(j),j) + c1\sum_{j=1}^{N} s1(i(j),j) + c2\sum_{j=1}^{N} s2(i(j),j) \\
& \quad s1(i(j),j) = Min(abs(a(i(j),j) - a(i(j-1),j-1))) \\
& \quad s2(i(j),j) = Min(abs(b(i(j),j)) - d(i(j-1),i(j))) \\
& S.T. \quad d(i(j-1),i(j)) = \tan^{-1}(i(j) - i(j-1)) \\
& \quad |i(j) - i(j+1)| \le K \\
& \quad 1 \le i(j) \le M \\
& \quad i.j \quad integer
\end{aligned}
$$

$$
\text{Where} \quad b(i,j) = \begin{cases} a(i,j), -\frac{\pi}{2} \le a(i,j) \le \frac{\pi}{2} \\ a(i,j) + \pi, a(i,j) \le -\frac{\pi}{2} \\ a(i,j) - \pi, a(i,j) \ge \frac{\pi}{2} \end{cases} \qquad (2)
$$

c1 and *c2* are weight factors to control the absolute value and the smoothness of the extracted path. If they are very big, the extracted path should be very smooth but may not be very smooth. On the other hand, if they are very small, the extracted path will be as bright as possible but may not be smooth. The proper factors should be selected by the users. Furthermore, same as in (1), the dynamic programming method can be applied to solve the problems described in (2).

2) Automatic stopping based on group comparison

Since the linear feature may stop inside the window, we have to develop a method which can help to automatically locate the ending point of the salient structure in the extracted path. Here, a simple group comparison method is proposed to find the ending point of the salient structure.

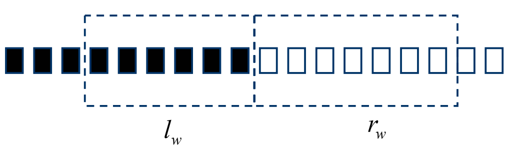

Fig.1: The left and right windows for the group selection

As shown in fig.1, the group comparison ratio is defined as follows:

$$
p_{l,r}(i,j) = \frac{\sum_{u=j-l_w+1}^{j} c(i(u),u)}{\sum_{v=j+1}^{j+r_w} c(i(v),v)} * \frac{r_w}{l_w} \qquad (3)
$$

Where $c(i(j),j) = g(i(j),j) + c1 * s1(i(j),j) + c2 * s2(i(j),j)$

The ending point is assumed to be the one with maximum value of group comparison factor. If the ending point is very near the beginning point, it is assumed there are no linear features in the current window. Furthermore, if the noise factor in the image is intense, a peer group filtering method [5] can be applied to filter out the pixels with high noise factor. However, that will increase the computational complexities significantly.

3. Experiment

In this paper, an IKONOS image is used to validate the efficiency of our algorithm. In fig.2 the path extracted by (1) is presented. The extracted path diverges from the desired one because of other linear features near the road. The result obtained by the improved model in (2) is demonstrated in fig. 3. Obviously, the result is much better than the one in fig. (2). The result with the automatic stopping by group comparison is shown in fig. 4. The initial segments are obtained by the conventional methods [2]. Finally, this method is applied for the edge linking, as demonstrated in fig (4). The longest edge in the upper part of this image For comparison, the result by the conventional Canny's detector is demonstrated in fig (5).

4. Conclusions

Linking method is very important for linear features extraction. This paper proposed an improved gradient assisted linking method. Besides the salient value, it also takes advantage of the direction of salient structure. Consequently, it is more robust to the gaps and noise factor than the conventional methods.

References

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Fig.2 Ridge extracted by considering only salient value of the original image

Fig.3 Ridge extracted by both salient value and direction of the salient structure

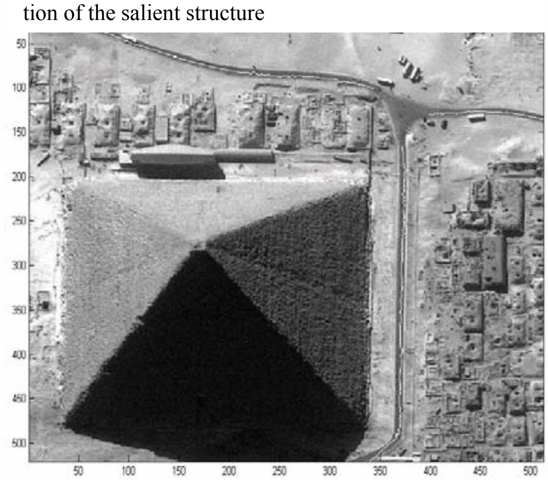

Fig.4 Extracted Ridge structure in the whole image

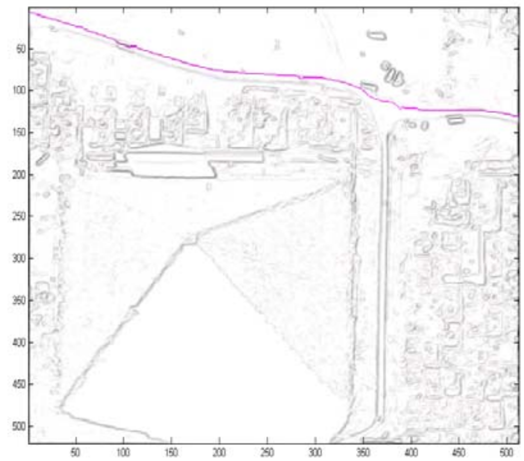

Fig.5 Edge detected by the improved linking method

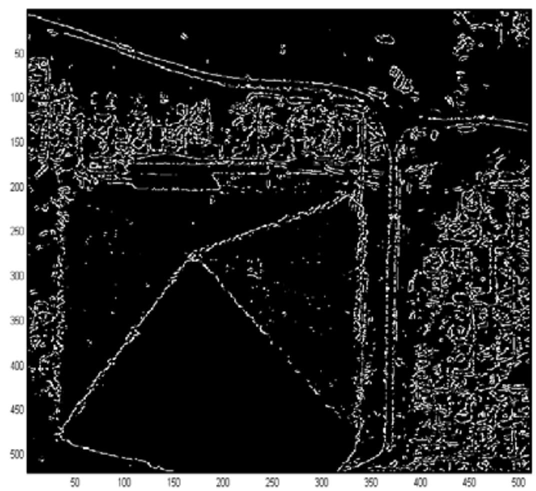

Fig.6 Extracted edge by the Canny's method