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Polynomial fitting-based shape matching algorithm for multi-sensors remote sensing images

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HIGHLIGHTS

- The registration method is based on shape for multi-sensors remote sensing images.
- Polynomial fitting-based feature extraction algorithm is proposed for feature points and the principal directions of them.
- The shape context descriptor is improved with rotation invariance based on the principal direction.
- The fine registration is accomplished after coarse registration.
- The registration method is automatic without GPS/INS prior knowledge.

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ABSTRACT

According to the characteristics of multi-sensors remote sensing images, a new registration algorithm based on shape contour feature is proposed. Firstly, the edge features of remote sensing images are extracted by Canny operator, and the edge of the main contour is retained. According to the characteristics of the contour pixels, a new feature extraction algorithm based on polynomial fitting is proposed and it is used to determine the principal directions of the feature points. On this basis, we improved the shape context descriptor and completed coarse registration by minimizing the matching cost between the feature points. The shape context has been found to be robust in Simple object registration, and in this paper, it is applied to remote sensing image registration after improving the circular template with rotation invariance. Finally, the fine registration is accomplished by the RANSAC algorithm. Experiments show that this algorithm can realize the automatic registration of multi-sensors remote sensing images with high accuracy, robustness and applicability.

1. Introduction

After more than half a century of development, the remote sensing technology has been widely used in geography and a lot of other fields, which has become an effective tool for human to analyze global environment [1]. With the resolution of satellite remote sensing image improved from tens of meters to more than 10 cm, high resolution remote sensing technology has not only been applied in traditional fields, but also be applied to the social public services [2]. Since the multi-sensors remote sensing images have great differences in scale, resolution and perspective, the registration of multi-sensors remote sensing images is essential before specific application. Efficient and accurate multi-sensors remote sensing image registration algorithm can be a powerful technical support for the applications of remote sensing image, such as missile guidance, terrain detection, moving targets detection and city traffic monitoring.

Automatic image registration can be divided into two types: feature-based and gray-based methods [3]. Feature-based methods are currently the most widely used registration method for remote sensing images as they do not depend on the gray characteristic and the calculation amount is smaller [4]. Wang et al. [5] proposed an automatic registration algorithm of remote sensing images by extracting SIFT feature points. The iterative Hough transform was used by Habib and Al-Ruzouq [6] to extract city road features, and it is utilized in remote sensing image registration. Merkle et al. [7] proposed a registration method with high accuracy by combining strength and feature characteristics.

Generally, the remote sensing image registration algorithm based on feature extraction rely on strong features [8], such as special points or straight lines. In this paper, a new registration

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algorithm based on shape contour feature is introduced, which can be used even for "weak" feature areas. The algorithm is different from the existing algorithms, the improved shape context is used for remote sensing images registration. Meanwhile, a new feature extraction algorithm based on polynomial fitting is proposed and it is used to determine the principal direction of the feature points. The new algorithm improves the robustness of the classic shape context descriptor, and the results demonstrate its applicability and accuracy.

2. Method

2.1. Feature point extraction based on polynomial fitting

The classic shape context-based method is proposed only for simple graphics registration. There is no dedicated feature extraction step, all the feature points are just uniformly sampled from the shape instead. For all the N points on the shape, the classic shape context-based method match two simple graphics just by computing the distribution of points around [9]. Therefore, for the complex remote sensing images, it is even impossible to extract the shape feature which consists of a set of uniform distribution of pixels. As a result, although the shape context is proved to be robust, it is hardly to achieve it in remote sensing images. Due to the large amount of data of remote sensing image, it is obviously difficult if we compute the shape context of all pixels on the shape boundary. In this paper, a new feature point extraction method based on polynomial fitting is developed to overcome this defect. Particularly, it is used to determine the principal directions of the feature points.

Before the feature extraction, firstly, it is necessary to extract the edge contour feature of remote sensing images. At present, there are several edge-extraction methods, such as Prewitt operator, Sobel operator, Laplacian operator and Canny operator [10]. According to experiments, edge features extracted from the Canny operator show the best results, and it is employed in this paper. After this, the polynomial fitting technique is employed, and in particular, the cubic polynomial is adopted as the undetermined coefficient model to obtain the tangent and normal of any point on a shape boundary. Supposing that P_i is a point on the shape boundary whose coordinate can be expressed as (x_i, y_i), and the points around it on the shape boundary can be represented as $P_{i-m}, \ldots, P_{i-1}, P_i, P_{i+1}, \ldots, P_{i+n}$ with their coordinates denoted by $(x_{i-m}, y_{i-m}), \ldots, (x_i, y_i), \ldots, (x_{i+n}, y_{i+n})$, as shown in Fig. 1a.

As we adopt the cubic polynomial as the undetermined coefficient model [11], the fitting curve can be expressed by the following formula:

$$y = ax^3 + bx^2 + cx + d \tag{1}$$

where a, b, c, d are the coefficients and x, y are the coordinates of the points used for polynomial fitting. Since the current point P_i must be in the fitting curve, the problem of estimating the coefficients can be transformed into the problem of calculating the extremum of multivariate function by using the Lagrange multiplier method. The coefficients a, b, c, d are treated as the independent variables, as a result, the coefficients estimation problem can be transformed into the extreme problem of function $z = f(a, b, c, d)$ in the condition of $\varphi(a, b, c, d)$. $f(a, b, c, d)$ and $\varphi(a, b, c, d)$ can be expressed as follows:

$$f(a,b,c,d) = \sum_{k=i-m}^{i+n} \left(ax_k^3 + bx_k^2 + cx_k + d - y_k\right)^2 \tag{2}$$

$$\varphi(a,b,c,d) = ax_i^3 + bx_i^2 + cx_i + d - y_i \tag{3}$$

Consequently, we can make the following Lagrange function, where λ is the Lagrange multiplier factor:

$$\begin{aligned} L(a,b,c,d) &= f(a,b,c,d) + \lambda\varphi(a,b,c,d) \\ &= \sum_{k=i-m}^{i+n} \left(ax_k^3 + bx_k^2 + cx_k + d - y_k\right)^2 \\ &\quad + \lambda\left(ax_i^3 + bx_i^2 + cx_i + d - y_i\right) \end{aligned} \tag{4}$$

Through the calculation of first-order partial derivative of a, b, c, d, the coefficients and λ can finally be estimated by the simultaneous equations as follows:

$$\begin{cases} \frac{\partial L(a,b,c,d)}{\partial a} = \frac{\partial f(a,b,c,d)}{\partial a} + \lambda \frac{\partial \varphi(a,b,c,d)}{\partial a} = 0 \\ \frac{\partial L(a,b,c,d)}{\partial b} = \frac{\partial f(a,b,c,d)}{\partial b} + \lambda \frac{\partial \varphi(a,b,c,d)}{\partial b} = 0 \\ \frac{\partial L(a,b,c,d)}{\partial c} = \frac{\partial f(a,b,c,d)}{\partial c} + \lambda \frac{\partial \varphi(a,b,c,d)}{\partial c} = 0 \\ \frac{\partial L(a,b,c,d)}{\partial d} = \frac{\partial f(a,b,c,d)}{\partial d} + \lambda \frac{\partial \varphi(a,b,c,d)}{\partial d} = 0 \\ \varphi(a,b,c,d) = 0 \end{cases} \tag{5}$$

By calculation, the estimated values can be expressed as follows:

$$[a, b, c, d, \lambda] = \left(X^T X\right)^{-1} X^T Y \tag{6}$$

where

$$X = \begin{bmatrix} 2\sum_{k=i-m}^{i+n} x_k^6 & 2\sum_{k=i-m}^{i+n} x_k^5 & 2\sum_{k=i-m}^{i+n} x_k^4 & 2\sum_{k=i-m}^{i+n} x_k^3 & x_i^3 \\ 2\sum_{k=i-m}^{i+n} x_k^5 & 2\sum_{k=i-m}^{i+n} x_k^4 & 2\sum_{k=i-m}^{i+n} x_k^3 & 2\sum_{k=i-m}^{i+n} x_k^2 & x_i^2 \\ 2\sum_{k=i-m}^{i+n} x_k^4 & 2\sum_{k=i-m}^{i+n} x_k^3 & 2\sum_{k=i-m}^{i+n} x_k^2 & 2\sum_{k=i-m}^{i+n} x_k & x_i \\ 2\sum_{k=i-m}^{i+n} x_k^3 & 2\sum_{k=i-m}^{i+n} x_k^2 & 2\sum_{k=i-m}^{i+n} x_k & 2(m+n+1) & 1 \\ x_i^3 & x_i^2 & x_i & 1 & 0 \end{bmatrix} \tag{7}$$

$$Y = \left[2\sum_{k=i-m}^{i+n} x_k^3 y_k \quad 2\sum_{k=i-m}^{i+n} x_k^2 y_k \quad 2\sum_{k=i-m}^{i+n} x_k y_k \quad 2\sum_{k=i-m}^{i+n} y_k \quad y_i\right]^T \tag{8}$$

Once the coefficients are estimated, we can obtain the curve fitting expression of any point P_i on a shape boundary. In this paper, we determine whether P_i can be used as feature point by a simple process of further calculation of the fitting error and the curvature at P_i. The fitting errors $D(i)$ and the curvature at P_i named $k(i)$ can be expressed as follows:

$$D(i) = \frac{1}{m+n+1} \sum_{k=i-m}^{i+n} \left(ax_k^3 + bx_k^2 + cx_k + d - y_k\right)^2 \tag{9}$$

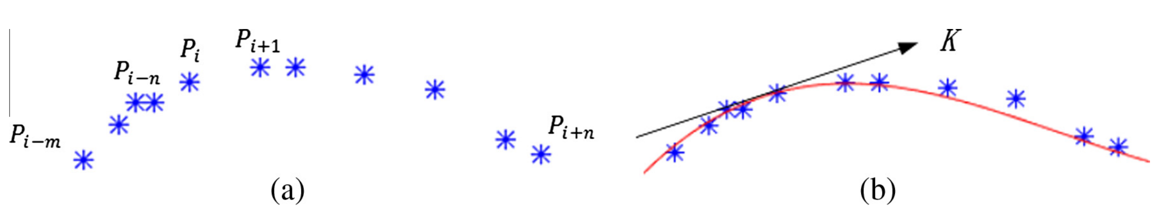

Fig. 1. (a) Schematic diagram of the pixels on the shape boundary. (b) Schematic diagram of the fitting curve and the principal direction of the feature points.