Abstract—Image matching is an important UAV (Unmanned Aerial Vehicle) navigation method. Traditional area-based image matching methods have high accuracy but are sensitive to scale and rotation variations. In order to matching images which have geometric and illumination variations quickly and robustly, a new image matching algorithm based on multi-scale segmentation is proposed in this paper. In our method, we first extract stable image objects which have rich and reliable statistical information by object-oriented convexity model based multi-scale segmentation. Next, shape features like invariant moments and shape curves are extracted and used in local object matching. Afterwards, similar triangles criterion based global object matching which can match objects in spatial relationship is done. Finally, the centroids of matched objects are used as control points to register the real time image. Many experiments have proved that the proposed method is fast and robust.

Keyword- image matching, multi-scale segmentation, shape curve correlation coefficient, similar triangles criterion

I. INTRODUCTION

With the development of UAV, navigation has been paid much attention on as it is a basic and vital step in UAV application. Image matching has been a more and more important UAV navigation method as its high accuracy and resistance to interference. Until now, many image matching methods have been proposed.

Generally speaking, image matching methods can be divided into two types: area-based and feature-based methods. In area-based methods, statistical information of gray value is directly used. Normalized cross-correlation [13], sequence similar detection arithmetic (SSDA) [4], absolute balance search (ABS) [14] are commonly used area-based methods. Area-based methods are relatively precise and robust as they only use statistical information of grey value. However, their computation is huge and they can not resistance to scale and rotation variations between the two images.

In feature-based method, various features are extracted and matched. Point features like Harris corners [2], SUSAN corners [12] and SIFT feature points [5] are introduced and then used in image matching. Edge features are usually matched based on hausdorff distance [7]. Region features are matched by cost function which is calculated from shape parameters [11].Shape context is introduced and used in remote sensing images registration in 2010 [9]. Feature-based methods are not sensitive to geometric variations. However, when there are illumination or scene changes between the two images, stable features can not be extracted or matched precisely.

In order to extract stable regions in images, convexity model based multi-scale segmentation is proposed in this paper. Using this object-oriented segmentation algorithm, stable region objects which have rich and reliable statistical information could be extracted. Besides, shape curves correlation coefficient and similar triangles criterion are proposed so as to improve the matching accuracy.

The rest of this paper is organized as the follows. In Section II, the proposed image matching method is presented. The experiments and accuracy evaluation are done in Section 3. Conclusions of the paper are educed in Section 4.

II. PROPOSED METHOD

The proposed method can be divided in 4 steps. Firstly, images are segmented into objects by convexity model based multi-scale segmentation algorithm, and object features are extracted. Secondly, objects are locally matched based on invariant moments and shape curve correlation coefficient. Thirdly, similar triangles criterion is used to match objects in global spatial relationship. Lastly, centroids of matched patches are used as control points to register real time image and calculate the position of the UAV. Figure 1 is the workflow of image matching method proposed in this paper.

Figure 1. Workflow of image matching method in this paper

A. Multi-scale image segmentation and feature extraction

When there are scene and illumination variations between real time and reference images, stable region objects can not be extracted by traditional segmentation algorithms in two images. But in our object-oriented multi-scale image segmentation method based on convexity model, objects which have rich and reliable statistical information could be extracted. In our method, we firstly use object-oriented convexity model based multi-scale segmentation algorithm to segment images into objects, and then objects are matched by invariant moments and shape curves correlation coefficient. Finally, global objects are matched based on similar triangles criterion.
segmentation method, stable region objects with rich and reliable statistical information were obtained.

1) Convexity model based multi-scale image segmentation
In remote sensing images, inside the region which represents one homogeneous ground object is correlative and its features are different from its surrounding heterogeneous regions. If the gray value of image is used as “altitude”, the image can be regarded as a convex surface of which the smooth parts represent homogeneous ground regions and the rough parts represent heterogeneous ground objects. This is the so-called “Convexity Model” (CM).

The CM is very useful to describe the image segmentation. It is assumed that the \( R \) represents the whole region of the image and \( R \) is segmented into \( \{R_1, R_2, \ldots, R_n\} \) where \( R_i \) is one sub-region of \( R \). So it is assumed that \( N_i \) is the set of all neighboring regions of \( R_i \), \( F(R_i) \) is the feature average value of \( R_i \), \( S(R_i, R_j) \) is the similarity between \( R_i \) and \( R_j \), \( CM(R) \) is a logical predicate defined over the \( R_i \). Thus the convexity model can be described that if the region \( R_i \) has following characters, it can be thought that this region accords with the convexity model.

\[
CM(R) = \begin{align*} \text{TRUE} \quad & F(R) \text{ is the feature average value of } R_i; \\ \text{FALSE} \quad & S(R_i, R_j) < S(R_i, R_k), R_i, R_j, R_k \in N_i, m \neq n \end{align*} \tag{1}
\]

The definition means that if the region \( R_i \) accords with the CM, its feature vector will be larger (smaller) than that of all neighboring regions and the similarity level between any two of its neighborhood is larger than that between it and its neighborhood.

In multi-scale image segmentation, all image objects which accord with the CM in different scales will be extracted and recorded in an object tree (Figure 2). The image object tree is composed of image objects with all kinds of scales, that is to say, one part of image objects accord with the CM and others background image objects. This is the big difference from the traditional multi-scale segmentation techniques and that is why the segmentation is called multi-scale image segmentation.

![Figure 2. The sketch map of multi-scale object tree created by the multi-scale segmentation](image)

2) Object features extraction
Two features of region objects are extracted after segmentation. One feature is seven invariant moments [10]. The other one is the shape curve of the region. Shape curve is an improved shape signature proposed in this paper. A shape signature represents a shape by a one dimensional function derived from shape boundary points [3]. Our shape curve is to plot the normalized distance from the centroid to the boundary as a function of sample distance. Experiments prove that our shape curve is not sensitive to scale and rotation variations. A lake shape and its shape curve are shown in Figure 3.

![Figure 3. A lake in the image and its shape curve](image)

B. Combined matching strategy
In object matching step, combined matching strategy is adopted. Firstly, objects with similar shapes are matched in local objects matching step. However, because some objects in different location may share similar shapes, similar triangles criterion is proposed to remove these wrong matched objects. After combined matching, objects are matched in local shape and global spatial relationship. The matching accuracy is improved in this step.

1) Local object matching
In local objects matching, a hierarchical coarse to fine strategy is adopted, invariant moments are used at coarse level to eliminate large amount dissimilar shapes and shape curve is used at fine level to match objects in detail.

In coarse matching, the distance between invariant moments in two objects is used as shape similarity criterion. Let \( \Phi_i(t) = \Phi_{i1}, \Phi_{i2}, \ldots, \Phi_{iL} \leq t \leq u \) and \( \Phi_j(t) = \Phi_{j1}, \Phi_{j2}, \ldots, \Phi_{jL} \leq t \leq u \) represent the invariant moment vector of objects in real time and reference images respectively. The invariant moment distance between \( i^{th} \) object in reference image and \( j^{th} \) object in real time image is defined as follows:

\[
d_{ij} = \sqrt{\sum_{t=1}^{L} (\Phi_i(t) - \Phi_j(t))^2} = \sqrt{\sum_{t=1}^{L} (\Phi_i^t - \Phi_j^t)^2} \tag{2}
\]

From the distance definition, we know that the smaller invariant moment distance \( d_{ij} \) is, the corresponding two objects are more similar.

The invariant moment distance between the first object in reference image and all the objects in real time image is calculated. Object A from reference image and B from sensed image are selected as a matched pair if the following conditions are satisfied:

(a) \( d_{AB} \leq d_{AB} \) i.e. B’ includes all the objects with similar shape to A;

(b) \( d_{AB} < T \) i.e. if the minimum distance is above the threshold, \( T \), there is no match.

The process is repeated for the second, third and all subsequent objects in reference image until they have all been matched with patches in real time image. To improve the matched precise, two-dimensional cross match is done. Let \( \Omega_c = (R_{c1}, R_{c1}'), (R_{c2}, R_{c2}'), \ldots, (R_{cm}, R_{cm}') \) represents the coarsely matched object pairs.

Afterwards, the shape curve correlation coefficient of matched pairs in \( \Omega_c \) is calculated. Let A and B denotes two objects, the shape curve correlation coefficient of them is calculated as follows:

...
In Eq.3, \( d_{ij}^A \) denotes the distance from centroid of \( A \) to the \( i^{th} \) sample point of \( A \), \( \overline{d}_{i}^{A} \) is the average value of all the \( d_{ij}^A \), \( d_{ij}^B \) denotes the distance from centroid of \( B \) to the \( i^{th} \) sample point which started from point \( j \) in \( B \), \( \overline{d}_{j}^{B} \) is the average value of all the \( d_{ij}^B \), \( N \) is the sample number. Figure 4 shows the calculation of shape curve correlation coefficient.

\[
p_{\text{CorShape}}(A,B) = \max \left( \frac{\sum_{i=1}^{N} (d_{ij}^A - \overline{d}_{i}^{A}) (d_{ij}^B - \overline{d}_{j}^{B})}{\sqrt{\sum_{i=1}^{N} (d_{ij}^A - \overline{d}_{i}^{A})^2} \sqrt{\sum_{j=1}^{N} (d_{ij}^B - \overline{d}_{j}^{B})^2}} \right)
\]

III. EXPERIMENTS

To evaluate the robustness of the proposed image matching method, many experiments were performed. One of the experiments is shown as follows. The two images are taken in Guizhou Province, China, the image Figure 4(a) is the real time image photographed by UAV, the image Figure 4(b) is the reference image photographed by satellite, the two images are photographed at different time and form different perspective so there are scale and rotation variations between them. Figure 4(c) and Figure 4(d) are segmentation result of the two images respectively, from them we can see that the lake, roads and farmlands are segmented well. Matched image is shown in Figure 4(e), we can see that the real time image are matched well with the reference image and the position of the UAV can be easily calculated.
Figure 5. Matching of images taken by UAV and satellite

After the real time image is matched, accuracy estimate is done. The root mean square error (RMSE) is calculated and used to evaluate the registration precise. The RMSE is defined and calculated as:

$$RMSE = \sqrt{\frac{1}{m} \sum \left( (x_R - x_r)^2 + (y_R - y_r)^2 \right)}$$

(4)

Where m is the number of selected points, \(x_R, y_R\) are the coordinate of reference image, \(x_r, y_r\) are the coordinate of warped real time image.

<table>
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<th>Registration error</th>
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<td>Y</td>
<td>x</td>
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RMSE=1.87

From the Table 1 we can see that the RMSE is 1.87, this precise can satisfy the requirement of UAV navigation.

**IV. CONCLUSIONS**

Aimed at rapid and robust image matching methods which can navigate UAV in real time, this paper proposed a image matching method based on convexity model based multi scale segmentation. Stable image objects can be obtained by object-oriented multi-scale segmentation algorithm. Besides, shape curve correlation coefficient which can depict objects precisely and similar triangles criterion which can match objects in spatial relationship are proposed to make precise image matching. Many experiments proved that this method can match images which have large geometric and illumination variations in real time with high accuracy. However, shape curve is deeply rely on the integrality and stability of the region, when region is changed or partly sheltered, the shape curve of region will change, this disadvantage will be paid more attention on to be solved.

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