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SIFT-based automatic tie-points extraction for airborne InSAR images①

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Abstract

The scale-invariant feature transform (SIFT) is often applied to extract tie-points for airborne SAR images. When a pair of airborne SAR images differs with look angles obviously, shadow sizes and shapes of same objects will differ obviously. In main and slave SAR images, key-points around shadows often match as tie-points, although they are not homologous points. The phenomenon worsens the performance of SIFT on SAR images. On the basis of SIFT, a modified matching method is proposed to decrease the number of incorrect tie-points. High-resolution airborne SAR images are used in Experiments. Experiment results show that the proposed method is very effective to extract correct tie-points for SAR images.

Key words: scale-invariant feature transform (SIFT), airborne InSAR images, tie-points extraction, image coregistration

0 Introduction

The block adjustment of SAR image is vital to building digital surface models (DSMs) and generating digital orthophoto maps (DOMs). Block adjustment makes full use of extra observation information of the tie-points[1]. Tie-point extraction is also a vital step in some other applications, which mainly involves feature extraction and feature matching[2,3].

Much work has been done in extracting tie-points. When a few of ground control points can behave as accurate tie-points, tie-points are usually extracted by searching maximum correlation[4]. The scale-invariant feature transform (SIFT) algorithm is an efficient algorithm for feature points detection and local features description[5,6]. A histogram-based preprocessing method and a method based on optimization of SIFT parameter are proposed to increase the number of correct tie-points for SAR images [7]. Image segmentation deducted by the geodesic active contour model is used to select closed points obtained by the geometric hashing theory[8]. SIFT and edge strength are combined to lessen the effect of multiplicative speckle[9]. A SIFT-like algorithm is proposed, which is dedicated to registering SAR images in different configurations[10]. Continually, a uniform SIFT-like algorithm is reported, solving two problems of SIFT-like[11]. The problems are the lack of controllability of the number of features and the lack of control of the spatial distribution of the extracted features. To high-resolution airborne SAR images, few of them consider shadows effecting tie-points accuracy. In towns and villages, a huge number of artificial buildings and surroundings contributes to lots of shadows. The key-points in shadows and shadow edges need to be removed as a result of not corresponding to meaningful ground objects.

Due to side-looking imaging, shadows are generated from blocked radar signals and do not represent any objects. In the proposed test, key-points located in or alongside shadows account for 50% of all the key-points extracted by SIFT from high resolution airborne SAR images. Some key-points around shadows are matched together because of similar feature descriptors. The phenomenon results in lots of tie-points extracted by SIFT cannot point to real ground objects. It is also found that key-points located in object are invariant to look angles, while key-points located in or alongside shadows are variant to look angles.

Aiming at enhancing the accuracy of tie-points ex-

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traction for high-resolution airborne SAR images with large differences in look angles, a modified, automatic and fast matching method is proposed. If a project contains many large images, there are three main lines of attack to bring down the matching time: reducing the number of feature points, reducing the number of relatively unimportant images, or reducing the number of potential image pairs[12]. The new method is based on a feature invariant to look angles and will save matching time by excluding the key-points variant to look angles. The proposed method consists of two fundamental parts: accepting all key-points that are extracted by SIFT as initial candidates, picking out key-points invariant to look angles as final candidates and discarding key-points variant to look angles. Experiment results demonstrate that the method is able to extract tie-points with computational cost saving and obtains higher accuracy tie-points for high-resolution airborne SAR images.

1 Method

When an object is detected under different look angles, the sheltered regions causes dissimilar shadows. Ortho-image processing with lower accuracy is finished before tie-points extraction, which rectifies the resolution of each pixel. In SIFT, key-points are extracted by comparing to its eight neighbours in the Difference of Gaussian (DoG) image and nine neighbours in the scale above and below[6]. Due to this principle, when SIFT is applied to high-resolution airborne SAR image registration, points covered by shadows are occasionally extracted as key-points. Moreover, a key-point descriptor of SIFT is based on the gradients in regional image patches aligned by its dominant orientation. Therefore, key-points in shadow pairs and less textured patches have remarkably similar descriptors, so do those alongside shadows. SIFT acquire tie-points by calculating Euclidean metric ratio of the nearest and second-nearest key-points. Key-points with similar descriptors in shadow pairs are most likely to match together. These matches greatly deteriorate the precision of tie-points extraction.

Fig. 1 shows that when the platform position P changes to P', the look angle changes from β' to β. Shadow length of the same tree changes from AC to AD. Always, point A, C and D are regarded as key-points. Sometimes SIFT operator also takes the position of point B and E as candidates. The positions of B, E, C and D vary from look angles and features on such positions can be regarded as look angle variant features. Obviously, the position A is fixed. No matter how platform position changes, features on such position can be regarded as look angle invariant feature.

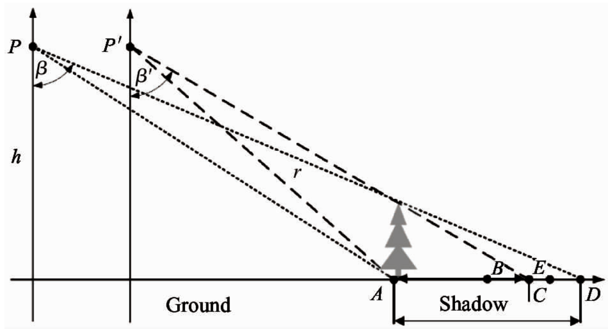


Fig. 1 The principle of shadow generated in high resolution airborne SAR image

As shown in Fig. 1, the change of h is related to the change of r. Fig. 2 represents two typical images of one same site. The shadow lengths of a same object differs more than 10 pixels in Fig. 2, representing more than 5 m real distance. The resolution of SAR images is 0.5 m. The change of ground range Δr is

$$\Delta r = \frac{5}{\sin\beta} \tag{1}$$

The change of elevation Δh is

$$\Delta h = \frac{\partial h}{\partial r}\Delta r \approx 5 \tag{2}$$

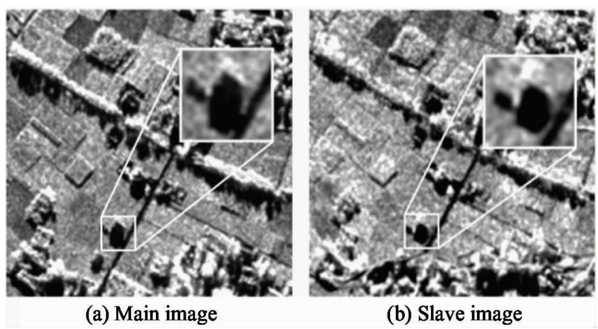


Fig. 2 An image pair with different look angles

The look angles of Fig. 2(a) and Fig. 2(b) are about 41° and 52°. When dealing with this kind of images, SIFT extracts large amount of feature points in or alongside shadow. In fact, shadow edges changes with look angles. Key-points in and alongside shadows vary from the shape and size of shadows. In fact, these key-points are variant to look angles.

In the experiment, the flight height is about 3 675 m. The average height of object area is about 452 m. Central incident angle is fixed to 45 °. The range of incident angle is 33 ° – 57 °. The reality is that, in order to increase efficiency of data acquisition, the overlapping area is limited to 30% of flight stripe. The smaller overlapping areas regions are along with larger look angles. Besides, SAR images are also contaminated by speckle. In this situation, it is a challenging work to match SAR images from overlapping regions.

In this work, the new adaptive method is supposed to avoid the features that are affected by look angles (in or alongside shadow areas). A shadow generates when an object is illuminated by the radar beam and blocks a region of the scene, the following is considered[8]:

Intensity, hue, and saturation change due to shadows tend to be predictable, namely, shadows are darker. Therefore, pixels that have a grey level below a certain threshold can be regarded as shadow points.

Shadows are only possible if there is an object obstructing the radar beam, suggesting that there should be a bright region around a dark shadow region.

The new method refers to the shadow identification techniques in field of computer vision[13-15] and SAR images[16-19]. Considering both effectiveness and efficiency, the new method is obtained by following steps. Fig. 3 shows the flow of the new method which is based on SIFT. Content in solid line box is the process of search features of SIFT. Content in dotted line box is what the new method added to SIFT. Next, corresponding to two simple characteristics of shadows, two vital steps in the dotted line box will be discussed.

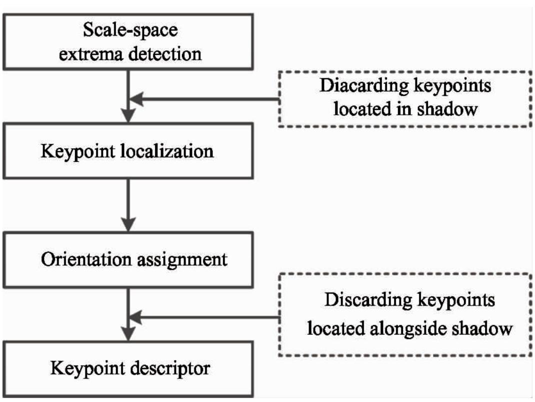


Fig. 3 The flow of the new method

1.1 Key-points in shadow detection

In this part, all pixels are dichotomized by a grey level k into two classes. Key-points will be discarded while their grey levels are less than k. Class C_0 contains $[1, 2, 3, \cdots, k]$ grey-level pixels. Class C_1 contains $[k, k+1, k+2, \cdots L]$ grey-level pixels. The threshold grey level is selected by Otsu method which maximizes the separability of the resultant classes in grey levels[15]. After key-point candidates being determined, the candidates in shadows could be detected:

$$g(x, y) < Tresh \tag{3}$$

where $g(x, y)$ is the grey level of candidate, $Tresh$ is a threshold used to extract shadows from the background.

1.2 Key-points alongside shadow detection

Pixels located on the contours of shadows usually have larger gradients. The orientation assignment in SIFT is a statistic of local image gradient directions[6]. Along the dominant direction, the grey level of pixels decreases. By discarding the key-points in shadows, key-points polluted by speckle or located alongside shadows still exist, which deteriorate the precision of tie-points extraction. Therefore, a sliding 3×3 window is used to detect whether the key-point is located alongside shadow. Sliding window starts at the location of each key-point. Sliding direction is the dominant direction which is computed in orientation assignment. When all grey levels of pixels in the window are less than $Tresh$, the sliding window stops.

The dominant direction is denoted by θ_d, each step of the sliding window is given:

$$dx = \cos\theta_d,\ dy = \sin\theta_d \tag{4}$$

A maximum searching distance dis is set:

$$\sum dx \leqslant dis,\ \sum dy \leqslant dis \tag{5}$$

Only searching in a dark area nearby a key-point is not enough sufficient. The searching direction of sliding windows is changed with the direction of targets obstructing the radar beam (the direction of shadow, denoted by θ_s). θ_s is given by the geometric relationship of SAR imaging. The rule is the same as the rule of searching in dark areas. The threshold to extract object region can be obtained by the method of extracting shadows. Maximum searching distance for searching object region is 64 pixels. If both the dark region and the object region are found, the position is voted to be alongside the shadow and will be discarded.

2 Experiments and results

Experiments are carried out to validate the effectiveness of the new method for high-resolution airborne SAR images. The proposed method is compared with SIFT. A set of airborne X-band images from different look angles is tested. The resolution of the tested images is 0.5 m. The observation system operates in single-pass and dual-antenna interferometric mode at X-band, aboard the Citation II aircraft of the Institute of Remote Sensing and Digital Earth (RADI), Chinese Academy of Sciences, over Jiangyou county of Sichuan province in July, 2011. The flight height is 3 675 m. The velocity is 90 m/s. Before feature extraction is executed, images need to be de-noised enough to avoid the effect of speckle. Here GAMMA filter is adopted. The evaluation has been carried out using the following criteria.

Root-mean-square error (RMSE): RMSE is computed to judge alignment accuracy. It can be expressed as

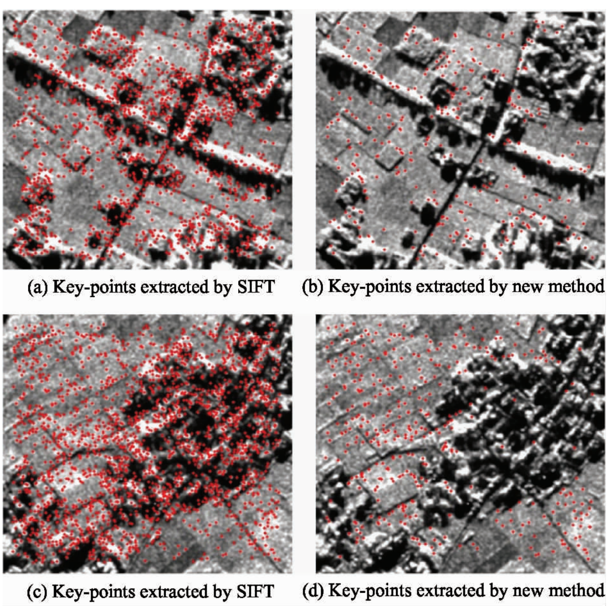
$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\left(f(x_i, y_i) - x_i'\right)^2 + \left(g(x_i, y_i) - y_i'\right)^2\right)} \quad (6)$$

where (x_i, y_i) and (x_i', y_i') are the coordinates of the ith matching key-point pairs, n denotes the number of the key-point pairs. Function f and function g are transformation models. For each test case, the algorithm is executed five times to avoid the instability caused by RANSAC. In addition, their average is computed as final RMSE.

Correct matching rate (CMT): the ratio of correct matches to the number of matches. CMT is calculated before RANSAC. If CMT value is too small, RANSAC will conduct numerous iterations and may even not be able to obtain the correct matches. Larger CMT indicates that it is more likely to get correct matching.

2.1 Key-points extraction results

Here, SIFT and the new method are carried out on the testing images with different look angles. Key-points extracted by two methods are marked by dark dots and shown in Fig. 4. The look angles of Fig. 4(a) and Fig. 4(c) are about 41 ° and 36 °. Comparing result is shown in Fig. 4, it is obviously that number of



(a) Key-points extracted by SIFT (b) Key-points extracted by new method

(c) Key-points extracted by SIFT (d) Key-points extracted by new method

Fig. 4 Key-points extracted by traditional SIFT and the new method

key-points in or along side shadow areas decrease sharply and key-points located in objects or the intersection of lines are preserved. Statistics results are shown in Table 1.

Table 1 Number of key-points extracted by the new method

Procedure	Fig. 4(b)	Fig. 4(d)
After orientation assignment	4108	4626
After key-points localization	1912	2357
After discarding in shadow	1017	1220
After discarding alongside shadow	1330	1515

2.2 Matching results

After the key-points are detected by SIFT, they are matched using the nearest neighbour ratio (NNDR) proposed by Lowe[6]. The final matches are refined by RANSAC. Fig. 5 shows the final matches. The look angles of the left and the right images of Fig. 5(a) are about 41 ° and 52 °, and those of Fig. 5(c) are about 36 ° and 46 °.

In Fig. 5(a) and Fig. 5(c), it can be found that most matches located in or alongside shadows are greatly affected by look angles and deteriorate the accuracy of registration. The number of matches lessens after the elimination processing. A statistics result is in Table 2. All the remnant matches that promise more precision are located in object area or flat area, shown in Fig. 5(b) and Fig. 5(d). The original aim of tie-points extraction for high resolution airborne SAR images is achieved. A statistics result is in Table 3.

Table 2 Matches number of two image pairs

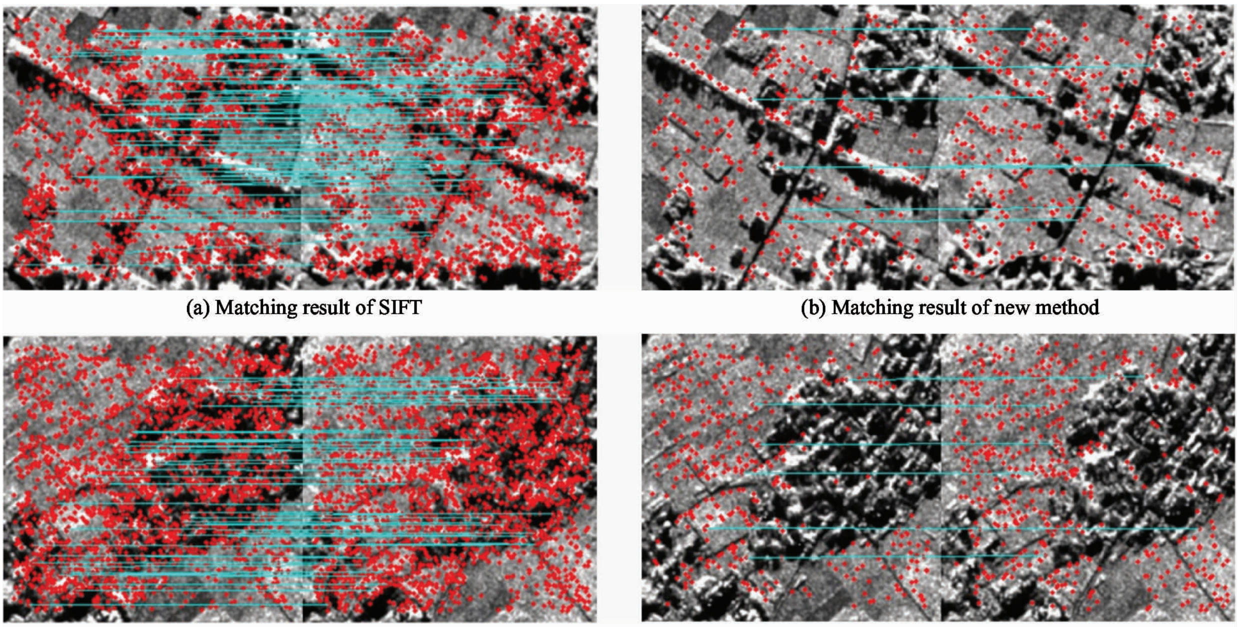
Image	Fig. 5(a)	Fig. 5(b)	Fig. 5(c)	Fig. 5(d)
Number	48	7	43	7

Table 3 Percentages of matcheslocation of two image pairs

Matches location	Fig. 5(a)	Fig. 5(c)
In the object or flat area	51%	57%
In or alongside shadow	49%	43%

2.3 More experiment results

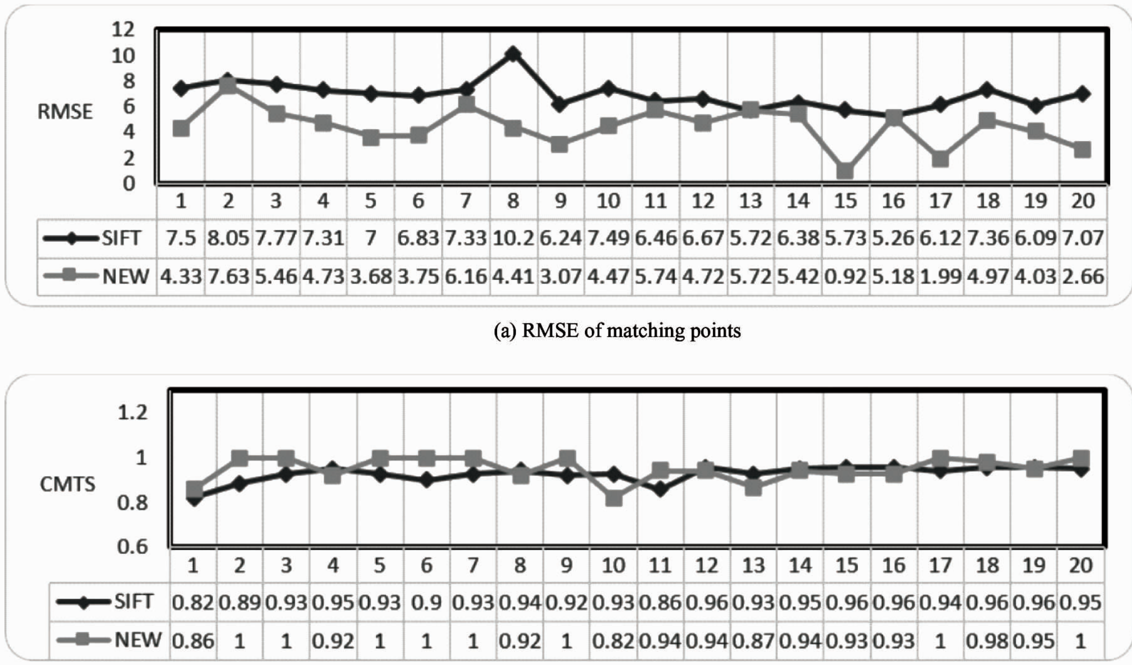
More experiments have been done. In this part, 20 pairs of high-resolution airborne SAR images are chosen to test. The test images are cut out from three fight strips. The first ten pairs of images are taken from the first and second flight strips. The rest ten pairs of images are from the second and third strips. RMSEs and CMTs of the results of two methods are presented in Fig. 6.



(a) Matching result of SIFT (b) Matching result of new method

(c) Matching result of SIFT (d) Matching result of new method

Fig. 5 Matching results of key-points extracted by SIFT and the new method



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
SIFT	7.5	8.05	7.77	7.31	7	6.83	7.33	10.2	6.24	7.49	6.46	6.67	5.72	6.38	5.73	5.26	6.12	7.36	6.09	7.07
NEW	4.33	7.63	5.46	4.73	3.68	3.75	6.16	4.41	3.07	4.47	5.74	4.72	5.72	5.42	0.92	5.18	1.99	4.97	4.03	2.66

(a) RMSE of matching points

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
SIFT	0.82	0.89	0.93	0.95	0.93	0.9	0.93	0.94	0.92	0.93	0.86	0.96	0.93	0.95	0.96	0.96	0.94	0.96	0.96	0.95
NEW	0.86	1	1	0.92	1	1	1	0.92	1	0.82	0.94	0.94	0.87	0.94	0.93	0.93	1	0.98	0.95	1

(b) CMTS of matching points

Fig. 6 Experimental results of the two matching methods on airborne X-band images

It is a challenge to match these two images with great difference in same scene. However, the new method shows the potential to solve this problem by significantly decreasing RMSE values, shown in Fig. 6(a). This method lessens the number of key-points and consequently lessens the number of matches, thus it is necessary to investigate CMTs. The figures shown in Fig. 6(b) demonstrate that discarding key-points in or alongside shadow areas does not deteriorate CMTs. In addition, the decreasing number of key-points greatly lowers the running time in the steps of orientation assignment, computing key-point descriptor and matching. The running time of two methods of five images is listed in Table 4. The method has a good performance in finding stable and robust look angle invariant tie-points on high-resolution airborne SAR images.

Table 4 Running time of two methods (unit: s)

Image	1	2	3	4	5
SIFT	188.00	98.69	168.94	368.89	278.56
NEW	27.55	31.75	21.04	43.98	28.25

3 Conclusions

The new method performs better than the original SIFT algorithm in discarding no homologous tie-points of high-resolution airborne SAR images. Nearly half of key-points extracted by original SIFT are inside or alongside shadows. In this study, a threshold method is chosen to detect key-points inside shadow in order to balance the effectiveness and efficiency. After discarding the key-points in shadows, a sliding window is used to detect key-points alongside shadow by searching on whole images. The detection process significantly discards key-points both inside and alongside shadows. Remnant key-points is used in final matching. Experiment results demonstrate the proposed method enhances the RMSE values without worsening CMTs. The method gets a better performance on tie-point extraction for high resolution airborne SAR images with large look angle difference.

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