OBJECT DETECTION FOR HIGH-RESOLUTION SAR IMAGES UNDER THE SPATIAL CONSTRAINTS OF OPTICAL IMAGES

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ABSTRACT

With the rapid development of sensor technology, we pay more attention to object detection for high-resolution SAR images. Besides, the traditional object detection methods which only use one SAR image to accomplish detection aren't enough appreciate for some cases that the background around the object is complex. In the paper, we propose an object detection method for high-resolution SAR images under the spatial constraints of optical images. It consists of three main steps: Establishment of the spatial relation between optical and SAR images, spatial constraints projection from optical images and detection under the spatial constraints in high-resolution SAR images. At the end of the paper, we take the inshore ship detection as an example to show that the proposed method can greatly improve the accuracy and efficiency of object detection against the traditional SAR object detection methods in conditions that background around the object is complex.

***Index Terms*—**High-Resolution SAR images, Object Detection, Spatial Constraints, Complex Background.

1. INTRODUCTION

With the observational capability of broad expanses during the day as well as during the night and as independent from weather effects, synthetic aperture radar (SAR) is widely used on military reconnaissance, surveying and resource exploration. Besides, with the development of the sensor technology, higher resolution SAR images can be acquired, in which we should pay more attention to the images interpretation about objects. Meanwhile, the interpretation of high-resolution SAR images is a hot issue all the time, and because object detection is an important part of interpretation [1], it is a matter of concern to improve the accuracy of object detection. There are plenty of researches about object detection for high-resolution SAR images, such as the two-parameter constant false alarm rate (CFAR) detector [2], object detection based on Markov Random Field (MRF) model and so on. These detection method has achieved good results in some high-resolution SAR images (such as MSTAR database) whose background interferences are less obvious. However, due to the special imaging mechanism, interferences caused by background around objects (such as land, anchor chains and so on) of some images (such as inshore ships) will influence the detection results seriously, and the detection results based on the traditional method are not enough ideal as shown. Besides, with the development of the remote sensing technology, we easily acquire the optical images corresponding to the high-resolution SAR images processed, and the object contour of the optical image is clearer, which can be beneficial for object detection for high-resolution SAR images [3], and we can acquire the refined detection regions with a spatial relation between optical and SAR images. Therefore, in the paper, we propose an object detection method for high-resolution SAR images under the spatial constraints from optical images.

The paper is organized as follows. Section 2 introduces the main process of the proposed method and some corresponding technological theories. In section 3, we take the inshore ships detection as an example to do some experiments with the proposed method and compare the detection results against those based on the traditional methods. In section 4, we introduce some conclusions and some questions about the proposed method for the readers to study further.

2. PRESENTATION OF METHOD AND BASIC THEORY

2.1. Description of Complete Process Flow

The sequence of the proposed method aims to explore the interconnection between optical and SAR images, which can improve the object detection accuracy for high-resolution SAR images. The proposed chain can be decomposed into three steps, as is shown in Fig.1:

1) Establishment of the spatial relation between high-resolution SAR image and the corresponding optical image by ex traction and matching of Scale-Invariant Feature Transform [4] (SIFT) features.

2) Minimum enclosing rectangle extraction of refined object in optical image after locating roughly the potential regions of objects.

3) Object detection in high-resolution SAR image under the constraint of the rectangle projected from the optical image to SAR image.

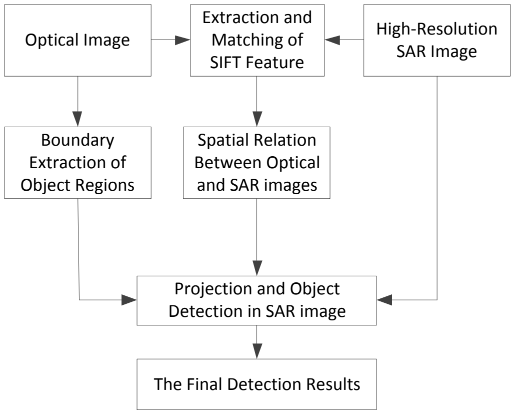


Fig1 Chart flow of the complete chain

2.2. Establishment of the Spatial Relation

We utilize the coordinate transformation to establish the spatial relation between optical and SAR images. To look for the transformation, we have the aid of the idea between the registration of the optical and SAR images [5]. The main method shows as follows:

1) Extraction of improved SIFT features: SIFT has been widely used for obtaining corresponding points. However, due to the intrinsic difference between optical and SAR sensors, the traditional extraction method usually fails to match optical and SAR images. Therefore, we introduce an improved SIFT extraction method [5]. Briefly speaking, it contains three major steps: First, constructing a Gaussian image pyramid and then obtaining a series of Difference of Gaussian (DoG) images by subtracting adjacent Gaussian images. Second, keypoints are detected from the second octave because many unrepeatable keypoints are detected in the first octave for SAR images. Third, descriptors are constructed based in gradients in the local image patches in multiple support regions.

2) Spatial Consistent Matching: For the registration of optical and SAR images, the matching features obtain by the popular matching strategies, which include the nearest neighbor (NN) matching, the NN distance ratio (NNDR) matching [6] and so on, usually contain a large amount of outliers, further resulting in the failure of the subsequent process. Therefore, we adopt a novel method: First, an initial set of matching features obtained by KNN, is denoted as,

$$M=\{(F_i^o,F_i^s,s_i),i=1,2,\cdots,N\} \quad (1)$$

In equation (1), (F_i^o,F_i^s,s_i) denotes a matching feature and s_i is its matching confidence. The superscripts "o" and "s" refer to the features of the optical and SAR images, respectively, and N is the number of initial matching features.

Then, the initial set M is sorted in descending order of confidence and refined by imposing the spatial consistent constraint called low distortion constraint which was widely used in computer vision [7]. The constraint of two matching features (F_1^o,F_1^s) and (F_2^o,F_2^s) can be formulated as follows:

$$\left|\theta(F_1^o,F_2^o)-\theta(F_1^s,F_2^s)\right|<t_\theta \quad (2)$$

$$\left|L(F_1^oF_2^o)/L(F_1^sF_2^s)-\alpha\right|<t_s \quad (3)$$

Where $\theta(F_1^o,F_2^o)$ indicates the angle between the horizontal axis and the line pass from F_1^o to F_2^o, $L(F_1^oF_2^o)$ indicates the distance between F_1^o and F_2^o, and α is the estimated scale ratio of the optical and SAR image which can be computed from a seed matching feature. t_θ and t_s are two thresholds controlling sensitivity on deformations.

3) Parameter Estimation: After obtaining the matching keypoints between optical and SAR image, we utilize the fitting of polynomial to estimate the spatial relation between optical and SAR images.

2.3. Minimum Enclosing Rectangle Extraction

The minimum enclosing rectangle of the objects can be determined by the object detection, and there are plenty of methods for accurate object detection in optical images. However, its computational cost and difficulty may be higher while coping with a high-resolution optical image whose background is complex. Therefore, before the object detection, we can locate roughly the region of the object [8], and then a two-phase process is exposed:

1) Rough location of object region: The spectral residual (SR) model [9] that utilizes human visual attention gives a simple and rapid approach to preselect salient regions in a scene. It is the main purpose to mimics the fixation selection mechanism and tend to find small distinct regions or points. Inspired by this, we introduce a saliency detection method to determine the object region, which is described as follows: At first, the optical image $I(x,y)$ is transformed into the frequency domain by using Fourier transform:

$$F(u,v)=\iint_\Omega I(x,y)e^{-2j\pi(ux+vy)}dxdy \quad (4)$$

Thus, we can get the amplitude $A(u,v)=\|F(I)\|_2$ and phase $P(u,v)=angle[F(I)]$, and after smoothing $A(u,v)$ with Gaussian kernels $Ker(u,v)$, we can get the SR model as,

$$\Delta(u,v)=A(u,v)-Ker(u,v)*A(u,v) \quad (5)$$

Then, we get the saliency map S using inverse Fourier transform as：

$$S=Ker*\left\|F^{-1}(e^{\Delta(u,v)+iP(u,v)})\right\|^2 \quad (6)$$

Finally, we use the method based on iterative threshold segmentation to locate roughly object region from saliency map.

2) Refined minimum enclosing rectangle extraction of object: At first, we utilize some priori knowledge to determine and shrink the final processed region of the object from the result in step 1, which can improve the efficiency and accuracy of the extraction. Then, the object is detected with the method based on border line between ship and shore extraction and threshold segment. Finally, we can achieve the minimum enclosing rectangle extraction of objects.

2.4. Object Detection in High-Resolution SAR Images

Due to the obvious imaging difference between optical and SAR data, the boundary projected from the optical image aren't enough accurate. Before detecting, we adjust the boundary of the rectangle projected in SAR image. Then, under the constraint of the rectangle boundary, we use the improved Active Contour Model (ACM) method to detect objects in the SAR image, which utilizes the high-level image information that is more appropriate for high-resolution SAR image, which outperforms classical object detection methods in terms of accuracy, and it consists of three steps as follows: At first, the contour C of the object in the SAR image $u(x,y)$ is extracted with Chan-Vese (CV) model [10]:

$$E_{cv}(c_1,c_2,\phi)=\mu \bullet Length(C(\phi))+\lambda_1\int_\Omega |u(x,y)-c_1|^2 H(\phi)dxdy$$
$$+\lambda_2\int_\Omega |u(x,y)-c_2|^2[1-H(\phi)]dxdy \qquad (7)$$

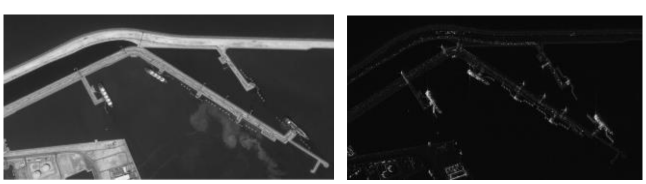
In equation, $\mu \geq 0, \lambda_1, \lambda_2 > 0$, the constants c_1, c_2 are respectively averages of u inside C and outside C, ϕ represents the level set function of C and $H(\phi)$ is the Heaviside function. Then, we deal with the result from the first step with a method based on morphological filter which include not only classical open and close operation but also methods based on reasoning by means of pixels surrounding objects. Finally, we fill the processed contours according to the prior knowledge and acquire the final detection results.

3. EXPERIMENTS

In this section, we take the inshore-ship detection as an example to present the detection results based on the proposed method for high-resolution SAR images whose background is complex. We also compare the performance of the proposed method against the traditional method with only one high-resolution SAR image. The detection accuracies are compared with three ships in one high-resolution SAR image.

3.1. Description of the Data

A couple of data consisting of an optical image from Google Earth (panchromatic model; resolution of 2.1m) and a TerraSAR-X image (high spotlight mode; resolution of 1.1m in ground range and 1.1m in azimuth) on the same are in Ras Laffan Port. Fig.2 (a) and (b) show the two scenes of interest studied throughout this experiment.



(a) Optical (b) SAR

Fig.2 Original images

3.2. Establishment of the Spatial Relation

For the Establishment of the spatial relation between optical image and SAR image, we first extract the improved SIFT features in two images and match them with the method based on spatial constraint. Fig.3 shows 22 couples of points after refinement among the 203 matching results. Finally, we utilize the correct matching results to fit a rational polynomial and establish the spatial relation between the optical image and high-resolution SAR image.

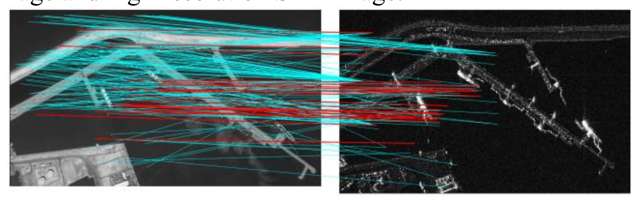
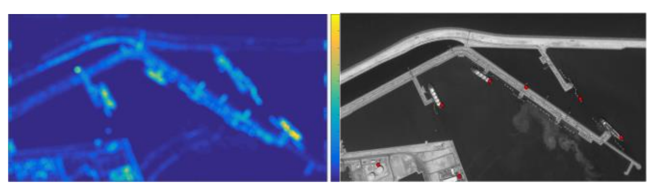


Fig.3 Matching results of the keypoints(22 correct matches among 203 matches)

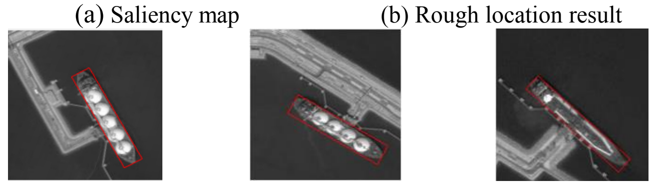
3.3. Minimum Enclosing Rectangle Extraction

We first locate the object roughly with the method based on saliency map, and Fig.4 (a) and (b) show the saliency map and the rough location results. Then, the regions ready for detecting are determined with the prior knowledge in optical image. Finally, we extract the minimum enclosing rectangle from the regions determined with the method based on border line between ship and shore and threshold segment as shown in Fig4. (d), (f) and (g).

As shown in Fig.4, the fine minimum enclosing rectangle of the three ships can be acquired in optical image with the proposed method, and then we can get the four points that can determine the minimum enclosing rectangle of the objects in SAR image by projecting with the spatial relation and the rectangle in optical image (as shown in Fig.5).



(a) Saliency map (b) Rough location result



(c) Ship 1 (d) Ship 2 (e) Ship3

Fig.4 Results of the minimum enclosing rectangle extraction.

3.4. Final Detection Results and Evaluation Criteria

After the projection of the minimum enclosing rectangle from optical image, the object is detected in SAR image with the method based on the improved ACM under the constraint of the rectangle boundary projected from optical images.

To show that the advantages of the proposed method against the traditional object detection methods (such as CFAR+Morphological Filter (MF) and MRF+MF) for SAR images with only one SAR image, objects are detect with the above two methods in the same image, the final result of ship3 is shown in Fig.6, and then we calculate the detection rate (DR) and false alarm rate (FAR) of the detection results. DR is defined as the ratio between the practical area of the detection results and the theoretical area of the corresponding inshore ships in high-resolution SAR image, and FAR is defined as the ratio between the area of the surrounding regions detected wrongly and the area of the detection results. Table. 1 shows the calculation result of the detection results of the proposed method and traditional methods. We can find that the accuracy of the detection results based on the proposed method is higher than that of detection based on the traditional method either from DR or from FAR.

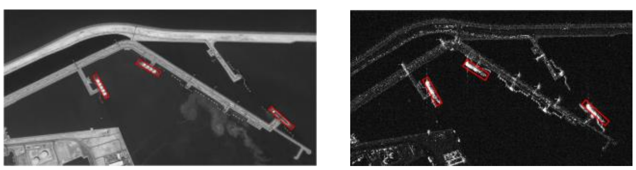
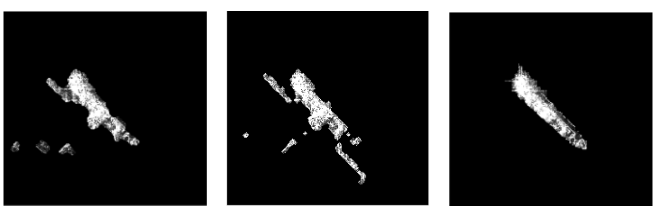


Fig.5 Results of the projection



(a) CFAR+MF (b) MRF+MF (c) proposed method

Fig.6 The final detection result of ship3

Table.1 Detection results of the proposed and traditional method

	CFAR+MF		MRF+MF		THE PROPOSED METHOD	
	DR	**FAR**	**DR**	**FAR**	**DR**	**FAR**
SHIP1	**0.76**	**0.36**	**0.74**	**0.28**	**0.92**	**0.22**
SHIP2	**0.78**	**0.43**	**0.62**	**0.21**	**0.96**	**0.22**
SHIP3	**0.85**	**0.47**	**0.73**	**0.52**	**0.96**	**0.21**

4. CONCLUSIONS AND DISCUSSION ABOUT THE FUTURER STUDY

The paper proposes an object detection method for high-resolution SAR images under the spatial constraints of optical images. Due to the special imaging mechanism, there are plenty of interferences in some high-resolution SAR images, which can result in some difficulties (such as noises, blurry boundary and so on) for object detection. Besides, the difficulties aren't serious in the optical images, so we can improve the accuracy of object detection by utilizing some information in optical images. By experiments in the paper, we can find that the proposed method can greatly improve the accuracy of the detection results. However, there are three difficulties that can be for the proposed method: First, optical and high-resolution SAR images with the same time and site are difficult to acquire. Second, due to the difference between optical and SAR sensors, it is difficult to get enough correct matching points. Third, due to the fitting error, it is difficult to make spatial relation enough accurate. With the development of sensor technology, the first difficulties will be easy to solve, and the last two ones are worth to study further for readers.

5. ACKNOWLEDGE

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6. REFERENCES

[1] Z. Jianxiong, S. Zhiguang, C. Xiao, and F. Qiang, "Automatic object recognition of SAR images based on global scattering center model," *IEEE transactions on Geoscience and remote sensing*, vol. 49, no. 10, pp. 3713–3729, Oct. 2011.

[2] D. E. Kreithen, S. D. Halversen, and G. J. Owirka, "Discriminating targets from clutter," Lincoln Lab. J., vol. 6, no. 1, pp. 25–52, 1993.

[3] H. Sportouche, F. Tupin, and L. Denise, "Extraction and Three-Dimensional Reconstruction of Isolated Buildings in Urban Scenes from High-Resolution Optical and SAR Spaceborne Images" *IEEE* transactions on Geoscience and remote sensing, vol.49, no. 10, pp.3932-3945, Oct. 2011.

[4] D. G. Lowe, "Distinctive Images Features from scale-invariant key-points." Int. J. Computer Vision, vol 60, no.2, pp.91-110, Nov. 2004.

[5] Bin Fan, Chunlei Huo and Chunhong Pan, "Registration of Optical and SAR Satellite Images by Exploring the Spatial Relationship of the Improved SIFT"IEEE Geoscience and Remote sensing Letters, vol. 10. no.4, pp.657-661, 2013.

[6] K. Mikolajczyk and C. Schmid, "A Performance Evaluation of Local Descriptors" IEEE Transactions on Patter Analysis and Matching Intelligence, vol. 27. No.10. pp. 1615-1630. Oct. 2005.

[7] B. Fan, F. Wu and Z. Hu, "Towards reliable matching of images containing repetitive patterns" IEEE Pattern Recognition Letters, vol.32, no.14, pp. 1851-1859. Oct. 2011.

[8] S. Tu and Y. Su. "Fast and Accurate Target Detection Based on Multiscale Saliency and Active Contour Model for High-Resolution SAR Images" IEEE Transactions on Geoscience and Remote Sensing, vol.54, no.10, pp.5729-5744, Oct. 2016.

[9] X.Hou and L.Zhang, "Saliency Detection: A Spectral Residual Approach" IEEE Conference on Computer Vision and Pattern Recognition, pp.1-8, 2007.

[10] Chan T F, Vese LA. "Active contours without edges". IEEE Transactions on Image Processing, pp.266-277 2001.