Optical-to-SAR Image Registration Using Modified Distinctive Order Based Self-Similarity Operator

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***Abstract*— Availability of the sufficient number of matching pairs is the major challenge for optical to SAR (Synthetic Aperture Radar) image registration. Recently, a distinctive order based self-similarity operator (DOBSS) has been proposed to register the optical images. In this paper, a modified version of the distinctive order based self-similarity (M-DOBSS) is proposed to register the optical and SAR images. The proposed M-DOBSS provides more distinctiveness than the standard DOBSS operator. It can significantly increase the number of matching pairs between the optical and SAR images. Experiments on different sets of optical-SAR image pairs demonstrates the effectiveness of the proposed method.**

Keywords— Modified distinctive order based self-similarity (M-DOBSS); Synthetic Aperture Radar (SAR); Local Self-Similarity (LSS).

I. Introduction

Image registration is the process of aligning different sets of images acquired from different view angles, at different times or from different sensors. It has a variety of applications such as image fusion and change detection. An accurate alignment of optical and SAR images is still a complex task due to the existence of large intensity variations and geometrical differences between the images. Another important factor is that the SAR images usually corrupted by the multiplicative speckle noise and as result, it the very difficult to find sufficient matching pairs.

The methods of optical-to-SAR image registration can be divided into groups: intensity-based methods and feature-based methods. Intensity-based methods use the pixel intensity of the input images, to register the optical and SAR images. However, these are very time consuming methods. The feature-based methods detect the invariant features like corners, lines, and curves. Harris corners [1] are the well-known feature extraction operator in image registration methods. However, it has no descriptor to match the features. Scale-invariant feature transform (SIFT) [2] is another popular approach for remote sensing image registration. But, the standard SIFT features are not uniformly distributed over the images and the performance of the SIFT descriptor degrades in optical-to-SAR image registration [3]. In [4], a new version of the SIFT algorithm can be found which is used for the homogeneous distribution of the SIFT features.

In [5], an improved SIFT algorithm is presented to register the optical and SAR images. In the presented method, the orientation of the SIFT features is skipped to improve the matching performance. However, the algorithm is applicable only for the same orientation images. In [6], a Local Self-Similarity (LSS) descriptor is developed to match images and video frames. The LSS uses the local shape property of the image to form the descriptor. Recently, it has been applied for the remote sensing image registration [7]. But, the performance of the LSS degrades for large scaling and orientation differences. In [8], Dense-LSS is developed for optical to SAR image registration. However, it can be applied to the same orientation and same scaled images. In [9], an improved version of LSS called distinctive order based self-similarity descriptor (DOBSS) is presented to register the optical images. The DOBSS operator is very effective registration approach for the optical images having large scaling and orientation differences. The objective of our proposed method is to enhance the matching performance of DOBSS.

In this paper, a modified distinctive order based self-similarity (M-DOBSS) descriptor is proposed to further improve the performance of the standard DOBSS operator. The optical and SAR images are registered by using proposed M-DOBSS method. The presented method can increase the number of correct matching pairs between the input images. It can also improve the correct matching rate (CMR) in feature matching process.

The paper is structured as follows: The standard DOBSS operator is described in Section II. Section III discuss the proposed method followed by Section IV which presents the experimental result analysis. The paper is concluded in Section V.

II. DOBSS Descriptor for Image Matching

The standard DOBSS descriptor is inspired from the LSS descriptor. The LSS descriptor is constructed by steps shown in Fig. 1. While forming the LSS, a circular region of radius=20 pixels is utilized. Fig. 1 (a) shows the circular region by the red circle. p is considered as the center of the region. The Sum of Square Differences (SSD) operation is performed between a patch of size 5x5 centered at p and the other surrounding patches. Then, a correlation surface Cp (m, n) is formed by using the SSD values. The correlation surface is defined as

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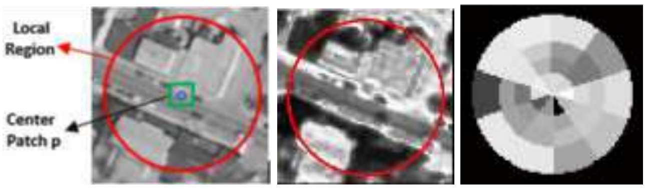
$$C_p(m,n) = \exp\left(-\frac{SSD_p(m,n)}{\max(\text{var}_N, \text{var}_A(p))}\right) \quad (1)$$



(a) (b) (c)

Fig. 1. Steps of LSS descriptor construction. (a) Local region, (b) Correlation surface formation, (c) Log-polar representation of LSS.

Here, var_N denotes acceptable variations of the intensity and $var_A(p)$ presents the maximum variation of the SSD values. The surface generated by the equation (1) is shown in Fig. 1(b). A log-polar representation is considered for the correlation surface and it is partitioned into angular as well as radial bins. This representation is shown in Fig. 1(c).

It is already mentioned that the LSS descriptor is only applicable for the same orientation images. In order to achieve rotation invariance, the DOBSS is proposed in [9]. In the mentioned method, the homogeneously distributed SIFT [4] features are detected from the optical images and DOBSS descriptor is constructed for each of the features. The orientation of the features are computed by utilizing a correlation surface *Cp*(*m, n*), where the radius is taken as 4 pixels. 36 bins orientation histogram is formed by using the correlation values and dominant orientations are determined.

Before the descriptor construction, the correlation surface is rotated using the value of dominant orientations. The pixels of oriented correlation surface are sorted according to their correlation value in a non-descending order. These are equally divided into 2 ordinal bins. The log-polar divisions are formed in these ordinal bins. In the log-polar structure, 16 angular divisions and 4 radial divisions are considered and a correlation value is chosen form every division to construct the descriptor. Hence, the dimensions of the DOBSS descriptor are 128.

III. PROPOSED METHOD

The DOBSS descriptor provides good performance for the registration of optical images. However, it requires some modifications to improve the performance in optical to SAR image registration. It is well known fact that the SAR images contain speckle noise which reduces the repeatability of the features. In our proposed method, the following modifications are made to improve the matching performance. In order to reduce the effect of speckle noise, filtering is performed on the SAR images before feature extraction. Moreover, we have proposed a modified DOBSS descriptor which improves the matching performance between the input images.

A. Speckle Noise Filtering

As the effect of speckle noise reduces the repeatability of the features, the noise effect should be minimized by proper filtering operation. In [10], it is mentioned that the infinite symmetric exponential filter (ISEF) is an effective approach to reduce the effect of speckle noise. Filtering the SAR images with the ISEF can increase the repeatability of the extracted features [10]. So, in our proposed method, the ISEF is utilized to reduce the noise effect. ISEF filter in one dimension can be defined as

$$h(n) = \frac{n}{2}\exp(-X.|n|) \quad (2)$$

where $X=-ln(\beta)$.

Another form of ISEF can be given as

$$h(n) = \alpha\beta^n \quad (3)$$

where the value of β lies in the range 0 to 1 and α is a logarithmic function of β.

B. Modified DOBSS (M-DOBSS)

1) More Supported Areas: In the standard DOBSS descriptor, a single supported area is used to construct the descriptor. In [5], the distinctiveness of the SIFT algorithm is improved by taking different supported areas. Motivated by the idea, different supported areas are considered in our proposed method. The DOBSS descriptor is constructed for each of the supported areas and these are concatenated to generate the proposed descriptor. More supported areas can improve the distinctiveness of DOBSS. However, the descriptor length increases with more supported areas and as a result, the computational time as also increases in registration. So, considering these facts, we have used 2 supported areas in our method.

*2) Multiple Correlation Values:*The standard DOBSS and LSS select a single correlation value from every log-polar division of the correlation surface. Selecting a single value can reduce the distinctiveness of the image which is corrupted by the noise effect. Therefore, the selection of multiple correlation values can improve the distinctiveness of the features. However, if too many values are selected, the size of the descriptor increases which increases the computational time in registration. Hence, considering these facts, we have selected the first and the second maximum correlation values to construct the descriptor.

As we are considering 2 supporting areas and 2 correlation values from every log-polar section, the dimensions of the descriptor are increased by (2x2) 4 times than the DOBSS descriptor. Therefore, the dimensions of the proposed descriptor are (4x128) 512.

C. Feature Matching

In our method, we have used the (UR-SIFT) algorithm [4], to extract the features form the optical and SAR images. The proposed M-DOBSS descriptor is constructed for every M-UR-SIFT features and finally, feature matching is accomplished. The features of the optical image are matched with the SAR images by utilizing the cross matching technique [4]. In this technique, the nearest neighbor distance ratio is taken as 0.9. The cross matching technique removes most of the incorrect matches. Then, Random Sample Consensus (RANSAC) [11] is used to identify the correct matches.

IV. SIMULATION AND ANALYSIS

The following parameters are used to evaluate the performance of the proposed method.

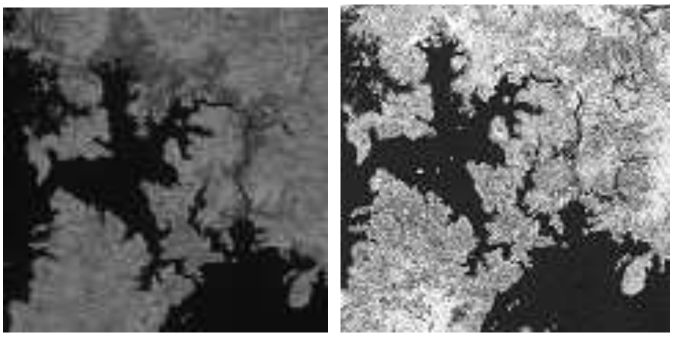
(a) Number of Correct Matches (*$Match_N$*)*:* In order to identify the correct matches 50 homogeneously distributed matching pairs are selected manually between the optical and SAR images. Then, 30 matching pairs having the lowest residual error are use to compute the affine transformation value between the images. The matching pairs obtained by the proposed method is checked with the manually obtained transformation using a threshold value of 2 pixels. The number of matching pairs satisfy the criterion is referred as $Match_N$.

(b) Correct matching ratio (R_{CM})*:* If N is the number of matching pairs found after cross matching process, then R_{CM} is the ratio of $Match_N$ to N.

(c) RMSE*:*The residual errors of the matches computed in vertical and horizontal directions are used to calculate the RMSE.

The proposed method is compared with the standard DOBSS descriptor to verify the effectiveness of the method. The performance of the two modification steps of the proposed method is also analysed. The first improvement step of the proposed method (i.e. the consideration of more supported areas) is called as M1-DOBSS. The second modification step of the proposed method (i.e. the consideration of multiple correlation values) is called as M2-DOBSS. The two modification are jointly called as M-DOBSS. We will also discuss the necessity of the ISEF filter in the optical-to-SAR image registration.

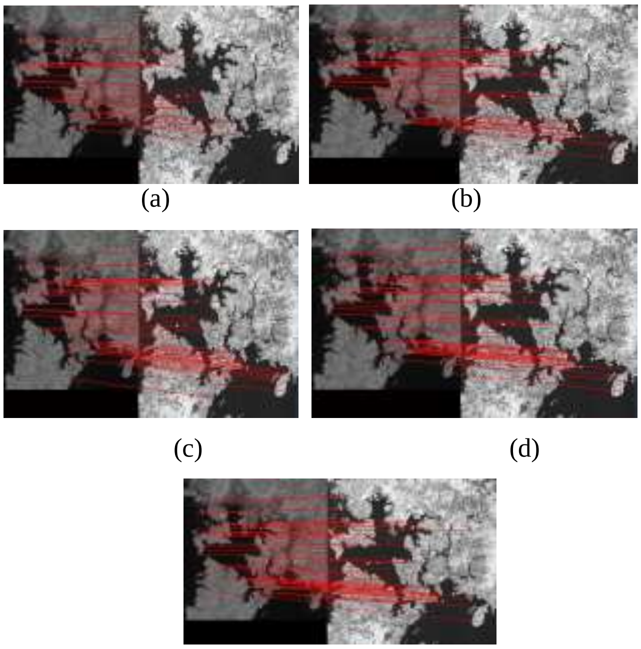
In order to verify the effectiveness of the proposed method, experiments are conducted on three data sets [12]-[14]. The images of the data ets have intensity, scaling and orientation variations. The optical image of the data set 1 is captured by the UK-DMC2 sensor (resolution: 22 meter) over the area of Kyushu, Japan on May 12, 2012. The image has the size of 500x500 pixels. The SAR image of the data set 1 is taken by the ALOS PALSAR sensor (resolution: 20 meter) on July 6, 2008. The size of the image is 600x600 pixels. Fig. 2 shows the first data set.



(a) (b)

Fig. 2. First data set. (a) Optical Image and (b) SAR image.

The matching results of the different methods are shown in Fig. 3. It can be observed that the proposed method gives more matches than the standard DOBSS. Table I presents the qualitative performance of the different method for the first data set. It can be seen that $Match_N$ and R_{CM} values are comparatively better and the RMSE value is lowest for the proposed method.



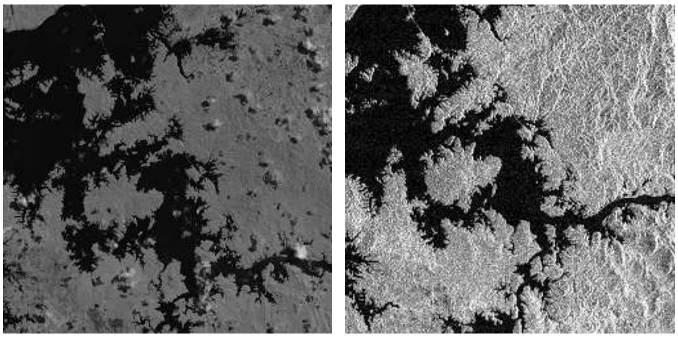
(a) (b) (c) (d) (e)

Fig. 3. Matching results of the different methods for the first data set. (a) DOBSS (b) M1-DOBSS (c) M2-DOBSS (d) M-DOBSS (e) ISEF M-DOBSS

TABLE I. MATCHING PERFORMANCE OF DIFFERENT METHODS FOR DATA SET1

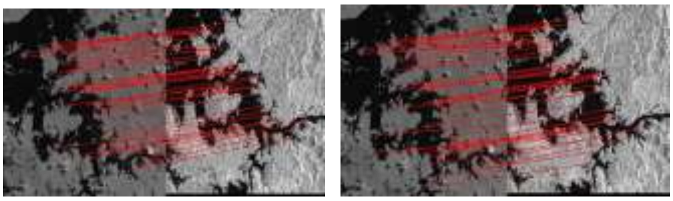
Method	Correct Matches	R_{CM}	RMSE
DOBSS	29	0.12	1.82
M1-DOBSS	38	0.17	1.67
M2-DOBSS	40	0.16	1.65
M-DOBSS	**43**	**0.20**	**1.42**

The optical image of the data set 2 are captured by the ETM+ sensor (resolution: 30 meter) over the area of Panama canal, Panama on May 28, 2002. The image has the size of 510 x 510 pixels. The SAR image of the data set 1 is taken the by Terra SAR-X sensor (resolution: 35 meter) on December 7, 2013. The size of the image is 500 x 500 pixels. Fig. 4 shows the second data set. The matching results of the different methods are shown in Fig. 5. In this case also the proposed method gives more correct matches. Table II presents the qualitative performance of the different method for the second data set. The proposed method provides better performance than standard DOBSS.

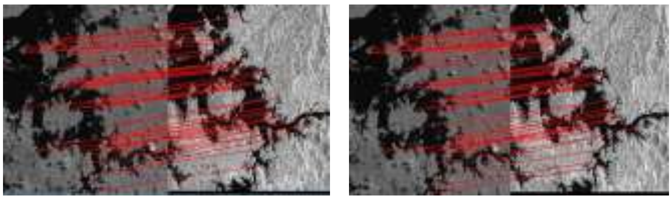


(a) (b)

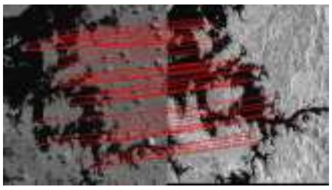
Fig. 4. Second data set. (a) Optical Image and (b) SAR image.



(a) (b)



(c) (d)



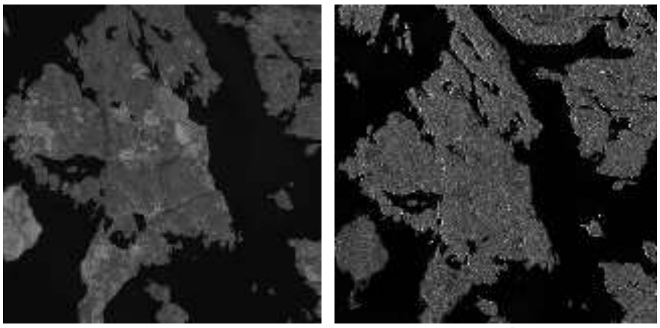
(e)

Fig. 5. Matching results of the different methods for the second data set. (a) DOBSS (b) M1-DOBSS (c) M2-DOBSS (d) M-DOBSS (e) ISEF M-DOBSS

TABLE II. MATCHING PERFORMANCE OF DIFFERENT METHODS FOR DATA SET2

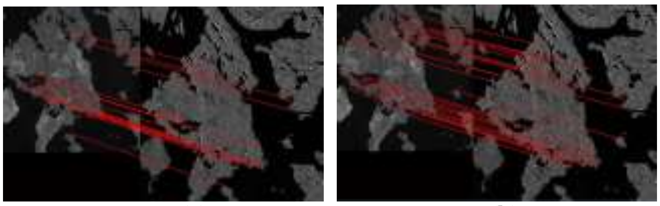
Method	Correct Matches	R_{CM}	RMSE
DOBSS	37	0.19	1.45
M1-DOBSS	42	0.25	1.40
M2-DOBSS	45	0.27	1.39
M-DOBSS	**47**	**0.30**	**1.37**

The optical image of the data set 3 are captured by the ETM+ sensor (resolution: 15 meter) over the area of Campbell River, British Columbia on June 26, 2000. The image has the size of 600x600 pixels. The SAR image of the data set 3 is taken the by ALOS PALSAR sensor (resolution: 20 meter) on June 5, 2010. The size of the image is 840x840 pixels. Fig. 6 shows the third data sets. The matching results of the different methods are shown in Fig. 7. Here, also the proposed method gives more correct matches. Table III presents the qualitative performance of the different method for the third data set. In this case also, the proposed method provides better performance than standard DOBSS.

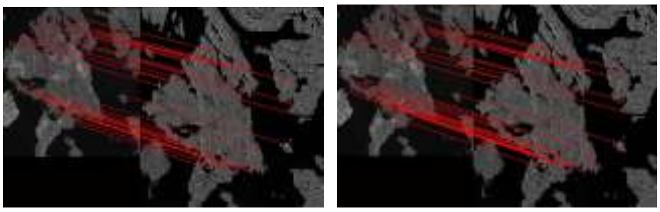


(a) (b)

Fig. 6. Third data set. (a) Optical Image and (b) SAR image.



(a) (b)



(c) (d)

(e)

Fig. 7. Matching results of the different methods for the third data set. (a) DOBSS (b) M1-DOBSS (c) M2-DOBSS (d) M-DOBSS (e) ISEF M-DOBSS

TABLE III. MATCHING PERFORMANCE OF DIFFERENT METHODS FOR DATA SET3

Method	Correct Matches	R_{CM}	RMSE
DOBSS	18	0.11	1.80
M1-DOBSS	26	0.16	1.63
M2-DOBSS	29	0.17	1.62
M-DOBSS	**33**	**0.21**	**1.60**

The two modifications i.e. M1-DOBSS and M2-DOBSS give more correct matches than the standard DOBSS. Moreover, R_{CM} value significantly increases for these two modification steps. In M1-DOBSS, more supported areas improve the distinctiveness of the descriptor. As a result, $Match_N$ and R_{CM} values significantly increases in M1-DOBSS. As more number of correct matches are obtained in M1-DOBSS, the RMSE value also becomes less. In M2-DOBSS, two correlation values are selected which also increases the distinctiveness of the descriptor. Hence, in this case also $Match_N$ and R_{CM} values are more than DOBSS. In M1-DOBSS, two supported areas are used and in the case of M2-DOBSS two correlation values are utilized. So, for both the cases, the descriptor length is twice than the descriptor of standard DOBSS. Therefore, both the methods need more computational time than the DOBSS to register the images.

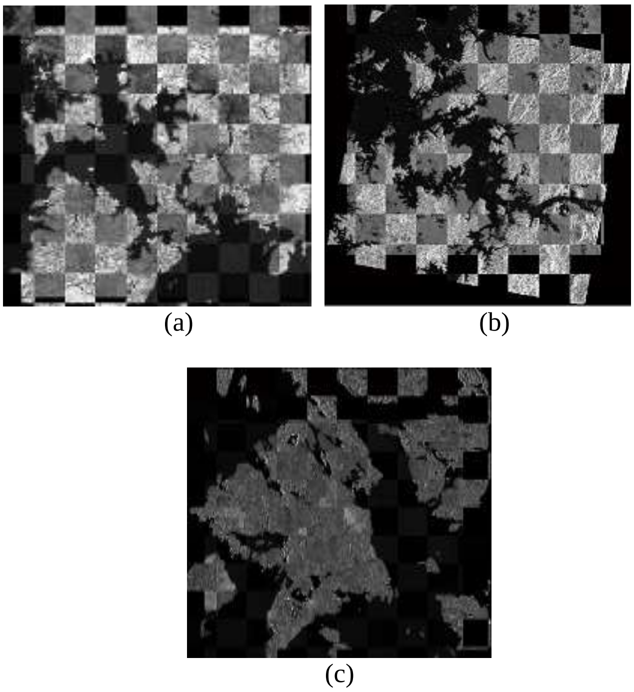


Fig. 8. Registration results of different data sets. (a) first data set (b) second data set and (c) third data set.

When the SAR images are filtered with the ISEF, the $Match_N$ value for the first, second and the third data sets become 49, 54 and 38 respectively. The filtering operation reduces the speckle noise in SAR images and increases the repeatability of features. As a result, more $Match_N$ values are obtained when the filtering is performed.

The combination of the two modifications i.e. M-DOBSS provides the best results as the distinctiveness of the features significantly improves by combining these modifications. However, it takes nearly 1.61, 1.54 and 1.69 times computational time than DOBSS to register the first, second and the third pair, respectively. The registration results of the proposed method are shown in Fig. 8. The images of the chess board representation are well aligned.

V. CONCLUSION

In this paper, we have proposed a new approach for optical to SAR image registration. Firstly, the SAR images are filtered by the ISEF filter to reduce the influence of noise. This approach, increase the repeatability of the extracted features. Then, a modified DOBSS descriptor is presented to improve the matching performance between the images. The presented method not only increases the number of correct matching pairs, also improves the correct matching rate. Experiments on three sets of optical and SAR image pairs demonstrate the effectiveness of the proposed method.

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