A NEW REGISTRATION METHOD BASED ON PIECEWISE SURFACE FITTING FOR INTERFEROMETRIC SYNTHETIC APERTURE SONAR

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Abstract: *Complex image registration is one of the most important steps in interferometric synthetic aperture sonar (InSAS) signal processing. The registration result directly influences the quality of interferogram and subsequent reconstruction of digital elevation model (DEM). In this paper, a registration method based on piecewise surface fitting is proposed for InSAS. Firstly, the whole image is partitioned into several pieces along range direction with partly overlapped. Secondly, polynomial surface fitting is performed using control points in each pieces. Finally, the global shift surface is obtained by merging those local surface fitting result. Experiments on simulation and real data confirm that the proposed method has high accuracy than global polynomial surface fitting.*

Keywords: *Interferometric synthetic aperture sonar(InSAS); complex image registration; piecewise surface fitting*

1. INTRODUCTION

Interferometric synthetic aperture sonar (InSAS)[1-3] provides a means of obtaining high resolution three-dimensional images of the sea floor. Three-dimensional information is derived from the phase difference between two complex images taken from separated receiving arrays of sonar. The main steps of SAS interferometry signal processing include complex image registration[4-6], phase filtering, phase unwrapping[7] and digital elevation model(DEM) reconstruction[8]. Image registration is the basis of the other steps. Registration quality directly affects the subsequent generation of the interferogram and reconstruction of DEM.

The complex image registration mainly compose of control points selection[9-11], geometric transformation [12] and image resampling. Once the control points between two complex images are determined, the geometric transformation can be done with the control points coordinates and offset. The most widely used geometric transformation model is polynomial transformation which utilizes the least square method, because the polynomial model is simple and solving easy. In fact, polynomial transformation is a procedure of surface fitting using the known control points coordinates and their offset. In InSAR complex image registration, since the mapping swath is small relative to imaging distance, global polynomial surface fitting, such as the first or the second order polynomial, performs well. However, different with InSAR, the range-variance in the InSAS image is more stronger, so the global polynomial surface fitting does not work well.

To solve the problem mentioned above, a piecewise surface fitting method for complex registration is presented in this letter. Firstly, the whole image is segmented into several pieces along range direction with partly overlapped. Secondly, polynomial surface fitting is performed using the control points in each piece. Finally, the global offset surface is obtained by merging those local surface fitting results.

This paper is organized as follows. In Section 2, the principle of polynomial transformation model is introduced and the piecewise surface fitting method is developed detailedly. The performances of the proposed method are shown by using simulated and real data in section 3.

2. PIECEWISE SURFACE FITTING METHOD

Since the InSAS system is single-pass, assuming the platform motion with constant speed in a straight line, thus the offset in azimuth can be ignored, so we just consider range offset in this paper. Suppose n is the number of the control points which has been determined, (x_i, y_i) denotes the coordinate of control points, d_i is the range offset of control points. The polynomial transformation model can be written as $d = \sum_{i=0}^{N}\sum_{j=i}^{N} a_{ij} x^i y^{j-i}$, where N is the polynomial order, $d = [d_1, d_2, \cdots d_n]^{\mathrm{T}}$ is a column vector composed of offset about the control points, a_{ij} is the polynomial parameters which should be solved using the least square method. So the offset surface can be obtained when $N=2$

$$d(x,y)=a_0+a_1x+a_2y+a_3x^2+a_4xy+a_5y^2 \quad (1)$$

From(1), the offset of each pixel in the image can be got by substituting the coordinate of each pixel into (1).

The piecewise surface fitting method can be divided into the following steps.

1) Segment the whole image into several parts along range direction, as shown in **Error! Reference source not found.**. The solid line in Fig.1 is dividing line of each piece. The two neighbored pieces are set some overlapped pixels, shown as the dashed line.
2) Choose the control points in each part and perform polynomial surface fitting using the chosen control points coordinate and offset. Then we get one surface of offset in each part.

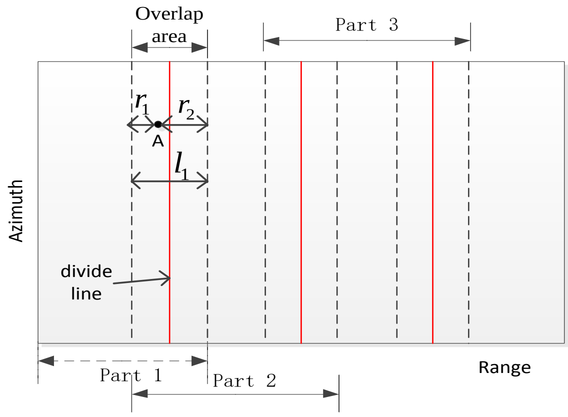


Fig.1: Sketch of partition of the image

3) Combine the offset surfaces in all parts into a whole offset surface. In the overlapped area, the offset value of pixel is obtained by weighted linear combination of the two neighbored surfaces. Which can be expressed as

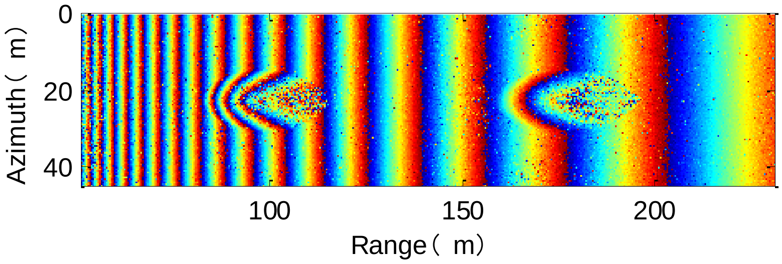
$$f(A)=w_1f_1(A)+w_2f_2(A) \quad (2)$$

where A is the pixel in the overlapped area, $f(A)$ is the offset value of pixel A in the whole offset surface which should be computed. $f_1(A)$, $f_2(A)$ are the offset value of pixel A in the local offset surface corresponding to part 1 and part 2, respectively. w_1 and w_2 are the normalized weights of pixel A in part 1and part 2 respectively. As is shown in **Error! Reference source not found.**, the weight can be calculated by $w_1=r_2/l_1$, $w_2=r_1/l_1$. l_1 is the width of the overlapped area, r_1,r_2 is the distance between pixel A and left boundary and right boundary of the overlapped area, respectively.

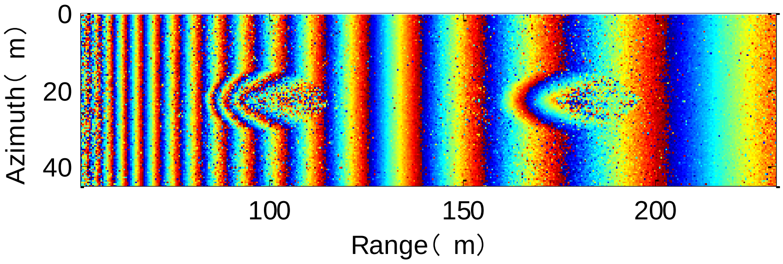
3. PERFORMANCES INVESTIGATION

In this section, the performance of the proposed method is investigated with the simulated InSAS data and real lake trial data of InSAS. In order to validate the effectiveness of the proposed method, its result is compared with global surface fitting result. The evaluation has been carried out using the root mean squared error (RMSE), residue numbers and mean of correlation coefficient as the criteria.

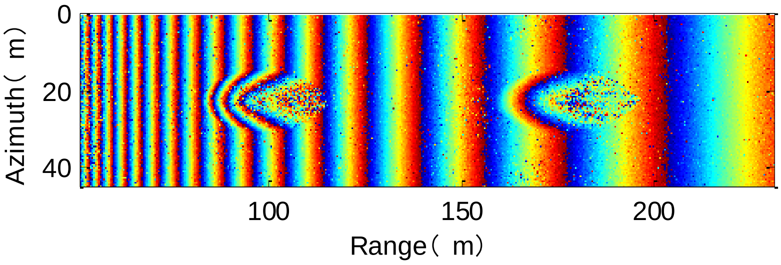
The simulated scene is two tapers on the flat, as shown in **Error! Reference source not found.**.



(a)*Interferogram using proposed method*

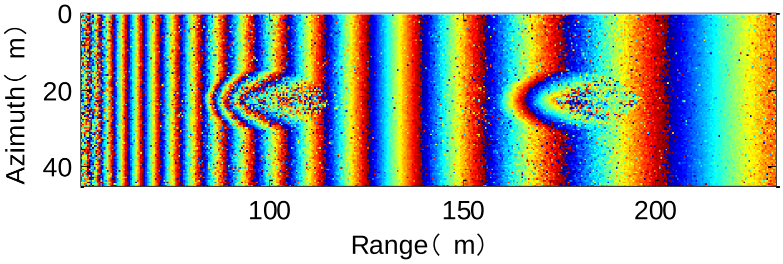


(b)Interferogram using global surface fitting method



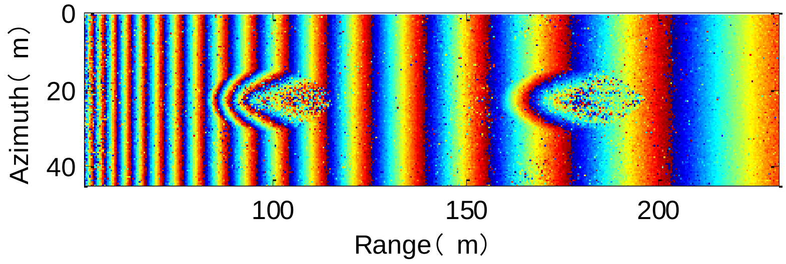
(a) and

(a)*Interferogram using proposed method*

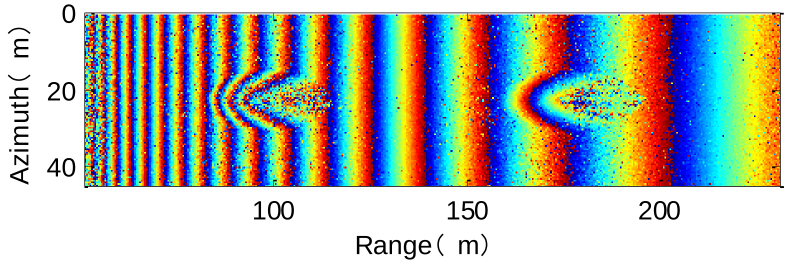


(b)Interferogram using global surface fitting method

(b) are the interferogram after registration using the proposed method and global surface fitting method, respectively. From

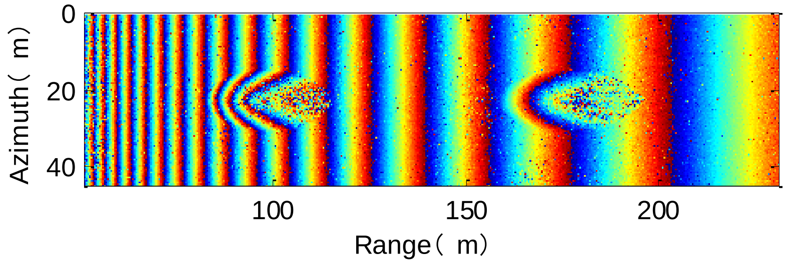


(a)*Interferogram using proposed method*

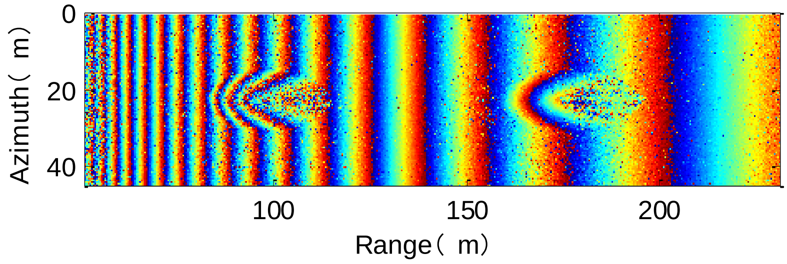


(b)Interferogram using global surface fitting method

, it can be seen that the interferometric fringe in

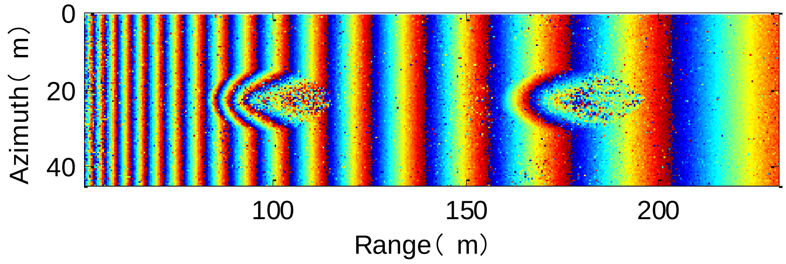


(a)*Interferogram using proposed method*

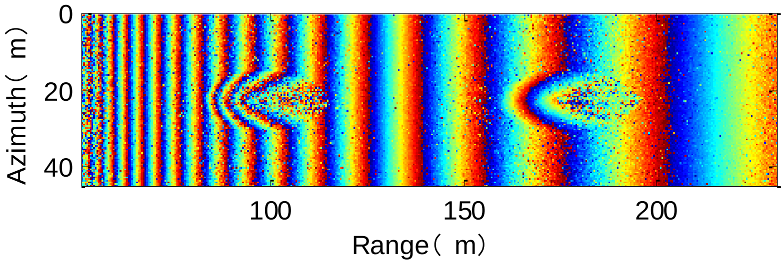


(b)Interferogram using global surface fitting method

(a) is clear than that in



(a)*Interferogram using proposed method*



(b)Interferogram using global surface fitting method

(b), especially in the left side of the interferogram.

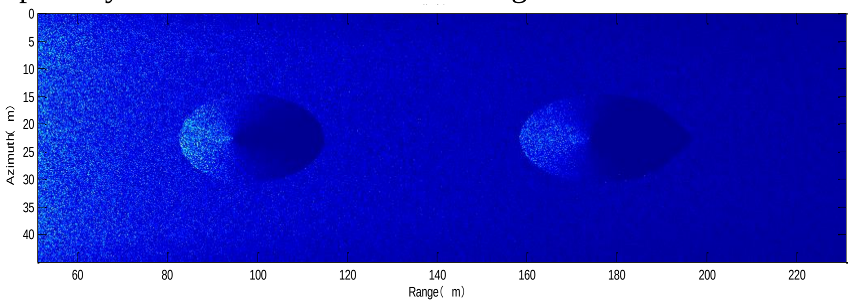
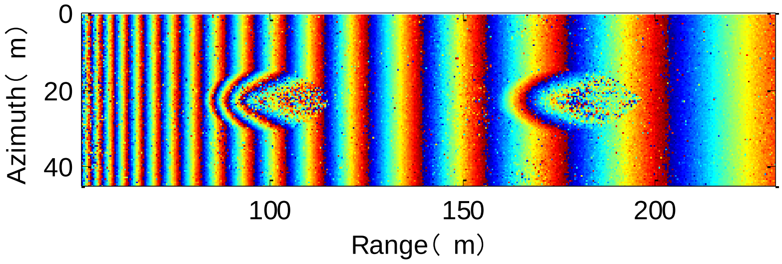
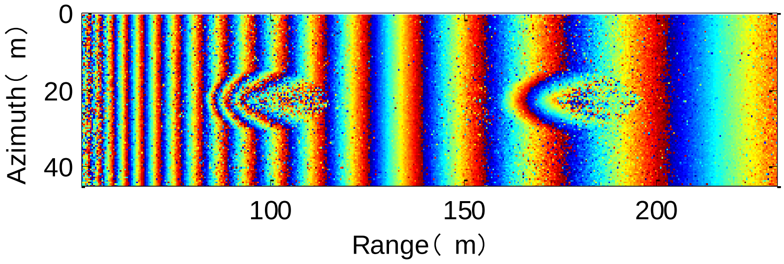


Fig.2: Amplitude image of simulated scene



(a)Interferogram using proposed method



(b)Interferogram using global surface fitting method

Fig.3: Interferogram after registration.

Quantified evaluation result is given in Table 1. From the three criteria in Table 1, the performance of the proposed method is better than the traditional global surface fitting method.

Method	RMSE [pixel]	Mean of correlation	Residue numbers
Global surface fitting	0.3056	0.9397	298400
Proposed Method	0.0687	0.9671	166057

Table 1: Registration quality comparison of simulation data.

For the real lake trial data, a complicated terrain image is chosen to be processed, as shown in Fig. .The interferogram after phase filtering with the proposed method and global processing are shown in Fig. 5(a) and Fig. 5(b), respectively. Comparing Fig. 5(a) and Fig. 5(b), we can see that fringe in Fig. 5(a) is more clear than Fig. 5(b), especially in the white four rectangles in the left-down of the Fig. 5(a) and Fig. 5(b). Table 1 gives the registration quality comparison of the proposed method and the global surface fitting method. It can be observed from Table 1 that the proposed method based on piecewise surface fitting has fine performance than global surface fitting method.

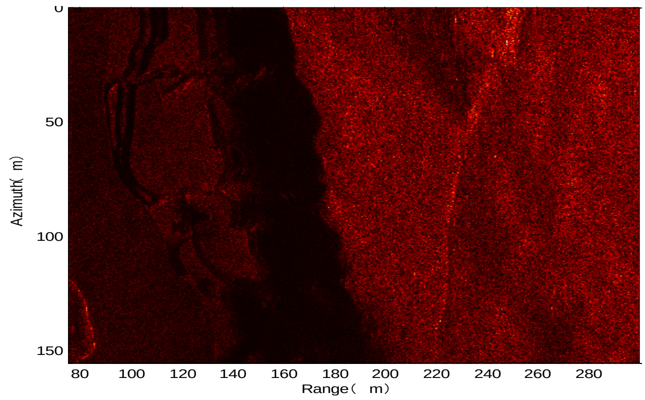
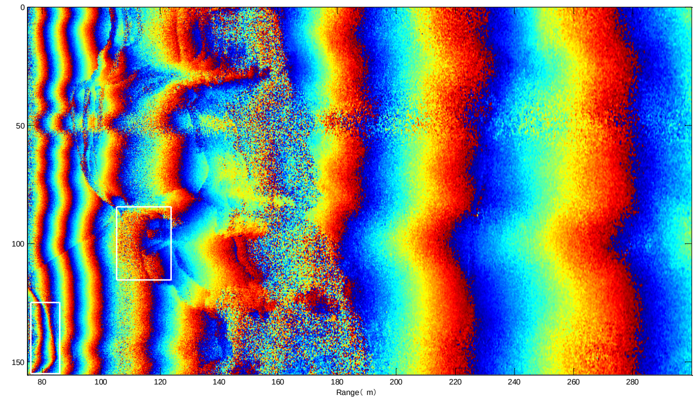
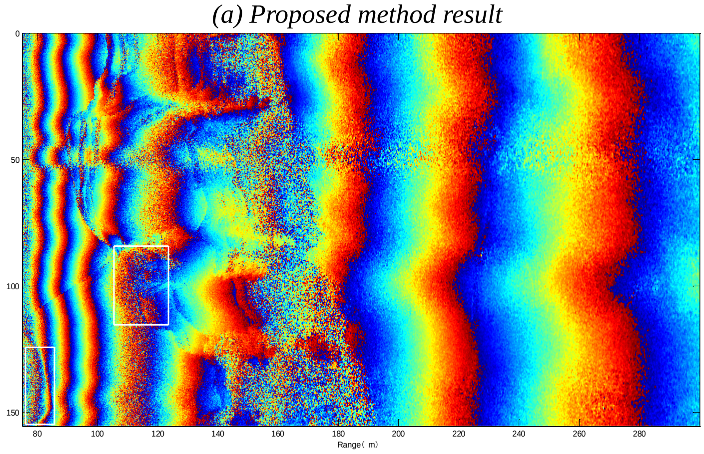


Fig. 4: Amplitude image of real lake trial data



(a) Proposed method result



(b) Global surface fitting result

Fig. 5: Interferogram after registration with two method.

Method	RMSE [pixel]	Mean of correlation	Residue numbers
Global surface fitting	0.1984	0.5802	81956
Proposed Method	0.1191	0.5824	69455

Table 1 Registration quality comparison of real data.

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