

RESEARCH ON SPACEBORNE INSAR IMAGES REGISTRATION AND REMOVAL OF THE EFFECT OF THE FLAT EARTH

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ABSTRACT:

Interferometric Synthetic Aperture Radar (INSAR) is a good technique to produce high resolution digital elevation model (DEM), to detect small earth motions, and so on. Therefore, it is very useful to study this technique. In this paper, some methods about data preprocessing, control points determining, image registration and removal of the phase of the flat earth are introduced, which are one big key step in INSAR technique. Usually, the original data is in a complex format. Only a few white points can be seen from this image, and it can be overcome by image histogram equalization or gray contrast enhancement. It has been tested that they improve the reliability of image registration. Image registration deals with pixel intensity transformation and geometrical transformation. In this paper, they are done separately. Histogram specialization is used to correct the former roughly, for it can satisfy requirements. The latter has two steps. At first, two images are registered coarsely by determining range and azimuth offsets because the two satellite orbital paths are very close together. Then sufficient identical points are selected by Forstner method on left image and their conjugation points are determined using normalized correlation coefficient based on the subpixel shifts between homologous areas or using the paraboloid polynomial. Finally, with the help of these control points, the geometric registration is performed by means of linear polynomials. Whose coefficients are computed with least-squares approximation. After image registration has been performed, the interferogram can be obtained by multiply each pixel in the left image by the corresponding pixel in the second image. Thus the phase difference can be gotten. This interferogram includes two parts: phase difference caused by terrain and phase difference caused by flat earth. A method called Removal of the Phase of the Flat Earth is performed. In this research, ERS-1, ERS-2 complex data in the area of Zhangbei is used. All experiments tried with methods discussed above have shown those methods are practically largely.

1. INTRODUCTION

Synthetic Aperture Radar records not only electromagnetic energy of backscattering, but also phase delay at the same time. Therefore researchers may use the phase information of the radar signal to extract three-dimensional information of the earth surface, which is called interferometric Synthetic Aperture Radar (INSAR). It makes global digitization possible, being extensively applied to produce digital elevation map, exploring slight deformation of the earth surface, calculating glacier movement, appraising calamity etc. So research on spaceborne INSAR is of much significance.

At present, spaceborne INSAR has only one pair of antenna, so it can only utilize repetition of the satellite track to survey in interferometric mode, namely, repetition track interferometric measurement. We know, the track data of the satellite have errors, some are inherent but difficult to eliminate, data precision provided for users does not usually meet the demand of interferometry; but time correlation-resistant caused by repetition track and geometric deformation arising from slant distance imaging are difficult to correct effectively, which can result in gradual reduction of grey correlation of homologous images points, and the difficulty for complex images registration of interferometry, removal of the phase of the flat

earth of interferogram and DEM production. This paper lays special emphasis on the former two aspects for discussion.

2. COMPLEX IMAGES REGISTRATION OF SPACEBORNE INSAR

In order to forming interferogram, a pair of single vision interferometry complex images must be registered, and registration precision of repetition track interferometry should reach sub-pixel level even more. At present, interferometry registration has two methods: Registration on the basis of the grey, like coefficient correlation method; Registration on the basis of the phase, like the average fluctuation function method. This paper adopts the former to study registration of complex images of spaceborne INSAR.

2.1 Preprocessing

As everyone knows, in general, original grey images obtained by using complex images SLC according to $g = \sqrt{i^2 + q^2}$ (i is imagine part, q is real part, g is grey value) shows only some light spots and hides partial object information, and difference exists in the grey radiation characteristics of a pair of homologous images. So before registration, you must

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preprocess grey images by histogram equalization, grey linear stretching, and so on. The experiment proves that these methods can improve the registration reliability obviously.

2.2 Registration

Images registration is, in essence, to recognize homologous images points from homologous images, and systematic deformation of homologous images has geometric distortion and radiation distortion. Usually, we adopt least square registration algorithm to introduce relevant parameters for rectifying these distortions, for instance:

One power geometric distortion:

$$\begin{cases} x_2 = a_0 + a_1x + a_2y \\ y_2 = b_0 + b_1x + b_2y \end{cases} \quad (1)$$

One power radiation distortion:

$$g_2 + n_2 = h_0 + h_1g + n \quad (2)$$

Taking the two kinds of distortion into account at the same time:

$$g_2(x, y) + n_2(x, y) = h_0 + h_1g(a_0 + a_1x + a_2y, b_0 + b_1x + b_2y) + n(x, y) \quad (3)$$

This method is flexible and of high precision. However, registration needs more accurate initial value and radiation parameter or geometric parameter may have discrepancy, which can lead to bad convergence. I think histogram specification can eliminate images radiation distortion to a certain extent, and at the same time, decrease calculation and improve reliability of registration. Practice has proved that the method has little influences on the accuracy of precise registration. Subsequently, the images are to be further rectified to eliminate geometric distortion. The whole processing is divided into precise registration and rough registration.

As far as spaceborne INSAR is concerned, two repetition tracks are almost parallel. So compared with left images, right images exist certain displacement in the azimuth direction and in the distance direction. According to the characteristic, we may choose several characteristic points in homologous images through manual selection point method. According to the chosen points, average displacement in the azimuth direction and in the distance direction can be calculated to conduct rough registration. The method is simple and fast, and the precision may reach 1-3 pixels.

Precise registration adopts least square fitting method, which can use data block principle to rectify geometric distortion better. With the principle of the minimum root mean square value of geometric difference between selected homologous images point, and based on grey images, The method determines several homologous control points in sub-pixel level from grey images to fit geometric distortion between right images and left images. The specific steps are:

2.2.1 Selecting the control points

Firstly, the whole left images are divided into several blocks, and then find the characteristic point automatically on each block by Forstner operator. Assuming all characteristic points in left images have the same coordinate with corresponding characteristic points in right images. Namely let:

$$X_L = X_R, Y_L = Y_R \quad (4)$$

Then using the correlation coefficient method can make it reach the precision of one pixel. Next, according to the correlation coefficient method based on interpolation or paraboloid fitting method given by this paper, registration precision of homologous images point may reach one pixel. The concrete method is as follows:

- The correlation coefficient method based on interpolation:

$$\bar{\rho} = \frac{\sum_{n=0}^N \sum_{m=0}^M |u_1(n, m)|^2 |u_2(n, m)|^2}{\sqrt{\sum_{n=0}^N \sum_{m=0}^M |u_1(n, m)|^4 \sum_{n=0}^N \sum_{m=0}^M |u_2(n, m)|^4}} \quad (5)$$

Among them, $u_1(n, m)$ is left complex images data for the left, $u_2(n, m)$ is right complex images data, n, m is registration window pixels in horizontal and longitudinal direction respectively.

As formula (5) shows, the correlation coefficient is a covariance function, therefore when linear distortion exists between the grey of the homologous images, we can still appraise the similarity between them well. After determining registration window, the target registration window is to be moved at the interval of 0.1 pixel each time on the right images, and the pixel grey of it is interpolated out based on bi-cubic polynomial. Finally, the position corresponding maximal value of correlation coefficient on the right images is regarded as the geometric position of homologous images point.

- paraboloid fitting method

In order to obtain registration points of the precision of sub-pixel level, we may use pixel coordinate (x, y) corresponding to maximal value of correlation coefficient and adjacent pixel to form a paraboloid equations. The concrete formula is as follows:

$$(x - x_0)^2 + (y - y_0)^2 = 2 * a * (\rho - z) \quad (6)$$

Among them, x is row coordinate of the images, y is column coordinate of the images, a is shape parameter of fitting paraboloid, z is the correlation coefficient value of images points.

Firstly, Calculate the maximal value ρ of paraboloid and its corresponding coordinates X_0, Y_0 . Then the pixel position of target images registration point is determined.

There is a little difference between two methods of acquiring high-precision control points. The former has high reliability comparatively, but needs much resampling, and its calculation is complex; the latter does not need resampling, calculation is fast, but the precision of homologous images point is related to the determination of initial value of coefficient a . Obviously, as to a smaller area (3*3), the correlation coefficient of each point changes little, so a value in two power paraboloid equation

should less than 1. Experiments show the result is optimum when a value gets 0.1 or so.

2.2.2 registration with least square fitting method

Using high-precision control points, according to formula (1), geometric distortion rectification is carried out on complex images of homologous stereopair, then, calculate iteratively out the six distortion parameters according to formula(7) in the following :

$$\begin{aligned}
 a_0^i &= a_0^{i-1} + da_0^{i-1} + a_0^{i-1} da_1^{i-1} + b_0^{i-1} da_2^i \\
 a_1^i &= a_1^{i-1} + a_1^{i-1} da_1^{i-1} + b_1^{i-1} da_2^i \\
 a_2^i &= a_2^{i-1} + a_2^{i-1} da_1^{i-1} + b_2^{i-1} da_2^i \\
 a_0^i &= b_0^{i-1} + db_0^{i-1} + a_0^{i-1} db_1^{i-1} + b_0^{i-1} db_2^i \\
 a_1^i &= b_1^{i-1} + a_1^{i-1} db_1^{i-1} + b_1^{i-1} db_2^i \\
 b_2^i &= b_2^{i-1} + a_2^{i-1} db_1^{i-1} + b_2^{i-1} db_2^i
 \end{aligned}
 \tag{7}$$

Among them, i indicates iterative times, $a_0^{i-1}, a_1^{i-1}, a_2^{i-1}, b_0^{i-1}, b_1^{i-1}, b_2^{i-1}$ is distortion parameter of the preceding once, $da_0^i, da_1^i, da_2^i, db_0^i, db_1^i, db_2^i$ is correction value of iterative calculation of this time.

3. INTERFEROGRAM PRODUCTION AND REMOVAL OF THE PHASE OF FLAT EARTH

As we know, the single image's phase of interferometry is of little significance, phase difference between homologous image points must be obtained, namely $\Phi = W(\theta_1 - \theta_2)$, calculation indicates Φ is in the range of $[0, 2\pi)$.

Because homologous complex images may be expressed as follows:

$$\begin{aligned}
 u_1 &= |u_1|e^{j\theta_1} = a_1 + b_1i \\
 u_2 &= |u_2|e^{j\theta_2} = a_2 + b_2i \\
 u &= |u_1|e^{j\theta_2} * |u_2|e^{-j\theta_2} = |u_1||u_2|e^{j(\theta_1 - \theta_2)} \\
 \Rightarrow &= (a_1a_2 + b_1b_2) + (a_2b_1 - a_1b_2)i
 \end{aligned}
 \tag{8}$$

$$\text{So } \phi = w(\arctan[\frac{a_2b_1 - a_1b_2}{a_1a_2 + b_1b_2}])
 \tag{9}$$

According to this principle, interferogram can be produced, and its phase is fuzzy about 2π , which is made up of two parts: the phase component caused by terrain relative elevation, and that caused by flat earth. when the elevation of two points on the ground are the same, as figure(1) shows, phase difference obtained in P_1, P_2 should be equal if there is no difference in phase difference caused by flat earth. but the oblique distance image-forming characteristic of INSAR results in phase difference displacement of the two points P_1, P_2 . Therefore, any

original interferogram needs subtracting phase difference $\Delta\phi$ caused by effect of flat earth from original phase difference of each point in the distance direction. Ultimately, the removal of

phase of flat earth finishes, thus, the achieved interferogram is just the one corresponding to the topography.

And phase difference $\Delta\phi$ is :

$$\Delta\phi = 4\pi n_s \Delta r / (\lambda * r_0 * \tan\theta)
 \tag{10}$$

n_s is baseline distance component perpendicular to oblique distance, Δr oblique distance difference, r_0 the length of oblique distance, and θ the angle of incidence.

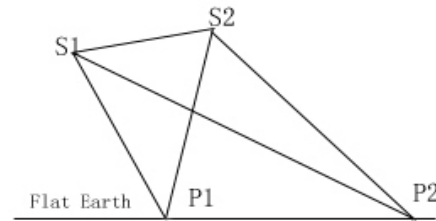


Fig.(1)

According to satellite track parameters provided by European Space Agency, the satellite track attitude may be expressed as linear function of time or low order polynomial, as the formula (11) shows:

$$X = a_0 + a_1t + a_2t^2 + a_3t^3 + a_4t^4
 \tag{11}$$

Among them: X is a coordinate (including X, Y, Z coordinate) of satellite, and T is the time.

In general, the satellite track parameters include θ_1 the angle of incidence of short distance, θ_3 the one of long distance, and θ_2 the one of middle point between θ_1 and θ_3 in the distance direction. so any angle of incidence θ in image may be expressed in formula (12):

$$\theta = ay^2 + by + c
 \tag{12}$$

Among them: y is the ratio of row coordinate and the width of the whole frame image, a, b, c is coefficient of fitting, the value of a, b, c can be calculated by $\theta_1, \theta_2, \theta_3$; Meanwhile, terrain surface is fit by using several ground control points, like the formula (13):

$$X = a_0 + a_1x + a_2y + a_3xy + a_4x^2 + a_5y^2
 \tag{13}$$

Among them: X is the coordinate (including the coordinate X, Y, Z) of points on the ground, x is the column coordinate of

image point, y is the row coordinate of corresponding image point.

In this way, as far as any point in left image is concerned, its corresponding point in the ground can be found easily, meanwhile, left satellite position at that time can be determined. Then according to matched right image, corresponding right satellite position of homologous image point may be found. And thus, oblique distance, baseline and the angle of incidence can be calculated easily. Certainly, absolute precision is low, but for the oblique distance of more than 800 kilometers, calculation result is enough to remove the effect of flat earth. Fig (2) indicates the interferogram before removing the phase of flat earth and the one after removing the phase of flat earth respectively.

4. CONCLUSION AND DISCUSSION

Because spaceborne radar has only a pair of antenna, when it receives scattering signals of same points on the ground at certain time interval, correlation of two signals received is reduced due to the natural condition change. at the same time, the complexity of geometric deformation caused by oblique distance projection, especially in the mountainous area, makes the correlation of the signal received further reduced, which results in lower phase correlation of two signals in the complex images, and greater difference between homologous image points in grey images. The two points bring extreme difficulty to precise registration of images. Data applied in the research are ERS-1, ERS-2 complex images of Zhang Bei mountainous area, and their time interval is about 24 hours. Based on the data source, the precision of registration accomplished by method described in the paper can reach 0.3 pixels or so. The high precision and the analysis of interferogram show the method put forward in the paper is basically feasible.

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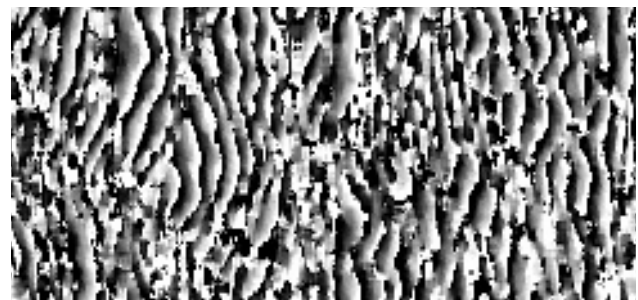
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(a)

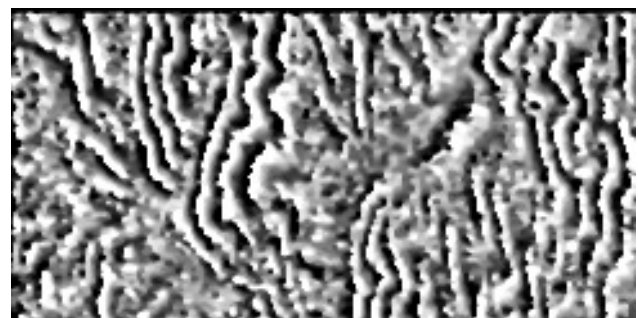


Fig.(2). (a)Original interferogram(only multiple vision processing),(b)Interferogram of removal of the phase of flat earth(processing by direction filter).