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A NEW REGISTRATION OF INTERFEROMETRIC SAR: LEAST-SQUARES REGISTRATION

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ABSTRACT Synthetic aperture radar interferometry is an imaging technique for measuring the topography of a surface, its changes over time, and other changes in the detailed characteristics of the surface.. In order to get interference patterns, the images from two satellite passes must be registered to subpixel accuracy. In the paper, we discuss the registration of two interfering SAR images based on Least-Squares method. A novel measure is proposed to compute sum of phase difference of two SAR images, and minimized to find the optimal registration parameters. The accuracy of registration based Least-Squares method is 0.05 pixel to 0.07 pixel in our test.

1.INTRODUCTION

Synthetic aperture radar interferometry is an imaging technique for measuring the topography of a surface, its changes over time, and other changes in the detailed characteristics of the surface. By exploiting the phase of the coherent radar signal, interferometry has transformed radar remote sensing from a largely interpretive science to an quantitative tool with applications in cartography, geodesy, land cover characterization, and natural hazards (Graham,1974; Massonnet,1993; Gabriel,1988).

During the interferometric processing, weighting elementary targets equally in both images require coregistering them to within a small fraction of a pixel. This operation requires large correlations, caused by different starting times of the images, different nearest distance of observation, and overall difference in viewpoint between the two images. There are mainly three methods of image registration, statistical correlation function, signal-to-noise ration (SNR) evaluation, and average fluctuation function(Madsen, 1993; Fornaro,1995;Lin,1992). The objective of this paper is to demonstrate a novel approach based Least-Squares to register the interferometric image pair. Least-Squares registration is a method of digital image registration by means of minimization of the root mean square value of the gray value differences of the registration images and achieved very high accuracy of registration (Ackermann,1983). Some parameters of transformation have been directly introduced as the values to be determined into least squares registration computation, the number of transformation parameters in this case should be sufficiently large to compensate for the radiometric and geometrical differences between the two registration windows. Here the principle of minimization of gray value difference is used instead of the conventional approach of maximization of the correlation coefficient. According to experimental results, the accuracy of determination for conjugate points by this way may reach the order of 1/50 to 1/100 pixel.

2. METHODOLOGY

The Least-Squares registration of complex SAR images is based on minimization of the root mean square value of the phase differences. Let v is the phase difference, the rules of registration are obtained as:

$$\sum vv = \min \tag{1}$$

In general, we don't consider systematic error of the phase of the images, only consider their accidental error (random noise n). We get

$$n_1 + p_1(x, y) = n_2 + p_2(x, y) \tag{2}$$

or

$$v = p_1(x, y) - p_2(x, y) \tag{3}$$

Eq.2 and eq.3 are the general models of Least-Squares registration. If we add systematic transformation parameters to general model and solve these parameters, we will obtain Least-Squares registration with systematic transformation parameters.

In this case, we only consider geometric transformation of the phase of the images. Geometric transformation, for example, the following affine transformation:

$$\begin{cases} x = a_1 + a_2 x^0 + a_3 y^0 \\ y = a_4 + a_5 x^0 + a_6 y^0 \end{cases} \tag{4}$$

where, $a_1, a_2, \ldots, a_6$ are geometrical transformation parameters.

Now let us consider the geometrical transformation as follows:

$$v = p_1(x, y) - p_2(a_1 + a_2 x^0 + a_3 y^0, a_4 + a_5 x^0 + a_6 y^0) \tag{5}$$

Eq.5 is a nonlinear function of the geometrical transformation parameters a_i .To estimate these parameters using Least- Squares method, we should linearise Eq.7,

$$v = p_1(x, y) - p_2(x^0, y^0) - dp_2(x, y) \tag{6}$$

where

$$dp_2(x, y) = \sum_{i=1}^{3} \frac{\partial p_2}{\partial x} \frac{\partial x}{\partial a_i} da_i + \sum_{i=4}^{6} \frac{\partial p_2}{\partial y} \frac{\partial y}{\partial a_i} da_i \tag{7}$$

and let

$$\begin{cases} p_{2x} = \dfrac{\partial p_2}{\partial x} \\ p_{2y} = \dfrac{\partial p_2}{\partial y} \end{cases} \tag{8}$$

Thus, we obtain

$$
\begin{aligned}
v(x,y) = & -p_{2x}(da_1 + x^0 da_2 + y^0 da_3) \\
& - p_{2y}(da_4 + x^0 da_5 + y^0 da_6) \\
& + p_1(x,y) - g(x^0, y^0)
\end{aligned} \tag{9}
$$

Eq.9 is a linear error equation. For simplified expression, let

$$
\begin{cases}
L_i = p_2(x^0, y^0) - p_1(x, y) \\
X = (da_1, da_2, \cdots, da_6)^T \\
A_i = (-p_{2x}, -p_{2x}x^0, -p_{2x}y^0, \\
\quad - p_{2y}, -p_{2y}x^0, -p_{2y}y^0)^T
\end{cases} \tag{10}
$$

where, X is a vector of correctional value of transformation parameters, L_i is a constant of ith pixel in registration window, A_i is a vector of coefficient of transformation parameters' correctional value.

Thus, linear registration error equation of ith registration pixel can be simplified as

$$
V_i = A_i X - L_i \tag{11}
$$

If there are N pixels in registration window, registration error equation can be expressed with matrix as

$$
V = AX - L \tag{12}
$$

where,

$$
\begin{cases}
V^T = (V_1, V_2, \cdots, V_N) \\
A^T = (A_1, A_2, \cdots, A_N) \\
L^T = (L_1, L_2, \cdots, L_N)
\end{cases} \tag{13}
$$

Thus, according to Least-Squares method, we can get normal equation from the error equation as

$$
A^T PA - A^T PL = 0 \tag{14}
$$

where,

$$
P = \begin{bmatrix} P_1 & & & \\ & P_2 & & \\ & & \ddots & \\ & & & P_N \end{bmatrix} \tag{15}
$$

P is the weight matrix of observation value matrix L. P_i is the weight value of observation value of ith pixel in registration window. To compute these normal equations, we can obtain the correctional value of transformation parameters as

$$
\hat{X} = (A^T PA)^{-1}(A^T PL) \tag{16}
$$

Because the weight of each pixel in registration window is same, the weight matrix is a unit matrix. The transformation parameters value a_i equal to initial value a_i^0 plus the correctional value da_i, thus the Least-Squares adjust value of the transformation parameters is

$$a_i = a_i^0 + da_i , \qquad i = 1,2,\cdots,6 \tag{17}$$

From eqs.17 and 4, we can obtain shift value of the secondly image and resample the image.

The accuracy of the registration can be estimated by unit weight variance s_0 and covariance matrix Q_{xx}.

$$k_{xx} = s_0^2 Q_{xx} = s_0^2 (A^T PA)^{-1} \tag{18}$$

where, Q_{xx} is the weight coefficient matrix of transformation parameters, and

$$s_0^2 = \frac{V^T PV}{N - M} \tag{19}$$

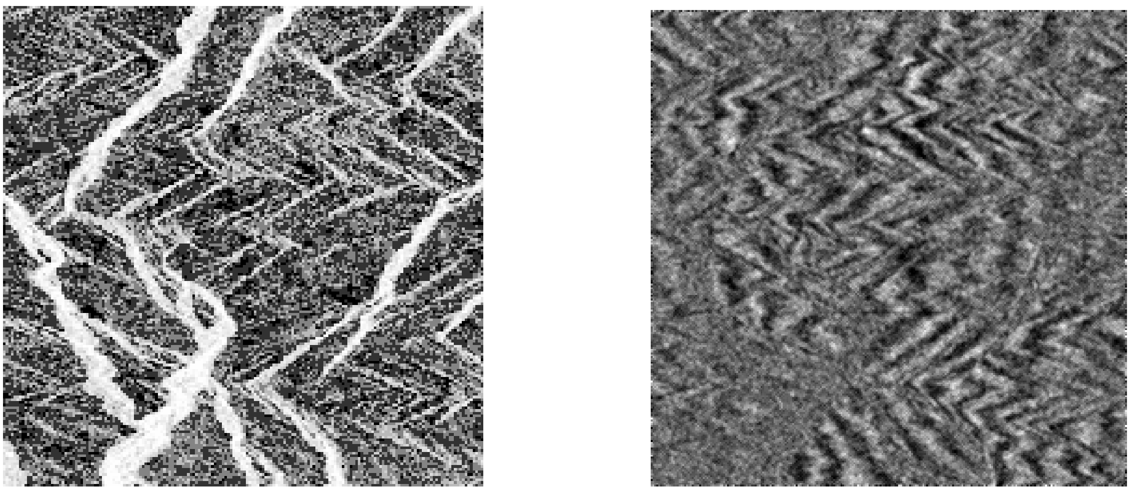
M is the size of transformation parameters, N is the size of pixel in registration window.

3.EXPERIMENTS AND RESULTS

ERS-1 and ERS-2 SAR images are selected to test our new registration method. The size of each image is 4901 pixels in the range direction, and 26042 pixels in the azimuth direction. The whole image is divided into 8*9 regions (i.e. each region is 512 pixels in range, 2575 pixels in azimuth).

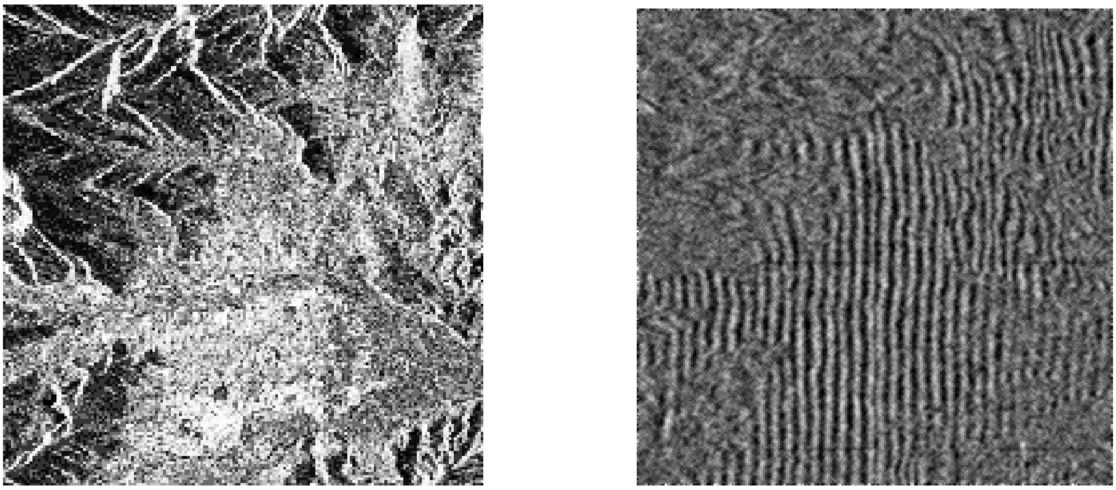
The image pair are registered by Least-Squares method. The interferogram is formed by taking the product of the complex amplitude of the ERS-1 image and the conjugate of the complex amplitude of the ERS-2 image. The interferogram was averaged by summing over five adjacent pixels in the azimuth direction, so the speckle effect was reduced, and the ground range and azimuth pixel sized were approximately the same.

The amplitude maps of ERS-1 SAR images of different regions are shown in Fig.1(a) and Fig.2(a). The phase maps acquired by SAR interferometry are shown in Fig.1(b) and Fig.2 (b).



(a) (b)

Fig.1. (a) The ERS-1 amplitude image of the mountainous region (b)The phase difference image



(a) (b)

Fig.2. (a) The ERS-1 amplitude image of the flat region (b)The phase difference image

For the general registration algorithm, we only can get a registration's quality index, e.g. the higher the coherence, the better the quality. But we can get registration's specific accuracy in the least square registration. We selected twelve registration points in six regions that can obtain better interference patterns, and computed registration's accuracy, as shown in Table1.

Table 1. The registration accuracy based on Least-Squares method

	Avg.	1	2	3	4	5	6	7	8	9	10	11	12
σ_x	.045	.038	.042	.045	.030	.073	.032	.050	.036	.040	.052	.061	.047
σ_y	.032	.028	.030	.034	.025	.042	.022	.054	.032	.038	.033	.040	.028

4.CONCLUSIONS

In the paper a new registration algorithm is presented based on the Least-Squares method. Results on real data demonstrate the excellent performance of the proposed technique. The images can be registered to an accuracy of 0.05 pixels. Although the algorithm requires more computation time than some conventional methods, the stability is improved, and the registration accuracy of each pixel can be o7btained.

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