INTERFEROMETRIC SAR CALIBRATION WITH AREA CALIBRATION SITE OF SAME HEIGHT

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1. INTRODUCTION

Interferometric parameters' calibration was a key requirement for achieving high accuracy Digital Elevation Model (DEM). Target's three-dimensional location is reconstructed by establishing the slant range vector's orthogonal basis and then rotating to geodetic coordinate system by attitude angle. Ground Control Points (GCPs)' three-dimensional location information, not only the height, is used to calibrate parameters. Except for common calibration parameters, Doppler centroid frequency is also proposed to rectify target's location error. Considering GCPs' number is limited, area calibration site of same height such as flat terrain is proposed. A scheme of establishing parameter biases and building DEM is designed. Some airborne InSAR data were used to do calibration experiments with the proposed processor. The results demonstrated its efficiency.

2. DEM RECONSTRUCTION

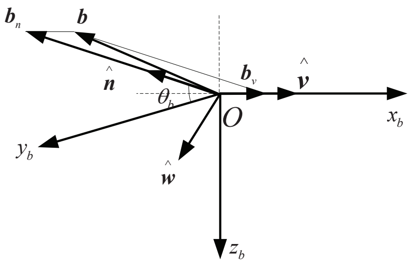

Fig.1 the slant range unit vector's orthogonal basis in motion coordinate system

As the motion coordinate system shown in Fig.1, x_b is along the flight velocity direction, z_b is pointing to the earth's core, y_b is derived by the right hand rule. We derive an orthogonal basis of unit vector $\hat{r}_1$ in the line-of-sight direction [1], and one is a unit vector $\hat{v}$ in flight velocity direction, the second is a unit vector $\hat{n}$ of baseline along the across-track direction, and the third is derived by right hand rule $\hat{w}$. The geometry implies that the radar is right side looking.

The slant range unit vector's orthogonal basis in motion coordinate system is transformed into geodetic coordinate system through the attitude rolling. Then the target's location in geodetic coordinate system can be expressed as follow.

$$
\begin{aligned}
\boldsymbol{P} &= \boldsymbol{A}_1 + r_1 \cdot \hat{\boldsymbol{r}}_1 \\
&= \boldsymbol{A}_1 + r_1 \times V R_z(-\theta_y) R_x(-\theta_r) R_y(-\theta_p) \Gamma \hat{\boldsymbol{r}}_{1vnw} \\
&= \boldsymbol{A}_1 + r_1 \times \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -1 \end{bmatrix} \begin{bmatrix} \cos\theta_y & -\sin\theta_y & 0 \\ \sin\theta_y & \cos\theta_y & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_r & -\sin\theta_r \\ 0 & \sin\theta_r & \cos\theta_r \end{bmatrix} \begin{bmatrix} \cos\theta_p & 0 & \sin\theta_p \\ 0 & 1 & 0 \\ -\sin\theta_p & 0 & \cos\theta_p \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_b & \sin\theta_b \\ 0 & -\sin\theta_b & \cos\theta_b \end{bmatrix} \begin{bmatrix} \sin\beta \\ \sin\theta_1 \\ \sqrt{1-\sin^2\beta - \sin^2\theta_1} \end{bmatrix}
\end{aligned}
\tag{1}
$$

$$
\theta_1 = \arcsin\left[\frac{b}{2r_1} - \frac{\lambda^2\varphi^2}{8b\pi^2 Q^2 r_1} - \frac{\lambda\varphi}{2b\pi Q}\right] \tag{2}
$$

$$
\sin\beta = \frac{\lambda f_{dc}}{2v} \tag{3}
$$

Where, $\boldsymbol{P}$ is target's three-dimensional location in geodetic coordinate system, $\boldsymbol{A}_1$ is the main antenna's location vector, r_1 is the slant range, θ_y θ_r θ_p are airborne attitude yaw angle, roll angle, pitch angle. θ_b is the angle between baseline vector and horizontal direction. θ_1 is look angle, β is the side-glance angle. φ is interferometric phase, Q is working mode, λ is wavelength, f_{dc} is Doppler centroid frequency , v is flight velocity.

3. AREA CALIBRATION SITE

Certain number of GCPs is needed in traditional calibration process. The GCPs' location information is obtained by measuring the target points using DGPS in fieldwork. The acquirement of GCPs in fieldwork is restricted by the terrain condition. In order to reduce the number of GCPs and keep the solution's stability simultaneously, the area calibration site of same height is proposed.

The relation of target height errors and interferometric parameter errors is built as follow[2][3],

$$
\triangle Z\Big|_{L\times 1} = \frac{\partial Z}{\partial\varphi}\bigg|_{L\times 1} \bullet \Delta\varphi + \frac{\partial Z}{\partial\theta_b}\bigg|_{L\times 1} \bullet \Delta\theta_b + \frac{\partial Z}{\partial b}\bigg|_{L\times 1} \bullet \Delta b \tag{4}
$$

Where, $\triangle Z$ is $L\times 1$ vector of height error, $\frac{\partial Z}{\partial \varphi},\frac{\partial Z}{\partial \theta_b},\frac{\partial Z}{\partial b}$ are $L\times 1$ vectors of interferometric parameters' sensitivity along range direction respectively, $\Delta\varphi$, $\Delta\theta_b$, Δb are interferometric parameter biases to be estimated, L is the pixel number of range direction in the area calibration site. Interferometric parameter biases are solved by utilizing the variation along range direction of interferometric parameters' sensitivity and the characteristic of area calibration site's same height.

According to (4), $\triangle Z\big|_{L\times 1}$ can be expressed as follow,

$$\triangle Z\big|_{L\times 1} = Z_{L\times 1}^{real} - Z_{L\times 1}^{iterative} \quad (5)$$

Where, $Z_{L\times 1}^{real}$ is the area's real height of same value, $Z_{L\times 1}^{iterative}$ is the area's iterative height. During area calibration site is used in SAR interferometry, the real height about the chosen area is not known. An estimated value of area's height is as the iterative initial value. For the solution's correct convergence, the initial height value's error is required less than 5m in our system (because the precision of interferometric phase in our system is about 0.05rad and will lead to about maximum 5m height error). After the first iteration is finished, $Z_{L\times 1}^{iterative}$ has been rectified to flat to a certain extent. So the iterative process is needed. The area's height $\left(Z_{L\times 1}^{real}\right)^{i}$ in next iterative process is updated by the mean of $\left(Z_{L\times 1}^{iterative}\right)^{i-1}$ in this iterative process (where i denotes the iterative times).

Since the pixel number involved in the formula (4) is much larger than the single GCPs' calibration, the anti-noise ability of formula (4) has been increased. The noise of interferometric phase has been reduced by averaging along azimuth direction and the solution is more stable than single GCPs' calibration.

The excellence of area calibration site can be summarized as below,

- Certain number of GCPs is not needed, or even no GCPs is needed when the area calibration site can spread enough width of the strip to express the variation along range direction of interferometric parameters' sensitivity.
- The solution is more stable than traditional calibration.
- The height of area calibration site need not to be measured by DGPS accurately, but the estimated value is needed to start the calibration process. And this point is also the main restrictive condition of using area calibration site.

4. EXPERIMENT AND RESULTS

A pair of airborne interferometric data obtained by Institute of Electronics, Chinese Academy of Sciences (IECAS) was used to do experiments. The test site is in China, which has 4096*2048 pixels (4096 in range, 2048 in azimuth) to form phase data. Initial parameters are listed in TABLE I,

TABLE I
INITIAL PARAMETERS SET

Parameters	**value**	**Parameters**	**value**
carrier frequency(GHz)	9.6	baseline length(m)	0.556
bandwidth(MHz)	120	baseline angle(rad)	0.355
altitude(m)	6000	Doppler centroid frequency (Hz)	80
working mode Q	1	interferometric phase offset (rad)	40
absolute time delay (us)	44.69	yaw angle (deg)	90.1936
flying velocity (m/s)	145.1515	Pitch angle(deg)	0

There are four processing steps in parameter bias' solution:

(1) estimate absolute time delay with all GCPs' three-dimensional location information;

(2) estimate bias of interferometric phase offset, baseline length and baseline angle with some GCPs' X and Z location information by Moore-Penrose Inverse method; estimate bias of above interferometric parameters with the area's height information by Ridge Estimate method; the final bias of above interferometric parameters is obtained by weighted processing above results.

(3) estimate bias of Doppler centroid frequency with some GCP s' Y location information by Moore-Penrose Inverse method;

(4) process of (2)~(3) is supposed to iterate by updating the parameters and starting again, and be closed until the GCPs' location errors between last time and this time reach the limit.

5. CONCLUSION

This paper proposed using target's three-dimensional location information to adjust interferometric parameters. Area calibration site of same height is proposed to replace some GCPs to calibrate interferometric parameters. The problem that sparse GCPs lead to calibrated parameters unstable is solved by this method. The adjustment of Doppler centroid frequency in calibration scheme is also proposed to build DEM more accurately. The experimental result shows that the method is efficient.

6. REFERENCE

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