AN IMPROVED CROSSTALK ESTIMATION ALGORITHM OF POLARIMETRIC AND INTERFEROMETRIC SAR CALIBRATION

Hong Zhang, Wuping Lu, Fan Wu, Chao Wang, Bo Zhang, Yixian Tang

Center for Earth Observation and Digital Earth, CAS, No. 9 Dengzhuangnan Road, Haidian District, Beijing, 100094, China

Email: hzhang@ceode.ac.cn

ABSTRACT

It is necessary to calibrate SAR data in order to use the data for science applications. When both polarimetric and interferometric data are collected simultaneously, these SAR data can be used for cross-calibration and verification. In this paper, we propose an improved algorithm to estimate the parameters stable and accurately based on the Ainsworth and the Quegan algorithms. Since there is no approximate in the process of the parameters estimation, this algorithm can accurately solve all parameters, even if the crosstalk is high. To verify the effect of proposed calibration algorithm, this paper analyzes the accuracy of proposed algorithm with Chinese airborne X-band PolinSAR data. The results confirm the proposed algorithm can solve all parameters more stable and accurately.

1. INTRODUCTION

Polarimetric SAR Interferometry (PoLinSAR) is new SAR remote sensing discipline with unique and powerful applications related to the vertical structure of natural and man-made volume scatterers. Critical to all analyses and applications of PoLinSAR is accurate calibration of the relative amplitudes of and phases between the various polarimetric channels. The calibration algorithms proposed by van Zyl in [1] and the more general approach proposed by by Quegan in [2] are today standards for phase and cross-talk calibration of polarimetric data. In 2006 Ainsworth presented an *a posteriori* means to calibrate both cross talk between channels and imbalances in the channel gains employing only the observed polarimetric SAR data without invoking reflection symmetry [3].

After lots of research and calibration experiments, we find that the Quegan algorithm can estimate parameters stable but inaccurately, while the Ainsworth's algorithm can estimate crosstalk parameters accurately but unstable. In this paper, we propose an improved algorithm to estimate the parameters stable and accurately based on the Ainsworth and the Quegan algorithms. The processing of this new algorithm is: 1) Initial the crosstalk parameters with the estimations of the Quegan algorithm; 2) Calculate the correction values of these four estimations and update the crosstalk parameters with Newton iteration method. Since there is no approximate in the process of the parameters estimation, this algorithm can accurately solve all parameters, even if the crosstalk is high. To verify the effect of proposed calibration algorithm, this paper analyzes the accuracy of proposed algorithm with Chinese airborne X-band PolinSAR data. The results confirm the proposed algorithm can solve all parameters more stable and accurately.

2. IMPROVED CALIBRATION ALGORITHM

In 2006, Ainsworth proposed an a posteriori method imposing only the weakest of constraints, scattering reciprocity, on the polarimetric data. Although Ainsworth's algorithm has many advantages, there is a theoretical flaw for solving the crosstalk parameters. The Ainsworth's algorithm uses the formula (1)-(2) for solving the crosstalk parameters.

$$\begin{bmatrix} \mathrm{Re}[X] \\ \mathrm{Im}[X] \end{bmatrix} = \begin{bmatrix} \mathrm{Re}[\varsigma+\tau] & -\mathrm{Im}[\varsigma-\tau] \\ \mathrm{Im}[\varsigma+\tau] & \mathrm{Re}[\varsigma-\tau] \end{bmatrix} \begin{bmatrix} \mathrm{Re}[\delta] \\ \mathrm{Im}[\delta] \end{bmatrix} \quad (1)$$

$$[X] = \begin{bmatrix} D_{21}-A \\ D_{31}-A \\ D_{24}-B \\ D_{34}-B \end{bmatrix} \quad \begin{aligned} A &= (D_{21}+D_{31})/2 \\ B &= (D_{24}+D_{34})/2 \end{aligned} \quad (2)$$

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Equations (1) does not actually independent, it solution is just a particular solution of the solutions of equations (3). As the initial value of the crosstalk parameters is 0, that, the crosstalk parameters estimated meet the minimum solution of equation,

$$E_{21} = E_{31}, \quad E_{24} = E_{34} \tag{3}$$

Therefore, the crosstalk parameters estimated by the method are smaller than the true vales.

In addition, the approximation is done for solving the cross parameters (u, v, w, z), retaining only the absolute term and the first term of parameters. When the crosstalk is small, this approximation is possible, but is these parameters are large, this approximation algorithm will not obtain the correct solution.

In response to the shortcomings of Ainsworth's algorithm, we present an improved algorithm, solving these crosstalk parameters using Newton's iterative method. while retaining the high order terms of these parameters.

As we know, the calibration model can be described as

$$[E] = \begin{bmatrix} & v & w & vw \\ z & 1 & wz & w \\ u & uv & 1 & v \\ uz & u & z & 1 \end{bmatrix}^{-1} [D] \begin{bmatrix} & v & w & vw \\ z & 1 & wz & w \\ u & uv & 1 & v \\ uz & u & z & 1 \end{bmatrix}^{H^{-1}} \tag{4}$$

Where, u, v, w, z are crosstalk parameters. $[D]$ is the covariance matrix with crosstalk, and $[E]$ is the covariance matrix without crosstalk.

Assuming co-polarization and cross-polarization have none correlation, Expand (4), we can get (5) as followed:

$$\begin{aligned} E_{21} &= D_{21} - wD_{41} - zD_{11} - v^* D_{22} - w^* D_{23} + \ldots = 0 \\ E_{31} &= D_{31} - uD_{11} - vD_{41} - v^* D_{32} - w^* D_{33} + \ldots = 0 \\ E_{24} &= D_{24} - wD_{44} - zD_{14} - u^* D_{22} - z^* D_{23} + \ldots = 0 \\ E_{34} &= D_{34} - uD_{14} - vD_{44} - u^* D_{32} - z^* D_{33} + \ldots = 0 \end{aligned} \tag{5}$$

Define $X, F, \Delta, u_R, u_I, v_R, v_I, w_R, w_I, z_R, z_I$ as followed:

$$\begin{aligned} X = [&\mathrm{Re}(E_{21})\,\mathrm{Re}(E_{31})\,\mathrm{Re}(E_{24})\,\mathrm{Re}(E_{34}) \\ &\mathrm{Im}(E_{21})\,\mathrm{Im}(E_{31})\,\mathrm{Im}(E_{24})\,\mathrm{Im}(E_{34})]^T \end{aligned} \tag{6}$$

$$\begin{aligned} u_R &= \mathrm{Re}(u), & v_R &= \mathrm{Re}(v), & w_R &= \mathrm{Re}(w), & z_R &= \mathrm{Re}(z), \\ u_I &= \mathrm{Im}(u), & v_I &= \mathrm{Im}(v), & w_I &= \mathrm{Im}(w), & z_I &= \mathrm{Im}(z), \end{aligned} \tag{7}$$

$$\begin{aligned} F = [&\frac{\partial(X)}{\partial(u_R)}, \frac{\partial(X)}{\partial(v_R)}, \frac{\partial(X)}{\partial(w_R)}, \frac{\partial(X)}{\partial(z_R)}, \\ &\frac{\partial(X)}{\partial(u_I)}, \frac{\partial(X)}{\partial(v_I)}, \frac{\partial(X)}{\partial(w_I)}, \frac{\partial(X)}{\partial(z_I)}] \end{aligned} \tag{8}$$

Then,

$$\Delta = F^{-1} X \tag{9}$$

Δ are the corrections of the unknown variable as,

$$\begin{aligned} [u_R] &= [u_R]_{-1} - [\Delta(1)]; \\ [u_I] &= [u_I]_{-1} - [\Delta(5)]; \\ [v_R] &= [v_R]_{-1} - [\Delta(2)]; \\ [v_I] &= [v_I]_{-1} - [\Delta(6)]; \\ [w_R] &= [w_R]_{-1} - [\Delta(3)]; \\ [w_I] &= [w_I]_{-1} - [\Delta(7)]; \\ [z_R] &= [z_R]_{-1} - [\Delta(4)]; \\ [z_I] &= [z_I]_{-1} - [\Delta(8)]. \end{aligned} \tag{10}$$

So the processing of this new algorithm is:

1) Initial u, v, w, z with the estimations of the Quegan algorithm;

2) Calculate matrix F with (5);

3) Calculate vector X with (6);

4) Calculate vector Δ with (9);

5) If each term of vector Δ is small enough, or if the number of iteration is big enough, exit the iteration; otherwise, return to 2).

Since there is no approximate process when estimate the parameters, this algorithm can accurately solve all parameters, even if the crosstalk is high.

The detailed flow scheme of the improved algorithm is shown in Fig.1

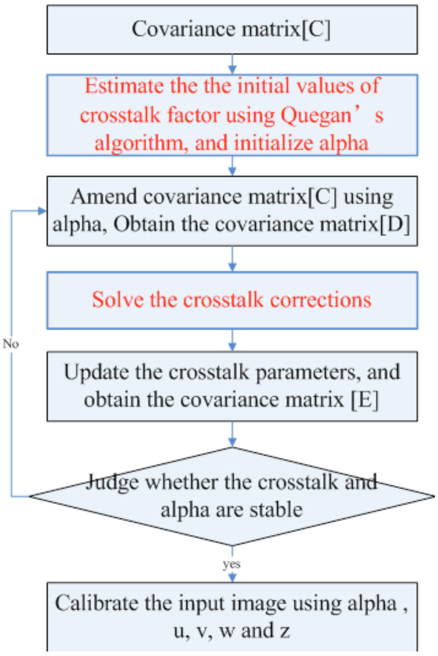


Figure 1 The detailed flow scheme of the improved algorithm

3. CALIBRATION OF CHINESE X-BAND POLINSAR DATA

To illustrate the performances of the proposed calibration method presented in Section 2, results obtained with real airborne polarimetric interferometric SLC images are reported. The Chinese PolinSAR flight took place on January , 8, 2010. It is the first dual-antenna polarimetric data in China. The instrument developed by East China Research Institute of Electronic Engineering, CETC, collected quad-pol images at X-band. The incidence angle was about 50°. The resolution of pixel is one meter. The test site is located in Lingshui Li Minority Autonomous County with a geographical position at 18°22′-18°47′ North and 109°45′-110°08′ East, Hainan province, China.

At present, many polarimetric SAR calibration algorithms are carried out for the low crosstalk data, but in practice there may be some polarimetric SAR data with high crosstalk, there is a need for calibration experiments and analysis of polarimetric SAR data with high crosstalk. Here, we define $|u|, |v|, |w|, |z| < 0.1$ as low crosstalk data, and $|u|, |v|, |w|, |z| > 0.1$as high crosstalk data.

First, we analyze the case of low crosstalk.Fig.2 shows Chinese airborne X-band PolinSAR data before and after calibration, rendered in Pauli basis. From Fig.2 we can see that, the original image is overall reddish, including vegetation area (volume scattering) and bare soil (odd scattering); after Quegan's calibration, the corresponding vegetation areas have improved, but bare soil is still reddish; Using our method, vegetation area and bare soil have their own color corresponding to the scattering mechanism.

(a) Before calibration

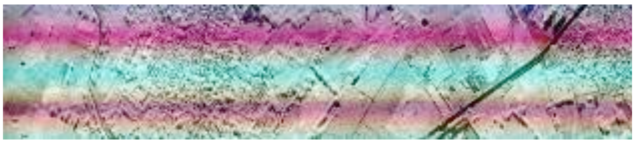
(b)Calibrated image using Quegan's method

(c)Calibrated image using our method

Figure 2 Chinese airborne X-band PolinSAR data before and after calibration rendered in Pauli basis

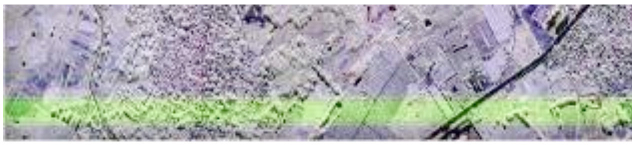
To further compare the accuracy of the calibration algorithms, we simulate a set of distorted data using real airborne X-band polinSAR data. Assuming this paper has given the whole subject of domestic airborne polarimetric SAR data simulation of a set of distorted data, assuming that the amplitudes of u, v, w, z uniformly vary in the range of (0, 0.5), the amplitude of α uniformly vary in the range of (0.9, 1.1), the phases of α, u, v, w, z uniformly vary between $\left[-\pi, \pi\right]$.The change in direction is increasing from near rang to far range.

(a) Simulated PolinSAR data with high crosstalk



(b)Calibrated image using Quegan's method

(c)Calibrated image using Anisworth's method ($A \neq 0, B \neq 0$)



(d)Calibrated image using Anisworth's method ($A = 0, B = 0$)

(e)Calibrated image using our method

Figure 3 Experimental results

Fig.2 shows the experimental results. We can conclude that,

(1) Due to crosstalk and channel imbalances, the un -calibrated data show a clear red in near range and far range, indicating that the imbalances in both ends are the largest.

(2) The results after the Quegan calibration are unreasonable, because of its inaccurate estimation of the crosstalk parameters.

(3) After the Ainsworth calibration ($A \neq 0, B \neq 0$), the red color in near-range and far-range is gone, it is related with the right estimation of channel imbalance factor. But the color in far range does not correspond with the scattering mechanism. This effect occurs because the crosstalk in far range has not been eliminated.

(4) The Ainsworth's method ($A = 0, B = 0$) solves some problems of the Ainsworth's method ($A \neq 0, B \neq 0$), but it cannot correctly estimate parameters in far range (high crosstalk range), shown in Fig.3(d). The light green in far rang is cause by wrong parameters

(5) Our algorithm solves the problems of the Ainsworth's method ($A = 0, B = 0$) .

4. CONCLUSION

In this paper, we propose an improved algorithm to estimate the parameters stable and accurately based on the Ainsworth and the Quegan algorithms. The improved algorithm solves the Ainsworth's problem in the case of the high crosstalk. The experimental results confirm the proposed algorithm can solve all calibration parameters more stable and accurately.

5. ACKNOWLEDGMENT

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6. REFERENCES

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