

Calibration of polarimetric SAR data subject to Faraday rotation using a Genetic algorithm

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1. Introduction

Recently, some spaceborne polarimetric synthetic aperture radars, such as TerraSAR X (X-band), RADARSAR-2 (C-band) and PALSAR (L-band), are available to measure a scattering matrix of terrain and polarimetric data analysis techniques are being developed for terrain classification, forest biomass and soil moisture estimations, etc. Thus polarimetric calibration is necessary to obtain the accurate results from the polarimetric SAR data [1]-[3]. In the case of spaceborne SAR, Faraday rotation affects a measurement of the polarimetric SAR data and its polarimetric calibration becomes complicated procedure. The calibration parameters are channel imbalance, cross-talk and Faraday rotation angle. Freeman proposed the polarimetric calibration method to estimate channel imbalance and Faraday rotation angle only under the condition that cross-talk is negligible and terrain has the reflection symmetry property [4].

In this paper, we propose a polarimetric calibration method to estimate all calibration parameters using a genetic algorithm [5] and polarimetric SAR data does not need to satisfy the reflection symmetry. In section 2, polarimetric calibration model affected by Faraday rotation is addressed. Next, polarimetric calibration method using the genetic algorithm is explained. Finally, we examine that the proposed method is applied to the actual polarimetric SAR data.

2. Polarimetric Calibration Model Affected by Faraday Rotation

For a spaceborne SAR system using linear horizontal (H) and vertical (V) polarizations, the polarimetric calibration model can be written as

$$\mathbf{M} = \mathbf{RFSFT} + \mathbf{n} \quad (1)$$

or

$$\begin{pmatrix} M_{HH} & M_{HV} \\ M_{VH} & M_{VV} \end{pmatrix} = \begin{pmatrix} 1 & \delta_1 \\ \delta_2 & f_1 \end{pmatrix} \begin{pmatrix} \cos \Omega & \sin \Omega \\ -\sin \Omega & \cos \Omega \end{pmatrix} \begin{pmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{pmatrix} \begin{pmatrix} \cos \Omega & \sin \Omega \\ -\sin \Omega & \cos \Omega \end{pmatrix} \begin{pmatrix} 1 & \delta_3 \\ \delta_4 & f_2 \end{pmatrix} \\ + \begin{pmatrix} n_{HH} & n_{HV} \\ n_{VH} & n_{VV} \end{pmatrix}$$

where \mathbf{S} and \mathbf{M} are the true and measured scattering matrices, \mathbf{F} represents the one-way Faraday rotation matrix, \mathbf{R} and \mathbf{T} are the receive and transmit distortion matrices of the radar system. In \mathbf{R} and \mathbf{T} the diagonal terms (f_1 and f_2) are channel imbalance and the off-diagonal terms ($\delta_1, \delta_2, \delta_3$ and δ_4) are cross-talk. A difference between airborne SAR and spaceborne SAR is an existence of Faraday rotation matrix in (1) and the airborne SAR assumes that one way Faraday rotation angle Ω is zero. \mathbf{n} is noise matrix.

A procedure for calibration of polarimetric SAR data that takes into account Faraday rotation is to estimate all parameters in \mathbf{R} , \mathbf{T} and \mathbf{F} . These parameters are composed of six

complex values and one real value. If \mathbf{R} , \mathbf{T} and \mathbf{F} are known and \mathbf{n} is ignored, the true scattering matrix can be obtained as

$$\mathbf{S} = \mathbf{F}^{-1} \mathbf{R}^{-1} \mathbf{M} \mathbf{T}^{-1} \mathbf{F}^{-1} \quad (2)$$

In [], an useful polarimetric calibration technique considering Faraday rotation was proposed by Dr. Freeman. In order to do polarimetric calibration, he uses a trihedral corner reflector and the natural distributed targets in a scene. The natural distributed targets are required to satisfy the reflection symmetry which means the co- and cross-polarized responses are uncorrelated as

$$\langle S_{HH} S_{HV}^* \rangle = \langle S_{HV} S_{VV}^* \rangle = 0 \quad (3)$$

where $\langle \rangle$ denotes an ensemble average. Moreover, his technique assumes that the cross-talks of SAR system are negligible (-30dB). Thus \mathbf{R} and \mathbf{T} are simplified as follows

$$\mathbf{R} = \begin{pmatrix} 1 & 0 \\ 0 & f_1 \end{pmatrix}, \quad \mathbf{T} = \begin{pmatrix} 1 & 0 \\ 0 & f_2 \end{pmatrix}. \quad (4)$$

In the next section, we explain a polarimetric calibration technique, which is based on a genetic algorithm (GA), to calibrate cross-talks between channels, imbalances and Faraday rotation angle using one trihedral corner reflector and the measured polarimetric SAR data without considering reflection symmetry.

3. Polarimetric Calibration Method using A Genetic Algorithm

Genetic algorithm can be used to find an approximately global optimal solution to a nonlinear optimization problem [5]. This algorithm prepares a set of candidate solutions (population) and evaluates the fitness to the objective function at each generation. If a fitness level is reached to a termination condition, it is considered that a solution is found. In order to produce a next generation, genetic algorithm uses crossover and mutation as biological evolution.

The true polarimetric SAR data is expressed as eq. (2) and consist of four polarimetric coefficients with respect to HH, HV, VH and VV. The covariance matrix $[C]$ can be obtained from these polarimetric coefficients.

$$\mathbf{k} = [S_{HH} \quad S_{HV} \quad S_{VH} \quad S_{VV}]^T \quad (5)$$

$$[C] = \langle \mathbf{k} \cdot \mathbf{k}^\dagger \rangle = \begin{bmatrix} \langle S_{HH} S_{HH}^* \rangle & \langle S_{HH} S_{HV}^* \rangle & \langle S_{HH} S_{VH}^* \rangle & \langle S_{HH} S_{VV}^* \rangle \\ \langle S_{HV} S_{HH}^* \rangle & \langle S_{HV} S_{HV}^* \rangle & \langle S_{HV} S_{VH}^* \rangle & \langle S_{HV} S_{VV}^* \rangle \\ \langle S_{VH} S_{HH}^* \rangle & \langle S_{VH} S_{HV}^* \rangle & \langle S_{VH} S_{VH}^* \rangle & \langle S_{VH} S_{VV}^* \rangle \\ \langle S_{VV} S_{HH}^* \rangle & \langle S_{VV} S_{HV}^* \rangle & \langle S_{VV} S_{VH}^* \rangle & \langle S_{VV} S_{VV}^* \rangle \end{bmatrix} \quad (6)$$

where \mathbf{k} is a target vector and \dagger is a complex conjugate transpose. When a monostatic radar system is used to observe the terrains on earth, the scattering matrix needs to satisfy scattering reciprocity meaning that S_{HV} is equal to S_{VH} . Thus, we can get some corresponding set of equations from (6) [6].

$$\langle S_{HV} S_{HV}^* \rangle = \langle S_{VH} S_{VH}^* \rangle, \quad \langle S_{HV} S_{VH}^* \rangle = \langle S_{VH} S_{HV}^* \rangle, \quad \text{Im}(\langle S_{VH} S_{HV}^* \rangle) = 0$$

$$\langle S_{HV} S_{HH}^* \rangle = \langle S_{VH} S_{HH}^* \rangle, \quad \langle S_{HV} S_{VV}^* \rangle = \langle S_{VH} S_{VV}^* \rangle \quad (7)$$

Equation (7) has to be satisfied anywhere in Polarimetric SAR data. We apply these sets to the objective function of genetic algorithm to find the polarimetric calibration parameters. Therefore, we do not need to use the reflection symmetry condition and the assumption that cross-talks are negligible. The objective function to evaluate the fitness is defined as [7]

$$f(m) = \frac{1}{N} \left\{ \begin{aligned} & \sum_{i=1}^N \left| \frac{\langle S(m)_{HV} S(m)_{HV}^* \rangle - \langle S(m)_{VH} S(m)_{VH}^* \rangle}{\langle S(0)_{HV} S(0)_{HV}^* \rangle - \langle S(0)_{VH} S(0)_{VH}^* \rangle} \right| + \sum_{i=1}^N \left| \frac{\text{Arg} \left(\frac{\langle S(m)_{HV} S(m)_{HV}^* \rangle}{\langle S(0)_{HV} S(0)_{HV}^* \rangle} \right)}{\text{Arg} \left(\frac{\langle S(0)_{HV} S(0)_{HV}^* \rangle}{\langle S(0)_{VH} S(0)_{VH}^* \rangle} \right)} \right| \\ & + \sum_{i=1}^N \left| \frac{\langle S(m)_{HH} S(m)_{HH}^* \rangle - \langle S(m)_{VH} S(m)_{VH}^* \rangle}{\langle S(0)_{HH} S(0)_{HH}^* \rangle - \langle S(0)_{VH} S(0)_{VH}^* \rangle} \right| + \sum_{i=1}^N \left| \frac{\langle S(m)_{HV} S(m)_{VV}^* \rangle - \langle S(m)_{VH} S(m)_{VV}^* \rangle}{\langle S(0)_{HV} S(0)_{VV}^* \rangle - \langle S(0)_{VH} S(0)_{VV}^* \rangle} \right| \\ & + \left| \frac{\langle S_{CR}(m)_{HH} S_{CR}(m)_{HH}^* \rangle - \langle S_{CR}(m)_{VV} S_{CR}(m)_{VV}^* \rangle}{\langle S_{CR}(0)_{HH} S_{CR}(0)_{HH}^* \rangle - \langle S_{CR}(0)_{VV} S_{CR}(0)_{VV}^* \rangle} \right| + \left| \frac{\text{Arg} \left(\frac{\langle S_{CR}(m)_{HH} S_{CR}(m)_{VV}^* \rangle}{\langle S_{CR}(0)_{HH} S_{CR}(0)_{VV}^* \rangle} \right)}{\text{Arg} \left(\frac{\langle S_{CR}(0)_{HH} S_{CR}(0)_{VV}^* \rangle}{\langle S_{CR}(0)_{HH} S_{CR}(0)_{VV}^* \rangle} \right)} \right| \end{aligned} \right\} \quad (8)$$

where N means a number of estimated area and m is a number of generation. The last two terms are related to the polarimetric coefficients of trihedral corner reflector with respect to HH and VV.

4. Experimental Results

To show the effectiveness of the proposed calibration method, two example of Advanced Land Observing Satellite (ALOS) / Phased Array type L-band SAR (PALSAR) data are given. ALOS was launched on January 24, 2006, and PALSAR is one of three sensors loaded on ALOS and first spaceborne L-band polarimetric SAR. Two data are as follows:

- 1) Tomakomai, Japan (observed on October 4, 2006, Descending path)
- 2) Nagasaki, Japan (observed on December 23, 2006, Ascending path)

When PALSAR observed both areas, trihedral corner reflector was deployed. To provide initial population, each parameter is chosen as $0.5 \leq |f| \leq 1.5$, $-\pi < \text{Arg}(f) \leq \pi$, $0.0 \leq |\delta| \leq 0.3$, $-\pi < \text{Arg}(\delta) \leq \pi$ and $-5^\circ < \Omega \leq 5^\circ$. The areas estimated in eq (8) consist of 12 areas (25×25 pixel) which are urban, mountain and firm areas. The estimation results are shown in Table 1 with JAXA(Japan Aerospace Exploration Agency)'s polarimetric calibration parameters (which are reference value). Moreover, Faraday rotation angle obtained by other technique is indicated in Table 1. Thus, f_1 , f_2 and Ω are close to reference values. Moreover, cross-talks are estimated to be small. This feature is similar to that of JAXA's cross-talks. Therefore, it is confirmed that the polarimetric calibration method using genetic algorithm can estimate not only channel imbalance and cross-talk of SAR system but also Faraday rotation angle at the same time.

5. Conclusions

This paper presented a polarimetric calibration method using a genetic algorithm. This method can estimate all polarimetric calibration parameters including Faraday rotation angle and does not need a polarimetric calibration data with reflection symmetry property. We apply the method to the polarimetric L-band data acquired by PALSAR. Thus, channel imbalance and Faraday rotation angles of Tomakomai and Nagasaki can be estimated accurately. Moreover, cross-talk is evaluated to be small. This feature is similar to that of JAXA's cross-talks.

Acknowledgments



(a) Tomakomai



(b) Nagasaki

Figure 1: PALSAR image of Tomakomai and Nagasaki, Japan, where red is $|HH-VV|$, green is $|HV|$ and blue is $|HH+VV|$.

Table 1: Polarimetric Calibration Parameters

	Proposed method		JAXA
	Tomakomai	Nagasaki	
f_1	$0.74 \angle -0.57^\circ$	$0.77 \angle 3.91^\circ$	$0.72 \angle 1.88^\circ$
f_2	$1.01 \angle 22.39^\circ$	$0.98 \angle 24.27^\circ$	$1.03 \angle 21.81^\circ$
δ_1	$0.029 \angle 97.26^\circ$	$0.040 \angle 132.21^\circ$	$0.010 \angle 131.48^\circ$
δ_2	$0.027 \angle -66.23^\circ$	$0.009 \angle -167.12^\circ$	$0.010 \angle 128.11^\circ$
δ_3	$0.015 \angle -52.64^\circ$	$0.006 \angle 35.31^\circ$	$0.013 \angle 79.37^\circ$
δ^4	$0.028 \angle 57.46^\circ$	$0.028 \angle 132.31^\circ$	$0.013 \angle -151.50^\circ$
Ω	$-1.73^\circ (-2.0^\circ)$	$0.08^\circ (-0.16^\circ)$	

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