Investigation of the capability of Compact Polarimetric SAR Interferometry to Estimate Forest Height

Hong Zhang Lei Xie Chao Wang Jiehong Chen

Center for Earth Observation and Digital Earth, CAS
E-mail: hzhong@ceode.ac.cn

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1 Introduction

Several limitations of **Full Polarimetric(FP)** system:

1. System complexity;
2. Data Downloading rate;
3. Power consumption;
4. Size of the processed swath;

Compact Polarimetry(CP) makes it possible to overcome the bottle neck of a FP system, and shows the potential in target detection, crop classification, forestry application, and environment monitoring.

1 Introduction

Three conventional modes of CP system

π/4	DCP	CTLR
• Proposed by Souyris et al. • Transmit: 45° linear • Receive: H, V linear	• Proposed by Stacy and Preiss • Transmit: left/right circular • Receive: left, right circular	• Proposed by Raney • Transmit: left/right circular • Receive: H, V linear

Two main ideas of CP data processing

Reconstruction

- Reconstruction methods: Souyris(2005),Nord(2009), Lavalle(2009) ,Collins(2012)
- Application: target detection, forest height retrieval, target decomposition

Without Reconstruction

- *m*-*δ* decomposition(2007)
- target decomposition(2010,2012)
- forest height retrieval(2008, 2011)
- target detection(2012)
- surface parameter estimation(2012)

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2 Reconstruction Method

The scattering vectors and PolInSAR covariance matrices of three conventional CP modes are expressed as:

$$k_{\pi/4} = [k_H \; k_V]^T = \frac{1}{\sqrt{2}}[S_{hh} + S_{hv} \quad S_{vv} + S_{hv}]^T$$

$$k_{DCP} = [k_R \; k_L]^T = \frac{1}{2}[S_{hh} - S_{vv} + i2S_{hv} \quad i(S_{hh} + S_{vv})]^T$$

$$k_{CTLR} = [k_H \; k_V]^T = \frac{1}{\sqrt{2}}[S_{hh} - iS_{hv} \; S_{hv} - iS_{vv}]^T$$

$$k_{cp} = [k_{cp1} \; k_{cp2}]^T \longrightarrow J_4 = \langle k_{cp} k_{cp}^H \rangle = \begin{bmatrix} J_{11} & J_{12} \\ J_{21} & J_{22} \end{bmatrix} \xrightarrow{\text{Reconstruction}} C_6$$

Take the reflection symmetry in π/4 mode for example, the matrix J_{12} is looked as observed parameters(4 equations), and matrix C_{12} (5 unknowns as listed below) is to be solved:

$$H = S_{hh_i} S^*_{hh_j}, \; X = S_{hv_i} S^*_{hv_j}, \; V = S_{vv_i} S^*_{vv_j}, \; M = S_{vv_i} S^*_{hh_j}, \; N = S_{hh_i} S^*_{vv_j}$$

$$J_{12} = \begin{bmatrix} j_{11} & j_{12} \\ j_{21} & j_{22} \end{bmatrix} = \frac{1}{2}\begin{bmatrix} H+X & N+X \\ M+X & V+X \end{bmatrix} \xrightarrow{\text{Reconstruction}} C_{12} = \begin{bmatrix} H & 0 & N \\ 0 & 2X & 0 \\ M & 0 & V \end{bmatrix}$$

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3 Experimental methods

The conventional or refined methods(Three-stage, ESPRIT, Music and Capon) will be performed on both reconstructed F-PolInSAR covariance matrix C_6 and C-PolInSAR covariance matrix J_4.

1. Three-stage

Reconstruction	Without Reconstruction
a. Obtain matrix C_6; b. Estimate a series of optimum coherence via Gomez-Dans algorithm; c. The medium filtering is applied*; d. Fitting a straight line and identify two intersection points with unitary circle; then select the volume decorrelation phase; e. Retrieve tree height from look-up table.	a. Get the initial estimation of volume decorrelation and ground phase via the coherence optimization; b. Volume decorrelation estimation is updated with coherence boundary extraction method; c. Retrieve tree height from look-up table.

* Targets in forest may not always hold the symmetry assumption, this uncertainty will bias the coherence in some scattering mechanism vectors, i.e., the interferometric coherence may exceed 1; the medium filtering here is to suppress coherence jumps.

3 Experimental methods

2. Hybrid algorithm

Reconstruction

To obtain the optimum scattering mechanisms:

$$w_{opt1} = [w_{11}, w_{12}, w_{13}]^T$$

$$w_{opt2} = [w_{21}, w_{22}, w_{23}]^T$$

Then the matrix C_{11}, C_{12}, C_{22} can be refined as:

$$w_{dopt1} = \begin{bmatrix} w_{11} & & \\ & w_{12} & \\ & & w_{13} \end{bmatrix} \quad w_{dopt2} = \begin{bmatrix} w_{21} & & \\ & w_{22} & \\ & & w_{23} \end{bmatrix}$$

$$C_{11}^{'} = w_{dopt1} C_{11} w_{dopt1}^H \quad C_{12}^{'} = w_{dopt1} C_{12} w_{dopt2}^H$$

$$C_{22}^{'} = w_{dopt2} C_{22} w_{dopt2}^H$$

With the refined matrix C_6, the ESPRIT algorithm is used to estimate volume decorrelation phase and three-stage algorithm to obtain ground phase.

Without Reconstruction

The unconstrained Lagrange multipliers are used to estimate optimum scattering mechanisms, and the scattering vectors are refined:

$$w_{opt1} = [w_{11}, w_{12}]^T \quad w_{opt2} = [w_{21}, w_{22}]^T$$

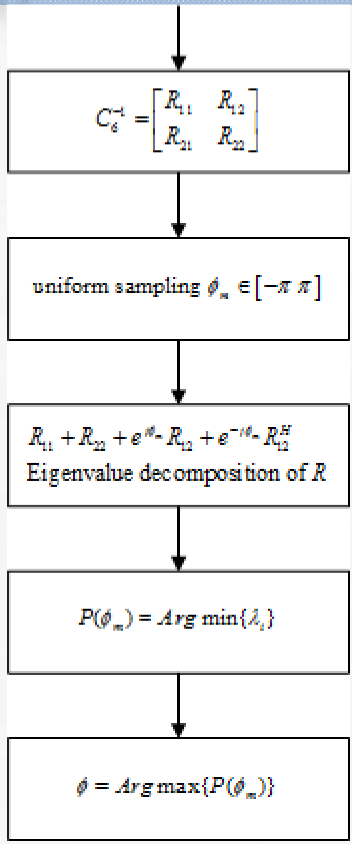
$$k_{cp}^1 = [w_{11} \square k_{cp1}^1 \ w_{12} \square k_{cp2}^1]^T$$

$$k_{cp}^2 = [w_{21} \square k_{cp1}^2 \ w_{12} \square k_{cp2}^2]^T$$

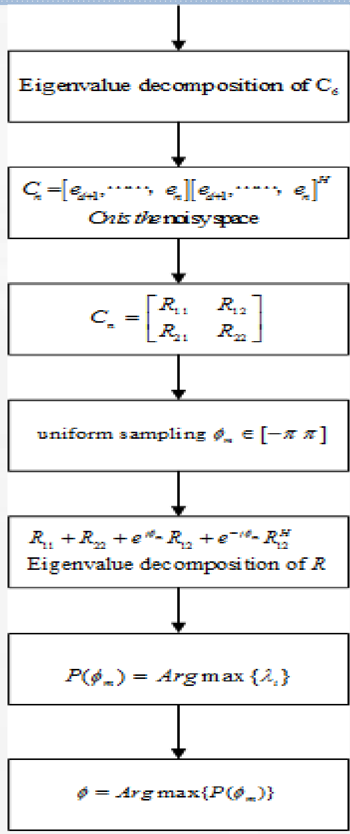
With the refined matrix J_4, ESPRIT algorithm is applied and estimate volume decorrelation phase and ground phase.

3 Experimental methods

3. Music and Capon



The flow chart of Capon algorithm



The flow chart of Music algorithm

3 Experimental results

Experiment 1

Experimental data

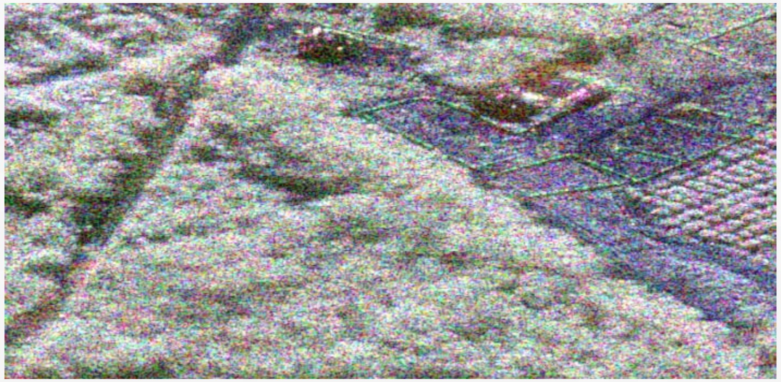
Frequency: X-band

Resolution: 1 meter

Incident Angle: 50°

Image Size： 400×1000

Site： Hainan Province, China



The Pauli decomposition result of the test area

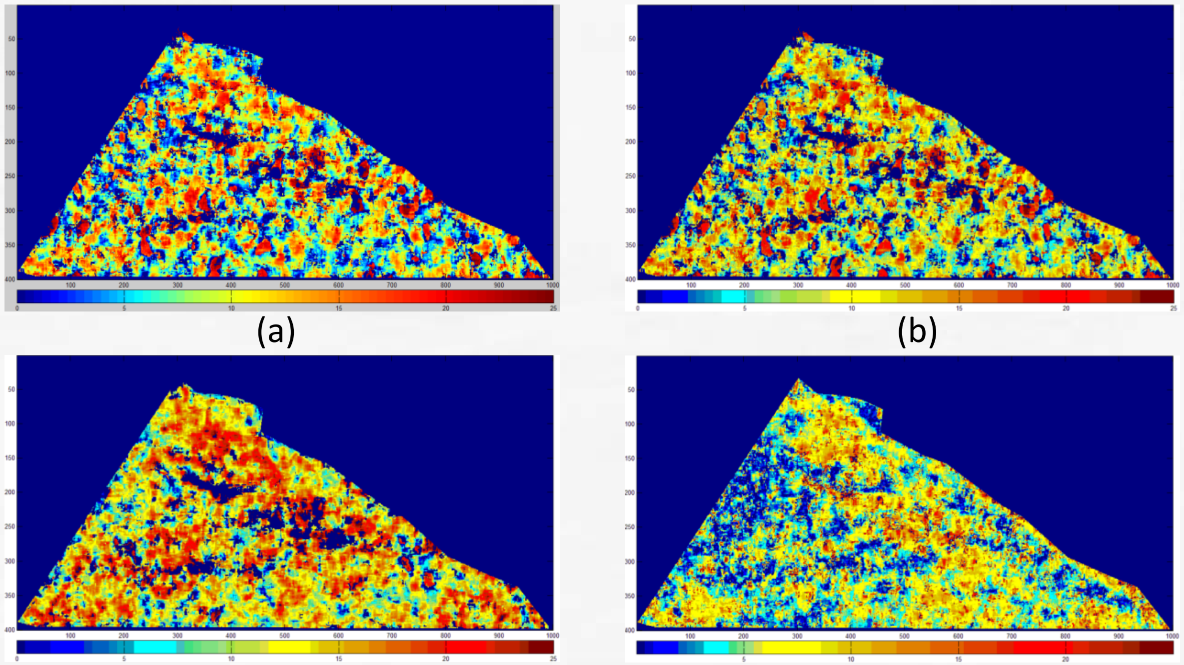
Reconstruction method: rotation symmetry in π/4 mode

Experimental Methods: Three-stage, Hybrid and refined ESPRIT algorithms

* It is the Chinese first dual-antenna airborne polarimetric data and used in compact PolInSAR for the first time.

3 Experimental results

Experiment 1



(a) (b) (c) (d)

Fig. 2. The experimental results (a) three-stage algorithm on matrix C_6; (b) hybird algorithm on matrix C_6; (c) three-stage algorithm matrix J_4; (d) refine ESPRIT algorithm on matrix J_4

3 Experimental results

Experiment 1

Table 1 Statistical result of experiment 1

Data	*Method*	*Mean(m)*	*Std(m)*
C_6	Three-stage	11.65	4.39
	Hybird	7.95	4.04
J_4	Three-stage	14.36	4.74
	ESPRIT	9.31	2.84
Insit	--	14.59	3.72

* Tree height from 5 ～25 m is counted;

Results of three-stage are much more consistent with the ground truth;

Results of hybrid and refined ESPRIT are only half of ground truth;

Results of matrix J_4 are better than that of matrix $C_{6;}$

3 Experimental results

Experiment 2

Table 2 The simulation parameters of experimental data

Platform Altitude	3000m	Slant Range Resolution	1.06m
Incident Angle	45°	Azimuth Ground Slope	2.0%
Horizontal Baseline	10.0m	Range Ground Slope	1.0%
Vertical Baseline	1.0m	Tree Height	10.0m
Centre Frequency	1.30GHz	Forest Stand Density	300 stems/Ha
Azimuth Resolution	1.5m	Forest Stand Circular Area	0.283Ha

Experimental methods: Music and Capon

3 Experimental results

Experiment 2

Table 3 Results of experiment 2

Data	*Method*	*Mean(m)*	*Std(m)*
C_6	Music	4.42	1.69
	Capon	5.19	2.5
J_4	Music	3.43	0.88
	Capon	4.03	1.24
Fully mode	Music	4.58	1.09
	Capon	3.81	1.23

*results of fully polarimetric mode are used as reference

Results of matrix C_6 and J_4 are similar with that of FP mode;

From the perspective of standard deviation, results of J_4 is much more stable than that of matrix C_6;

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In this paper, conventional and refined methods are applied to both reconstructed F-PolInSAR covariance matrix C_6 and C-PolInSAR covariance matrix J_4, X-band airborne data and L-band simulated data are used in our experiments, experimental results show:

1. Compact Polarimetry shows potential in forest height estimation;

2. Results of matrix J_4 are better than that of matrix C_6;

3. The reconstruction procedure of pseudo F-PolInSAR matrix influences the estimation results;

Thank you!