Stokes Vector Based Polarimetric SAR Data Interpretation with Coordinate Rotation

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Outline

1. Introduction

2. Stokes Vector Based PolSAR Data Interpretation

3. Proposed Method with Coordinate Rotation

4. Experimental Results

5. Conclusion
Fully Polarimetric SAR

Measurements: Scattering Matrix

\[
\begin{bmatrix}
E_{r,H} \\
E_{r,V}
\end{bmatrix} = \frac{e^{ikd}}{d} \begin{bmatrix}
S_{HH} & S_{HV} \\
S_{VH} & S_{VV}
\end{bmatrix} \begin{bmatrix}
E_{i,H} \\
E_{i,V}
\end{bmatrix}
\]

Transmitter: H & V
Receiver: H & V
The Conventional Analysis Parameter: C/T Matrix

In application, instead of the scattering matrix $S$, the second order operators are widely used for analysis.

$$S = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix}$$

Statistic averaging for power parameters

**In Pauli Basis**

$$k = \frac{1}{\sqrt{2}} \left[ S_{HH} + S_{VV} \quad S_{HH} - S_{VV} \quad 2S_{HV} \right]^T$$

$$T = \langle k \cdot k^T \rangle$$

$$= \begin{bmatrix} 2\langle A_0 \rangle & \langle C \rangle - j\langle D \rangle & \langle H \rangle + j\langle G \rangle \\ \langle C \rangle + j\langle D \rangle & \langle B_0 \rangle + \langle B \rangle & \langle E \rangle + j\langle F \rangle \\ \langle H \rangle - j\langle G \rangle & \langle E \rangle - j\langle F \rangle & \langle B_0 \rangle - \langle B \rangle \end{bmatrix}$$

**In Lexicographic Basis**

$$\Omega = \begin{bmatrix} S_{HH} & \sqrt{2}S_{HV} & S_{VV} \end{bmatrix}^T$$

$$C = \langle \Omega \cdot \Omega^* \rangle$$

$$= \begin{bmatrix} \langle |S_{HH}|^2 \rangle & \sqrt{2}\langle S_{HH}S^*_{HV} \rangle & \langle S_{HH}S^*_{VV} \rangle \\ \sqrt{2}\langle S_{HV}S^*_{HH} \rangle & 2\langle |S_{HV}|^2 \rangle & \sqrt{2}\langle S_{HV}S^*_{VV} \rangle \\ \langle S_{VV}S^*_{HH} \rangle & \sqrt{2}\langle S_{VV}S^*_{HV} \rangle & \langle |S_{VV}|^2 \rangle \end{bmatrix}$$
**C/T Metric Based Land Cover Classification**

\[ C/T = \text{classifier} \]

**Degree of Depolarization (DoP) Information cannot be used sufficiently**

Sometimes, using C matrix-based classification we can not obtain good enough result. (man-made targets, complicate terrains)

Y. Yamaguchi et al, IEEE TGRS 2011
Stokes Vector Based Land Cover Classification

\[
\begin{bmatrix}
E^r_H \\
E^r_V \\
E^i_H \\
E^i_V \\
\end{bmatrix} =
\begin{bmatrix}
S_{HH} & S_{HV} \\
S_{VH} & S_{VV} \\
\end{bmatrix}
\begin{bmatrix}
E^i_H \\
E^i_V \\
\end{bmatrix}
\Rightarrow
J =
\begin{bmatrix}
\langle E^r_H E^r_H \rangle & \langle E^r_H E^r_V \rangle \\
\langle E^r_V E^r_H \rangle & \langle E^r_V E^r_V \rangle \\
\end{bmatrix}
\Rightarrow
G =
\begin{bmatrix}
\langle g_0 \rangle \\
\langle g_1 \rangle \\
\langle g_2 \rangle \\
\langle g_3 \rangle \\
\end{bmatrix} =
\begin{bmatrix}
J_{HH} + J_{VV} \\
J_{HH} - J_{VV} \\
J_{HV} + J_{VH} \\
J_{HV} - J_{VH} \\
\end{bmatrix}
\]

\[G = A \left[ \rho G^{PO} + (1 - \rho) G^{UN} \right] \]

\[= A \left\{ \rho \begin{bmatrix}
1 \\
\tilde{g}_1 \\
\tilde{g}_2 \\
\tilde{g}_3 \\
\end{bmatrix} + (1 - \rho) \begin{bmatrix}
1 \\
0 \\
0 \\
0 \\
\end{bmatrix} \right\} \]

- Intensity: \(A\)
- Dop: \(\rho\)
- Completely polarized component: \(G^{PO}\)
- Completely un-polarized component: \(G^{UN}\)

Information: information of C/T + DoP

F. Shang, A. Hirose, TGRS 2014 & 2015
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Orientation / Aperture Routes

Completely Polarized Wave Component (Vector)

\[
G^{PO} = \begin{bmatrix}
1 \\
g_1 \\
g_2 \\
g_3
\end{bmatrix}
\]

A point on Poincare Sphere

Observe \(G^{PO}\) on Poincare Sphere

1. For serious constant of \(\phi\), observe the routes with various \(\tau\).
   
   Orientation Routes

2. For serious constant of \(\tau\), observe the routes with various \(\phi\).

Aperture Routes

http://fp.optics.arizona.edu/detlab/Research/Research.htm
Orientation / Aperture Routes
Zero Orientation / Aperture Route

Zero orientation route

\[ \phi = 0 \]

Zero aperture route

\[ \tau = 0 \]
**Extract Discriminators & Target Layers**

From $A$: sensitive to topography, especially very smooth areas

From $\rho$: express the incoherence degree of targets in a small window

From $G^{PO}$: describe scattering mechanisms, symmetric degree…
Example of The Result

- **Patch A**
- **Patch B**

- Low back scattering
- Man-made
- Low coherence
- Basic structure
Coordinate Rotation

Dihedral Model

$$S_{di} = \begin{bmatrix} \cos 2\beta & \sin 2\beta \\ \sin 2\beta & -\cos 2\beta \end{bmatrix}$$

$$\hat{v}_d, \hat{h}_d$$: coordinate system of the dihedral.

$$\hat{v}, \hat{h}$$: polarization basis of incident wave.

Coordinate system of SAR.

Local Coordinate System of Target.

Same type of target may corresponding different Stokes vector.
Proposed Method with Coordinate Rotation

Effect of Coordinate Rotation on Zero Orientation / Aperture Route

before

after

$G_{365}^{PO}$

$G_{56}^{PO}$

$G_{45}^{PO}$
Effect of Coordinate Rotation on Zero Orientation / Aperture Route

before

after
Effect of Coordinate Rotation on Zero Orientation / Aperture Route

For zero orientation routes and orientation triangles:

1) The zero orientation routes usually have different shapes before and after coordinate rotation.

2) The starting terminals of zero orientation routes before and after coordinate rotation will coincide with each other, if we rotate the original route around the z-axis of the Poincare sphere from east to west by angle $2\theta$. The ending terminals of these two routes will also coincide with each other with the same $2\theta$ angle.

F. Shang and A. Hirose, IGARSS2015
Proposed method

In a small local window, if the z coordinate of “terminal” is almost the same, we treat the all target in the small window as the same type of target.

Associative Detection
Man Made Target Detection Result (original)
Man Made Target Detection Result (with associative detection)
Final Result (Original)
Final Results (with Associative Detection)
Consider the coordinate rotation effect to implement associative detection.

- Find the same type of targets with different Stokes Vector
- Have a better final result
Relative Papers Published by Our Group

F. Shang, A. Hirose, **Averaged Stokes Vector Based Polarimetric SAR data Interpretation.** IEEE Transactions on Geoscience and Remote Sensing 53/8, 4536-4547 2015

F. Shang, A. Hirose, **Quaternion Neural-Network-Based PolSAR Land Classification in Poincare-Sphere-Parameter Space.** IEEE Transactions on Geoscience and Remote Sensing 52/9, 5693-5703 2014