Comparison of L- and X-band POLSAR Data for Characterization of Polarization Orientation Angle Shift Induced by Man-made Structure

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Shift of Polarization Orientation Angle

Induced by Ground Surface Patch
The induced polarization orientation angle shift $\theta$ is represented,

$$\tan \theta = \frac{-\tan \omega}{-\tan \gamma \cos \phi + \sin \phi}$$

Where $\tan \omega$ is the azimuth slope, $\tan \gamma$ is the range slope, $\phi$ is the radar look angle.

Induced by Dihedral Structure
Hiroshi Kimura, et al.

$$\tan \theta = \frac{-\tan \alpha}{\cos \phi}$$

Where $\tan \alpha$ is the target azimuth angle, $\phi$ is the radar look angle.
Estimation of PO Angle $\theta$ from POLSAR data

The Circular Co-Pol method:

$$\theta = \left[ \text{Arg}(O_{RR}^* O_{LL}) + \pi \right] / 4$$

For $\theta > \pi/4$, replace $\theta$ by $(\theta - \pi/2)$

Where $O_{RR}$ and $O_{LL}$ represent the observed scattering matrix of RR and LL.
Pi-SAR

New R&D for monitoring Earth Environment.

NiCT and JAXA developed Pi-SAR in 1996.

Pi-SAR: Airborne High-resolution Multi-parameter SAR

<table>
<thead>
<tr>
<th></th>
<th>X-band</th>
<th>L-band</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>9.55GHz</td>
<td>1.27GHz</td>
</tr>
<tr>
<td>Wave length</td>
<td>3.14cm</td>
<td>23.6cm</td>
</tr>
<tr>
<td>Resolution</td>
<td>1.5m</td>
<td>3m</td>
</tr>
<tr>
<td>Observation mode</td>
<td>Polarimetry [HH/HV/VH/VV]</td>
<td>Polarimetry [HH/HV/VH/VV]</td>
</tr>
</tbody>
</table>

Investigation of the frequency dependence.
The azimuth angle of dihedral structures is an important parameter which represents the characteristics of Urban area.

Investigate the properties of PO angles from the view point of wavelength.
Polarimetric Analysis of Urban Area

Difficulties, such as layover, shadowing, and multi-bounce, etc. In addition, our targets are dihedral structures.

A model fit for Urban structures.
A Model fit for Urban Structures

Polarimetric correlation coefficient

\[
\langle S_{hh}S_{hv}^* \rangle = \langle S_{hv}S_{vv}^* \rangle = 0 \quad \longleftrightarrow \quad \langle S_{hh}S_{hv}^* \rangle \neq 0, \quad \langle S_{hv}S_{vv}^* \rangle \neq 0
\]

for natural distributed area. for urban area.

Scattering Model

(1) Odd-bounce scattering

\[
[S]_{Odd} = \begin{bmatrix} \beta & 0 \\ 0 & 1 \end{bmatrix}, \quad \text{Re}(\beta) > 0
\]

where \(\beta\) is a ratio of HH to VV.

(2) Even-bounce scattering

\[
[S]_{Even} = \begin{bmatrix} \alpha & 0 \\ 0 & 1 \end{bmatrix}, \quad \text{Re}(\alpha) < 0
\]

where \(\alpha\) is a ratio of HH to VV.

(3) Cross scattering

\[
[S]_{Cross} = \begin{bmatrix} \gamma & \rho \\ \rho & 1 \end{bmatrix}, \quad \text{where} \ \gamma \ \text{and} \ \rho \ \text{are a ratio of HH and HV to VV.}
\]

Wire (Re(\(\gamma\)) > 0) or Dihedral structure (Re(\(\gamma\)) < 0).
Algorithm

\[
\langle S_{hh}S_{hh}^* \rangle = f_{\text{Odd}} |\beta|^2 + f_{\text{even}} |\alpha|^2 + f_{\text{Cross}} |\gamma|^2
\]

\[
\langle S_{vv}S_{vv}^* \rangle = f_{\text{Odd}} + f_{\text{even}} + f_{\text{Cross}}
\]

\[
\langle S_{hh}S_{vv}^* \rangle = f_{\text{Odd}} \beta + f_{\text{even}} \alpha + f_{\text{Cross}} \gamma
\]

\[
\langle S_{hv}S_{hv}^* \rangle = f_{\text{Cross}} |\rho|^2, \quad \langle S_{hh}S_{hv}^* \rangle = f_{\text{Cross}} \gamma \rho^*, \quad \langle S_{hv}S_{vv}^* \rangle = f_{\text{Cross}} \rho
\]

where \( f_{\text{Odd}}, f_{\text{Even}}, \) and \( f_{\text{Cross}} \) are the odd-bounce, even-bounce, and cross scattering contributions to \( \langle S_{vv}S_{vv}^* \rangle \), respectively.

If \( \Re(S_{hv}S_{vv}^*) > 0 \), then \( \alpha = -1 \).

If \( \Re(S_{hv}S_{vv}^*) < 0 \), then \( \beta = 1 \).

Total power \( P \) can be decomposed into the three contributions for each scattering model.

\[
P = P_{\text{Odd}} + P_{\text{Even}} + P_{\text{Cross}}
\]

\[
P_{\text{Even}} = \begin{cases} 
 f_{\text{Even}} (1 + |\alpha|^2) & \text{for } \Re(\gamma) > 0 \\
 f_{\text{Even}} (1 + |\alpha|^2) + f_{\text{Cross}} (1 + |\gamma|^2 + 2|\rho|^2) & \text{for } \Re(\gamma) < 0 
\end{cases}
\]

Not zero for Urban area
Dihedral Structures in an Image

Target azimuth angle $\alpha = 0$

$\alpha \neq 0$

500m*500m

Intensity of (HH-VV). $P_{Even}$

X-band, HH, HV, VV

X-band, HH, HV, VV
Extraction of Dihedral Structures

Right upper figure:
Pauli Polarimetric decomposition Image.
HH-VV, 2HV, HH+VV.

Right lower figure:
Binary Image. Threshold: $P_{\text{even}} > -2.0 \text{[dB]}$
PO Angle Shifts by Dihedral Structures

PO Angle Shifts

Masked PO Angle Shifts
Built-up Area

- Residential block
- L-band, HH-VV, 2HV, HH+VV
- Estimated PO Angle $\theta$
- X-band, HH-VV, 2HV, HH+VV
- Estimated PO Angle $\theta$

1250m$^2$1250m
Not Built-up Area

Large-scale buildings

500m*500m

L-band, HH-VV, 2HV, HH+VV

Estimated PO Angle $\theta$

X-band, HH-VV, 2HV, HH+VV

Estimated PO Angle $\theta$
Estimation of Target Azimuth Angle $\alpha$

Conversion of PO angle $\theta$ to target azimuth angle $\alpha$:

$$\alpha = \tan^{-1}(-\cos \phi \tan \theta)$$

where $\phi$ is the radar look angle.

Radar look angle $\phi = 40.5$ (deg)

L-band, Window Size is 3*3 pixels.

X-band, Window Size is 3*3 pixels.
Comparison of Measured and Estimated $\alpha$

Low accuracy for larger target azimuth angle $\alpha$.

Since the resolution of L- and X-band is 9m and 4.5m respectively, (window size is 3*3 pixels) X-band is effective for wider range estimation of $\alpha$. 
Summary

• The azimuth angle of man-made structure is an important parameter which represents the characteristics of Urban environment.

• We focused on PO angle shifts induced by dihedral structure formed by a vertical wall and the ground.

• We estimated the target azimuth angle from PO angle shift, and investigated the accuracy of the estimation from the viewpoint of wave length.

• As for the estimation of azimuth angle of large-scale buildings, X-band data of 3*3 pixels window size shows good accuracy.

• We will change the target and the window size for averaging.