Automated feature extraction by combining polarimetric SAR and object-based image analysis for monitoring of natural resource exploitation

Simon Plank, Alexander Mager, Elisabeth Schoepfer
Deutsches Zentrum für Luft- und Raumfahrt (DLR) | German Aerospace Center
1. Motivation

Several studies have found a positive correlation between the dependence on oil exports and violent conflicts in developing countries. Environmental destruction, social dislocation, and cost/benefit distribution between central governments and local populations are the main drivers for local conflicts.

**Purpose:** Detection and monitoring of implemented infrastructure for oil exploitation

- The aim is to identify oil infrastructure and to link this information with:
  - the development and situation of/in surrounding settlements
  - reports on past, ongoing or potential violent/armed conflict
- Earth Observation (EO) data can provide valuable information, especially in case where detailed field assessments are not possible due to security issues
2. Study area
3. Advantages of SAR vs. optical sensors

• **Active sensor** → Independent of sun light: day & night

• **Larger wavelength** → almost weather independent:
  can penetrate “normal” clouds

→ Probability to receive a useful image within a **short timeframe**
  is much higher
4. Advantages of PolSAR vs. SAR

Dual or Quad Polarimetric SAR data

- Much **more information** than with ‘simple’ single polarized SAR data
- **Better differentiation** of the **different scattering mechanisms**

→ Enables more **detailed land cover and land use classification**
5. Methodology – Automated extraction of oil well pads by means of PolSAR & OBIA (Object-based image analysis)
Step 1: Polarimetric Speckle Filtering

• **Mean (box car) filter**
  - $3 \leq N \leq 19$, $3 \leq M \leq 9$

• **Refined Lee speckle filter**
  - Searches for edges in 8 directions
  - $7 \leq N \leq 11$, $1 \leq M \leq 9$

• **Intensity-Driven Adaptive Neighborhood filter (IDAN)**
  - Region growing into areas of similar statistical properties
  - 50 pixels maximum region growing, $1 \leq M \leq 9$
Step 2: Polarimetric Decomposition (Entropy/Alpha)

Covariance Matrix $C_2$
Dual-polarimetric case (HH/VV)

\[
\langle C_2 \rangle = \begin{bmatrix}
|S_{HH}|^2 & S_{HH}S_{VV}^* \\
S_{VV}S_{HH}^* & |S_{VV}|^2
\end{bmatrix}
\]

- **Alpha $\alpha$**
  - Describes the type of backscattering

SAR polarimetry

Unsupervised Wishart $(H/\alpha)$ Classification

Polarimetric Decompositions $(H/A/\alpha)$

Unsupervised Wishart $(A/H/\alpha)$ Classification

Iteration

Lee & Pottier 2009
Step 2: Polarimetric Decomposition (Entropy/Alpha)

Covariance Matrix $C_2$
Dual-polarimetric case (HH/VV)

$$\langle C_2 \rangle = \begin{bmatrix} \left| S_{HH} \right|^2 & S_{HH} S_{VV}^* \\ S_{VV} S_{HH}^* & \left| S_{VV} \right|^2 \end{bmatrix}$$

- **Entropy $H$**
  - Represents the randomness of the scattering
  - $H = 0 \rightarrow$ Pure target (simple scattering)
  - $H = 1 \rightarrow$ random mixture of scattering mechanisms (completely depolarized)
Step 3: Unsupervised Wishart Classification

- 2 Unsupervised Wishart classifications
  - ➔ based on H/\alpha
  - ➔ based on A/H/\alpha
5. Methodology – Iterative process to find the best suited combination for the pixel-based classification

Pixel-based Classification

SAR polarimetry
- Polarimetric Speckle Filter: Mean (Box Car) - Lee Refined - IDAN
- Polarimetric Decompositions (H/A/α)

Unsupervised Wishart (H/α) Classification

Unsupervised Wishart (A/H/α) Classification

From SAR geometry to Map Projection
- Terrain Correction and Map Projection

Decision analysis
- Choose best suited parameters for H/α and for A/H/α
- H/α best Result
- A/H/α best Result

Accuracy Assessment

Iteration
6. Results – Training – PolSAR Classification

Plank et al. 2014
6. Results – Training – PolSAR Classification

Reference oil well pads
IDAN 50, M = 9, H/α

Plank et al. 2014
6. Results – Training – PolSAR Classification – $H/\alpha$

![Chart showing user's accuracy for different box sizes and other methods]
6. Results – Training – PolSAR Classification – $A/H/\alpha$

![Graph showing user's accuracy vs. M for different window sizes and methods. The graph includes lines for BoxCar and Lee refined methods with varying window sizes.](image-url)
7. Methodology – Object-based Post-Classification – refinement of the PolSAR Classification (OBIA)
7. Methodology – Object-based Post-Classification – refinement of the PolSAR Classification (OBIA)
7. Methodology – Object-based Post-Classification – refinement of the PolSAR Classification (OBIA)
7. Methodology – Object-based Post-Classification – refinement of the PolSAR Classification (OBIA)

Plank et al. 2014
8. Results – Training – OBIA Post-Classification

![Graph showing Producer's accuracy vs. User's accuracy for H/α IDAN 50 M=9x9 and A/H/α IDAN 50 M=9x9 with data points marked.]

Plank et al. 2014
8. Results – Training – OBIA Post-Classification

PolSAR Classification

Plank et al. 2014
8. Results – Training – OBIA Post-Classification

[Chart showing a scatter plot with data points indicating User's accuracy and Producer's accuracy. The points are labeled as H/α IDAN 50 M=9x9 and A/H/α IDAN 50 M=9x9.]

First s-e

Plank et al. 2014
8. Results – Training – OBIA Post-Classification

Plank et al. 2014

OBIA & Second s-e
8. Results – Training – OBIA Post-Classification

Plank et al. 2014
8. Results – Training – Final results (PolSAR & OBIA)
9. Methodology – Test on 2nd TerraSAR-X acquisition
9. Methodology – Test on 2nd acquisition → automated
10. Results – 2nd acquisition – OBIA Post-Classification

![Graph showing producer's and user's accuracy for different classes.]

- H/α IDAN 50 M=9x9
- A/H/α IDAN 50 M=9x9

Plank et al. 2014
10. Results – 2nd acquisition – OBIA Post-Classification

Plank et al. 2014
### 11. Number-based Accuracy Assessment

#### 5 September 2010 H/α

<table>
<thead>
<tr>
<th>Classification</th>
<th>Reference Data</th>
<th>∑</th>
<th>User’s Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Oil Well Pad</td>
<td>Non Oil Well Pad</td>
<td></td>
</tr>
<tr>
<td>Oil well pad</td>
<td>113</td>
<td>19</td>
<td>132</td>
</tr>
<tr>
<td>Non oil well pad</td>
<td>26</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>∑</td>
<td>139</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Producer’s accuracy</td>
<td>81.29%</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

#### 19 October 2010 H/α

<table>
<thead>
<tr>
<th>Classification</th>
<th>Reference Data</th>
<th>∑</th>
<th>User’s Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Oil Well Pad</td>
<td>Non Oil Well Pad</td>
<td></td>
</tr>
<tr>
<td>Oil well pad</td>
<td>129</td>
<td>45</td>
<td>174</td>
</tr>
<tr>
<td>Non oil well pad</td>
<td>16</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>∑</td>
<td>145</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Producer’s accuracy</td>
<td>88.97%</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
12. Conclusions

- Development of an automated feature extraction methodology to independently monitor the exploitation of natural resources.

- **Combination of unsupervised pixel-based classification & OBIA strongly increases the accuracy** of the feature extraction procedure (e.g. user’s accuracy increased from ca. 6% to >71%)

- Intensity-Driven Adaptive-Neighborhood (IDAN) filter best suited for the presented application (extraction of large, homogenous targets)

- H/α-based classification much better suited than A/H/α ➔ for dual-pol SAR data: no surplus value by anisotropy (especially valid for the presented application)
12. Conclusions

- Application on 2nd TerraSAR-X acquisition demonstrated fully transferability of the feature extraction procedure

- Outlook: Adaption of the methodology planned for Sentinel-1 imagery ➔ high frequent monitoring of the oil exploitation
The research leading to these results has received funding from the European Union’s Seventh Framework Program for research, technological development and demonstration under grant agreement No. 312912.
Thank you!