Detection of wind turbines using multi-polarization C- and X-band spaceborne SAR data

Ferrentino, Emanuele\textsuperscript{1}; Marino, Armando\textsuperscript{2}; Nunziata, Ferdinando\textsuperscript{1}; Migliaccio, Maurizio\textsuperscript{1} and Li, Xiaoming\textsuperscript{3}

\textsuperscript{1}Università di Napoli Parthenope, Italy; \textsuperscript{2}The University of Stirling, Scotland (UK); \textsuperscript{3}Chinese Academy of Sciences, China
Outline

- Motivations
- Background
- Methodology
- Experiments
Outline

- Motivations
- Background
- Methodology
- Experiments
Motivations

- Wind is a sustainable and alternative resource for producing energy and it is one of the green electricity pillars.

- A wind turbine, or alternatively referred to as a wind energy converter, is a device that converts the energy of moving air into electrical power.

- They are widely used at onshore and offshore sites.

- They are a critical infrastructure whose monitoring is an important issue for both economy and environment protection.
• Usually, the generation of energy is provided by a group of wind turbines.

• They can cover an area that extends up to hundreds of square miles.

• Field surveys results difficult and not cheap.
Outline

- Motivations
- Background
- Methodology
- Experiments
Microwave Remote Sensing

- All-day acquisitions
- Almost all-weather acquisitions
- Fine spatial resolution (SAR)

SeaSat, Image Credit: NASA/JPL
Polarimetric SAR

- Polarimetric SAR is an advanced imaging radar system.
- It plays an important role in radar remote sensing.
- With a polarimetric SAR, we can obtain much more information than conventional SAR systems.
Motivations

Background

Methodology

Experiments
- Polarimetric Notch Filter
- Change Detection Method
Coherence between the scene and the sea clutter:

\[ \gamma = \frac{1}{\sqrt{1 + \text{RedR} \frac{P_{\text{sea}}}{P_T}}} \]

- \( P_T \) Power of the “non-sea” target
- \( P_{\text{sea}} \) Power of the sea clutter
- \( \text{RedR} \) Reduction Ratio: defines the sensitivity of the detector.
If we perform change detection we have two polarimetric acquisitions:

The power of each scattering mechanism in the two acquisitions can be evaluated using projection vectors and quadratic forms:

$$\omega^T C_1 \omega$$

$$\omega^T C_2 \omega$$

We want to study how scattering mechanisms change their power between the first and second acquisitions.
**Change Detector**

**Change Matrix**

\[ C_{CD} = C_2 - C_1 \]

- \( C_1 \): Covariance matrix associated with the reference scenario (sea clutter).
- \( C_2 \): Covariance matrix associated with a moving window that scans the whole scene.

\[ \Delta = \frac{C_2 - C_1}{\lambda} \]

\[ \lambda = |\lambda_1| + |\lambda_2| + |\lambda_3| \]

where \( \lambda_i \) with \( I = 1, 2, 3 \) being the eigenvalues of \( C_{CD} \) that maximize/minimize the difference between \( C_{11} \) and \( C_{22} \).
Outline

- Motivations
- Background
- Methodology
- Experiments
Rudong County, China

Wind turbines

Google Earth ©
Datasets

RadarSAT-2 Quad Pol (HH/VV/HV/VH)
- Ascending mode
- Resolution: 4.7 m x 4.8 m
- Angle of Incidence: 29°
- C Band
- Acquisition: 10 April 2014 and 16 April 2014

TerraSAR-X Dual Pol (HH/VV)
- Ascending mode
- Resolution: 1 m x 2.4 m
- Angle of Incidence: 40°
- X Band
- Acquisition: 10 April 2014 and 16 April 2014
RadarSAT-2 VV channel
Polarimetric Notch Filter
Polarimetric Notch Filter $\gamma$

- QUAD POL
- DUAL POL HH VV
- DUAL POL VV VH
- DUAL POL HH HV

$RedR = 0.7$

10 April 2014
Experiments – RadarSAT-2

ZOOM

QUAD POL
HH VV
VV VH
HH HV
Change Detector
Change Detector $\lambda$

Quad Pol

DUAL POL HH VV

DUAL POL VV VH

DUAL POL HH HV

10 April 2014
Area between the ROC curves and the left top part

<table>
<thead>
<tr>
<th></th>
<th>R2 10/04/14</th>
<th>R2 16/04/14</th>
<th>T-X 10/04/14</th>
<th>T-X 16/04/14</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma$ FP</td>
<td>7.39e-05</td>
<td>8.52e-05</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$\gamma$ HH-VV</td>
<td>8.41e-05</td>
<td>8.53e-05</td>
<td>1.96e-05</td>
<td>1.94e-05</td>
</tr>
<tr>
<td>$\gamma$ VV-VH</td>
<td>1.07e-04</td>
<td>1.39e-04</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$\gamma$ HH-HV</td>
<td>1.10e-04</td>
<td>1.5e-04</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$\lambda$ FP</td>
<td>8.29e-05</td>
<td>1.24e-04</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$\lambda$ HH-VV</td>
<td>1.15e-04</td>
<td>1.47e-04</td>
<td>2e-05</td>
<td>1.96e-05</td>
</tr>
<tr>
<td>$\lambda$ VV-VH</td>
<td>8.28e-05</td>
<td>1.37e-04</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$\lambda$ HH-HV</td>
<td>7.71e-05</td>
<td>1.07e-04</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>NRCS HH</td>
<td>2.12e-04</td>
<td>2.81e-04</td>
<td>7.51e-05</td>
<td>7.21e-05</td>
</tr>
<tr>
<td>NRCS HV</td>
<td>1.89e-04</td>
<td>2.64e-04</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>NRCS VV</td>
<td>-</td>
<td>-</td>
<td>7.06e-05</td>
<td>7.51e-05</td>
</tr>
</tbody>
</table>
• Model-based Decomposition

• YD decomposes the measured covariance matrix $C_3$ as follows

$$C_3 = f_v < C_3 >_v + f_d < C_3 >_d + f_s < C_3 >_s + f_h < C_3 >_h$$

where $f_s$, $f_d$, $f_v$ and $f_h$ are the surface, double-bounce, volume and helix scatter contributions.
Yamaguchi Decomposition

Surface

Double Bounce

Volumetric

Helix
Yamaguchi Decomposition

Surface | Double Bounce | Volumetric | Helix
---|---|---|---
![Surface Image](image1.png) | ![Double Bounce Image](image2.png) | ![Volumetric Image](image3.png) | ![Helix Image](image4.png)

Mean scattering mechanism of wind turbines

<table>
<thead>
<tr>
<th>Surface</th>
<th>Double Bounce</th>
<th>Volumetric</th>
<th>Helix</th>
</tr>
</thead>
<tbody>
<tr>
<td>21%</td>
<td>27%</td>
<td>28%</td>
<td>24%</td>
</tr>
</tbody>
</table>
TerraSAR-X VV channel
Polarimetric Notch Filter
Polarimetric Notch Filter $\gamma$
Change Detector
Change Detector $\lambda$
ROC CURVE

10 April 2014

16 April 2014
Area between the ROC curves and the left top part

<table>
<thead>
<tr>
<th></th>
<th>R2 10/04/14</th>
<th>R2 16/04/14</th>
<th>T-X 10/04/14</th>
<th>T-X 16/04/14</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \gamma ) FP</td>
<td>7.39e-05</td>
<td>8.52e-05</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>( \gamma ) HH-VV</td>
<td>8.41e-05</td>
<td>8.53e-05</td>
<td>1.96e-05</td>
<td>1.94e-05</td>
</tr>
<tr>
<td>( \gamma ) VV-VH</td>
<td>1.07e-04</td>
<td>1.39e-04</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>( \gamma ) HH-HV</td>
<td>1.10e-04</td>
<td>1.5e-04</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>( \lambda ) FP</td>
<td>8.29e-05</td>
<td>1.24e-04</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>( \lambda ) HH-VV</td>
<td>1.15e-04</td>
<td>1.47e-04</td>
<td>2e-05</td>
<td>1.96e-05</td>
</tr>
<tr>
<td>( \lambda ) VV-VH</td>
<td>8.28e-05</td>
<td>1.37e-04</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>( \lambda ) HH-HV</td>
<td>7.71e-05</td>
<td>1.07e-04</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>NRCS HH</td>
<td>2.12e-04</td>
<td>2.81e-04</td>
<td>7.51e-05</td>
<td>7.21e-05</td>
</tr>
<tr>
<td>NRCS HV</td>
<td>1.89e-04</td>
<td>2.64e-04</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>NRCS VV</td>
<td>-</td>
<td>-</td>
<td>7.06e-05</td>
<td>7.51e-05</td>
</tr>
</tbody>
</table>
Multi polarimetric techniques have been exploited to detect wind turbines in a challenging scenario.

Polarimetric information always improve detection performance

- Detection is based on:
  - Polarimetric Notch Filter
    - Wind turbines are well detected
    - The method is computer-time effective
    - FP combination performs best
  - Change detector technique based on the difference of covariance matrices
    - Wind turbines are well detected
    - The method is not computer-time effective
    - The method turns out to be more sensitive to background variability

- Scattering analysis undertaken using YD shows that wind turbines are characterized by a non-trivial scattering mechanism.
Thank you for your kind attention

Emanuele Ferrentino
email: emanuele.ferrentino@uniparthenope.it
Dipartimento di Ingegneria
Università degli studi di Napoli “Parthenope”