Data Processing, Information Extraction and Object Recognition based on SAR Imagery
– Studies on GF-3 Satellite

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Outline

1. Introduction of GF-3 and Our Tasks
2. GF-3 data processing and analysis
3. Applications of GF-3 products
4. Summary
### 1.1 GF-3 Satellite

#### Working Mode of GF-3 Satellite

<table>
<thead>
<tr>
<th>Index</th>
<th>Imaging mode</th>
<th>Resolution (m)</th>
<th>Imaging Swath (km)</th>
<th>Incidence angle (°)</th>
<th>look Number A×R</th>
<th>Polarization mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sliding Spotlight</td>
<td>1, 1.0~1.5</td>
<td>0.9~2.5</td>
<td>10×10</td>
<td>10×10</td>
<td>20~50</td>
</tr>
<tr>
<td>2</td>
<td>Ultra-fine strip Azimuth double beam</td>
<td>3, 3</td>
<td>2.5~5</td>
<td>30</td>
<td>30</td>
<td>20~50</td>
</tr>
<tr>
<td>3</td>
<td>Fine strip 1</td>
<td>5, 5</td>
<td>4~6</td>
<td>50</td>
<td>50</td>
<td>19~50</td>
</tr>
<tr>
<td>4</td>
<td>Fine strip 2</td>
<td>10, 10</td>
<td>8~12</td>
<td>100</td>
<td>95~110</td>
<td>19~50</td>
</tr>
<tr>
<td>5</td>
<td>Standard strip</td>
<td>25, 25</td>
<td>15~30</td>
<td>130</td>
<td>95~150</td>
<td>17~50</td>
</tr>
<tr>
<td>6</td>
<td>Narrow Scan 1</td>
<td>50, 50~60</td>
<td>30~60</td>
<td>300</td>
<td>300</td>
<td>17~50</td>
</tr>
<tr>
<td>7</td>
<td>Narrow Scan 2</td>
<td>100, 100</td>
<td>50~110</td>
<td>500</td>
<td>500</td>
<td>17~50</td>
</tr>
<tr>
<td>8</td>
<td>Fully polarized strip 1</td>
<td>8, 8</td>
<td>6~9</td>
<td>30</td>
<td>20~35</td>
<td>20~41</td>
</tr>
<tr>
<td>9</td>
<td>Fully polarized strip 2</td>
<td>25, 25</td>
<td>15~30</td>
<td>40</td>
<td>35~50</td>
<td>20~38</td>
</tr>
<tr>
<td>10</td>
<td>Wave imaging mode</td>
<td>10, 10</td>
<td>8~12</td>
<td>5×5, 5×5</td>
<td>5×5</td>
<td>20~41</td>
</tr>
<tr>
<td>11</td>
<td>Global observing mode</td>
<td>500, 500</td>
<td>350~700</td>
<td>650</td>
<td>650</td>
<td>17~53</td>
</tr>
<tr>
<td>12</td>
<td>Ext. Low incidence angle</td>
<td>25, 25</td>
<td>15~30</td>
<td>130</td>
<td>120~150</td>
<td>10~20</td>
</tr>
<tr>
<td></td>
<td>Ext. High incidence angle</td>
<td>25, 25</td>
<td>20~30</td>
<td>80</td>
<td>70~90</td>
<td>50~60</td>
</tr>
</tbody>
</table>
1.2 Tasks of Our Laboratory

Tasks from China Centre For Resources Satellite Data and Application

- GF-3 Satellite product generation software
- GF-3 Satellite echo simulation software
- GF-3 Satellite calibration software

Research projects from

- GF-3 Satellite Polarization Data Processing and Analysis (Leader)
- Ground parameter inversion using GF-3 Data (participant)
- Quality enhancing of GF-3 Satellite ocean images (participant)

Most of our work focuses on the raw data processing or the post-processing, which aims to provide high quality images for further applications.
Outline

1. Introduction of GF-3 and Our Tasks
2. GF-3 data processing and analysis
3. Applications of GF-3 products
4. Summary
2.1 Sliding spotlight mode

- There are only a few orders of this mode (totally 127 scenes, about 0.243% of all orders)
- Radiometric quality of this mode, which we observed, is quite good

Data acquisition time: 2016-08-17 10:14:32
Wave band: C  Polarization mode: HH
Incidence angle: 35.40 degree
Imaging mode: (SL)
Nominal resolution: 1.0m × 1.0m
E118.0_N24.5
Haicang District, Xiamen City, Fujian Province
2.2 Standard strip mode

- This mode is frequently used

Calibration constant

<table>
<thead>
<tr>
<th>Wave No.</th>
<th>Wave code</th>
</tr>
</thead>
<tbody>
<tr>
<td>18Vp</td>
<td>56</td>
</tr>
<tr>
<td>18Pp</td>
<td>53</td>
</tr>
<tr>
<td>18Pp</td>
<td>52</td>
</tr>
<tr>
<td>18p</td>
<td>51</td>
</tr>
<tr>
<td>18p</td>
<td>50</td>
</tr>
<tr>
<td>1R8p</td>
<td>56</td>
</tr>
</tbody>
</table>

1. The system is stable, but there is a deviation between the ground test antenna pattern and the actual antenna pattern.
2. "Rainforest Estimation" correction produced a better image.
2.3 Ultra-fine strip (dual-beam)

- **Difficulty**: Dual channel error compensation
- **Processing and results**
  - External calibration is not done
  - There is residual error after the internal calibration compensation
  - As the estimation and compensation is often turned on, the detection results are basically stable

Before estimation and compensation

After
2.3 Ultra-fine strip (dual-beam)

- Difficulty: Dual channel error compensation

- Processing and results
  - External calibration is not done.
  - There is residual error after internal calibration compensation.
  - As the estimation and compensation are turned on, the detection results are basically stable.
  - In the case of low SNR, the estimated deviation will be larger.
  - Batch processing cannot solve the problem of moving targets and false targets.
2.4 Fully polarized strip mode

Processing and results:

- External calibration—limited (only 4 times): high isolation, but its amplitude and phase unbalance is not constant (different in each beam).
- We use the method of amplitude and phase error estimation based on distribution target, analyzing and monitor the amplitude and phase error of each beam, find out the error sources.

Amplitude estimation
Looking for ground objects: $\text{if } \left| hh \right|_L - \left| vv \right|_L \approx 0$
$\left| hv \right|_L - \left| vh \right|_L \approx 0$

Phase estimation
Looking for ground objects:
\[
\begin{align*}
\text{phase}\left( \langle S_{HV} S_{VH}^* \rangle \right) &\approx 0 \\
\text{phase}\left( \langle S_{HH} S_{VV}^* \rangle \right) &\approx 0
\end{align*}
\]

Limitation factors
Amplitude: $< 0.3\, \text{dB}$
Phase: $< 4\, \text{degree}$

Calibrated RadarSAT-2 image
2.4 Fully polarized strip mode

Error model

\[
\begin{bmatrix}
M_{nn} & M_{nm} \\
M_{mn} & M_{mm}
\end{bmatrix} =
\begin{bmatrix}
1 & 0 \\
0 & f_x
\end{bmatrix}
\begin{bmatrix}
1 & \delta_x \\
\delta_x & 1
\end{bmatrix}
\begin{bmatrix}
\cos \Omega & \sin \Omega \\
\sin \Omega & \cos \Omega
\end{bmatrix}
\begin{bmatrix}
\cos \varphi & \sin \varphi \\
\sin \varphi & \cos \varphi
\end{bmatrix}
\begin{bmatrix}
\xi_{11}(t, \tau) & \xi_{21}(t, \tau) \\
\xi_{21}(t, \tau) & \xi_{22}(t, \tau)
\end{bmatrix}
\begin{bmatrix}
S_{nn}(t | \tau_2, \tau) \\
S_{nm}(t | \tau_1, \tau)
\end{bmatrix}
\begin{bmatrix}
\cos \psi & -\sin \psi \\
\sin \psi & \cos \psi
\end{bmatrix}
\begin{bmatrix}
\cos \Omega & \sin \Omega \\
-\sin \Omega & \cos \Omega
\end{bmatrix}
\begin{bmatrix}
1 & \delta_x & 1 & 0 \\
\delta_x & f_x & 0 & f_x
\end{bmatrix}
\]
2.4 Fully polarized strip mode

Through in-depth analysis on the SAR payload and the antennas, we solved the problem of phase center deviation and channel delay inconsistency.

By March 30, 2017, we have updated the system and the quality of the polarized products are guaranteed.

Parameter Requirements GF-3 Data
---
Polarization isolation >35dB OK
Amplitude imbalance <0.5dB OK
Phase imbalance <10° OK
2.4 Fully polarized strip mode

- **Notice**: Different polarized channel data are quantized using different quantization peaks (see xml), see the manual for use.

\[
\text{DNimg} = \frac{\text{DN}}{\text{QualifyValue}} \times 32767
\]
2.4 Fully polarized strip mode

Range ambiguity phenomenon
2.5 ScanSAR mode

- Attitude measurement and beam pointing accuracy are not yet guaranteed that scallops are not visible.
- Using the **center frequency estimation**, in the non-uniform and low SNR region, the estimation accuracy decreases, the scallops exist.
- The noise has a large effect on the correction of the direction map, and the internal calibration has only the center beam data. At present, with the **noise estimator works**, it shows that the noise difference may be larger in the area where the signal-to-noise ratio changes violently.
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1. Introduction of GF-3 and Our Tasks
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3.1 InSAR/DInSAR Processing

- Commercial software
- Our research filter algorithm
- Coherence graph

Ground Phase removal by the original orbital data

Phase results using the processed Orbital data

rough DEM is used to remove the flat ground phase
3.1 InSAR /DInSAR Processing

Comparison: average elevation error is 4 meters in flat area, the average height error is about 30 meters in mountain area.
In Songshan mining area, mining led to ground subsidence, the red frame within the circular area shown as the ground subsidence 3 cm.

**3.1 InSAR/DInSAR Processing**

Songshan area results: using the proposed method, get a good coherent results, observed some areas of the deformation, as shown below.
3.2 Polarization Analysis and Application

GF3 Polarization Data Processing and Analysis

Research content of the project

- File
  - Create a new document
  - Open the document
  - Data read
  - Image format conversion
- Polarization quality evaluation
  - Spatial resolution quality
  - Radiation quality
  - Polarization channel quality
  - Polarization enhancement effect
- Polarization Decomposition and Synthesis
  - Coherent decomposition
  - Noncoherent decomposition
  - Fine decomposition
  - Pseudo color synthesis
- Dominant scattering coefficient separation
  - Polarization filtering and information enhancement
  - Polarization point target analysis
  - Scattered fine statistics
- Corner reflector evaluation
  - Dynamic Range
  - Noise level
  - Corner reflector evaluation
- Regional evaluation
  - Scattered fine statistics
  - Mean scattering characteristics
  - Backscatter retention capability
- Polarization information enhancement effect
  - Color factor and information entropy
  - EPI
3.2 Polarization Analysis and Application
3.2 Polarization Analysis and Application

Pauli decomposition pseudo-color image, Chongming Island area, Shanghai
3.2 Polarization Analysis and Application

Refined Freeman decomposition, Jiangsu Rudong area
3.2 Polarization Analysis and Application — Image segmentation

- Polarimetric SAR Image Segmentation Algorithm Based on Non-Gaussian Mixture Model

Non-Gaussian distribution

\[
k_n(C; L, S, q) = \begin{cases} 
  y_d^{(0)}(L) + \ln|S| - d \ln L + d \ln k_1 \\
  y_d^{(n-1)}(L) + d^n k_n(T; q) 
\end{cases} \
\]

Goodness-of-fit Testing

- The degree of fitting the model to the data sample is examined
- Avoid the initial split settings - initialize to a single class
- Automatically judge the number of categories – separate the worst fitting category
3.2 Polarization Analysis and Application ——Image segmentation

GF3's data set

C-band, Full polarization mode, Resolution 8m

<table>
<thead>
<tr>
<th>Image number</th>
<th>Size (pixels)</th>
<th>Center Point Incident (°)</th>
<th>Latitude and longitude</th>
<th>Scenes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1200*1200</td>
<td>29.3076</td>
<td>(31.1260° N, 121.8114° E)</td>
<td>Pudong Airport</td>
</tr>
<tr>
<td>2</td>
<td>1200*1200</td>
<td>29.8435</td>
<td>(30.9974° N, 121.5748° E)</td>
<td>Shanghai City</td>
</tr>
<tr>
<td>3</td>
<td>1200*1200</td>
<td>28.1484</td>
<td>(31.2684° N, 121.5187° E)</td>
<td>suburbs</td>
</tr>
<tr>
<td>4</td>
<td>1200*1200</td>
<td>36.4334</td>
<td>(33.8211° N, 120.3504° E)</td>
<td>Farmland area</td>
</tr>
<tr>
<td>5</td>
<td>1200*1200</td>
<td>35.4514</td>
<td>(34.0812° N, 120.5168° E)</td>
<td>Offshore and vessel</td>
</tr>
</tbody>
</table>
3.2 Polarization Analysis and Application

--- Image segmentation

To extract the complete structure of the airport, and to distinguish the SAR image on the more close to the airport runway and water

Separate the building with different orientations and densities in the scene

Extracted from the scene of the discrete distribution of water and construction area

Separate the vegetation coverage area and bare soil in the scene

Detection of the scene to extract the ship and other artificial targets, but the strong side of the target sideline affect the extraction results
3.3 Simulation and Interpretation of High Resolution SAR Target

- Simple shape modeling and simulating- interpreting the details of the image

\[
\begin{align*}
\begin{cases}
    P_x = r \cos \varphi_n - r h \tan \theta \tan \varphi_n \sin \varphi_n \\
    P_y = r \sin \varphi_n + r h \tan \theta \tan \varphi_n \cos \varphi_n
\end{cases}
\end{align*}
\]

Top Outer wall secondary scattering
Outer scattered
Inner wall secondary scattering

The radius of the secondary scattering arc is larger than the radius of the tank;
The inner radius of the secondary scattering arc is larger.

3.3 Simulation and Interpretation of High Resolution SAR Target

- Simple shape modeling and simulating - interpreting the details of the image

Flat roof building 1: Simulation, Measurement and Markings

Flat roof building 2: (a) Markings of feature A, B, C, D
(b) Amplitude Comparison of simulation and measurement for each feature
3.3 Simulation and Interpretation of High Resolution SAR Target

- Complex target modeling and simulating
  - Method: 3D modeling + POVRay + PO method + point target impulse response convolution According to the actual image, optimize the model parameter settings
### 3.3 Simulation and Interpretation of High Resolution SAR Target

<table>
<thead>
<tr>
<th>Building name</th>
<th>Optical image</th>
<th>SAR image</th>
<th>Actual height (m)</th>
<th>Measuring height (m)</th>
<th>Accuracy</th>
<th>Average accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shanghai Center Building</td>
<td></td>
<td></td>
<td>632.00</td>
<td>624.28</td>
<td>98.78%</td>
<td></td>
</tr>
<tr>
<td>Hong Kong Global Trade Plaza</td>
<td></td>
<td></td>
<td>484.00</td>
<td>476.33</td>
<td>98.41%</td>
<td>98.54%</td>
</tr>
<tr>
<td>Hong Kong International Financial Center Phase II</td>
<td></td>
<td></td>
<td>412.00</td>
<td>405.98</td>
<td>98.53%</td>
<td></td>
</tr>
</tbody>
</table>
3.3 Simulation and Interpretation of High Resolution SAR Target

- Three-dimensional Visualization Based on Simulation of Inverse Projection
  - **OBJECTIVE:** To establish a more intuitive connection between the SAR scattering properties and the target physical structure
  - **Use:** Interpreter training, target recognition
  - **Methods:** The relationship between the scattering point and the three-dimensional position is obtained, and the inverse projection is matched
  - **Display:** VR and other means
3.3 Simulation and Interpretation of High Resolution SAR Target

- Three-dimensional Visualization Based on Simulation of Inverse Projection

- **OBJECTIVE:** To establish a more intuitive connection between the SAR scattering properties and the target physical structure

- **Use:** Interpreter training, target recognition

- **Methods:** The relationship between the scattering point and the three-dimensional position is obtained, and the inverse projection is matched

- **Display:** VR and other means
The building is facing about 45 degrees in the direction of SAR flight, and the scattering of the building is mainly dihedral angle scattering. Since the 45 degree dihedral angle is strong in the cross polarization, the polarization is weak, Figure shows the phenomenon.
Outline

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Outline

1. Introduction of GF-3 and Our Lab’s Task
2. GF-3 data processing and analysis
3. Application of GF-3 satellite
4. Summary
4. Summary

My colleagues and I will continue to focus on the critical requirements from Gaofeng-3 application, to improve the quality of our satellite products, and to refine our information extracting toolset. Our ongoing research on calibration of system based on big data mining have also made some progress. We hope to bring more values to all customs of our SAR satellite and the up-coming constellation.
THANK YOU!