Super Resolution with GF-4 for Finer Scale Earth Observing

Dr. Feng Li
lifeng@qxslab.cn

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Backgrounds

**Gaofen 4 (GF 4)** is a geostationary disaster relief satellite in the Gaofen series of Chinese civilian remote sensing satellites, which was launched on December 28, 2015. Each snapshot covers around 400 x 400 Square kilometres. A ground resolution of 50 meters is achieved in the visible wavelengths while the mid-wavelength infrared with 400 meters.

<table>
<thead>
<tr>
<th>Channel</th>
<th>Wavelength (um)</th>
<th>Spatial resolution (m)</th>
<th>Field of view (km)</th>
<th>Revisit cycle (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visible and near-infrared</td>
<td>1</td>
<td>0.45~0.90</td>
<td>50</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.45~0.52</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.52~0.60</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>4</td>
<td>0.63~0.69</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.76~0.90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mid-wavelength infrared</td>
<td>6</td>
<td>3.5~4.1</td>
<td>400</td>
<td></td>
</tr>
</tbody>
</table>
Resolution:

Definition: the ability to detect two closely spaced objects
Twofold meaning: optical resolution and sensor resolution

The optical cutoff frequency for an imaging system is $1/\lambda F_{\#}$ (lp/mm), where $F_{\#}$ is the f-number; It limits the spatial resolution that can be imaged with sensors; The Nyquist frequency for a sensor is defined as $\text{Nyquist} = 1/2p$ (lp/mm), where $p$ is the pixel size;

Bear in mind: $\lambda F_{\#}/p=2$ is perfect, but nothing is perfect
Most of earth observing systems follows:

$\lambda F_{\#}/p < 2$

<table>
<thead>
<tr>
<th>卫星</th>
<th>$F_{#}$</th>
<th>像元尺寸 $p$ (μm)</th>
<th>$\lambda F_{#}/p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>GF-4</td>
<td>10</td>
<td>9</td>
<td>0.67</td>
</tr>
</tbody>
</table>
Super Resolution (SR)

SR: restoring a high spatial resolution image from a series of low resolution images of the same scene.

- Make full use of remote sensing resources in orbit or in disk;
- Lower the cost for the future optical remote sensing satellites;

Target detection | Disaster relief | Classification accuracy | Lower cost
Group Sparse Representations (GSR) is proposed for solving ill-conditioned problem SR, GSR is regarded as a prior for Maximum a Posteriori.
Registration is an important step in SR, an elastic registration is proposed;

Local warps inevitable caused by air turbulence and platform vibrations;
卫星运动方向

超分辨率重构

超分辨率重构

超分辨率重构

超分辨率重构

超分辨率重构

图像拼接

Moving target

Sampling efficiency improves 46%

CMOS相机获取的图像
Advantages:
- High temporal resolution
- CMOS array
- Geo-stationary
- Staring imaging

Experiments with GaoFen-4

Forbidden city
- Beijing, 3 frames within 2 days

Panchromatic band test

Original
SR (2X GSD)
Panchromatic band test

Original

Original

SR

Google Earth

Wanning, Hainan Provience, 7frames on 26 Aug, 2016
South of Hainan
Vietnam, 2018-03-04
12 images within minutes
Mid-wavelength infrared test

Different scenes contain similar noise pattern
Mid-wavelength infrared test (1)

Two neighbor pixels’ sea temperature (within 800 meters) are not suppose to have over 4°C difference.

Temperature retrieved from the SR image is more reliable.

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</thead>
<tbody>
<tr>
<td>28.2</td>
<td>28.3</td>
<td>25.7</td>
<td>28.0</td>
<td>27.3</td>
<td>27.6</td>
<td>28.1</td>
<td>26.9</td>
</tr>
<tr>
<td>28.0</td>
<td>23.9</td>
<td>26.5</td>
<td>27.8</td>
<td>27.3</td>
<td>28.0</td>
<td>27.7</td>
<td>28.1</td>
</tr>
<tr>
<td>27.8</td>
<td>27.6</td>
<td>27.6</td>
<td>27.1</td>
<td>27.3</td>
<td>27.8</td>
<td>27.5</td>
<td>27.4</td>
</tr>
</tbody>
</table>

One LR from Datacube

Interpolated the red box

The super resolved red box
Mid-wavelength infred test (2)

Central area locates the border of Vietnam and Laos

Data fusion along time series

37 frames within about 1 hour
2018-03-04 14:30:01~15:25:21
5 Conclusions

- SR benefits: Detection, Measure, Sub-pixel classification……
- SR reconstruction is possible, but … not always! (needs aliasing, accurate image registration, enough frames, …).
- Make full use of remote sensing resources in orbit or in disk; decrease the cost for the future optical remote sensing satellites
- Airborn based CMOS cameras bring hopes……
  - Digital Time Delay Integration (TDI)
  - Super Resolution
  - Modulation Transfer Function Compensation (MTF)

![Image of remote sensing equipment]

Digital TDI
SR
MTFC
Relevant publications

Journal Papers:

Books:

Patents:
[1]Group Group Sparse Representations based super resolution , 201610032463.5, Feng Li , Lei Xin , Kun Zhan , Granted