PERSPECTIVES ON CHINESE DEVELOPMENTS IN SPACEBORNE IMAGING SPECTROSCOPY: WHAT’S NEW IN 2016

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1. Introduction
2. Onboard Chinese Hyperspectral Missions
3. New Spaceborne Imaging Spectroscopy
4. Upcoming missions
5. Conclusions
Introduction

- Concept of hyperspectral remote sensing

Observing the Earth

Ground target Spectral

Soil

Water

Tree

Sorghum

Sand
Introduction

What is hyperspectral remote sensing?

- Spectral Resolution $\geq \lambda/10$ : Multi-spectral
- Spectral Resolution $\geq \lambda/100$ : Hyper-spectral
- Spectral Resolution $\geq \lambda/1000$ : Super-spectral
Why is hyperspectral remote sensing? (i)

- It offers revolutionized concepts from a spectral perspective which is completely different from traditional spatial domain-based wisdom in remote sensing community.
- It solves many problems that cannot be resolved by multispectral imaging such as subsample and mixed sample issues;

Multispectral imagery
Introduction

Why is hyperspectral remote sensing? (ii)

Hyperspectral imagery can classify 10 categories of the objects.
Introduction

Hyperspectral remote sensing a research hot spot

Number of projects supported by the NSFC from 1990 to 2016 (data taken from http://www.nsfc.gov.cn/Portal0/default152.htm).

High-quality papers related to HRS written by Chinese and world wide scientists from 1995 to 2017 (data taken from Web of Science).
Introduction

Who is interested in Hyperspectral remote sensing

[Pie chart showing distribution of main HRS application domains in China]

Distribution of the main HRS application domains in China
OUTLINE

1. Introduction
2. Onboard Chinese Hyperspectral Missions
3. New Spaceborne Imaging Spectroscopy
4. Upcoming Hyperspectral Missions
5. Conclusions
## Onboard Chinese Hyperspectral Missions

### Overview

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Spectral Coverage /µm</th>
<th>Spectral Res. /nm</th>
<th>No. of Bands</th>
<th>Available Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMODIS</td>
<td>0.4-12.5</td>
<td>20</td>
<td>34</td>
<td>2002</td>
</tr>
<tr>
<td>HJ-1A HSI</td>
<td>0.45–0.95</td>
<td>5</td>
<td>115</td>
<td>2008</td>
</tr>
<tr>
<td>FY-3 MERSI</td>
<td>0.44–0.89</td>
<td>50</td>
<td>5</td>
<td>2008</td>
</tr>
<tr>
<td></td>
<td>0.39–1.04</td>
<td>20</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.62–2.15</td>
<td>50</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10–12.5</td>
<td>2500</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Chang‘E-1 IIM</td>
<td>0.48–0.96</td>
<td>15</td>
<td>32</td>
<td>2009</td>
</tr>
<tr>
<td>TG-1 HSI</td>
<td>0.40–1.0</td>
<td>10</td>
<td>128</td>
<td>2011</td>
</tr>
<tr>
<td></td>
<td>1.0–2.5</td>
<td>23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPARK</td>
<td>0.40–1.0</td>
<td>5</td>
<td>148</td>
<td>2016</td>
</tr>
</tbody>
</table>
CMODIS: first satellite hyperspectral imager

- **No. bands**: 34, Include:
  - **Visible**: 20 (20nm, from 412 nm)
  - **NIR**: 10 (20nm, from 822 nm)
  - **SWIR**: 1 (2.150-2.250 μm)
  - **TIR**: 3 (8.40-8.90, 10.30-11.30 μm, 11.50-12.50 μm)

Launched in 25th March, 2002

A typical CMODIS image
A Constellation of 2 Small Satellites (HJ-1) was launched in Sept. 6, 2008 for Environment and Disasters Monitoring.

One of the Main Payloads on Board of the Satellite is a VIS-NIR Imaging Spectrometer (HSI)

Spec.Range: 450nm-900nm
Number of Bands: 115
Spatial Resolution: 100m
Ground Coverage: 50km
Side Looking: ±30°
Revisit: 4-31days
Radiometric Correction: Data analysis, Homogenization, Noise remove, CCD mosaic, Bands co-registration.

Geometric Correction: Geometric correction, Generating map projection.

Systematic Correction: Eliminating the influence of Attitude and Orbit parameter changes.
Onboard Chinese Hyperspectral Missions

**MERSI/ FY-3A**

Launched in 2008

A global image mosaic from MERSI with natural color and resolution of 3 km

(Courtesy: Chaohua Dong *et al*.)

Spec.Range: 0.4-12.5μm  
Spatial Resolution: 0.25-1km  
Quantization: 12 bit  
Assembling two onboard calibration systems  
Number of Bands: 20  
Scanning range: ±55.4°  
Radiometric calibration Accu. <7%
Onboard Chinese Hyperspectral Missions

Chang’E-1 IIM: for Lunar exploration

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width of Swath</td>
<td>25.6km</td>
</tr>
<tr>
<td>Spatial Resolution</td>
<td>200m</td>
</tr>
<tr>
<td>Imaging Region</td>
<td>75° N~75° S</td>
</tr>
<tr>
<td>Spectral Range</td>
<td>480~960nm</td>
</tr>
<tr>
<td>Spectral Bands</td>
<td>32</td>
</tr>
<tr>
<td>Digitization</td>
<td>12bit</td>
</tr>
<tr>
<td>MTF</td>
<td>≥0.2</td>
</tr>
</tbody>
</table>

Global lunar surface (IIM hyperspectral cube)
Onboard Chinese Hyperspectral Missions

TG-1 HSI: China’s first target vehicle

29-Sep-2011

TG-1 Image, South Australia

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral Coverage /nm</td>
<td>400-2500</td>
</tr>
<tr>
<td>Spectral Res. /nm</td>
<td>10/23</td>
</tr>
<tr>
<td>No. of Bands</td>
<td>128</td>
</tr>
<tr>
<td>MTF</td>
<td>0.34</td>
</tr>
<tr>
<td>Swath/km</td>
<td>10</td>
</tr>
<tr>
<td>SNR</td>
<td>180@1600nm</td>
</tr>
</tbody>
</table>
1. Introduction

2. Onboard Chinese Hyperspectral Missions

3. New Spaceborne Imaging Spectroscopy

4. Upcoming Hyperspectral Missions

5. Conclusions
New Spaceborne Imaging Spectroscopy

SPARK: China’s first commercial hyperspectral nano-satellite

Capture hyperspectral images with the spatial resolution of 50 meters
SPARK: China’s first commercial hyperspectral nano-satellite

The first commercial hyperspectral nano satellite (SPARK-01, SPARK-02) were launched on December 22, 2016.
New Spaceborne Imaging Spectroscopy

SPARK: China’s first commercial hyperspectral nanosatellite

- Swath: 100km@700km;
- Revisit period: 16 days;
- Spatial resolution: 50m@700km;
- Spectral range: 420~1000nm;
- Number of band: 148;
- Spectral resolution: 4nm;
- Weight: 42kg;

The first image product of SPARK-02
The images obtained by SPARK in the region of China within two months.
New Spaceborne Imaging Spectroscopy

Radiation calibration of SPARK data

- SPARK satellite
  - On-orbit calibration preparation
  - Relative radiometric calibration
  - Geometric correction
  - Absolute radiometric calibration
    - Error estimation based on radiative transfer model
      - Dark current calculation
        - Based on rectilinear flight
      - Based on the reflectivity method
        - Ground reflectance error
        - Optical thickness error
        - Aerosol error
        - Water vapor error
        - Atmospheric model error
        - SNR error
        - Other errors

End of the calibration
### New Spaceborne Imaging Spectroscopy

#### Data products of SPARK

<table>
<thead>
<tr>
<th>Product level</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 0</strong></td>
<td>Data decompression, data cutting out and disparting products</td>
</tr>
<tr>
<td><strong>Level 1</strong></td>
<td><strong>L1A</strong> Relative radiometric correction products based on L0</td>
</tr>
<tr>
<td></td>
<td><strong>L1B</strong> Absolute radiometric calibration and spectral calibration products based on L1A</td>
</tr>
<tr>
<td></td>
<td><strong>L1C</strong> Atmospheric correction products based on L1B</td>
</tr>
<tr>
<td><strong>Level 2</strong></td>
<td><strong>L2A</strong> Systematically geometric correction products based on L1A</td>
</tr>
<tr>
<td></td>
<td><strong>L2B</strong> Systematically geometric correction products based on L1B</td>
</tr>
<tr>
<td></td>
<td><strong>L2C</strong> Systematically geometric correction products based on L1C</td>
</tr>
<tr>
<td><strong>Level 3</strong></td>
<td><strong>L3A</strong> Geometric accurate correction products based on L2A</td>
</tr>
<tr>
<td></td>
<td><strong>L3B</strong> Geometric accurate correction products based on L2B</td>
</tr>
<tr>
<td></td>
<td><strong>L3C</strong> Geometric accurate correction products based on L2C</td>
</tr>
<tr>
<td><strong>Level 4</strong></td>
<td><strong>L4</strong> Orthographic correction products</td>
</tr>
<tr>
<td><strong>Level 5</strong></td>
<td><strong>L5</strong> Mosaic and fusion products</td>
</tr>
<tr>
<td><strong>Special application products</strong></td>
<td>Typical application products such as agriculture, forestry, water environmental</td>
</tr>
</tbody>
</table>
New Spaceborne Imaging Spectroscopy

- Data products of SPARK
Applications of SPARK data

Image data captured by SPARK-02 (Putnam County, Georgia, America)

Classification based on hyperspectral features
New Spaceborne Imaging Spectroscopy

Applications of SPARK data

Liaoning province, China

Wide range of land use monitoring
New Spaceborne Imaging Spectroscopy

- Applications of SPARK data

Complex terrain area - investigation of vegetation distribution
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Upcoming Hyperspectral Missions

GF-series: high-resolution satellite program

- GF-1 (2013) 2m/8m/16m
- GF-2 (2014) 1m/4m
- GF-3 (2016) CSAR
- GF-4 (2015) 50m-geostationary
- GF-5 (2017) HRS
- GF-6 (2017) Like GF-1
- GF-7 (2018) cartographic optical satellite

The GF project indicates that Chinese Earth observation enters high-resolution phase
## Upcoming Hyperspectral Missions

### GF-5

<table>
<thead>
<tr>
<th>Sensors</th>
<th>HyperSpectral Camera (VNIR, SWIR)</th>
<th>Full-spectrum spectral imager</th>
<th>Greenhouse gas detector</th>
<th>Atmospheric environment NIR hyperspectral detector</th>
<th>Atmospheric trace-gas absorption spectrometer</th>
<th>Aerosol Multi-angle polarization detectors</th>
</tr>
</thead>
</table>
| Spec. range | **VNIR:** 0.4μm-0.9μm  
**SWIR1:** 0.9μm-1.75μm  
**SWIR2:** 1.75μm-2.5μm | **VNIR:** 0.45μm  
**SWIR1:** 0.765μm (O₂)  
**SWIR2:** 1.575μm (CO₂) | **VNIR:** 750～4100cm⁻¹  
**SWIR1:** 240～315nm  
**SWIR2:** 750～4100cm⁻¹  
**SWIR1:** 240～315nm | **VNIR:** 433-453nm  
**SWIR1:** 480-500nm (P)  
**SWIR2:** 660-680nm (P)  
**SWIR2:** 758-768nm  
**SWIR2:** 745-785nm  
**SWIR2:** 845-885nm (P)  
**SWIR2:** 900-920nm | **VNIR:** 433-453nm  
**SWIR1:** 480-500nm (P)  
**SWIR2:** 660-680nm (P)  
**SWIR2:** 758-768nm  
**SWIR2:** 745-785nm  
**SWIR2:** 845-885nm (P)  
**SWIR2:** 900-920nm | **VNIR:** 433-453nm  
**SWIR1:** 480-500nm (P)  
**SWIR2:** 660-680nm (P)  
**SWIR2:** 758-768nm  
**SWIR2:** 745-785nm  
**SWIR2:** 845-885nm (P)  
**SWIR2:** 900-920nm |
| Spec.Res | **VNIR:** 5nm  
**SWIR:** 10nm | **VNIR:** 0.06um~1.1um  
**SWIR1:** 0.6cm⁻¹ (O₂)  
**SWIR2:** 0.27cm⁻¹ (CO₂, CH₄) | **VNIR:** 0.03cm⁻¹ | **VNIR:** 0.3～0.5nm | **VNIR:** 0.3～0.5nm | **VNIR:** 0.3～0.5nm |
| Spatial Res | **VNIR:** 20m  
**M-LWIR:** 40m | **VNIR:** 14.6mrad  
**M-LWIR:** IFOV: 1.25mrad | **VNIR:** IFOV: 1.25mrad | **VNIR:** 48km (across orbit) × 13km (orbit direction) | **VNIR:** 3.5km | **VNIR:** 3.5km |
| Swath | **VNIR:** ≥200  
**SWIR1:** ≥150  
**SWIR2:** ≥100 | **VNIR:** 60km  
**M-LWIR:** 60km | **VNIR:** -- | **VNIR:** -- | **VNIR:** -- | **VNIR:** -- |
| SNR | **VNIR:** ≥200  
**SWIR1:** ≥150  
**SWIR2:** ≥100 | **VNIR:** ≥200  
**M-LWIR:** NEΔT≤0.2K | ≥300@p=30% (O₂, CO₂)  
≥250@p=30% (CH₄, CO₂) | >100(@5800K) | -- | >500 (Land) |
Upcoming Hyperspectral Missions

CarbonSat: Super-spectral spectrometer

Objective: Global carbon cycle monitoring by integrating vegetation reflectance and sun-induced fluorescence emission flux.

The finer the spectral resolution, the deeper the Fraunhofer Lines

A balance between SNR and Spectral resolution
### Upcoming Hyperspectral Missions

<table>
<thead>
<tr>
<th>Sensor Parameters</th>
<th>GOSAT</th>
<th>OCO-2</th>
<th>GOME-2</th>
<th>SCIAMACHY</th>
<th>CarbonSat</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data Acquisition</strong></td>
<td>Non-imaging</td>
<td>Non-imaging</td>
<td>Non-imaging</td>
<td>Non-imaging</td>
<td>Imaging</td>
</tr>
<tr>
<td><strong>Launch time</strong></td>
<td>2009</td>
<td>2014</td>
<td>2006</td>
<td>2002</td>
<td>2020</td>
</tr>
<tr>
<td><strong>Overpass time</strong></td>
<td>13:00</td>
<td>13:00</td>
<td>9:30</td>
<td>10:00</td>
<td>10:00</td>
</tr>
<tr>
<td><strong>Visit circle</strong></td>
<td>3 day</td>
<td>16 day</td>
<td>1.5 day</td>
<td>6 day</td>
<td>27 d</td>
</tr>
<tr>
<td><strong>Spectral range</strong></td>
<td>757 – 775 nm</td>
<td>650 – 790 nm</td>
<td>670 - 780 nm</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>FWHM</strong></td>
<td>0.025 nm</td>
<td>0.05 nm</td>
<td>0.5 nm</td>
<td></td>
<td>~0.3 nm</td>
</tr>
<tr>
<td><strong>Spatial resolution</strong></td>
<td>10 km</td>
<td>1.3×2.25 km</td>
<td>40×80 km</td>
<td>30×40 km</td>
<td>300 m</td>
</tr>
<tr>
<td><strong>SNR</strong></td>
<td>&gt;300 (30%, SZA=30°)</td>
<td>360 (5%, SZA=60°)</td>
<td>&gt;1000</td>
<td>3000</td>
<td>&gt;200</td>
</tr>
</tbody>
</table>
New MDD format for time series image data storage

- MDD is a multi-dimensional data storage format that can integrate the temporal, spatial, and spectral features of remote sensing data. The MDD has two files: a header file and a data file.

### Head File
- Spatial, spectral and temporal size of the dimension
- The storage format used in the data file
- Coordinate projection and affine transformation coefficients
- The storage type of the data
- The name of spectral and temporal dimension
- File name and type, data offset, and so on

### Data File
- TSB
- TSP
- TIB
- TIP
- TIS
Upcoming Hyperspectral Missions

- New *.mdd multidimensional storage structures

- 5 MDD structure, TSB, TSP, TIB, TIP, TIS
Multidimensional analysis software: MARS V1.0

MARS is a computer software, which can be used for MDD data building, opening, display, processing, analysis and output.

Free download for all users on the website: http://www.geodoi.ac.cn

Visualization of time series spectral features

Multi-dimensional analysis module
Inter-operational tool for Temporal-Spatial Data Analysis in Multi-Dimension Data Format (.mdd)

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HUANG Changping$^{1}$, YANG Hang$^{1}$, ZHANG Hongming$^{1}$, LIU Jia$^{1}$
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Published: Jun. 2017

Visitors: 110  Data Files Downloaded: 58
Data Downloaded: 295.99 MB  Citations:
Conclusions

- What’s new in 2016 and 2017:
  - China launched the first commercial hyperspectral nano-Satellite: SPARK, in 2016;
  - Chinese GF-5 hyperspectral satellite will be launching in Aug. 2017;
  - Chinese Carbon Satellite is undergoing demonstration research;
  - We defined a new multidimensional remote sensing data structure for time-series analysis;
  - We published our multidimensional analysis software, which can be download at

http://www.geodoi.ac.cn/WebEn/doi.aspx?Id=702
Thank you!

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