INSTRUMENT DEVELOPMENT STATUS AND PERFORMANCES OF HYPERSPECTRAL IMAGER SUITE (HISUI) -Onboard Data Correction-

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1. HISUI Instrument Overview

**HISUI (Hyperspectral Imager SUIte)**

- Japanese earth observation project for resource exploration, vegetation and environment monitoring
- Follow-on mission of ASTER (Advanced Spaceborne Thermal Emission and reflection Radiometer) onboard TERRA
- Consists of 2 instruments
  - Hyperspectral sensor (185 bands from VIS to SWIR)
  - Multispectral sensor (4 bands of VNIR)

HISUI (Hyperspectral Imaging SUrface) = "jade" in Japanese

http://www.moonmadness.jp/itoigawahisui.html
### HISUI Specifications

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Hyperspectral sensor</th>
<th>Multispectral sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VNIR</td>
<td>SWIR</td>
</tr>
<tr>
<td>Spatial Scanning</td>
<td>Push broom type by satellite moving</td>
<td>Same as left</td>
</tr>
<tr>
<td>IFOV (Spatial resolution)</td>
<td>48.5 u.rad (30 m)</td>
<td>8.1 u.rad (5 m)</td>
</tr>
<tr>
<td>FOV (swath width)</td>
<td>48.5 m.rad (30 km)</td>
<td>144.7 m.rad (90 km)</td>
</tr>
<tr>
<td>Observation frequency</td>
<td>&lt; 4.36 ms</td>
<td>&lt; 0.73 ms</td>
</tr>
<tr>
<td>Wavelength region and number of bands / Center wave length</td>
<td>400-970 nm (57 bands)</td>
<td>900-2500 nm (128 bands)</td>
</tr>
<tr>
<td>Spectral resolution (sampling) for Hyper</td>
<td>10 nm</td>
<td>12.5 nm</td>
</tr>
<tr>
<td>Spectral Band width for Multi</td>
<td>Same as band width</td>
<td></td>
</tr>
<tr>
<td>Spectral resolution (ILS FWHM)</td>
<td>&lt; 11 nm</td>
<td>&lt; 16 nm</td>
</tr>
<tr>
<td>Dynamic range</td>
<td>Saturated at &gt; 70% albedo</td>
<td>Same as left</td>
</tr>
<tr>
<td>SNR</td>
<td>&gt;450 (@620 nm)</td>
<td>&gt;300 (@2100 nm)</td>
</tr>
<tr>
<td>MTF</td>
<td>&gt;0.2</td>
<td>&gt;0.3</td>
</tr>
<tr>
<td>Smile and Keystone</td>
<td>&lt; 1 image pixel</td>
<td>N/A</td>
</tr>
<tr>
<td>Calibration accuracy (radiometric)</td>
<td>Absolute:±5%, Among bands:±2%</td>
<td>Same as left</td>
</tr>
<tr>
<td>Calibration accuracy (spectral)</td>
<td>&lt; 0.2 nm</td>
<td>&lt; 0.625 nm</td>
</tr>
<tr>
<td>Quantization</td>
<td>12 bit</td>
<td>Same as left</td>
</tr>
<tr>
<td>Mission life</td>
<td>5 years</td>
<td>Same as left</td>
</tr>
</tbody>
</table>
1. HISUI Instrument Overview

HISUI Functional Block Diagram

**Hyperspectral Imager**
- Fore optics
- VNIR Spectrometer
- VNIR Detector
- VNIR Signal Processor
- SWIR Spectrometer
- SWIR Detector
- SWIR Signal Processor
- SWIR Cooling Unit
- Calibration Unit
- Power Supply
- Hyper Electronics Unit (HELU)

**Multispectral Imager**
- Fore optics
- Detector
- Signal Processor
- Multi Electronics Unit (MELU)
- Calibration Unit
- Power Supply
1. HISUI Instrument Overview

HISUI Hyperspectral Sensor Function Diagram

- **Observing Light**
  - Hyper Spectral Sensor System (HISUI)
  - Hyper-spectral scanning radiometer unit (HSRU)

- **VNIR/SWIR Detectors**
  - VNIR/SWIR Spectrographs
  - VNIR/SWIR Detectors

- **Electronics Unit**
  - VNIR science signal
  - SWIR science signal
  - Primary Power supply
  - Telemetry & Command interface

- **VNIR/SWIR Signal Processors**
  - VNIR Signal processor (VSP)
  - SWIR Analogue Signal Processor (SASP)

- **Telescope**
  - Light from the Earth

- **Other Components**
  - Hyper calibration electronics (HCALE)
  - Cooler control electronics (CCE)
  - HYPER heater control electronics (HHCE)
1. HISUI Instrument Overview

**Hyperspectral Sensor Unit**

- **Optical Calibrator**
- **Telescope (TMA)**
- **SLIT**
- **VNIR Grating Spectrometer (Offner)**
- **SWIR Grating Spectrometer (Offner)**
- **Si-CMOS 2D-Detector**
- **MCT 2D-Detector**
- **Stirling Cooler**

- **Three-Mirror Anastigmat Telescope**
- **Light Beam**
- **Incident Light**
- **VNIR Spectrometer Sub-assembly**
- **Signal Processor**
- **SWIR Spectrometer Sub-assembly**
1. HISUI Instrument Overview

Design of Hyperspectral Sensor Unit

Design for The Telescope and Spectrograph

- **Telescope**
  - TMA (off-axis three mirror anastigmat type)
  - The diameter of telescope is approximately 30cm and the F-number is 2.2. It is matched for the ground sampling distance (GSD) of 30 meters.

- **Spectrograph**
  - Two Aberration-corrected Offner type Grating spectrographs
    - VNIR spectrograph and SWIR spectrograph
    - High diffraction efficiency
    - Equal interval of Spectral Sampling
    - Minimize the wavelength shift/ smile/ keystone
  - Robust in alignment against temperature change
  - Stable temperature control within +/-1K in orbit to minimize the wavelength shift.
Design for The Telescope and Spectrograph

- **Detector**
  - VNIR detector: 2Dimentional backside illuminated silicon CMOS
  - SWIR detector: 2Dimentional PV-MCT

- **Cooler and Dewar**
  - SWIR detector is integrated inside the dewar
  - and cooled down to 145K using Stirling-type cryocooler.
1. HISUI Instrument Overview

Flight Model of Hyperspectral Sensor Unit
Function of HELU (Hyper Electronics Unit) for Digital Data

- **Data correction** of items as follows;
  - Offset-Gain-Non linearity
  - PRNU (Photo Response Non-Uniformity)
  - Smile distortion (using weight-coefficients during the binning)

- In order to reduce data size,
  - data binning in spectral direction
    - 4 pixels in VNIR       2 pixels in SWIR
  - lossless **data compression**

- Observation Mode:
  - With Onboard Data Correction and Data Compression

- Calibration Mode:
  - Without Onboard Data Correction nor Data Compression
    - (Onboard Calibration with Lamps, Vicarious Calibration, ……)
2. Onboard Data Correction

Flow of Onboard Data Correction in HELU

Sensor Data (12bit DN) before correction and binning
VNIR: 228 Channels (2.5nm interval)
SWIR: 256 Channels (6.25nm interval)

Radiometric correction
offset-gain-(non)linearity, PRNU

Binning (including smile correction using Weight Function)

Corrected Radiance data of each band (12bit DN)
VNIR: 57 bands (10nm interval),
SWIR: 128 bands (12.5nm interval)

Down Link
2. Onboard Data Correction

Onboard Radiometric Correction

Formulae for non Linearity/Offset Correction

Radiance: $W$ ($\text{W/m}^2\text{sr}/\mu\text{m}$)

- Calculation formula 1
  
  $W = A(X-C)^2 + B(X-C)$
  
  • For low response pixel
  • For low radiance band

- Calculation formula 2
  
  $W = A(X-C)^2 + B(X-C)$

- Calculation formula 3
  
  $W = A1X + B1$, $W = A2(X-C-50)$
  
  * For bad linearity pixel
2. Onboard Data Correction

Onboard Radiometric Correction

Examples of PRNU/Gain Correction

PRNU: Photo Response Non-Uniformity

(*) Based on the data of Evaluation Model of the sensor
2. Onboard Data Correction

**Onboard Spectral Correction**

**Concept of Binning/Smile Correction**

![Diagram of 2D-Array Detector with Spatial, Spectral, and Binning Pixels* labels]

\[ p = \frac{w_1 x_1 + \cdots + w_n x_n}{w_1 + \cdots + w_n} \]

- \( p \): Radiance data after smile correction
- \( w_n \): Weight function of pixel No \( (n) \)
- \( X_n \): Radiance data of pixel No \( (n) \) after radiometric correction
- \( n \): VNIR = 1-6, SWIR = 1-4

(*) Binning is executed along spectral direction

(*) Based on the data of Evaluation Model of the sensor
2. Onboard Data Correction

Onboard Spectral Correction

Examples of Binning/Smile Correction

(*) Based on the data of Evaluation Model of the sensor
2. Onboard Data Correction

**Onboard Spectral Correction**

Concept of Binning and Spectral Response

- **2.5nm**
  - Binning/Smile Correction
  - 4 pixels in VNIR
  - 2 pixels in SWIR

- **10nm**
  - Wide Flatness
  - Sharp Response

Data binning in spectral direction
- 4 pixels in VNIR
- 2 pixels in SWIR
## Summary of Onboard Data Correction

<table>
<thead>
<tr>
<th>Items</th>
<th>Performance after onboard correction</th>
<th>Performance before onboard correction*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smile</td>
<td>&lt;10-5nm@VNIR &lt;10-5nm@SWIR</td>
<td>&lt;1nm@VNIR &lt;2.5nm@SWIR</td>
</tr>
<tr>
<td>Linearity</td>
<td>&lt;5%@VNIR (over99.99% data) &lt;5%@SWIR (over99.99% data)</td>
<td>&lt;5%@VNIR (over99.97% data) &lt;5%@SWIR (over99.99% data)</td>
</tr>
<tr>
<td>PRNU</td>
<td>PRNU&lt;13%@VNIR (over99.7 data) PRNU&lt;20%@SWIR (over99.7 data)</td>
<td>PRNU&lt;34%@VNIR (over99.7 data) PRNU&lt;33%@SWIR (over99.7 data)</td>
</tr>
</tbody>
</table>

(*) Based on the data of Evaluation Model of the sensor
2. Onboard Data Correction

Spectral Performance

Spectral Performance:
Wavelength Shift/ Smile/ Keystone

Before Launch
- Spectrometer Performance
- Misalignment of Assembly
- Onboard correction parameter Table
  (install into Onboard Data Processor of HELU)

Launch/In Orbit
- Offset: Launch Vibration Condition
- Variable: Onboard Thermal Vacuum Condition
  Correction Parameter Table: install into Ground Data Processing System
### Spectral Performance

Table: Spectral Performance

<table>
<thead>
<tr>
<th>Remarks</th>
<th>VNIR</th>
<th>SWIR</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specification</td>
<td>&lt;10nm</td>
<td>&lt;12.5nm</td>
<td>&lt;1 pixel</td>
</tr>
<tr>
<td>Normal Temp. &amp; Pressure</td>
<td>&lt;1.0nm</td>
<td>&lt;2.5nm</td>
<td></td>
</tr>
<tr>
<td>After Onboard Correction</td>
<td>&lt;10⁻⁵nm</td>
<td>&lt;10⁻⁵nm</td>
<td></td>
</tr>
<tr>
<td>After Launch Vibration Test</td>
<td>Negligible</td>
<td>Negligible</td>
<td>Offset</td>
</tr>
<tr>
<td>Thermal Vacuum Test</td>
<td>&lt;0.058nm</td>
<td>&lt;0.106nm</td>
<td>Variable</td>
</tr>
<tr>
<td>Total</td>
<td>&lt;0.06nm</td>
<td>&lt;0.11nm</td>
<td></td>
</tr>
<tr>
<td>Onboard Calibrator</td>
<td>0.2nm</td>
<td>0.625nm</td>
<td>Expected Value Onboard</td>
</tr>
</tbody>
</table>

Wavelength shift of Flight Model (expected)

- VNIR <0.06nm
- SWIR <0.11 nm

including launch and space environment conditions

Onboard spectral calibrator monitors the wavelength shift.
3. Conclusions

Conclusions

- Onboard Data Correction of Hyperspectral Sensor of HISUI
  - The validation tests of Onboard Data Correction function have been completed using the data of functional evaluation model of Instrument.
  - The smile performance after correction is very well.
  - The method of Onboard Data Correction has been established.

- Status of HISUI Instrument
  - Analyzing test results, FM is expected to achieve the spectral performance better than specifications.
  - The critical parts of FM, such as the telescope, the spectrographs and the detectors, have been manufactured and the integration & tests of the sensor is proceeding.

Acknowledgements

- HISUI project proceeds under the contract with METI (Ministry of Economy, Trade and Industry).
Thank you very much for your attention!
3. Design of Flight Model

Spectral Performance

Test Data of Evaluation Model: (Spectral Calibration Accuracy at Normal Temp.)

**VNIR**

![Calibration Accuracy (Spectral) in VNIR Region](image1)

**SWIR**

![Calibration Accuracy (Spectral) in SWIR Region](image2)
3. Design of Flight Model

Spectral Performance

VNIR: Wavelength Shift vs. Temp. (Thermal Vacuum Test)

- Temperature shift of Hg-Ar lamp line by VNIR spectrometer assembly
- Onboard Temp. Range

- Temperature shift ≤0.023 pixel / 2 degC
- Temperature range: 10 to 40°C

Graph showing wavelength position (Pixel No.) at 546nm vs. temperature.

- 33°C -> 13°C
- 33°C -> 20°C
3. Design of Flight Model

Spectral Performance

SWIR: Wavelength Shift vs. Temp. (Thermal Vacuum Test)

b) Temperature shift of Hg-Ar lamp line by SWIR spectrometer assembly

<0.17 pixel = 1.08 nm

Onboard Temp. Range

≤ 0.017 pixel / 2 degC
3. Design of Flight Model

Spectral Performance After Onboard Correction

**Onboard correction**
- Using the weighting function at the binning

Optimize the weighting function

<0.06nm

<0.008nm

<0.00001nm

The test result is less than 0.000002nm

<0.00001nm

The test result is less than 0.000003nm

<0.00001nm

The test result is less than 0.000002nm
Onboard Calibrator of Hyperspectral sensor

Filter Wheel Assembly
- 4 Bandpass filters
- NIST SRM2065 + Filter

Si -PD

InGaAs -PD

Si -PD

Halogen lamps

Telescope
Onboard Calibrator of HISUI

HISUI has Optical onboard calibrators.

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Hyperspectral Sensor</th>
<th>Multispectral Sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Source</td>
<td>Two halogen lamps</td>
<td>Two halogen lamps</td>
</tr>
<tr>
<td>Detector to monitor</td>
<td>• Si-photodiode for VNIR</td>
<td>Si-photodiodes</td>
</tr>
<tr>
<td></td>
<td>• In-Ga-As-photodiode for SWIR</td>
<td></td>
</tr>
<tr>
<td>Filters</td>
<td>Band pass filters</td>
<td>4 band pass filters</td>
</tr>
<tr>
<td></td>
<td>Spectral calibration filter</td>
<td>The band pass</td>
</tr>
<tr>
<td></td>
<td></td>
<td>wavelength of</td>
</tr>
<tr>
<td></td>
<td></td>
<td>filter is matched to</td>
</tr>
<tr>
<td></td>
<td></td>
<td>the spectral band</td>
</tr>
<tr>
<td></td>
<td></td>
<td>for observation.</td>
</tr>
<tr>
<td>Spectral Calibration Accuracy (Target)</td>
<td>0.2nm (VNIR), 0.625nm (SWIR)</td>
<td>N/A</td>
</tr>
</tbody>
</table>