LABORATORY CHARACTERIZATION OF THE HYPERSPECTRAL IMAGER FOR THE COASTAL OCEAN (HICO)

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July 14, 2009
HREP on the International Space Station

• In the Fall of 2006, the DoD Space Test Program proposed the possibility of a combined payload on the ISS Japanese Experiment Module – Exposed Facility
• HREP- HICO RAIDS Experiment Payload
• RAIDS- Remote Atmospheric and Ionospheric Detection System
• HICO instrument development sponsored by Office of Naval Research
  – Innovative Naval Prototype
    • Goal: reduced cost and schedule
    – Commercial parts used where possible
    – Imager delivered in 16 months
• Launch provided by DoD Space Test Program
• HICO manifested for September 14, 2009 launch from Japanese Space Center, Tanegashima Island, Japan

HICO flight imager
HICO Launch to Space Station

Launch from Tanegashima Island Space Center
Program Status and Schedule

Completed

• Mission Requirements Review     Completed February 28, 2006
• Mission Requirements Document    Completed March 16, 2006
• HICO manifested on Space Station March 2007
• Preliminary Design Review       Completed June 18, 2007
• Critical Design Review          Completed November 8, 2007
• HICO imager delivery            May 30, 2008
• HICO test readiness review      July 16, 2008
• HICO delivery to HREP           September 1, 2008
• HREP Testing completed          February 2009
• Experiment Payload ship to JAXA  April 9, 2009

Scheduled

• Launch to International Space Station September 14, 2009
• On-orbit checkout complete      November 1, 2009
# HICO Requirements

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Requirement</th>
<th>As-built Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Off-nadir pointing</td>
<td>45 deg port, 30 deg starboard</td>
<td>45 deg port, 45 deg starboard</td>
</tr>
<tr>
<td>Spectral Range</td>
<td>400 to 860 nm (goal 380 to 1000 nm)</td>
<td>350 to 1070 nm</td>
</tr>
<tr>
<td>Spectral Channel Width (normal mode)</td>
<td>10 nm (goal 5 nm)</td>
<td>5.73 nm</td>
</tr>
<tr>
<td>Spectral Channel Width (HR mode)</td>
<td>No requirement</td>
<td>1.91 nm</td>
</tr>
<tr>
<td>Signal to Noise Ratio</td>
<td>&gt; 200 to 1 for a 5% surface albedo (10 nm spectral bins)</td>
<td>&gt; 200 to 1 for a 5% surface albedo (11.46 nm spectral bins)</td>
</tr>
<tr>
<td>Polarization Sensitivity</td>
<td>&lt; 5% (goal &lt; 2%)</td>
<td>&lt; 5% for most wavelengths</td>
</tr>
<tr>
<td>Crosstrack Ground Sample Distance</td>
<td>100 m @ 400 km alt.</td>
<td>94 meters @ 400 km alt.</td>
</tr>
<tr>
<td>Along-track Ground Sample Distance</td>
<td>100 meters</td>
<td>99 meters</td>
</tr>
<tr>
<td>Scene Size</td>
<td>(50 km wide)×(200 km long)</td>
<td>(48 km wide)×(198 km long)</td>
</tr>
<tr>
<td>vignetting</td>
<td>No vignetting</td>
<td>No vignetting</td>
</tr>
<tr>
<td>Saturation</td>
<td>Will not saturate when viewing 95% albedo cloud</td>
<td>Close</td>
</tr>
<tr>
<td>Image quality</td>
<td>MTF &gt; 0.35 at Nyquist spatial frequency of 0.5 cycles/pixel</td>
<td>PSF about 1 pixel</td>
</tr>
<tr>
<td>Spectral stray light</td>
<td>&lt; 1% albedo error</td>
<td>Not strictly measured</td>
</tr>
<tr>
<td>Jitter</td>
<td>&lt; 0.2 IFOV per frame</td>
<td>Space craft dependent</td>
</tr>
<tr>
<td>Long term stability</td>
<td>+/- 5% after calibration</td>
<td>On orbit measurement</td>
</tr>
</tbody>
</table>
Rotating Sensor Assembly

<table>
<thead>
<tr>
<th>Envelope (mm)</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>885</td>
<td>525</td>
<td>425</td>
</tr>
</tbody>
</table>

Mass (kg) 43

Spectrometer

Bearing A-Arm Support Assembly (Free Side)

Camera Hermetic Enclosure

Optics Deck

Cradle

HREP Coordinate Sys.

Bearing A-Arm Support Assembly (Fixed Side)

Spindle Assembly: All Rotating Components

View Slot

Shield Assembly

HICO Coordinate System
HICO Imager Architecture

- HICO imager architecture based on NRL experience with designing and deploying airborne hyperspectral imagers
  - Offner spectrometer for very low optical distortion
    - Low cross-talk between spectra of spatial pixels (spectral purity)
    - All spectral samples are acquired simultaneously (important for moving platform)
    - Brandywine Optical model 3035 VNIR
  - Lens optimized for broad-band spot size and color correction
    - Broad-band coatings for high optical transmission
    - Brandywine design matches spectrometer
  - Backside-illuminated focal plane array
    - High quantum efficiency in the blue for high SNR
    - Frame transfer operation (Minimal read-out smear)
    - Qimaging Rolera MGi
- Must meet HICO MRD performance requirements
Optical Design
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Design</th>
<th>As-built Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focal Length</td>
<td>60 mm</td>
<td>68.1 mm</td>
</tr>
<tr>
<td>F#</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Pixel Size</td>
<td>16 μ</td>
<td>16 μ</td>
</tr>
<tr>
<td>FPA Size, total: used:</td>
<td>512×512</td>
<td>512×512</td>
</tr>
<tr>
<td></td>
<td>512(spatial)×384(spectral)</td>
<td>512(spatial)×384(spectral)</td>
</tr>
<tr>
<td>Spectral smile</td>
<td>&lt; 2 nm</td>
<td>&lt; 0.3 nm (tilt only)</td>
</tr>
<tr>
<td>Keystone</td>
<td>&lt; 3 microns</td>
<td>&lt; 3 microns</td>
</tr>
<tr>
<td>Frame Time (normal)</td>
<td>13.7 ms</td>
<td>13.7 ms</td>
</tr>
<tr>
<td>Frame Time (HR mode)</td>
<td>30 ms</td>
<td>30 ms</td>
</tr>
</tbody>
</table>
Characterization

- Characterization
  - Smile (rotation)
  - Keystone
  - Spectral alignment (PSF)
  - Spatial alignment (PSF)
  - Spectral calibration
  - Pointing
  - Polarization
Test Setups

Small Sphere and Spectral Sources
- Spectral PSF, wavelength calibration, smile, polarization
- Sources - spectral pen lamps, lasers, incandescent

Collimator Setup
- Keystone, pointing, spatial PSF

Large NIST-traceable Integrating Spheres
- Radiometric Calibration, Frame Transfer Smear, Second Order
HICO Smile and Keystone
(real data from thermal vacuum testing)

128 bands

Continuum Source

Keystone example
Real data

384 wavelength bands

Laser Sources

Real data

Smile example

512 spatial samples

#2 Horizontal Profile

#2 Vertical Profile
shift from column 256 Hg 365nm
shift from column 256 Hg 405nm
shift from column 256 Hg 436nm
shift from column 256 HeNe laser 543nm
shift from column 256 HeNe laser 594nm
shift from column 256 at He 667.8nm
shift from column 256 Ox 844.6nm
shift from column 256 Ox 926.6nm
shift from column 256 He 1083nm
Spectral Channel Widths

- fwhm at Hg 365nm
- fwhm at Hg 405nm
- fwhm at H 436nm
- fwhm at HeNe laser 594nm
- fwhm at HeNe laser 543nm
- fwhm at at He 667.8nm
- fwhm at Ox 844.6nm
- fwhm at Ox 926.6nm
- fwhm at He 1083nm

Graph showing spectral channel widths across different wavelengths.
Keystone - spatial shift from 631nm band
Spatial Alignment

- FWHM at column ~2.64
- FWHM at column ~77.85
- FWHM at column ~151.75
- FWHM at column ~225.23
- FWHM at column ~298.7
- FWHM at column ~372.17
- FWHM at column ~446.3
- FWHM at column ~506.22

wavelength (nm)
Polarization Sensitivity

HICO Polarization sensitivity June 25 and July 8, 2008

\[
\frac{(I_{\text{max}} - I_{\text{min}})}{(I_{\text{max}} + I_{\text{min}})}
\]

- Polarization Sensitivity spatial pixel 10 (0-511)
- Polarization Sensitivity spatial pixel 254 (0-511)
- Polarization Sensitivity spatial pixel 498 (0-511)
Radiometrics

- Radiometrics
  - Calibration
    - Dark current
    - Frame transfer smear
    - Second order
    - Gain coefficients
  - Confirm radiometric model
Dark Current varies over course of scene

Use dark collection before scene to model scene dark
Dark Current

![Graph showing the ratio of second to first orders vs. wavelength (nm).]
HICO measured response to known integrating sphere source compared to model
(DN = Digital Numbers, Correction is for smear and second order)
Blue Sphere Scene modeling

- On-orbit radiance, 5% albedo (W/m²-sr-nm)
- Blue sphere lamp (Xe+ext) 2008-07-03 w/ ND0.4
- Blue sphere lamp (Xe+ext) 2008-07-03 w/ ND0.6
- Blue sphere lamp (Xe+ext) 2008-07-03 w/ ND0.2
Summary

- Instrument description
- HICO meets most requirements
- Calibration algorithm presented
  - Dark
  - Smear
  - 2\textsuperscript{nd} order
- Radiometric model verified

- **Acknowledgments.** The HICO instrument was sponsored by the Office of Naval Research and built at the Naval Research Laboratory.