Laboratory and On-site Radiometric Calibration of Aerial Multispectral Digital Cameras

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Background

• Z/I has upgraded their radiometric calibration process for DMC and RMK-D/DX digital cameras to include absolute radiometry
  – Builds upon the relative radiometric calibration processes (flat fielding or normalization, linearity, and band-to-band relative radiometry)
Absolute Radiometric Calibration

- Absolute radiometric calibration ties acquired DN values to physical values in engineering units
  - Watts/(m²sr) within a specified spectral band

![Graph showing the relationship between Digital Number (DN) and Radiance (L)]

For a specified tau
Benefits of Radiometrically Calibrated Aerial Imaging Systems

• Simulates satellite remote sensing systems
  – Evaluate alternate bands and algorithms with actual data
  – Augment satellite acquisitions
• Predicts performance a priori
  – Supports mission planning activities
• Improves quality control in manufacturing process by measuring camera sensitivities during laboratory calibration
• Supports the ability to atmospherically correct products to surface reflectance
  – More challenging than with satellites because entire atmospheric boundary layer is not between the sensor and the target and the Earth’s varying topography induces a larger percent error.
Absolute Radiometry Improves Repeatability

• Tying each camera measured value to the same “national standards laboratory-traceable sphere-produced” radiance value through a calibration coefficient ensures:
  – “Clone” cameras
  – Differences between acquisitions of the same target are due to atmospheric, solar and viewing angle differences only
  – Larger acquisitions involving multiple cameras can be integrated more easily (mosaics)
Absolute Radiometry Provides Consistent Colorimetry

- Colorimetry is the science and technology used to quantify and describe human color perception.
  - CIE System of Colorimetry (1931) is the only internationally agreed metric for color measurement.
  - XYZ tristimulus values and color matching functions

Yoshi Ohno, 2000, CIE Fundamentals for Color Measurements, IS&T NIP16 Conference, Vancouver, Canada
Absolute Radiometry Enables Atmospheric Correction

• Atmospherically corrected imagery (reflectance maps) enable:
  – Change detection with reduced influence of atmosphere and solar illumination variations
  – Improved comparisons between different instruments and acquisitions
  – Derived products such as Normalized Difference Vegetation Index (NDVI)
Importance of Atmospheric Correction

![Graph showing spectral radiance against wavelength for different reflectance types.]

TOA Radiance SZA 60 MLS Rural 23 km

- Blue line: Water
- Green line: Vegetation
- Red line: Zero Reflectance

Spectral Radiance, Wm$^{-2}$sr$^{-1}$microns$^{-1}$

Wavelength, microns

0 0.4 0.5 0.6 0.7 0.8 0.9 1
Digital Mapping Camera (DMC)

- Large format digital camera
- Field of view 69.3° x 42°
- Multispectral 3,072 x 2,048 pixels
  - 12 μm pixel size
  - 4 channels RGB & NIR
  - 4 separate optics-25mm focal length
- Panchromatic 13,824 x 7,680 pixels
  - 12 μm pixel size
  - 4 separate optics-120mm focal length
- Variable aperture shutter
- 12 bit radiometric resolution
- Telecentric design
DMC Spectral Response

Normalized Response

Description

<table>
<thead>
<tr>
<th>Band</th>
<th>Peak (nm)</th>
<th>50% Points (nm)</th>
<th>10% Points (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>475</td>
<td>429-514</td>
<td>319-579</td>
</tr>
<tr>
<td>Green</td>
<td>545</td>
<td>514-600</td>
<td>497-635</td>
</tr>
<tr>
<td>Red</td>
<td>620</td>
<td>600-676</td>
<td>584-690</td>
</tr>
<tr>
<td>NIR</td>
<td>725</td>
<td>695-831</td>
<td>681-968</td>
</tr>
<tr>
<td>Pan</td>
<td>540</td>
<td>450-739</td>
<td>392-944</td>
</tr>
</tbody>
</table>

Wavelength, microns

Response

Normalized Response
RMK-D/DX

• Super medium format digital camera
• Field of view: 49.5° x 54.2° (-D)
  51.2° x 48.1° (-DX)
• Multispectral 6,096 x 6,846 pixels
  – 7.2 μm pixel size
  – 4 channels RGB & NIR
  – 4 separate optics-45mm focal length
• Panchromatic 12,240 x 11,418 pixels (-DX only)
  – 7.2 μm pixel size
  – 92 mm focal length
• Variable aperture shutter
• 14 bit radiometric resolution
RMK-D Spectral Response

Normalized Response

Description

<table>
<thead>
<tr>
<th>Band</th>
<th>Peak (nm)</th>
<th>50% Points (nm)</th>
<th>10% Points (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>450</td>
<td>419-488</td>
<td>390-503</td>
</tr>
<tr>
<td>Green</td>
<td>525</td>
<td>499-557</td>
<td>482-592</td>
</tr>
<tr>
<td>Red</td>
<td>620</td>
<td>600-662</td>
<td>580-704</td>
</tr>
<tr>
<td>NIR</td>
<td>733</td>
<td>709-816</td>
<td>695-921</td>
</tr>
</tbody>
</table>
Absolute Radiometric Calibration Laboratory System

- Tungsten Lamp
- Xenon Arc Lamp
- Camera Mount
- Spectrometer
- Integrating Sphere
- Camera Electronics
- Computer with Integrating Sphere Software
- Tungsten Lamp Power Supply
Integrating Sphere Spectral Radiance

- Designed to approximately emulate at-sensor radiance for a 25% gray target, 30° solar zenith angle, midlatitude summer aerosol, 23Km visibility at an aircraft altitude above the boundary layer.

Graph showing the spectral shape of Xe and Tungsten lamps, integrating sphere lamp spectral shape (maximum light), and approximate gray target with a 30° solar zenith angle.
Custom Software Controls Sphere

- Records camera information
- Calibrates sphere radiance
- Sets, measures and records sphere radiance
- Monitors lamp usage
Calibration Process - General Theory

**Absolute Radiometric Calibration**

\[
L(i, j) = \frac{F \#^2}{\tau} \cdot C \cdot DN'(i, j)
\]

- Radiance
- Integration Time
- Aperture
- Calibration Coefficient
- Relative Radiometrically Corrected Imagery
Relative Radiometry

• Pixel-to-pixel relative radiometry corrects:
  – Vignetting (fall-off in signal off axis) image normalization or flat fielding correction
  – Detector variation including any bad detectors

• Typical remote sensing industry goal <1%
  (Landsat Data Continuity Mission (LDCM) Data Specification, March 2000)
Sample RMK-D Integrating Sphere Raw and Corrected Image

Green Channel – Double Tap
Sample RMK-DX Integrating Sphere
Raw Data and Histogram (PAN)
Sample RMK-DX Integrating Sphere Corrected Data and Histogram (PAN)
Original Relative Calibration

Absolute Calibration
Expected Performance

- Initial analysis indicates laboratory radiometric calibration for DMC and RMK-D/DX should be better than 3% and comparable to satellite-based land imagers.
- Vicarious calibration processes will be necessary to validate radiometric performance in flight.
- This technology can be extended into the field for on-site radiometric calibrations.
Portable Integrating Sphere Concept
Summary

• Z/I has instituted an absolute radiometric calibration process that will enable
  – Development of a new generation of remote sensing products for framing cameras
  – Improved operation for the DMC and RMK-D/DX
Acknowledgements

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- I2R staff in Mississippi, USA