High Spatial Resolution Commercial Satellite Imaging Product Characterization

Science Systems and Applications, Inc.
John C. Stennis Space Center, MS

Robert E. Ryan, Mary Pagnutti, Kara Holekamp, Slawomir Blonski, Kenton W. Ross

NASA Applied Sciences Directorate
John C. Stennis Space Center, MS

Thomas Stanley

2005 CALCON Technical Conference
Utah State University
Logan, UT, USA
Contributors

• Computer Sciences Corporation (CSC) / Science Systems and Applications, Inc. (SSAI)
  – Kelly Knowlton, SSAI
  – Jeff Russell, CSC
  – Ronnie Vaughan, CSC

Participation in this work by Computer Sciences Corporation and by Science Systems and Applications, Inc., was supported under NASA Task Order NNS04AB54T.
High Spatial Resolution Product Characterization

• Very important when using commercially obtained imagery for scientific investigations
  – Systems designed and operated outside the scientific community

• High spatial resolution (<4 m GSD) and limited swath (<17 km) allow different approaches than with coarser resolution wider swath systems
  – Designed targets are commonly used
  – Single site can be used to measure most geopositional, spatial and radiometric characteristics
## Relevant High Spatial Resolution Sensors

<table>
<thead>
<tr>
<th>Asset</th>
<th>Revisit Time</th>
<th>Spectral Bands/Spatial Resolution (GSD)</th>
<th>Swath (Standard Product)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IKONOS</td>
<td>1-2 days</td>
<td>B, G, R, NIR, Pan Nadir 3.84 m (multi) 0.86 m (pan)</td>
<td>11 km</td>
</tr>
<tr>
<td>QuickBird 2</td>
<td>1- 5 days</td>
<td>B, G, R, NIR, Pan Nadir 2.44 (multi) 0.61 m (pan)</td>
<td>16.5 km</td>
</tr>
<tr>
<td>OrbView-3</td>
<td>&lt; 3 days</td>
<td>B, G, R, NIR, Pan Nadir 4 m (multi) 1 m (pan)</td>
<td>8 km</td>
</tr>
</tbody>
</table>
Product Characterizations & Uses

• Spatial Resolution (MTF, PSF, Edge Response)
  – Smallest object detection & identification
  – Pixel mixing
  – Image restoration

• Radiometry (Linearity, Relative, Absolute)
  – Atmospheric correction
  – Change detection
  – Sensor intercomparison

• Geopositional Accuracy (Absolute & Relative)
  – Map creation
  – Measurements
  – Repeatability for accurate change detection
Spatial Product Parameters & Targets

• Parameters of interest
  – Ground Sample Distance
  – Optical Transfer Function
    • Modulation Transfer Function (MTF)
    • MTF @ Nyquist
  – Point Source Function (PSF)
  – Edge Response
    • Slope and ringing
  – Line Spread Function
  – \textit{Point Source Transmittance (PST) / Stray light}

• Target types
  – Edge, pulse, line and point targets

\textbf{High spatial resolution allows the use of designed and man made targets}
Spatial Characterization

Method: Utilize edge targets (tarps, SSC concrete edge target or other man-made features such as painted runways or buildings) and ground reflectance measurements (spectroradiometer) to determine the edge response of remote sensing systems.
SSC Concrete Edge Targets

QuickBird Imagery
Feb 17 2002

Tilted edge allows for proper sampling of the edge response

Includes material © DigitalGlobe™. All rights reserved.

RELEASED - Printed documents may be obsolete; validate prior to use.
Radiometric Product Parameters & Targets

• Parameters of Interest
  – Relative radiometry
  – Absolute radiometry
  – Signal-to-noise

• Target types (Reflective Based Calibration)
  – Large bright uniform areas such as playas
  – Natural features and manmade targets
    • Grass fields, concrete parking lots, etc.
    • Engineered uniform targets

High spatial resolution allows the use of designed and man made targets.
Relative Radiometry

Large uniform scenes support the determination of pixel-to-pixel uniformity and SNR estimation.

IKONOS Image of Antarctica – RGB, POID 52847

Normalized Average Row Values for Antarctica

Includes material © Space Imaging LLC

RELEASED - Printed documents may be obsolete; validate prior to use.
Radiometric calibration is the process of converting digital imagery values to radiance.

\[ L_{TOA} = K \ DN + C \]

Where:
- \( L_{TOA} \) Top-of-the-Atmosphere radiance
- \( K \) Calibration coefficient
- \( DN \) Pixel digital number (Value)
- \( C \) Offset (Many times near zero)

Commercial vendors often provide calibration coefficients with \( C \) equal to zero.
Radiometric Calibration Uncertainty

\[
\frac{\sigma_K}{K} = \sqrt{\left(\frac{\sigma_L}{L}\right)^2 + \left(\frac{\sigma_{DN}}{DN}\right)^2}
\]

- Bright calibration targets typically provide best accuracy
  - Minimizes radiative transfer errors
  - Maximizes SNR (Important for small targets)
- Uniform targets minimize DN variations
Absolute Radiometric Characterization
Reflective Region

• Site Requirements
  – Uniform targets large enough to minimize finite PSF errors (5 pixels or greater)
  – Reflectance measurements
  – Atmospheric measurements
    • Aerosols
    • Water vapor
    • Ozone

• Characterization Technique
  – At time of acquisition measure:
    • Target reflectance
    • Atmospheric parameters
  – Predict at-sensor radiance using:
    • Target reflectance
    • Modeled atmosphere
    • Sensor spectral response
    • Sensor-target-solar geometry
Reflective Radiometric Characterization Sites

• Playas and other “bright” naturally occurring land features (Adjacency is not an issue)
  – White Sands Missile Range
  – Lunar Lake Playa
  – Railroad Valley Playa
  – Ivanpah Playa

• Complex sites with targets (Adjacency is important)
  – Brookings/South Dakota State University
  – Stennis Space Center and surrounding area
Reflective Radiometric Characterization

Method: Utilize ground reflectance measurements (Spectroradiometer) and atmospheric measurements (Sun Photometer and Radiosonde) to determine radiometric accuracy of remote sensing systems.
20-Meter Reflectance Tarps

- Four 20 m x 20 m tarps; reflectance values:
  - less than 5%
  - between 20% and 25%
  - between 30% and 40%
  - between 50% and 55%
- Spectral measurement range of 400 to 1050 nm
- Standard deviation about average reflectance, less than 1% spatially
- Peak to peak variation in reflectance less than 10% (within any 100 nm spectral band)
- When measuring tarps from 10 to 60 degrees off axis, less than 10% variation in reflectance values
- Each side is straight and within ±6.0 cm over the 20 m length
- Each tarp panel has 60 square witness samples measuring 30.5 cm x 30.5 cm
Target Reflectance Data

Spectral Albedo for Stennis Space Center, 1/15/02

NASA SSC
January 15, 2002

Reflectance vs. Wavelength (μm)

- 52% Tarp
- 22% Tarp
- 3.5% Tarp
- Concrete
- Grass

TARGET REFLECTANCE DATA

released - printed documents may be obsolete; validate prior to use.
The spherical albedo approach approximates the signal observed by the satellite as the summation of successive scattering terms. Useful for estimating uncertainty.

\[ L_{TOA} = L_o + A\rho_{tgt} + A\rho_{tgt}s\rho_{bg} + A\rho_{tgt}s^2\rho_{bg}^2 + \ldots + B\rho_{bg} + B\rho_{bg}s\rho_{bg} + B\rho_{bg}s^2\rho_{bg}^2 + \ldots \]
Case I Target and background are the “same”

\[
L_{TOA} = L_o + \frac{(A + B) \rho_{tgt}}{1 - s \rho_{tgt}}
\]

Where:
- \( \rho_{tgt} \) = Target reflectance
- \( L_{TOA} \) = Target radiance signal observed by the satellite
- \( A, B, s, \) and \( L_o \) = Constants that depend on atmospheric properties and geometry

• Adjacency (background reflectance) is not significant
• High reflectance targets provide the highest accuracy results
Spherical Albedo Formulation, cont’d

Case II Target and background have different reflectances

\[ L_{TOA} = L_o + \frac{A \rho_{tgt}}{1 - s \rho_{bg}} + \frac{B \rho_{bg}}{1 - s \rho_{bg}} \]

Where:

- \( \rho_{tgt} \) = Target reflectance
- \( \rho_{bg} \) = Effective reflectance of the area surrounding the target (background) that contributes to the observation of the target via an atmospheric scattering

\( L_{TOA} \) = Target radiance signal observed by the satellite

- \( A, B, s, \) and \( L_o \) = Constants that depend on atmospheric properties and geometry

• Adjacency (background reflectance) needs to be accounted for.
• High reflectance targets provide the highest accuracy results.
Radiometric Error Associated With Adjacency

- Spherical Albedo approximation of TOA radiance estimates for geometries of interest agreed with MODTRAN estimates to better than 0.6%.
- For low visibility days (<25 km), B coefficient can be almost 50% the value of the A coefficient
  - Most measurements made with > 100 km visibility
- Ignoring adjacency effects (by modeling an infinite sized target) can lead to TOA radiance errors greater than 20% when large differences exist between target and background reflectance.
  - e.g., 52% tarp against largely vegetative background in the blue band
  - Reasonable knowledge of background reflectance required
Empirical Line Method for Estimating Background Reflectance

- DNs and target reflectance are “linearly” related.
- Effective background reflectance is estimated through empirical line method and weighting pixels using the atmospheric Point Spread Function.
- Reduces adjacency uncertainty to < 1%

$$\rho = \left( \frac{\rho_{\text{Bright}} - \rho_{\text{Dark}}}{L_{\text{Bright}} - L_{\text{Dark}}} \right) DN + \text{Offset}$$
Radiometric Error Associated with Finite Size Tarp

Cross Sectional Plot of Response

Simulated 20 m Tarp Image with 4 m GSD with MTF @ Nyquist of 0.1

- Finite size of tarp limits radiometric accuracy
- Error at the center pixels will be less than a percent, for typical background/tarp reflectances
- MTF @ Nyquist is specified to be greater than 0.2 for most commercial multispectral bands
Geopositional Product Parameters & Targets

• Parameters of Interest
  – CE90
  – RMS
  – LE90

• Target types
  – Array of positionally known and identifiable points
    • Evenly positioned throughout the image acquisition area
    • Location known to be an order of magnitude better than the spatial resolution of the system being characterized

High spatial resolution allows the use of designed and man made targets.
Geopositional Characterization

Method: Utilize geodetic targets and GPS instrumentation to determine the geopositional accuracy of remote sensing systems.
Painted Manhole Covers:
- Approximately 136 painted manhole covers
  - ~ 0.65 paint reflectivity
  - 0.6- to 2.9-m diameter
- Target centers geolocated by GPS to within 6 cm horizontal accuracy and 9 cm vertical accuracy

SSC Geodetic Targets:
- 44 targets currently deployed
- 2.44-m diameter painted white
- 0.6-m diameter center painted red
- Additional targets being procured (minimum of 45)
- Target centers geolocated by GPS to within 6 cm horizontal and 9 cm vertical accuracy
A standard metric often used for horizontal accuracy in map or image products is circular error at the 90% confidence level (CE90). The National Map Accuracy Standard (NMAS) established this measure in the U.S. geospatial community. NMAS (U.S. Bureau of the Budget, 1947) set the criterion for mapping products that 90% of well-defined points tested must fall within a certain radial distance.
Geolocational Accuracy Example
Data scatter plot showing the geolocational errors present in this imagery. Additionally, the $CE_{90}$ (calculated by the FGDC standard method and by a percentile method) and the typical pixel size are shown on this plot.
Summary

• Single sites are capable of performing a wide range of spatial, radiometric and geolocation characterizations

• Spatial Resolution
  – Variety of parameters can be determined with a variety of targets

• Radiometry
  – Single acquisitions can be used to characterize the linearity and dynamic range of a system
  – Radiometric targets need to be at least 5 pixels to find pure pixels (for typical MTF imaging performance)
  – Complex sites require adjacency correction
  – Relative radiometry and SNR estimates benefit from very large uniform scenes

• Geopositional
  – Small swath enables a relatively small site with easily identifiable targets to characterize products
High Spatial Resolution Commercial Satellite Imaging Product Characterization

4. AUTHOR(S)
Ryan, Robert E. (1)
Pagnutti, Mary (1)
Blonski, Slawomir (1)
Ross, Kenton W. (1)
Stanley, Thomas (2)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
(2) Applied Sciences Directorate, National Aeronautics and Space Administration, Code MA00, Bldg. 1100, John C. Stennis Space Center, MS 39529

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Applied Sciences Directorate, National Aeronautics and Space Administration, Code MA00, Bldg. 1100, John C. Stennis Space Center, MS 39529

11. SPONSORING/MONITORING REPORT NUMBER
SSTI-2220-0047 (Modified)

14. ABSTRACT
NASA Stennis Space Center's Remote Sensing group has been characterizing privately owned high spatial resolution multispectral imaging systems, such as IKONOS, QuickBird, and OrbView-3. Natural and man made targets were used for spatial resolution, radiometric, and geopositional characterizations. Higher spatial resolution also presents significant adjacency effects for accurate reliable radiometry.

15. SUBJECT TERMS
Commercial Imaging Characterization