On-orbit Modulation Transfer Function (MTF) Measurements for IKONOS and QuickBird

Civil Commercial Imagery Evaluation Workshop
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Outline

• Introduction
• Techniques
• Target/Site Description
• Results
  – Ikonos
  – Quickbird
• Conclusions

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Introduction

• Point Spread Function
  – A method of evaluating the spatial resolution of an imaging system.
  – A measure of the spread of a single point of light.

• Modulation Transfer function (MTF)
  – MTF is a measure of the spatial frequency response.
  – MTF is often calculated from the point spread function (PSF).
  – System response at the Nyquist frequency (or 0.5 cycle/pixel) is often used as a figure of merit.
\[ H(\omega_x, \omega_y) = \mathcal{F}\{PSF(x, y)\} \]

\[ MTF(\omega_x, \omega_y) = \left| \frac{H(\omega_x, \omega_y)}{H(0,0)} \right| \]

- 2-dimensional PSF and MTF are difficult to obtain.
- Often 1 dimensional functions are used:
  - 1-D PSF is the line spread function (LSF).
  - LSF can be obtained by differentiation of the edge spread function (ESF).
Techniques

• Edge Method
  – Sub-pixel edge locations were found by Fermi function fit.
  – A least-square error line was calculated through the edge locations.
  – Modified Savitzky-Golay filtering was applied on each line.
  – The filtered profile was differentiated to obtain LSF
  – MTF calculated by applying Fourier transform to LSF.
• Pulse method
  – A pulse input is given to the imaging system.
  – Output of the system is the resulting image.
  – Edge detection and mSG filtering was applied to obtain output profile.
  – Take Fourier transform of the input and output.
  – MTF is calculated by dividing output by input and normalizing DC component to unity.
SNR Definition

\[ \text{SNR} = \frac{\text{DN difference}}{(\text{STD}_{\text{bright}} + \text{STD}_{\text{dark}}) / 2} \]
Target Description

Field Plan
Field campaign pictures on 6-22-2005
• NASA Stennis Tarp Target
  – Radiometrically and spectrally stable target with a large DN difference from 3.6% and 52.1% reflectance panels.
  – Edge oriented to obtained sub-sampled edge profile.
  – Blue tarps oriented at same angle.

NASA Stennis tarps
## IKONOS Acquisitions

- **IKONOS Scene Information**

<table>
<thead>
<tr>
<th>Date</th>
<th>Sensor</th>
<th>Targets</th>
<th>Resampling or MTF processing</th>
<th>Product Type</th>
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<tbody>
<tr>
<td>8/1/2005</td>
<td>IKONOS</td>
<td>Stennis tarps</td>
<td>CC / MTFC On</td>
<td>Standard Geometrically Corrected</td>
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<tr>
<td></td>
<td></td>
<td>Blue tarps</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mirrors</td>
<td>CC / MTFC Off</td>
<td>Standard Geometrically Corrected</td>
</tr>
<tr>
<td>Date</td>
<td>Sensor</td>
<td>Band</td>
<td>Product</td>
<td>Target</td>
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<tr>
<td>8/1/2005</td>
<td>IKONOS</td>
<td>Pan.</td>
<td>CC/MTF off</td>
<td>Stennis</td>
</tr>
</tbody>
</table>

**Test image**

Angle = 5.404 [deg]

Sub-pixel edge location

Least square error line

**mSG filtering with raw data**

- DN\_diff = 1040.92
- STD\_ave = 11.25
- SNR = 92.54

**Trimmed LSF**

FWHM = 1.6226 [Pixel]

**MTF**

Value at Nyquist = 0.1117
Date: 8/1/2005  
Sensor: IKONOS  
Band: Pan.  
Product: CC/MTF on  
Target: Stennis  
Elevation: 66.0  
Azimuth: 118.7
<table>
<thead>
<tr>
<th>Date</th>
<th>Sensor</th>
<th>Band</th>
<th>Product</th>
<th>Target</th>
<th>Elevation</th>
<th>Azimuth</th>
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<tr>
<td>8/1/2005</td>
<td>IKONOS</td>
<td>Blue</td>
<td>CC/MTF off</td>
<td>Blue tarp</td>
<td>66.0</td>
<td>118.7</td>
</tr>
</tbody>
</table>

Angle = 5.112 [deg]

Fermi edge location
Least square error line

Modified S-Golay interpolation with raw data

DN diff = 629.36
STDave = 8.17
SNR = 77.03

Trimmed LSF

FWHM = 3.0169 [Pixel]

Fourier transform of input and output

MTF from Continuous Input

Value at Nyquist = 0.3745
Multi-year IKONOS Comparison

- Consistent FWHM: 1.61 +/- 0.08
- Values at Nyquist frequency were very stable.
  - Mean = 0.11, STD = 0.01
- No trends in PSF/MTF over 5 years.

<table>
<thead>
<tr>
<th>Date</th>
<th>Sensor</th>
<th>Band</th>
<th>Product</th>
<th>Target</th>
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<tbody>
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<td>IKONOS</td>
<td>Pan.</td>
<td>CC/MTFC off</td>
<td>Stennis / Big Springs</td>
</tr>
</tbody>
</table>


IKONOS SDSU campus on 8/1/2005

CC With MTFC

CC Without MTFC

Noisier & Sharper than CC
IKONOS Summary

- Very consistent, high-quality sensor
  - Pan FWHM = 1.61 +/- 0.08
  - Pan MTF @ Nyquist = 0.11 +/- 0.01
  - Multispectral MTF @ Nyquist = 0.52 (2005 data)
- ‘MTFC on’ processing provides increased MTF response with typical trade-off of increased contrast with some additional noise in Pan, less in Blue band.
  - Pan FWHM = 1.08 +/- 0.10
  - Pan MTF @ Nyquist = 0.48 +/- 0.08
- No indication of sensor degradation in five years.
# Quickbird Acquisitions

- **Quickbird scene information**

<table>
<thead>
<tr>
<th>Date</th>
<th>Sensor</th>
<th>Targets</th>
<th>Resampling or MTF processing</th>
<th>Product Type</th>
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<tbody>
<tr>
<td>8/30/2004</td>
<td>Quickbird</td>
<td>Blue tarps Mirrors</td>
<td>Resampling Kernel = CC MTF</td>
<td>Standard2A (Radiometrically corrected)</td>
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<tr>
<td>10/5/2004</td>
<td>Quickbird</td>
<td>Blue tarps Mirrors</td>
<td>CC MTF</td>
<td>Standard2A</td>
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<tr>
<td>6/22/2005</td>
<td>QuickBird</td>
<td>Vertical Stennis tarps Blue tarps Mirrors</td>
<td>CC MTF</td>
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<tr>
<td>10/18/2005</td>
<td>QuickBird</td>
<td>Stennis tarps Blue tarps Mirrors</td>
<td>MTF CC</td>
<td>Standard2A</td>
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<tr>
<td>Date</td>
<td>Sensor</td>
<td>Band</td>
<td>Resampling</td>
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<td>Quickbird</td>
<td>Pan.</td>
<td>CC</td>
<td>Stennis</td>
</tr>
</tbody>
</table>

Test image

Sub-pixel edge location

Angle = 5.787 [deg]

DN diff = 1038.19
STD ave = 10.02
SNR = 103.62

FWHM = 1.8939 [Pixel]

Value at Nyquist = 0.0364

Trimmed LSF

mSG filtering with raw data

mSG filtering

Normalized Differentiation value

MTF

Normalized frequency
### Table

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<thead>
<tr>
<th>Date</th>
<th>Sensor</th>
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<th>Target</th>
<th>Elevation</th>
<th>Azimuth</th>
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<tr>
<td>6/22/2005</td>
<td>Quickbird</td>
<td>Pan.</td>
<td>MTF</td>
<td>Stennis along</td>
<td>88.2</td>
<td>75.9</td>
</tr>
</tbody>
</table>

### Figures

1. **Trimmed LSF**
   - **FWHM = 1.6925 [Pixel]**

2. **MTF**
   - **Value at Nyquist = 0.1043**

### Graphs

- **mSG filtering with raw data**
  - Raw data
  - mSG filtering
  - **DNdiff = 1041.02**
  - **STDave = 15.78**
  - **SNR = 65.97**

### Text

Along-track Stennis tarp target MTF result of QuickBird on 6/22/2005 (MTF)
<table>
<thead>
<tr>
<th>Date</th>
<th>Sensor</th>
<th>Band</th>
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<th>Target</th>
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<tbody>
<tr>
<td>6/22/2005</td>
<td>Quickbird</td>
<td>Blue</td>
<td>CC</td>
<td>Blue tarp cross</td>
<td>88.2</td>
<td>75.9</td>
</tr>
</tbody>
</table>

Modified S-Golay interpolation with raw data

- **DN** = \(12.68\)
- **STD Ave** = 5.47
- **SNR** = 173.16

Trimmed LSF

- **FWHM** = 2.3216 [Pixel]

Fourier transform of input and output

- **MTF from Continuous Input**
  - **Value at Nyquist** = 0.1679
<table>
<thead>
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<th>Date</th>
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<th>Target</th>
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<td>6/22/2005</td>
<td>Quickbird</td>
<td>Blue</td>
<td>MTF</td>
<td>Blue tarp cross</td>
<td>88.2</td>
<td>75.9</td>
</tr>
</tbody>
</table>

**Test image**
- Test image
- Fermi edge location
- Least square error line

**Modified S-Golay interpolation with raw data**
- Raw data
- Modified S-Golay filtering

**Trimmed LSF**
- Trimmed LSF
- FWHM = 2.0699 [Pixel]

**Fourier transform of input and output**
- Discrete Output
- Discrete Input
- Continuous Input
- Continuous Output

**MTF from Continuous Input**
- Value at Nyquist = 0.2306

**Date**
- 6/22/2005
**Sensor**
- Quickbird
**Band**
- Blue
**Resampling**
- MTF
**Target**
- Blue tarp cross
**Elevation**
- 88.2
**Azimuth**
- 75.9
QuickBird panchromatic band Along / Cross Track Direction Comparison

<table>
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<th>Date</th>
<th>Sensor</th>
<th>Band</th>
<th>Resampling</th>
<th>Target</th>
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<td>Quickbird</td>
<td>Pan.</td>
<td>MTF / CC</td>
<td>Stennis</td>
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</tbody>
</table>

- First estimate of along-track PSF/MTF.
- Along-track PSF/MTF not significantly different than cross-track.
QuickBird Blue Band Along / Cross Track Direction Comparison

<table>
<thead>
<tr>
<th>Date</th>
<th>Sensor</th>
<th>Band</th>
<th>Resampling</th>
<th>Target</th>
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<td>Blue</td>
<td>CC only</td>
<td>Blue tarps</td>
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<tr>
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<td>Cross / along-track</td>
</tr>
</tbody>
</table>

- Cross-track profile exhibits narrower PRF FWHM and under shoots.
- System MTF shape differs in the orthogonal directions.
QuickBird Blue Band Along / Cross Track Direction Comparison

- FWHM values were reduced by MTF resampling process.
- MTF values were increased—most significantly in cross track direction.

<table>
<thead>
<tr>
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<th>Target</th>
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<tr>
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<td></td>
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<td></td>
<td>Cross / along-track</td>
</tr>
</tbody>
</table>

**PRF plots for QuickBird on 6/22/05 and 10/18/05 with MTF resampled scenes**
- 6/22/05 Cross-T. FWHM = 2.0699 [pixel], SNR = 112.8
- 10/18/05 Cross-T. FWHM = 2.0988 [pixel], SNR = 86.1
- 6/22/05 Along-T. FWHM = 2.2864 [pixel], SNR = 33.3
- 10/18/05 Along-T. FWHM = 2.2398 [pixel], SNR = 44.4

**MTF plots for QuickBird on 6/22/05 and 10/18/05 with MTF resampled scenes**
- 6/22/05 Cross-T. MTF = 0.2306
- 10/18/05 Cross-T. MTF = 0.2070
- 6/22/05 Along-T. MTF = 0.2729
- 10/18/05 Along-T. MTF = 0.2153
## Quickbird Results Summary 2004-2005

<table>
<thead>
<tr>
<th>Band</th>
<th>Resamp.</th>
<th>Scan Direction</th>
<th>FWHM (gsd)</th>
<th>MTF at Nyquist (cycles/gsd)</th>
<th>Notes</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td>mean</td>
<td>sigma</td>
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<tr>
<td>Pan.</td>
<td>CC</td>
<td>Cross</td>
<td>1.89</td>
<td>0.09</td>
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<tr>
<td></td>
<td></td>
<td>Along</td>
<td>1.89</td>
<td>0.04</td>
<td>1</td>
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<tr>
<td></td>
<td>MTF</td>
<td>Cross</td>
<td>1.71</td>
<td>0.26</td>
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<td></td>
<td></td>
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<td>1.69</td>
<td>0.10</td>
<td>1</td>
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<tr>
<td>Blue</td>
<td>CC</td>
<td>Cross</td>
<td>2.32</td>
<td>0.01</td>
<td>4</td>
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<tr>
<td></td>
<td></td>
<td>Along</td>
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<td>MTF</td>
<td>Cross</td>
<td>2.11</td>
<td>0.05</td>
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<td>Along</td>
<td>2.27</td>
<td>0.02</td>
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</tbody>
</table>

**Notes:**

1. Blue Band FWHM’s are for Pulse Response Functions.
2. Only one Pan band observation! Essentially same PSF/MTF in both scan directions.
3. MTF resampling provides noticeable contrast improvement; SNR is lowered, but still acceptable.
4. Overall SNR is good to excellent.
5. PRF is very repeatable in Blue band; MTF is noticeably less so.
Quickbird SDSU campus on 6/22/2005

MTF resampling

CC resampling

Noisier & Sharper than CC
2002/2003/2005 QuickBird Comparisons

- GSD changed from 0.7 to 0.6 meters after 2003.
- Spatial resolution performance appears consistent from 2002 to 2005.

<table>
<thead>
<tr>
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<th>Sensor</th>
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<th>Resampling</th>
<th>Target</th>
</tr>
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<td>Quickbird</td>
<td>Pan.</td>
<td>CC</td>
<td>Stennis tarp</td>
</tr>
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</table>

MTF over plot for Stennis tarp target

- Nyquist location in 2002
- Nyquist location after 2003
Overall Quickbird Conclusions

• Initial along-scan PSF/MTF estimates indicate slightly more blur than cross-scan, as expected.
• Good to excellent SNR.
• MTF compensation provides noticeable contrast boost with normal loss of SNR in Panchromatic band, but minimal loss of SNR in Blue band.
• No degradation of Panchromatic band PSF/MTF indicated from 2002 through 2005.