On-orbit Modulation Transfer Function (MTF) measurement of IKONOS satellite

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Introduction

- SDSU and NASA Stennis have collaborated to estimate spatial resolution performance of IKONOS satellite since 2000.
- NASA's Scientific Data Purchase (SDP) specified IKONOS spatial image quality using Modulation Transfer Function (MTF) value at Nyquist frequency.
- What is MTF?
  - A method of evaluating the spatial resolution of an imaging system.
  - MTF is normalized Fourier transform of Point Spread Function (PSF).
  - Nyquist frequency is the maximum resolution in digital imaging system corresponding to one half cycle per pixel.

$$H(\omega_x,\omega_y)=\Im\{PSF(x,y)\} \quad \Rightarrow \quad MTF(\omega_x,\omega_y)=\frac{|H(\omega_x,\omega_y)|}{|H(0,0)|}$$

Procedures

- Method Description
  - Edge Method
    - Sub-pixel edge locations were found by Fermi function fit (see below).
    - Savitzky-Golay Helder-Choi (SGHC) interpolation method was applied(see below).
    - The filtered profile was differentiated to obtain the LSF
    - MTF was calculated by applying the Fourier transform to the LSF.

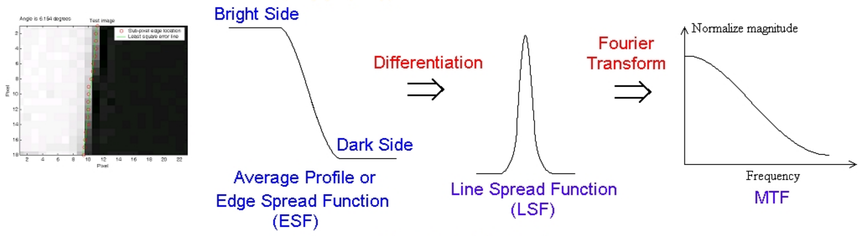

Figure 1. Edge Method

  - Pulse Method
    - A pulse input is given to an imaging system; output of it is the resulting image.
    - Edge detection and SGHC filtering is applied to get output profile.
    - MTF is calculated by dividing Fourier transform of output by input.

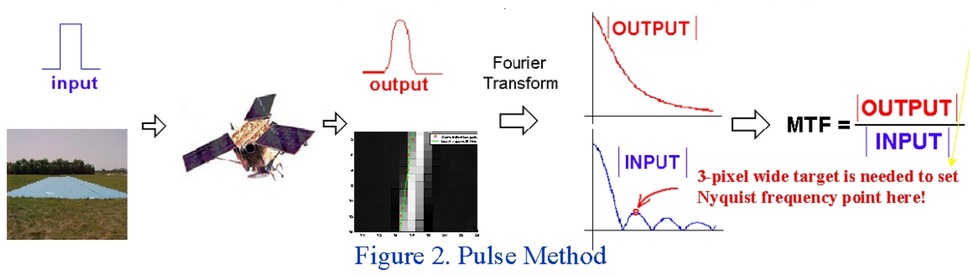

Figure 2. Pulse Method

  - Improved Parametric Edge Detection
    - Fermi function sub-pixel edge detection was superior to the 3rd order polynomial fitting edge detection (see the sensor modeling poster)
    - Sub-pixel edge locations were calculated on each line by finding best fitting parameter 'b'.

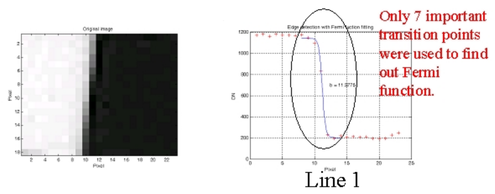

Figure 3. Parametric edge detection using Fermi Function

  - Savitzky-Golay Helder-Choi (SGHC) Filtering
    - Previous cubic Spline interpolation underestimated MTF values (see the sensor modeling) and produced under/overshoot in PSF.
    - A variation of S-Golay filter was developed to process randomly spaced input.
    - By using the original concept, the best fitting 2nd (or 4th) order polynomial was calculated within 1-pixel window using the MATLAB 'fmeansearch' function.
    - One point was evaluated by the fitting polynomial in the middle of the window.
    - The next value was found by shifting window in steps of the sub-pixel resolution.
    - The shift step size determined output resolution.

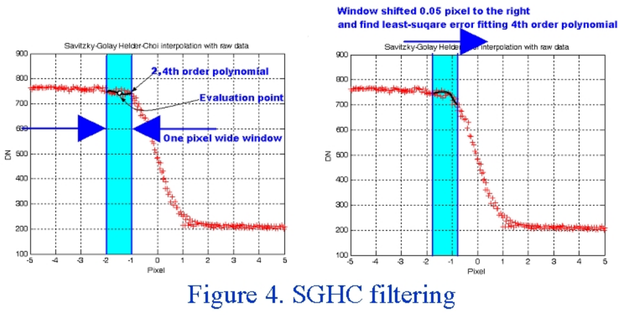

Figure 4. SGHC filtering

- Target Layout
  - Target layout is shown in Fig. 5.
  - Blue Tarp (Fig. 6)
    - Pulse width was determined to be 3 pixels wide in multispectral bands to locate desirable Nyquist frequency position.
    - 6° angle measured between "Image North" and tarp edge (8° angle desired).
    - All tarp grommets were aligned by a transit to maintain straight edges
  - Stennis Tarp (Fig. 7)
    - Radiometrically and spectrally stable edge target had a large difference in reflectance (dark - 3.6%, bright - 52.1%).
    - Edge angle was parallel to blue tarps.
    - In tarp, edge transition was at least two pixels wide in panchromatic band.
  - Tarp Angle (Fig. 8)
    - Dashed lines are projections of ground sample interval (GSI) points.
    - Resolution of sub-pixel profile is determined by the edge angle.
    - At least two horizontal pixels were covered by the edge line in multispectral bands.

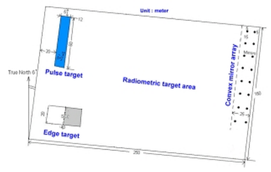

Figure 5. Field campaign plan and layout on July 22, 2002

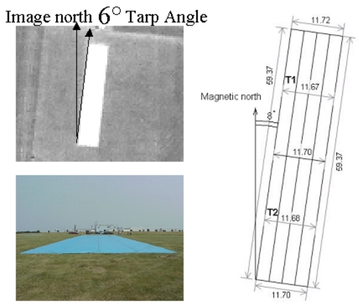

Figure 6. Blue tarp physical layout on June 20, 2002

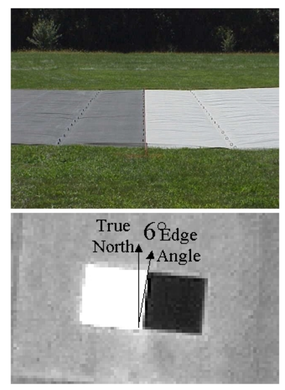

Figure 7. Stennis tarp.

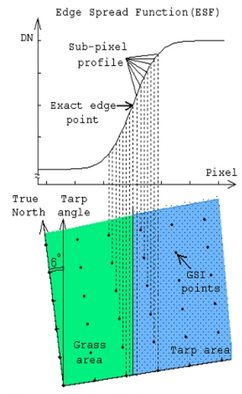

Figure 8. ESF projection from angled GSI points.

Results

- Image Information
  - Acquisition Dates

Date	MTFC	Interpolator Method	Azimuth	Elevation
6/27/02	On	Cubic Convolution	111.0177	65.36405
	Off	Cubic Convolution	111.0177	65.36405
7/3/01	On	Cubic Convolution	232.7466	77.98392
	Off	Cubic Convolution	232.7466	77.98392
7/22/02	On	Cubic Convolution	29.6459	67.65013
	Off	Cubic Convolution	29.6459	67.65013
	On	Nearest Neighbor	29.6459	67.65013
	Off	Nearest Neighbor	29.6459	67.65013

- MTF compensation (MTFC) filter on/off and Resampling methods
  - Visual Inspection

	Cubic convolution (CC)	Nearest neighbor (NN)
MTFC 'on'	• Noisy • Smooth edge transition	• Not noisy compared to MTFC on images • Smooth edge transition
MTFC 'off'	• Noisy in uniform area • Step edge transition (blocky)	• Not noisy • Step edge transition (blocky)

  - Edge Target Results (Fig. 9)

Dates	Sensor	Band	MTFC	Interpolator	Target	Method
7/22	IKONOS	Pan	On/Off	CC / NN	Stennis	Edge

MTFC	On	On	Off	Off
Interpolator	CC	NN	CC	NN
FWHM	1.1694	0.8371	1.5932	1.4797
MTF	0.4321	0.5384	0.1169	0.1212
SNR	72.6	63.6	142.6	130.7

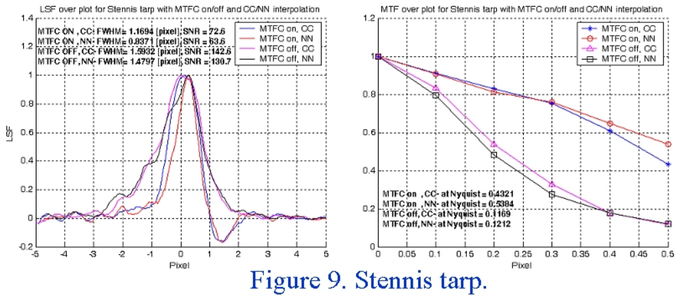

Figure 9. Stennis tarp.

- Result Comparison from 2000 to 2002.
  - Panchromatic Band (Fig. 10)

Dates	Sensor	Band	MTFC	Interpolator	Target	Method
3/26/00 17:13 and 17:14 5/31, 6/22, 8/5/, 9/26/01 7/22/02	IKONOS	Pan	On	CC	Big Spring – from 2000 to 2001 Stennis -2002	Edge

Date	3/26/00 17:13	3/26/00 17:14	5/31/01	6/22/01	8/5/01	9/26/01	7/22/02
FWHM	0.9610	0.9455	1.0212	1.0950	1.1359	0.9235	1.1452
MTF	0.4722	0.4808	0.4662	0.4388	0.4313	0.5962	0.4596
SNR	59.7	70.9	64.9	52.6	31.3	53.3	77.1

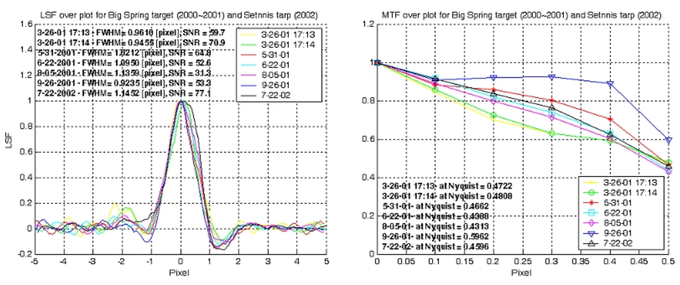

Figure 10. Pan-band over plots from 2000 to 2002.

  - Multispectral Bands (Fig. 11)

Dates	Sensor	Band	MTFC	Interpolator	Target	Method
5/01, 6/30/00 7/17, 7/25, 8/13/01 6/27, 7/3, 7/22/02	IKONOS	Blue	On	CC	Tarp	Pulse

Date	6/30/00	7/17/01	7/25/01	8/13/01	6/27/02	7/3/02	7/22/02
FWHM	2.1104	2.8146	2.8214	2.9291	2.9149	2.8689	2.8336
MTF	0.5187	0.4390	0.4828	0.5753	0.4722	0.4511	0.3347
SNR	189.4	84.8	133.7	70.0	55.7	102.0	82.1

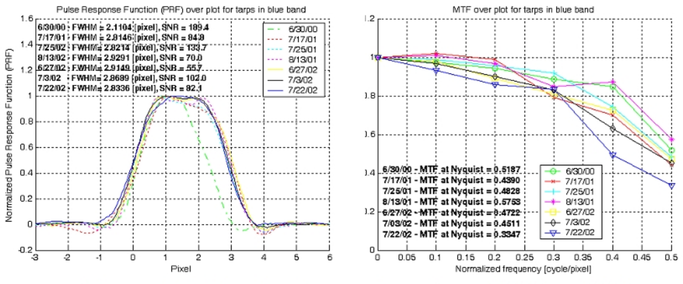

Figure 11. Blue-band over plots from 2000 to 2002.

- Specification Comparison.

Sensor \ Value	# of scenes	MTF ±1σ	FWHM±1σ	SNR ±1σ	SDP Spec.	Spec. Margin
Pan. Band	7	0.48 ±0.07	1.03 ±0.09	58.54 ±14.97	0.15	0.33
Blue Band	7	0.47 ±0.07	2.86 ±0.05#	102.53 ±45.65	0.30	0.17

2000 tarp FWHM was excluded (smaller tarp width)

Conclusions

- Physical layout of target is extremely important for MTF measurement.
- Stennis tarp provided panchromatic band MTF value of 0.48 ±0.07 at Nyquist frequency using data from 2000 to 2002.
- Average MTF value at Nyquist in blue band was 0.47 ±0.07 using data from 2000 to 2002.
- Significant tradeoff exists between MTFC and SNR.
- The IKONOS imagery met the SDP specification.