**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.

\[
H(\omega_x, \omega_y) = \mathcal{F}[PSF(x, y)] \Rightarrow MTF(\omega_x, \omega_y) = \frac{H(\omega_x, \omega_y)}{H(0,0)}
\]

**Procedures**

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

  - **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.

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

- **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 ‘fitsearch’ function.
  - One point was evaluated by 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.

**Results**

- **MTF compensation (MTFC) filter on/off and Resampling methods**
  - Cubic convolution (CC) Nearest neighbor (NN)
    - Smooth edge transition
    - Not many compared to MTFC on images
    - Step edge transition
    - Not many

- **Image Information**
  - **Acquisition Dates**
    - Dates
      - 2000-06-25
      - 2000-06-26
      - 2000-06-27
      - 2000-06-28
      - 2000-06-29
      - 2000-06-30
      - 2000-07-01
      - 2000-07-02
    - Source: DOD, USGS, NDMA, NCA, USAF, BOA, ORGC, USN, NASA, SNR

- **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 positions.
    - 6° angle measured between “image North” and tarp edge (8° angle desired).
    - All tarp grommets were aligned by a transit to maintain straight edges.

- **Savitzky-Golay Helder-Choi (SGHC) Filtering**
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**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**.