Effect of Pulse Width vs. GSD on MTF Estimation

Jason Choi, Dr. Dennis Helder

choit@sdstate.edu, Dennis_Helder@sdstate.edu,

Electrical Engineering and Computer Science Department

South Dakota State University

Introduction

- Modulation Transfer Function (MTF)
  - Frequency response of an imaging system
  - Normalized Fourier transform of a Point Spread Function (PSF)
  - MTF at Nyquist frequency is a standard measure of spatial quality of a imaging system.

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

Procedures

- Pulse MTF Estimator
  - A **'three-pixel-wide'** pulse input is given to an imaging system
  - Output is the resultant image as shown in Fig. 1
  - Edge detection and modified Savitzky-Golay filtering was applied to get output profile.
  - MTF is calculated by dividing Fourier transform of output by input.

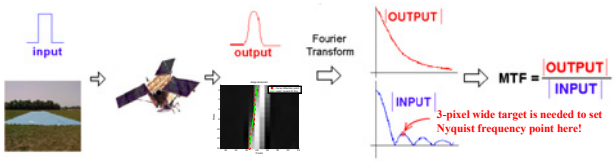

Figure 1.Pulse MTF Estimator

- Tarp Width Error
  - As shown in Fig. 2, Input 'sinc' function is very sensitive to the measurement error especially at 0.3 and 0.4 [cycle/pixel], because those are very close to the first zero-crossing point.
  - Tarp width measurement error or GSD error can be introduced to the pulse MTF estimator.
  - These errors were simulated by changing the input 'sinc' function in the frequency domain by linearly increasing pulse width from 2.75 to 3.25 pixels.

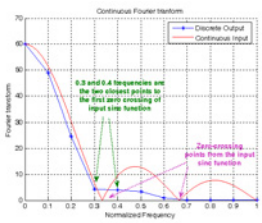

Figure 2. Fourier transform of input and output.

- Simulation Steps
  - Synthetic pulse images were convolved with the developed generic sensor model as shown in Fig. 3.
  - Pulse width was linearly increased from 2.75 to 3.25 pixels with step of 0.05 pixels.
  - Pulse MTF estimation was applied to the synthetic output images in a noise free situation.

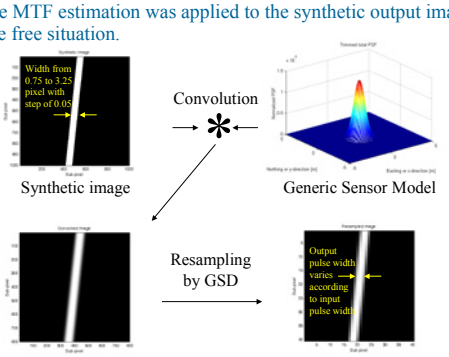

Figure 3. Synthetic pulse output images

Results

- Simulation Results
  - Pulse Width Change vs. Sinc Function (Fig. 4)
    - As the pulse width increased, the sinc function became narrower.
    - At 0.3 cycle/pixel, the sinc functions decreased as pulse width increased—shown as a blue arrow in Fig. 4.
    - Similarly, values at 0.4 cycle/pixel increased—shown as a red arrow in the Fig. 4.
    - Nyquist frequency at 0.5 cycle/pixel was stable regardless of the tarp width change.

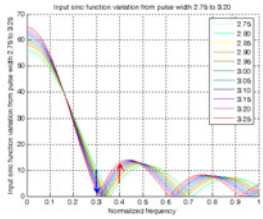

Figure 4. Pulse width change vs. FT of sinc function in frequency domain

  - MTF Plot Change vs. Pulse Width Change (Fig. 5)
    - Since MTF plots were calculated by dividing the Fourier transform of the output profile by the input, changes of the input sinc function in Fig. 5 resulted in deformations in the final MTF plots.
    - The most sensitive frequency was 0.3 in MTF plot and MTF values changed dramatically from 0.3 to 2.7.
    - Similarly, at 0.4 cycle/pixel values changed approximately from 0.7 to 0.3.
    - When there is no measurement error, MTF plots show a smooth transition without any shape deformation especially on 0.3 and 0.4 cycle/pixel, as indicated by the dark yellow line in Fig. 5 with 3.00 pulse width.

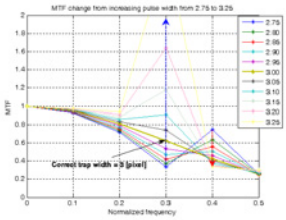

Figure 5. MTF plot change vs. pulse width change

- Simulation Results Applied On Quickbird Image of Sept 15, 2002.
  - In previous MTF plots, 0.3 and 0.4 frequency values were unstable and can serve as indicators of tarp width or GSD measurement error.
  - The MTF plot in Fig. 6 had a shape similar to the red curve in Fig. 5 which suggested ground measurement was smaller than actual tarp width.
  - Fig.7 shows Fourier transform of input and output signals with original tarp width 8.83 meters in red and modified tarp width 8.95 meters in green.
  - The corrected tarp width 8.95 meters was chosen to obtain a smooth MTF curve and to meet the input and output DC points.
  - Fig 8 shows corrected MTF plot in green.

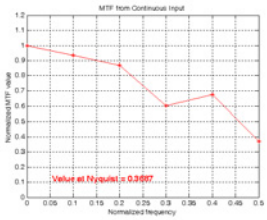

Figure 6. MTF plot change

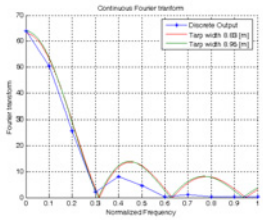

Figure 7. Fourier transform of step pulses 8.83 and 8.95 meters.

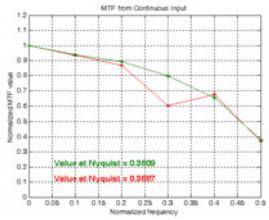

Figure 8. MTF plots from pulse width 8.83 and 8.95 meters.

- The Tarp Width Correction On 2002 Quickbird MTF results
  - In Fig. 9, two Quickbird images were processed by using corrected tarps width from
    - 8.77m → 8.85m on July 20th MTF process,
    - 8.83m → 8.95m on September 7th MTF process.
  - Nyquist frequency values changed very little after correction.

Date	Original	Corrected	% Diff.
7/20/2002	0.3333	0.3399	1.98%
9/7/2002	0.3687	0.3809	3.30%

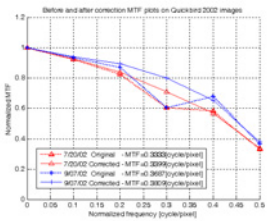

Figure 9. Pulse width correction applied on July 20 and Sept. 7, 2002 pulse images.

Conclusions

- In calculation of MTF from the pulse method, unstable frequency points at 0.3 and 0.4 [cycle/pixel] values were used as indicators of tarp width measurement error or GSD error.
- The MTF value at 0.3 [cycle/pixel] was dramatically increased by larger pulse width than actual.
- The MTF value at 0.3 [cycle/pixel] was decreased and 0.4 [cycle/pixel] was increased by smaller measurement than actual target width.
- Pulse target width and GSD must be known accurately (to within a 2-3 cm) for this procedure to produce satisfactory results
- The changes at Nyquist frequency were less than 3.3% .