Two-dimensional on-orbit MTF Analysis of Quickbird using Convex mirror Array

Dr. Dennis Helder, Manjunath K Rangaswamy, Larry Leigh

Dennis_Helder@sdstate.edu, manjukr_27@hotmail.com, Sideshow.Jr@usa.net

South Dakota State University
College of Engineering
Electrical Engineering Department

Electrical Engineering Department
South Dakota State University
Brookings, SD 57007-2220

SDSU

Introduction

- Objective
  - -One-dimensional (1-D) parametric techniques are commonly used to estimate system Point Spread Function (PSF)
  - -Purpose was to estimate two-dimensional (2-D) PSF using a parametric method with convex mirrors as point sources.
  - -Validation of results obtained from 2-D parametric method by comparing with results of 1-D non-parametric method.
- Point Spread Function (PSF)
  - -PSF is the Impulse response of the imaging system
  - -For point source input, output of the system is two-dimensional PSF [Fig 1]
  - -Convex mirror array were used as point sources for the Quickbird sensor

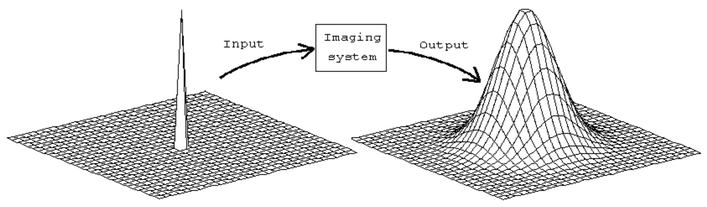


Figure 1. Two-dimensional PSF

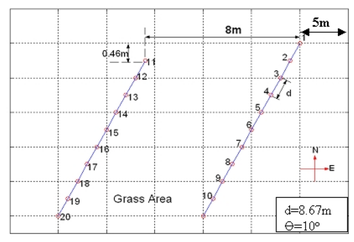
- Spatial Response components
- Overall system PSF is represented by a combination of individual PSF's
  - - PSF due to characteristics of optical components
  - - PSF due to motion of sensor over the scene
  - - PSF due to characteristics of sensor electronics
  - - PSF due to physical size and shape of detector elements
- Modulation Transfer function (MTF)
  - - MTF is an approach to determine the normalized frequency response of an imaging system.
  - - MTF value at Nyquist frequency often used to specify spatial quality of an image

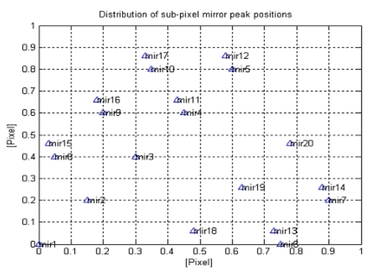
Procedures

- Convex Mirror Dimension
  - -Focal length of convex mirror was calculated using the incident and at-sensor energy relation in [Fig 2].
  - -At-sensor radiance (E_s)was calculated assuming DN value of 1638 (80% of Saturation level i.e., $2^{11} = 2048$)
    - *DN = Gain * (At sensor radiance) + bias*
  - -Attenuation constant k was calculated using IKONOS 2001 data
  - -Gain estimate was from current Quick-bird radiometric calibration
  - -Sensor distance (d_{sat}) was given as 450 km.
  - -Incident sun radiance (E_t) measured from Reagan sun photometer was 1319 W/m^2/sr
  - -Estimated focal length (f) was 0.67 meters

Figure 2. Mirror focal length

- Target development
  - -Angle and distance are critical to get a uniformly distributed sub-pixel sampled Point Spread Function (PSF) [Fig 3(b)]
  - -Two columns of convex mirrors were placed on uniform grass background[Fig 3(c)]
  - -Mirror array was inclined at an angle of 10^o from North to East and were placed at a distance of 8.67m from each other to get desired uniform distribution.[Fig 3(a)]

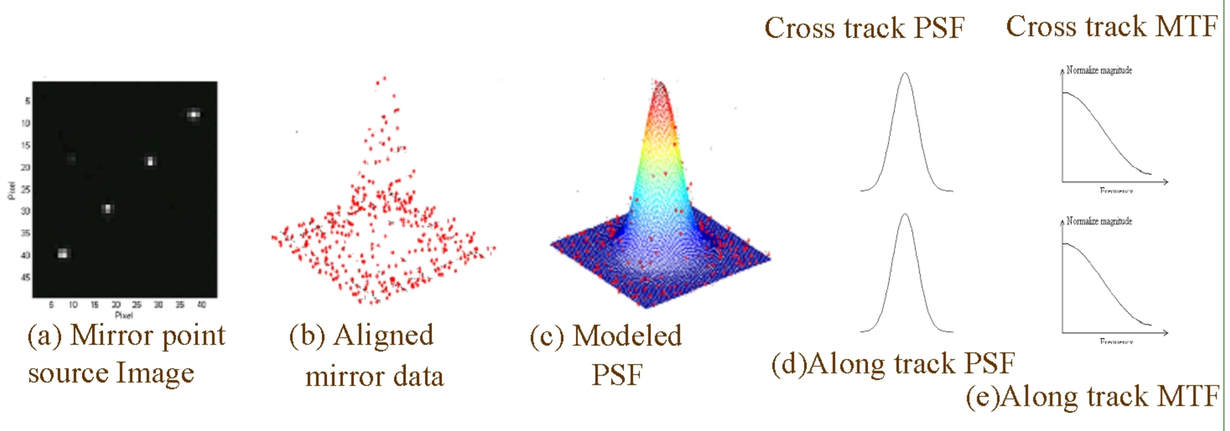




(a) Physical layout of mirror positions (b) Sampling distribution of Mirrors (c) Deployment

Figure 3. Target development and deployment

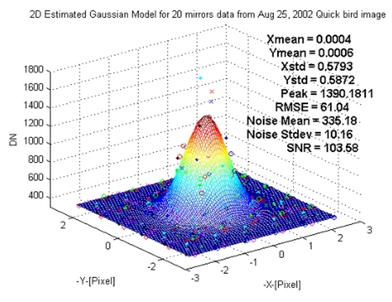
- Simulation Steps
  - -Estimate peak location of each mirror by applying 2-D Gaussian model to individual mirror responses [Fig 4(a)]
  - -Align to a common reference grid [Fig 4(b)]
  - -Apply 2-D Gaussian model on the aligned data set to estimate the PSF of imaging system [Fig 4(c)]
  - -Estimate Full Width of Half Maximum (FWHM) measurements from one-dimensional profiles of PSF in cross and along track directions [Fig 4(d)].
  - -Obtain normalized MTF values at Nyquist frequency in cross and along track directions by applying Fourier transform on 1-D PSF profiles [Fig 4(e)]



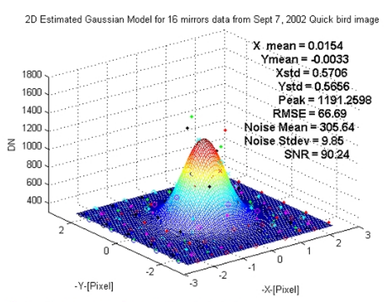
(a) Mirror point source Image (b) Aligned mirror data (c) Modeled PSF (d)Along track PSF (e)Along track MTF

Figure 4. Two-dimensional MTF estimation

Results: Applied on Quickbird 2002 images

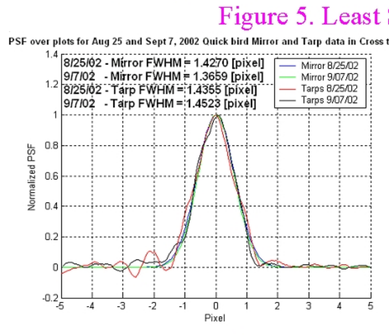


(a) August 25, 2002

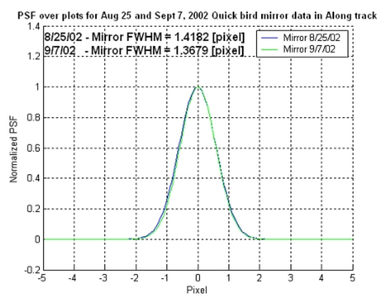


(b) September 7, 2002

Figure 5. Least Square Error Gaussian PSF

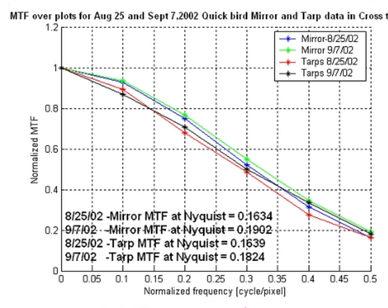


(a) Cross track

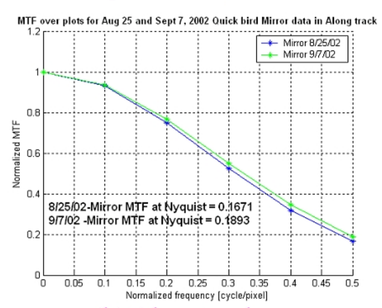


(b) Along track

Figure 6. 1-D PSF over plots of August 25 and September 7, 2002



(a) Cross track



(b) Along track

Figure 7. 1-D MTF over plots of August 25 and September 7, 2002

- Comparison of FWHM and MTF values obtained using parametric, two-dimensional Gaussian model and non-parametric methods

Panband	PSF				MTF			
Quick-bird	08/25/02		09/07/02		08/25/02		09/07/02	
2002 Targets	Along track	Cross track	Along track	Cross track	Along track	Cross track	Along track	Cross track
Mirrors	1.4187	1.427	1.3679	1.3659	0.1671	0.1634	0.1893	0.1902
Tarps	n/a	1.4355	n/a	1.4523	n/a	0.1639	n/a	0.1824

Conclusions

- MTF values (normalized) at Nyquist frequency ranges from 0.16 to 0.19 in cross track and 0.17 to 0.19 in along track direction.
- MTF and FWHM measurements obtained from the two-dimensional parametric method were validated by results obtained previously from one-dimensional parametric method.
- Physical layout of point sources (mirrors) is extremely important for PSF measurement.
- Quick-bird imagery met the NASA SDP specification.