A Framework for
Geo/Spatial Quality

CEOS-WGCV-IVOS
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Outline

- The task and opening thoughts
- Proposed Framework
- Proposed Actions

<u>Current Sub-committee members</u>:
Dennis Helder, Chair
Francoise Viallefont, Co-Chair
Jack Xiong, NASA
Derek Griffith, CSIR

South Dakota State University
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Task and Opening Thoughts

- Develop a framework for Geo/Spatial Quality for CEOS/IVOS to endorse.
- Explain concept and importance from IVOS perspective.
- Develop recommendations for procedures—test sites and analysis.

- Is the task concept captured adequately?
- This can become a large amount of work; how to keep it contained?
- Unique aspects of MTF targets/analyses are difficult to capture.
- Can an academic properly capture the needs of space agencies???

Proposed Framework

- Definition and Importance
- Measurement
- Pre-Flight Estimation
- On-Orbit Estimation
- Recommendations for Determining Geo/Spatial Quality

Proposed Framework

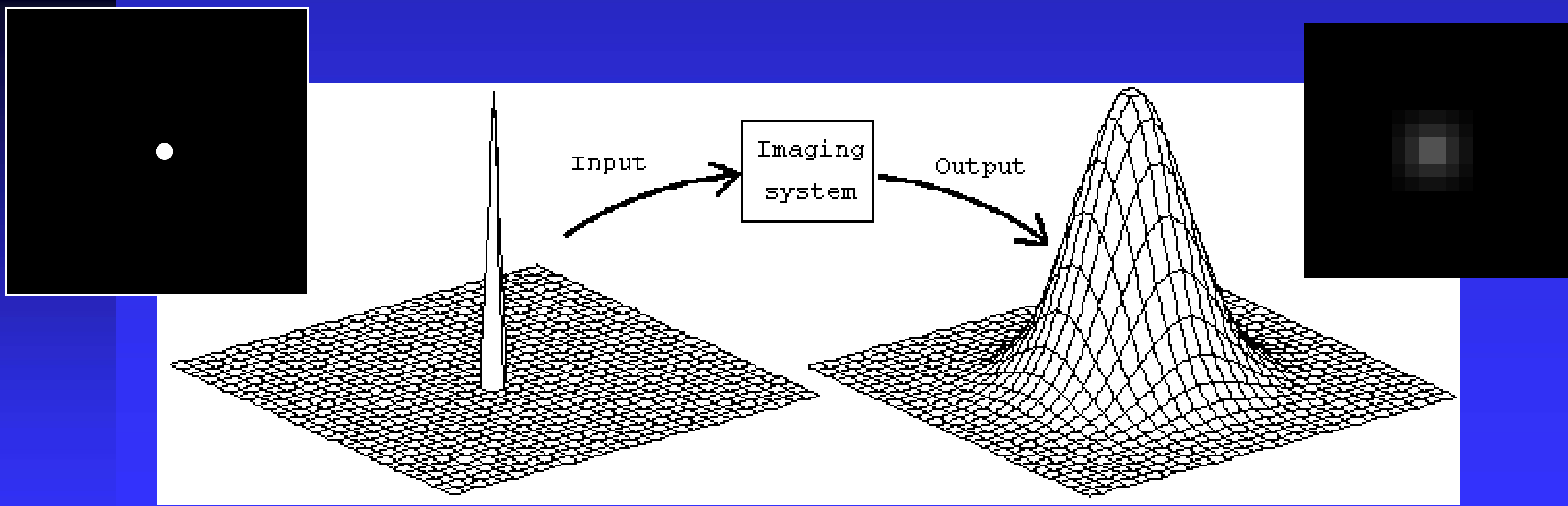
- Definition and Importance (short introductory section)
- Measurement (background and basic theory)
- Pre-Flight Estimation(to be developed later)
- On-Orbit Estimation(substantial portion of document)
- Recommendations for Determining Geo/Spatial Quality(final effort)

Proposed Framework

Definition and Importance (short introductory section)

- What exactly do we mean?
- Terms and Definitions
- Why is spatial quality important?
- How does this impact sensor/system design?
- Reference Materials

- What is Geo/Spatial Quality
  - Impulse response of imaging system is PSF.
  - Consider a very small point source.
  - PSF represents system response.
  - Normalized absolute Fourier transform value of PSF is Modulation Transfer Function (MTF).



Customer	: ESA/ESRIN	Document Ref	: TN-WP210-001-ARMINES
Contract No	: 21125/07/1-OL	Issue Date	: 04 March 2008
WP No	: 210	Issue	: 0.2

Title : Calibration Test Sites Selection and Characterisation – WP210

Abstract : ARMINES's contribution to WP210

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Can. J. Remote Sensing, Vol. 36, No. 5, pp. 583–601, 2010

Targets, methods, and sites for assessing the in-flight spatial resolution of electro-optical data products

Mary Pagnutti, Slawomir Blonski, Michael Cramer, Dennis Helder, Kara Holekamp, Eija Honkavaara, and Robert Ryan

Abstract. The spatial resolution of a digital, electro-optical remote sensing imaging system or product is an important image quality characteristic that helps determine the utility of an imaging source. Although spatial resolution is often described by a single image quality parameter, the ground sample distance, there are several other parameters that affect image sharpness and need to be considered. These other parameters are associated with the point-spread function, signal-to-noise ratio, and dynamic range of the image product. This review paper covers the various approaches to in-flight measurement of spatial resolution parameters, including ground sample distance, point spread function, optical transfer function, modulation transfer function, far field response, and edge response and their significance, as well as target types and methods to determine these spatial resolution parameters. To this end, the paper lists and describes various targets found across the world, as well as astronomical ones. These targets are appropriate for evaluating a wide range of image scale products. For high spatial resolution imaging systems, the types of targets range from engineered fixed and deployable targets to agricultural and urban features, allowing almost any site to be used for determining spatial resolution. Independent, comprehensive image product evaluation sites that are currently in use in the US and Europe are also described.

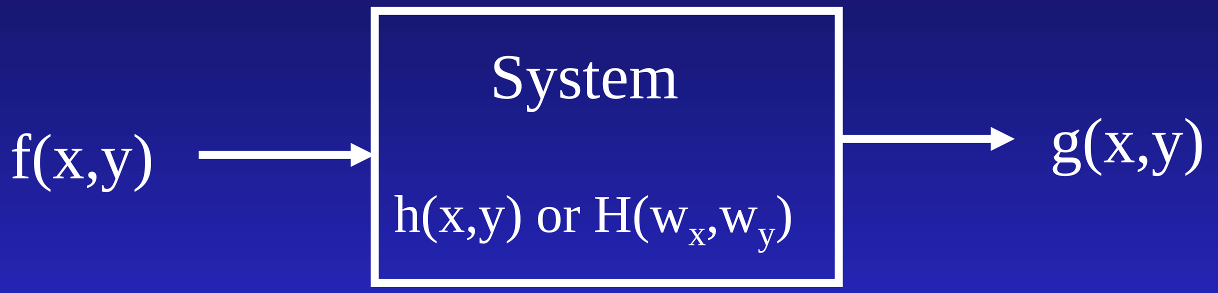
Resume. La résolution spatiale d'un système imageur numérique électro-optique de télédétection ou d'un produit dérivé est une caractéristique importante de la qualité de l'image qui permet de déterminer l'utilité d'une source imageante. Bien que la résolution spatiale soit souvent définie à partir d'un seul paramètre de qualité d'image, la résolution au sol, il y a plusieurs autres paramètres qui affectent la netteté de l'image et qui méritent d'être pris en considération. Ces autres paramètres sont associés à la fonction d'étalement du point, au rapport signal sur bruit et à la dynamique du produit image. Dans cet article de synthèse, on présente les différentes approches utilisées pour la mesure en vol des paramètres de la résolution spatiale incluant la résolution au sol, la fonction d'étalement du point, la fonction de transfert optique, la fonction de transfert de modulation, la réponse de champ lointain et l'effet de lisière ainsi que leur signification, de même que les types de cibles et les méthodes pour déterminer ces paramètres de la résolution spatiale. À cette fin, on énumère et on décrit dans l'article les diverses cibles rencontrées à travers le monde de même que les cibles astronomiques. Ces cibles sont appropriées pour l'évaluation d'une large gamme de produits à l'échelle de l'image. Pour les systèmes imageur à haute résolution spatiale, les types de cibles varient des cibles fixes et déployables aux cibles caractéristiques du milieu agricole et urbain, ce qui permet d'utiliser presque n'importe quel site pour déterminer la résolution spatiale. On décrit également les sites indépendants et intégrés pour l'évaluation des produits images présentement utilisés aux États-Unis et en Europe.
[Traduit par la Rédaction]

Proposed Framework

Measurement (background and basic theory)

- Spatial-based measurements
  - Point Spread Function
  - Line Spread Function
  - Edge Spread Function
  - Relative Edge Response
- Non-spatial-based measurements
  - Optical Transfer Function
  - Modulation Transfer Function
  - Contrast Transfer Function
- Units and SI traceability

- Basic System Properties

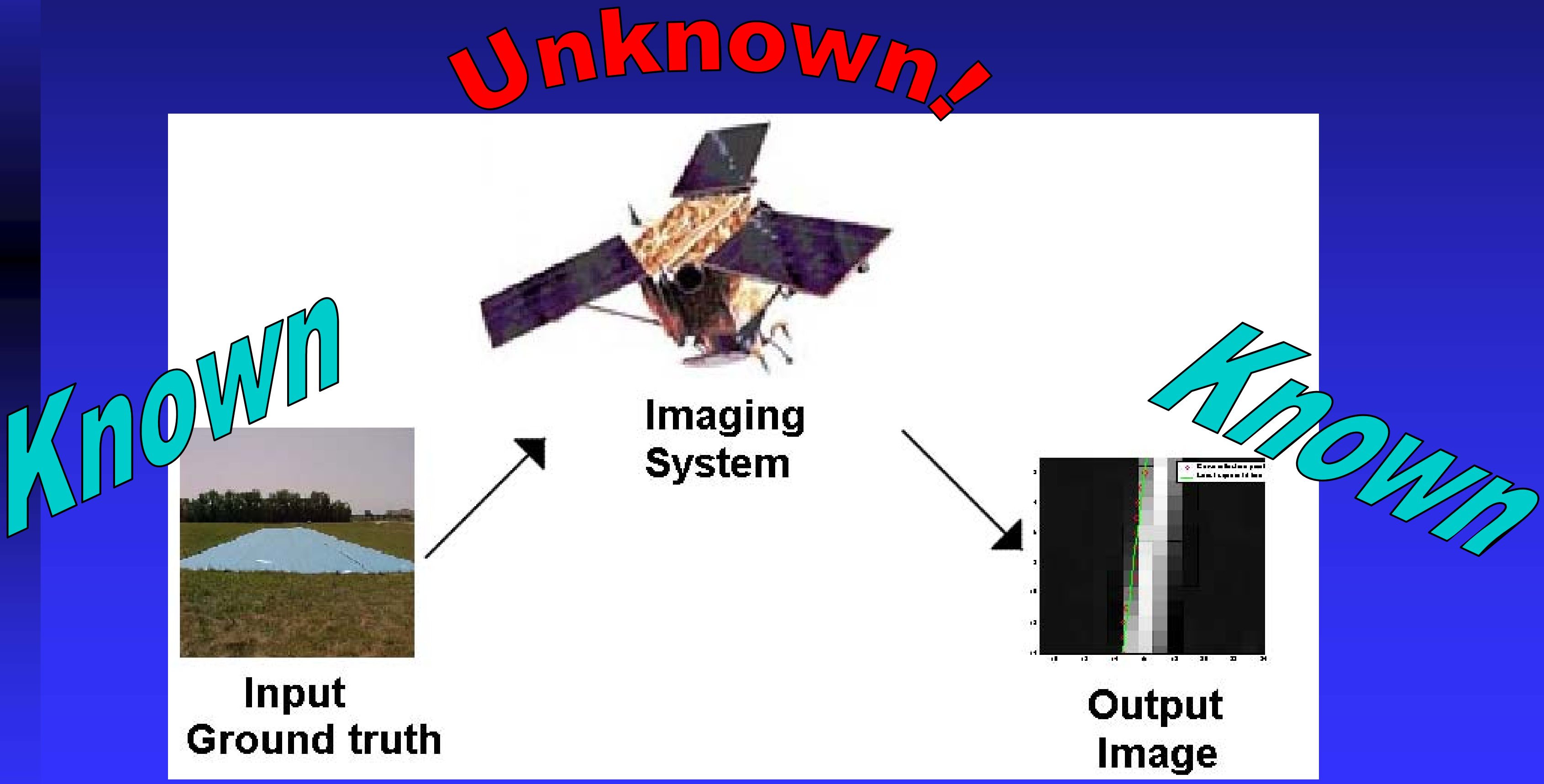


$$g(x,y)=f(x,y)*h(x,y)=\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(\alpha,\beta)h(x-\alpha,y-\beta)d\alpha d\beta$$

Or, in Fourier space…

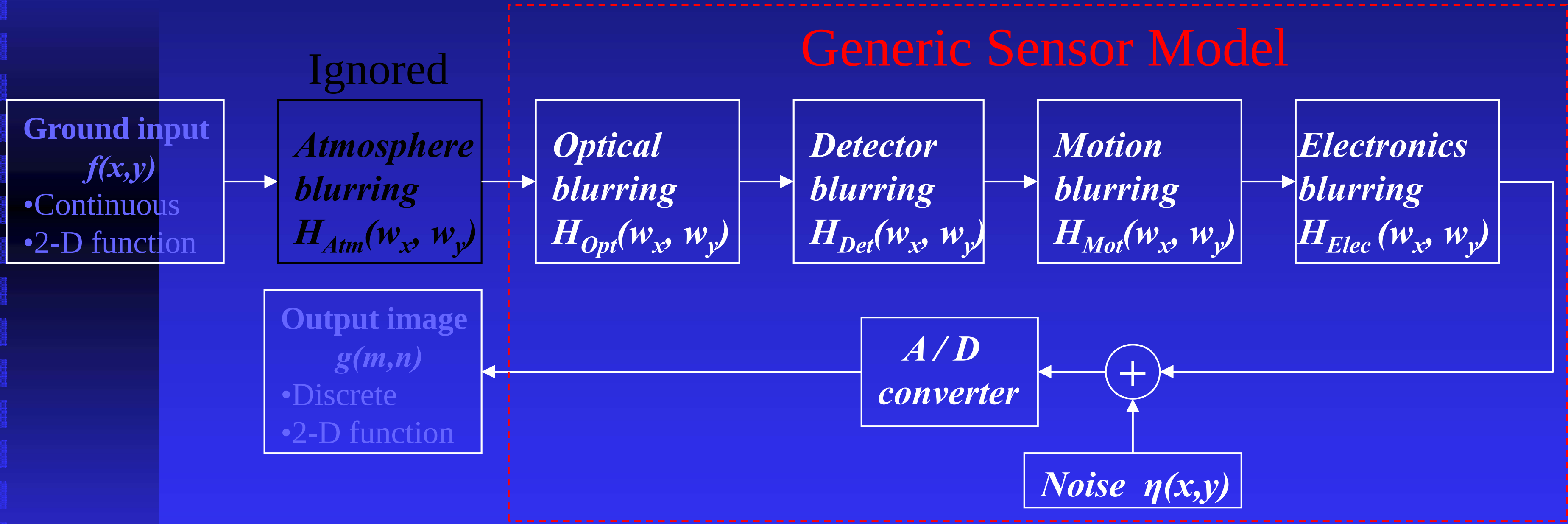
$$G(\omega_x,\omega_y)=F(\omega_x,\omega_y)H(\omega_x,\omega_y)$$

- Ground truth (lab source) is the input signal.
- System is the satellite sensor (and atmosphere).
- Output signal is the image.



A system identification problem!

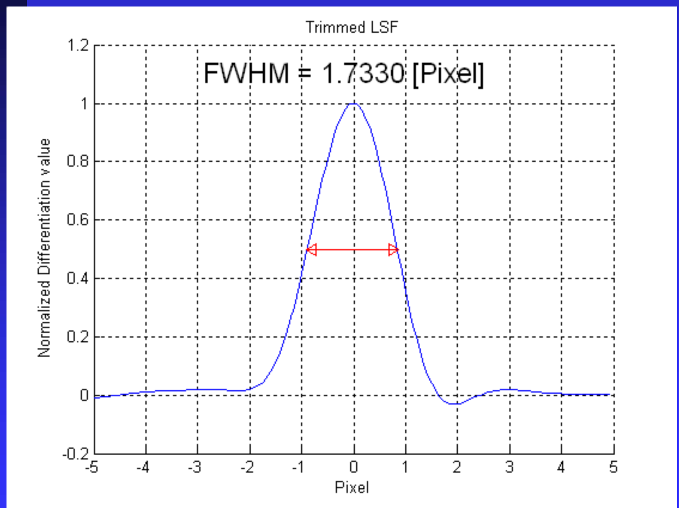
• Imaging System Model



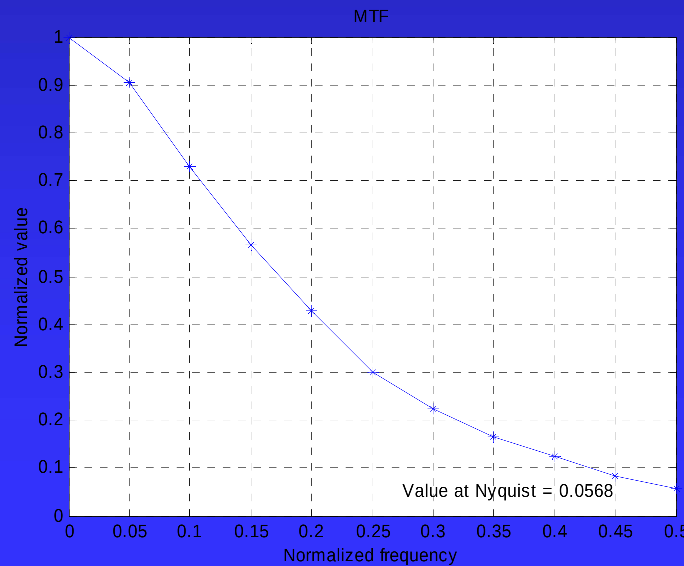
$$PSF_{net}(x,y) = PSF_{opt}(x,y) * PSF_{\det}(x,y) * PSF_{mot}(x,y) * PSF_{elec}(x,y).$$

- Some Limitations and conventions
  - Usually only a 1-D PSF estimate is possible
    - Termed Line Spread Function (LSF).
  - Normalized absolute value of the Fourier transform of the LSF is MTF.
  - MTF @ Nyquist is often specified…

Line Spread Function



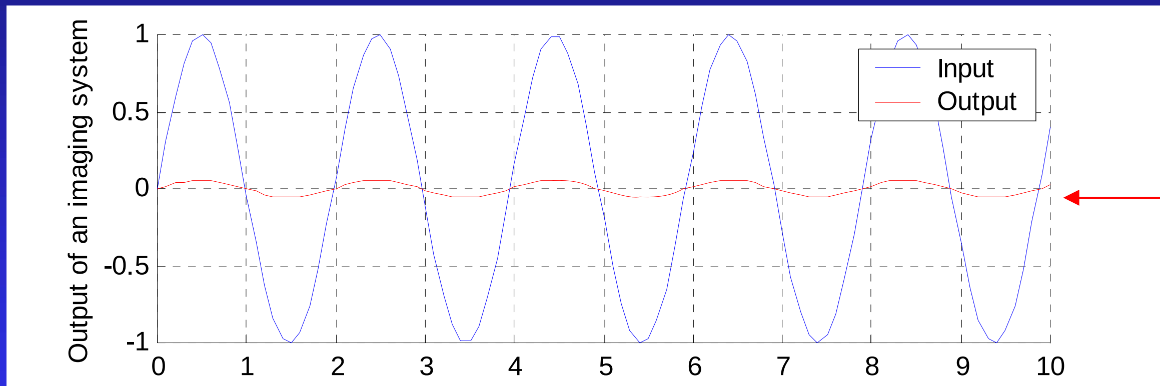
Modulation Transfer Function



[Cycles/Pixel]

MTF @ Nyquist

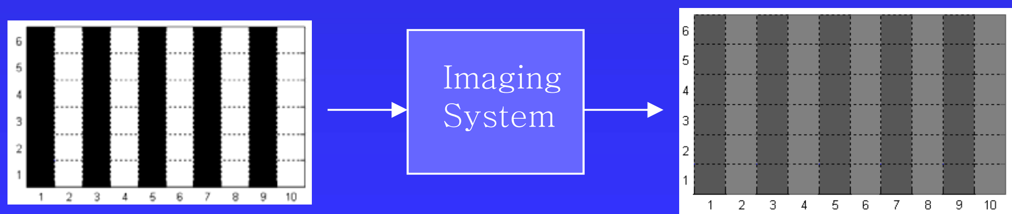
- A Fourier domain specification.
- Normally only at one spatial frequency.
- Is this intuitive?



Amplitude = 0.057

MTF value at Nyquist is 0.0057!

Frequency = 0.5 [Cycle / Pixel] ⇒ Nyquist frequency



Pixels

Original input

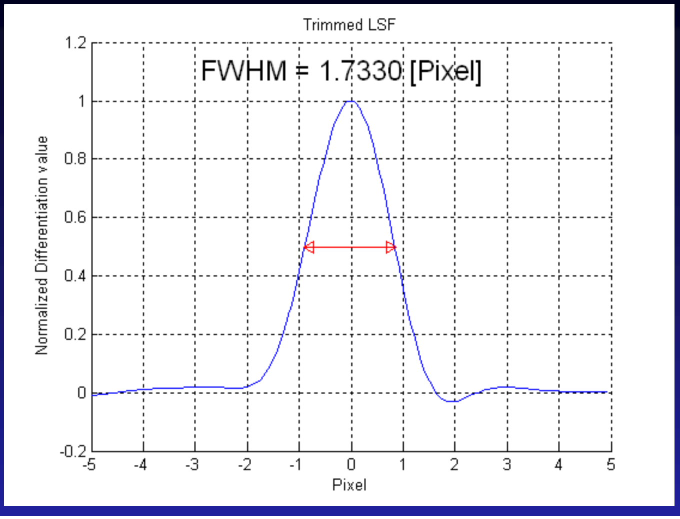
Pixels

Imaging system output

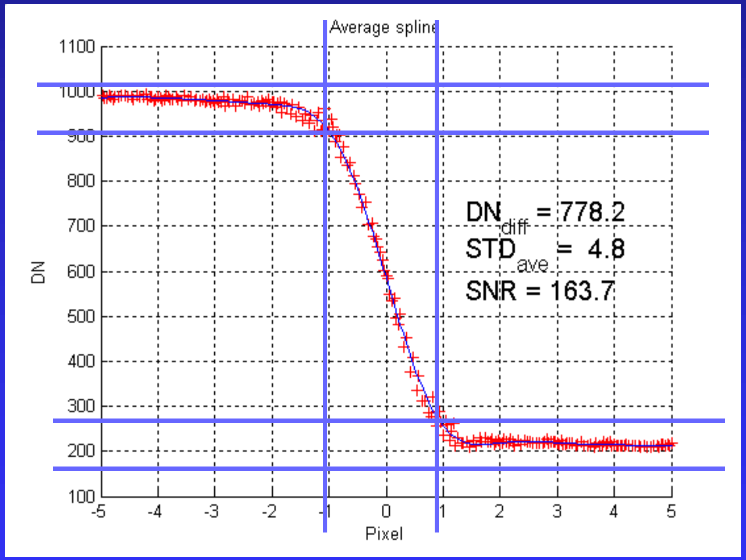
Specifications:

- Which one?

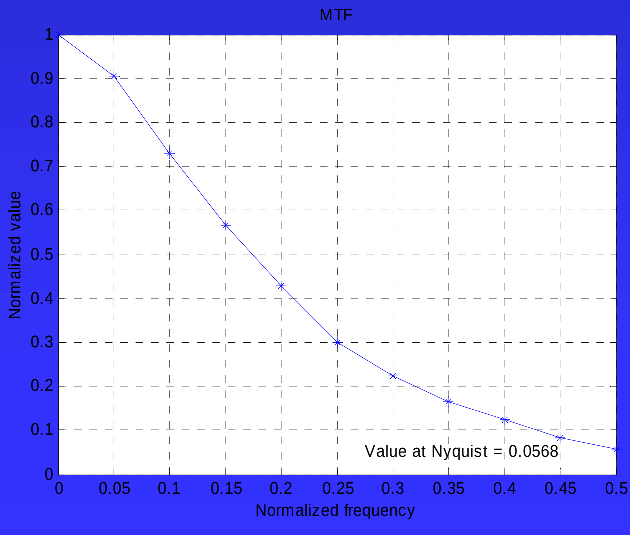
Line Response?



Edge Response?



Or MTF?



Spatial Domain or Frequency Domain

- Most specifications are written in terms of MTF as a function of spatial frequency
  - Dominant parameter is typically MTF @ Nyquist frequency
  - Nyquist frequency depends on GSD
    - Nyquist frequency = 1/(2*GSD)
  - MTF at Nyquist is a measure of aliasing
  - MTF measurements at Nyquist are difficult to estimate in-flight
- Full Width Half Max *(FWHM)* of Line Spread Function *(LSF)* is more easily measured and highly related to image quality
  - Edge response slope depends on FWHM of LSF

Proposed Framework

Pre-flight Estimation (to be developed later)

- Laboratory methodologies
  - Targets
  - Equipment
- Data Analysis, PSF/MTF Estimation

Proposed Framework

On-orbit Estimation (substantial portion of document)

- Field Methods Survey
- Targets
  - Artificial/Man-made
    - Points
    - Lines
    - Edges
    - Pulses
  - Image feature-based
    - Linear ('Rich') features
    - Bridges
    - Moon
  - Matrix of Targets
    - Type vs. GSD
    - Availability/Maintenance
    - Point of Contact
    - Recommended for operational acquisition
  - Database of 'Standard' Imagery for PSF/MTF estimation
- Data Analysis, PSF/MTF Estimation
  - Image data format
  - Models
  - Parametric/Nonparametric Methods
  - Database of 'Standard' estimation methods

Proposed Framework

On-orbit Estimation (substantial portion of document)

- **Field Methods Survey**
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Who is doing what?

Types of Targets

- Point Targets
  - Several types are possible:
    - Lasers?
    - Spotlights?
    - Stars?
    - Mirrors?

Spotlights/Lasers:

Advantages

•Easily deployed and controlled.

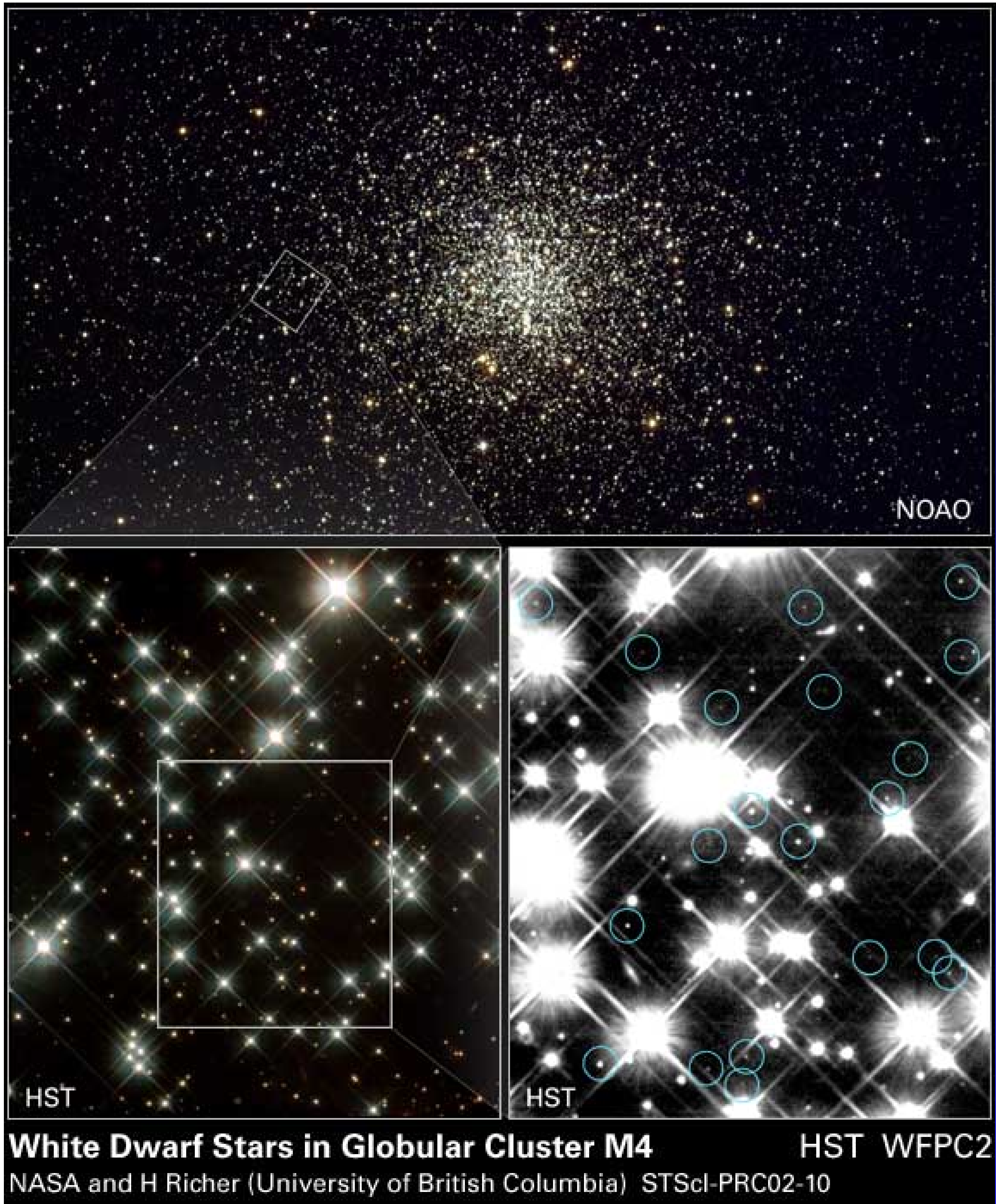
Disadvantages:

•Location is important.

•Atmospheric effects.

•Deployment…

•Multiple sources



Stars: The ultimate point source!

Advantages:

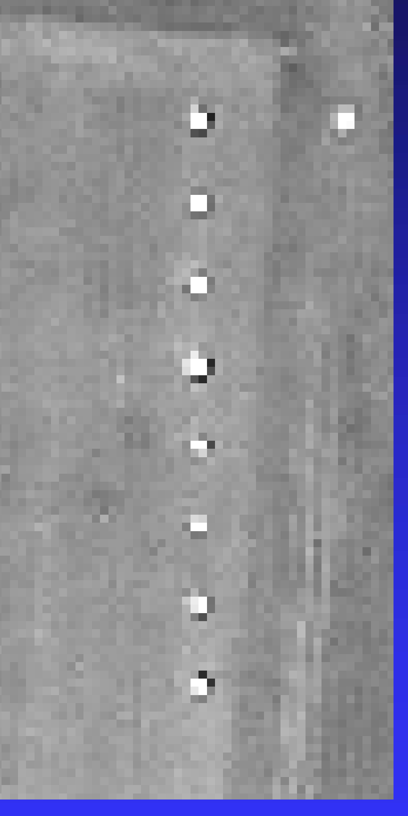
- •Truly a point source.
- •No atmosphere.
- •Many are available.
- •Radiances accurately known

Disadvantages:

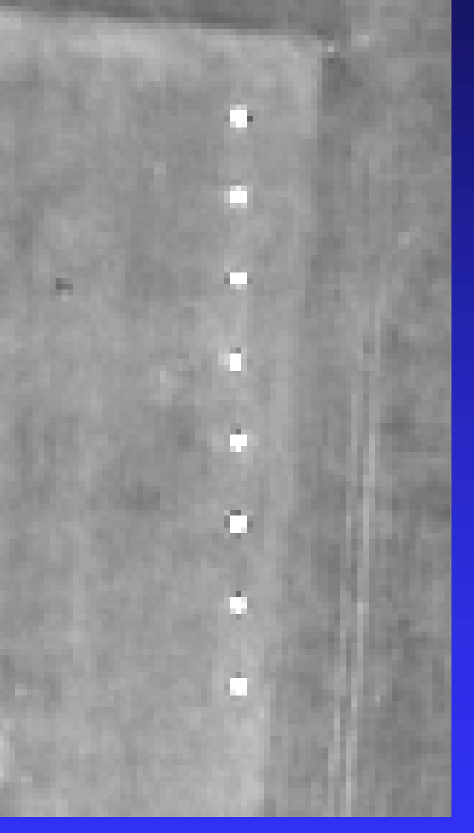
- •Instrument must be pointable.
- •Alignment of multiple samples.

Convex Mirrors:

- Images of Convex Mirrors



IKONOS on
July 22, 2002



QuickBird on
July 20, 2002

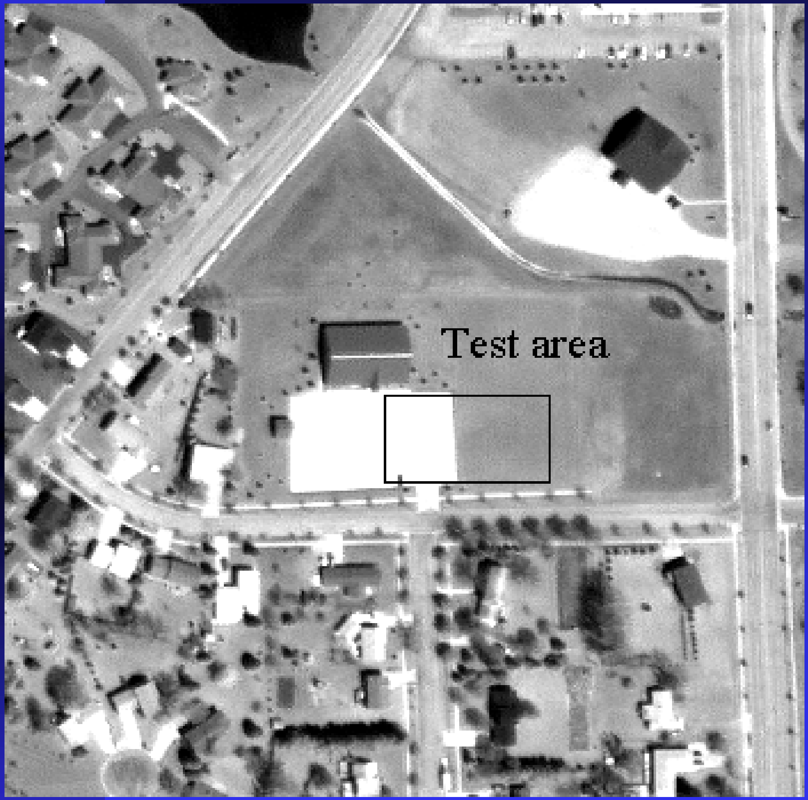
Types of Targets

- Edge Targets
  - Several types are possible:
    - “Natural”
      - Field boundaries
    - “Man-made”
      - Parking lots
      - Tarps
    - Easily done in a laboratory

- Edge Targets
  - Parking Lot 2 (Natural Target)

Parking lot 2 from South to North

◆ Parking Lot 2 (IKONOS Images)



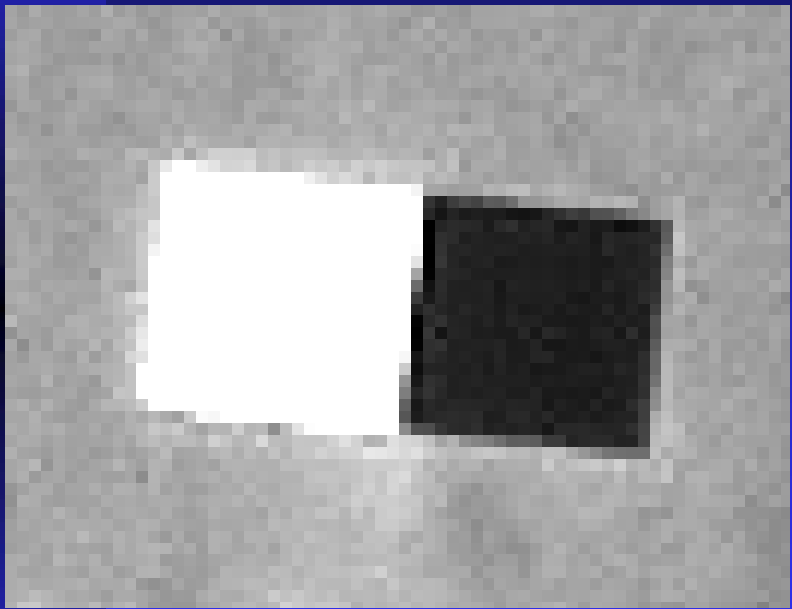
(a) Panchromatic band (b) RGB Multispectral bands

Parking lot 2 on May 1 2000.

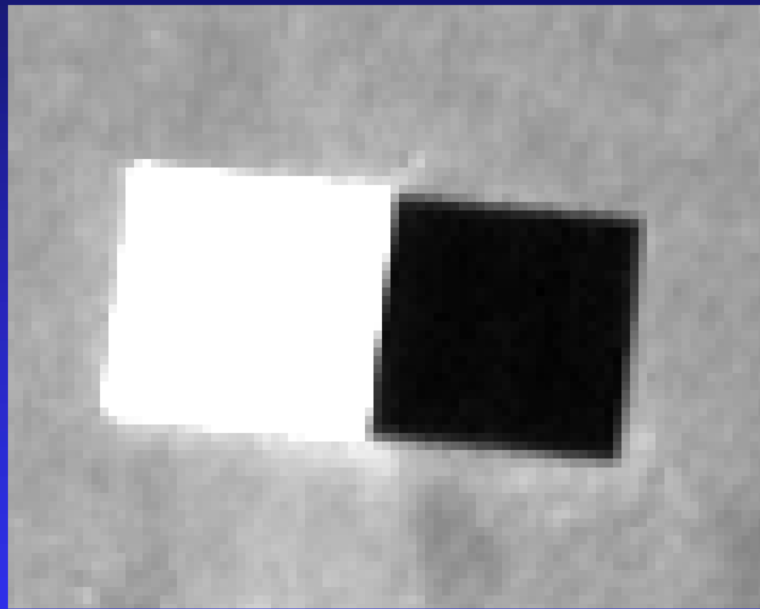
- Stennis Tarps (Artificial Target)
  - 53% reflectance on bright side
  - 3% reflectance on dark side

August 25, 2002

- Stennis Tarp (IKONOS & QuickBird Images)



IKONOS Panchromatic Band
July 22, 2002



OuickBird Panchromatic Band
July 20, 2002

◆ Pulse Targets

Tarp placement viewed from the South on July 2, 2002

Every stake was aligned by transit.

◆ Pulse Target Image

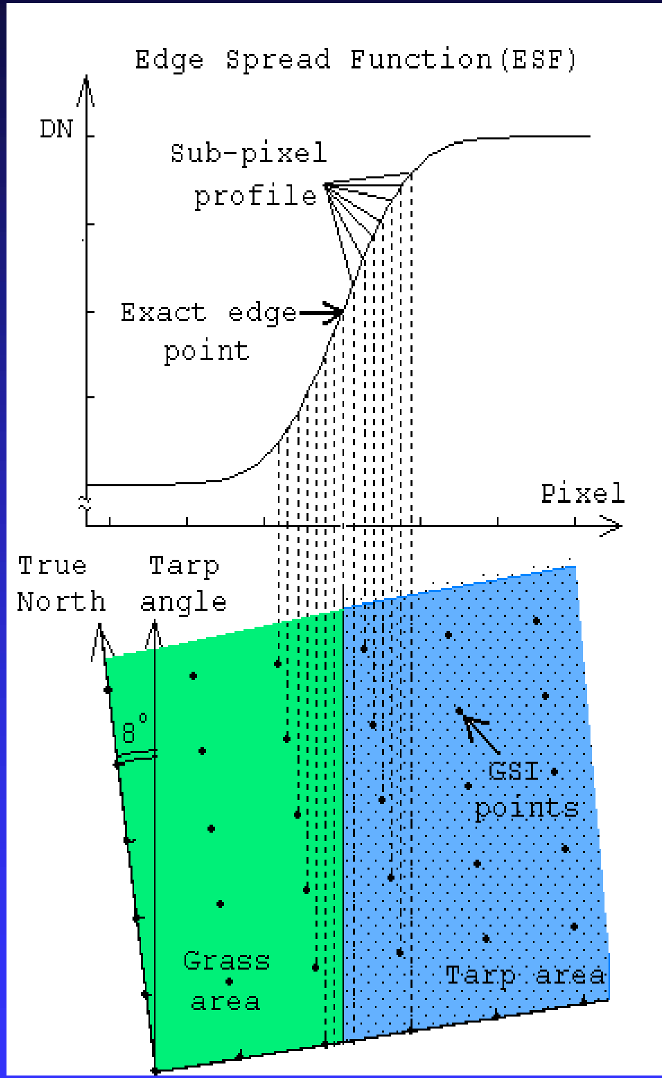
IKONOS Image of the Blue Tarps

Matrix of Targets

	Point	Edge	Pulse	Image Feature
High Resolution (<10m)		Big Spring, TX Digital Globe(?)  Avail/Main. Operational?		
Moderate Resolution (10—50m)				
Coarse Resolution (>50m)				

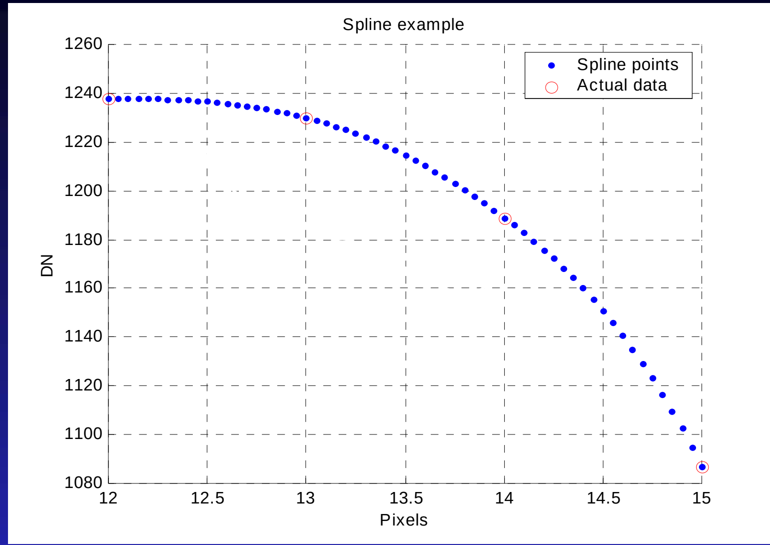
Processing Methodologies

- Edge angle
  - Edge spread function (ESF) is shown in the figure.
  - Dashed lines are projections of ground sample interval (GSI) points.
  - Sampling of sub-pixel profile is determined by the edge angle.
  - An 'optimal' angle is 6 degrees.
  - Aliasing of data points occurs for angle >10º
  - 8° was chosen to allow for alignment errors



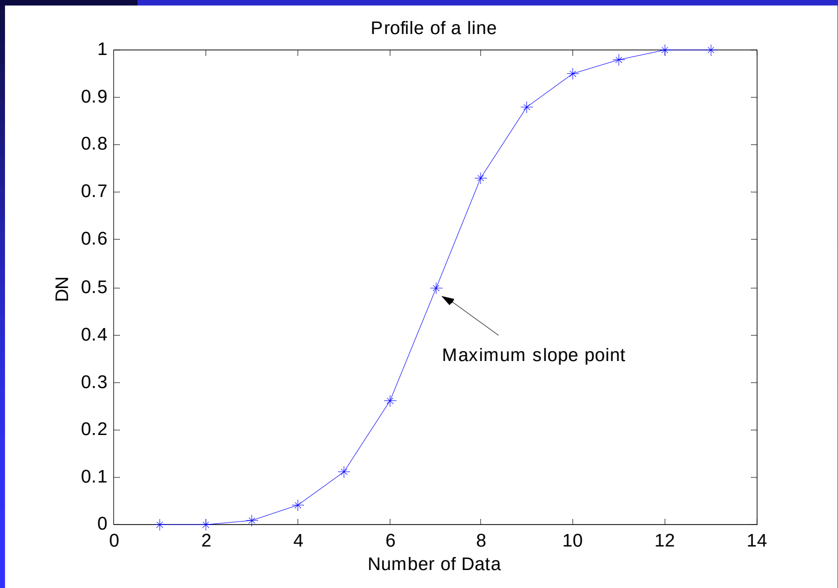
ESF projection from angled GSI

◆ Line-by-Line Interpolation

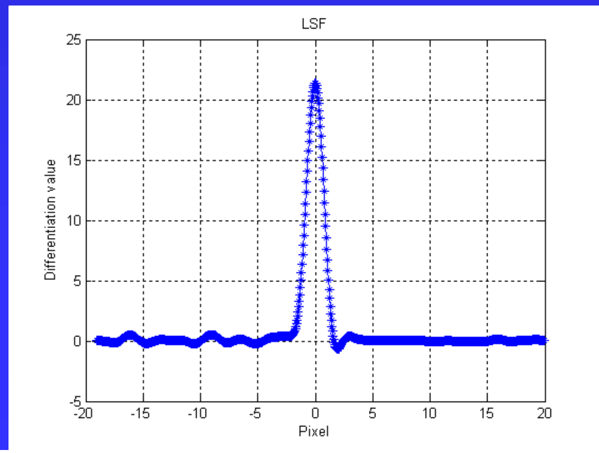


◆ Sub-pixel Edge Detection

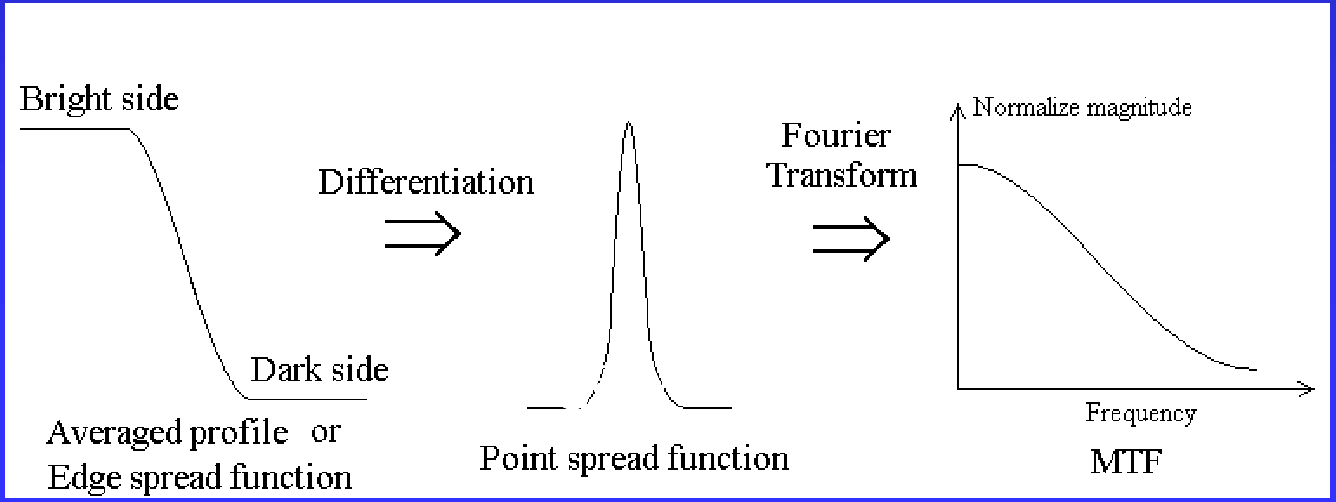
- Find point of maximum slope
- Fit cubic polynomial to surrounding four points.
- Find location of inflection point



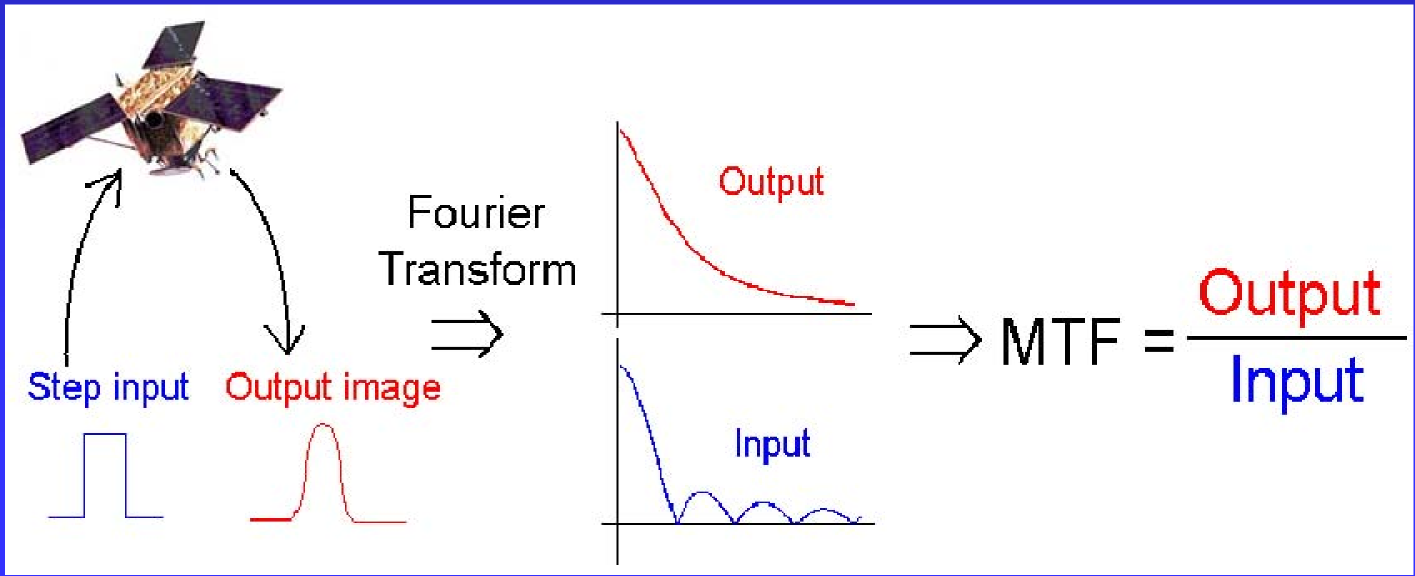
- Conversion from ESF to PSF: First Order Differentiation



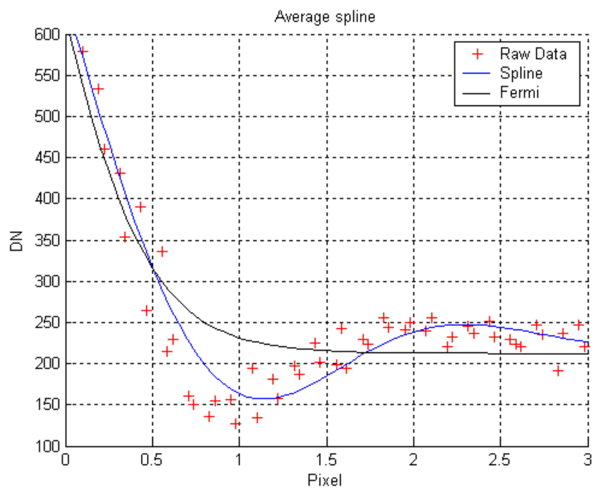
- **Transform Analysis**
  - Edge Method
    - Data Alignment
    - Differentiation of the averaged profile yields PSF.
    - Taking Fourier transform, normalization yields MTF.

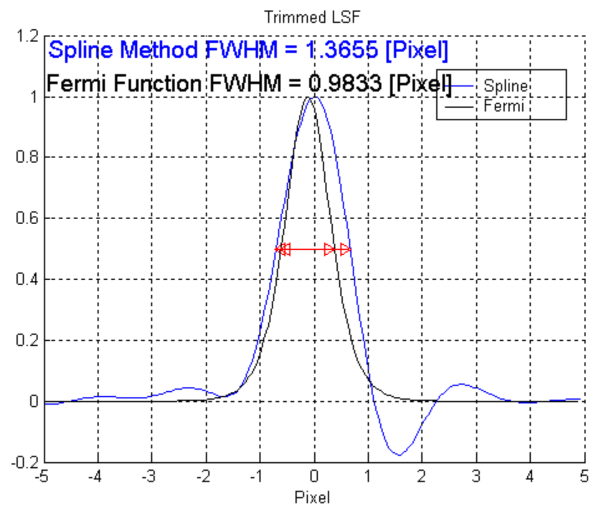


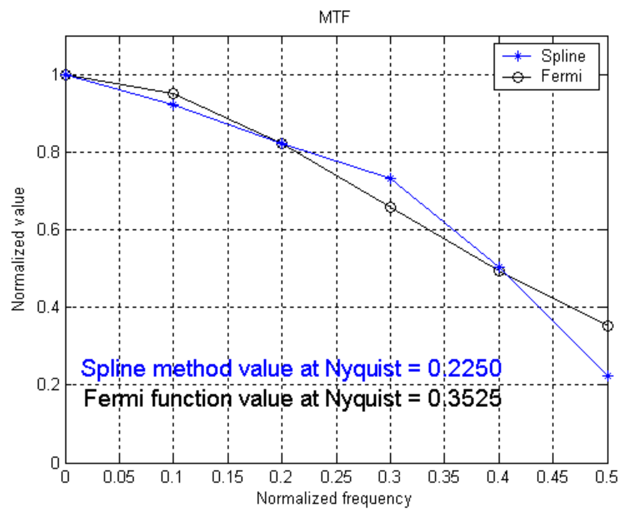
- Transform Analysis
  - Pulse Method
    - A *pulse* input is given to an imaging system.
    - Output of the system is the result image.
    - Take Fourier transform of the input and output.
    - MTF is found by dividing output by input



- Parametric vs. Non-parametric modeling
  - Parametric modeling:
    - Assumes knowledge of underlying system to be identified.
    - Greatly simplifies search for 'optimal' model parameters.
  - Non-parametric modeling
    - Only minimal knowledge of system required.
    - Can capture 'unexpected' behavior…
    - More difficult to separate signal and noise.







Spline and Fermi ESF, PSF and MTF plots of IKONOS image on July 22, 2002

Proposed Framework

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Proposed Actions

Proposed Framework

Recommendations for Determining Spatial Quality (final effort)

- Pre-flight recommendation (to be developed later)
- Operational On-orbit recommendations
- Interoperability and SI traceability

Summary/Actions

- Continue working on proposed framework
- Survey current operational methods
- Develop database of imagery for PSF/MTF/RER estimations
- Develop database of analysis methods
- And?