Radiometric Performance of Digital Image Data Collection – A Comparison of ADS40, DMC, UltraCamD and Emerge DSS

Eija Honkavaara & Lauri Markelin

Department of Remote Sensing and Photogrammetry
Finnish Geodetic Institute

In Collaboration with Blom Kartta, Estonian Land Board, National Land Survey
Financially supported by Ministry of Agriculture and Forestry of Finland

Photogrammetric Week 2007, 4.9.2007

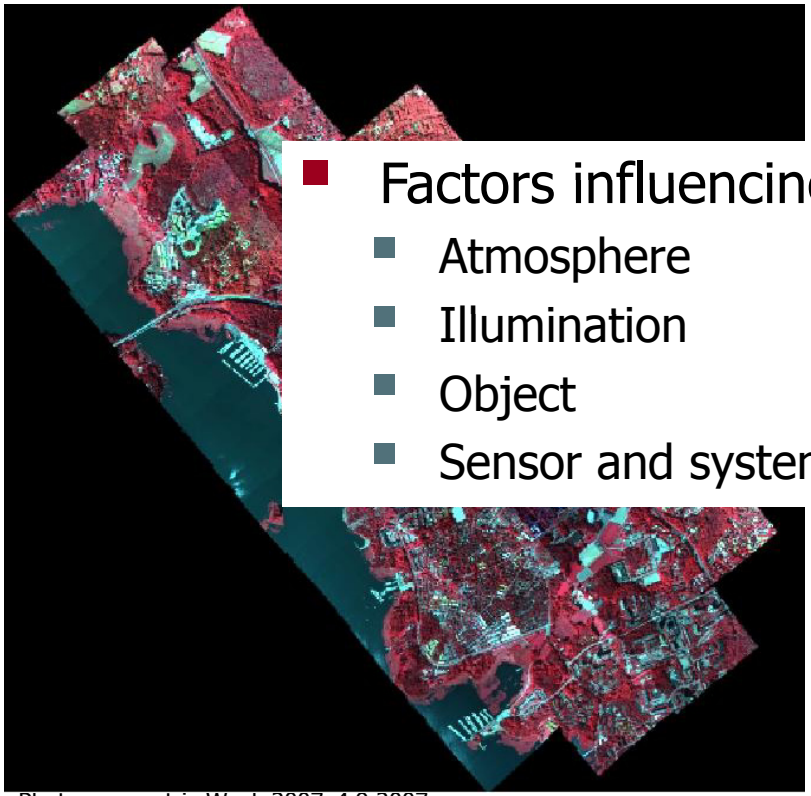
Contents

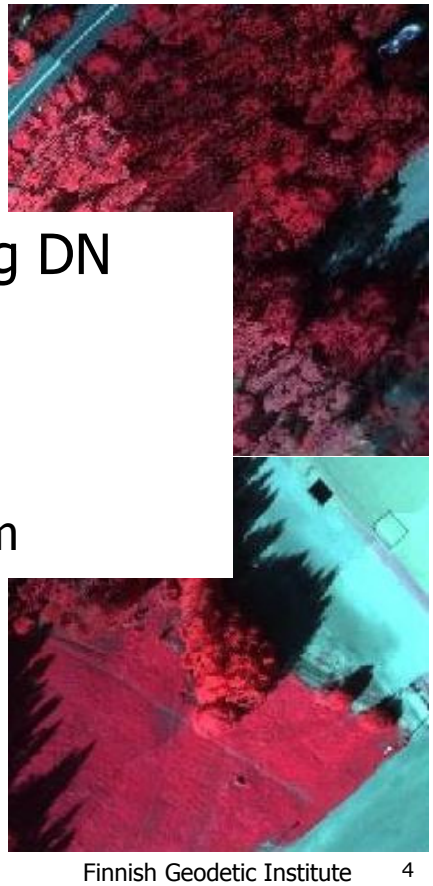
Introduction

- Radiometry: Measurement of electromagnetic radiation in wavelength range 0.01-1000 µm
- Digital number (DN)
- Radiometric properties of CCD sensors: linearity, low noise level, stability, good resolution, multispectral data
- Application of digital photogrammetric images
  - Improved performance and automation potential of conventional applications
  - New applications, quantitative use: multispectral classification, monitoring, change detection, …
- Rigorous radiometric processing new issue for photogrammetric processing lines -> efficient radiometric processing chains needed to process huge amounts of photogrammetric data
- Radiometric performance of photogrammetric sensors is evaluated from public literature and empirically

Finnish Geodetic Institute
Eija.Honkavaara@fgi.fi

Image radiometry
DMC orthophoto mosaic





- Factors influencing DN
  - Atmosphere
  - Illumination
  - Object
  - Sensor and system

Finnish Geodetic Institute
Eija.Honkavaara@fgi.fi

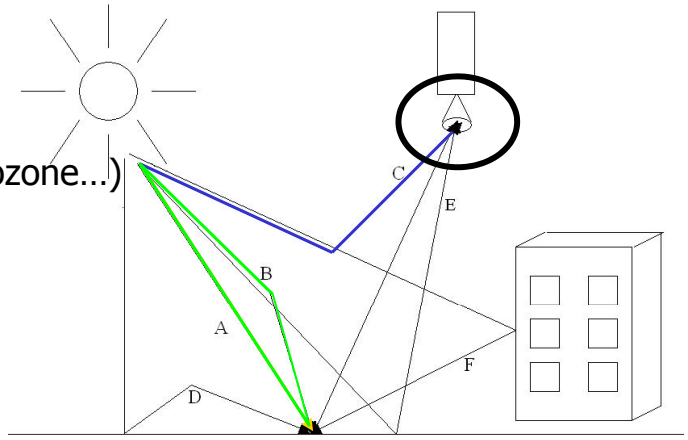
Influence of atmosphere and illumination

Atmosphere

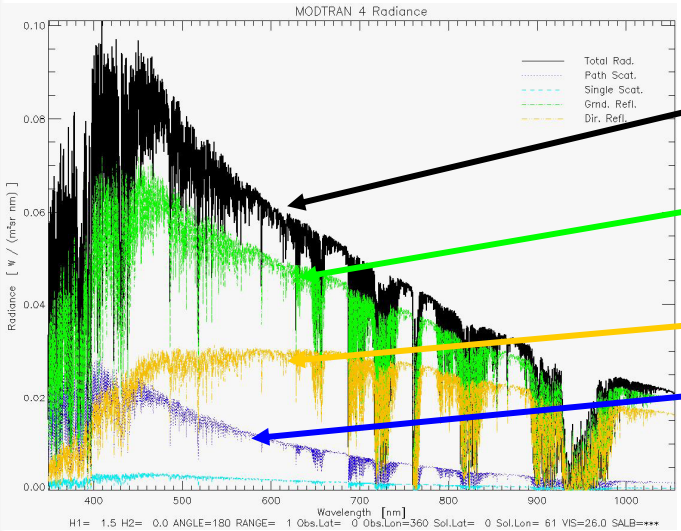
- Molecular and aerosol scattering
- Absorption by gases (water vapor, ozone…)

Major radiation components

A Direct component
B Skylight
C Path scattered radiance



Beisl, U., 2001



Total radiance

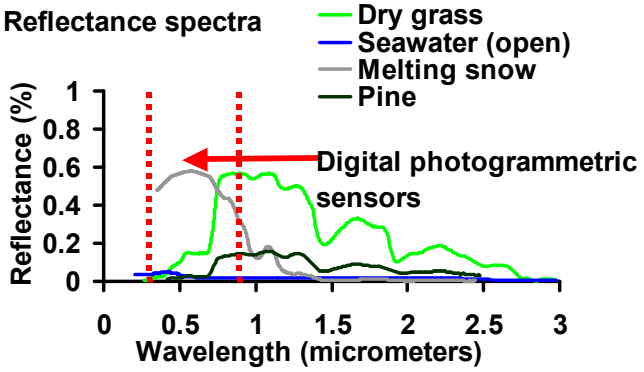
Direct radiation + skylight

Direct radiance

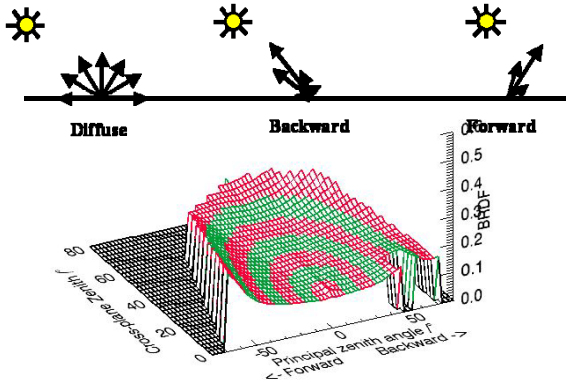
Path scattered radiance

Object properties

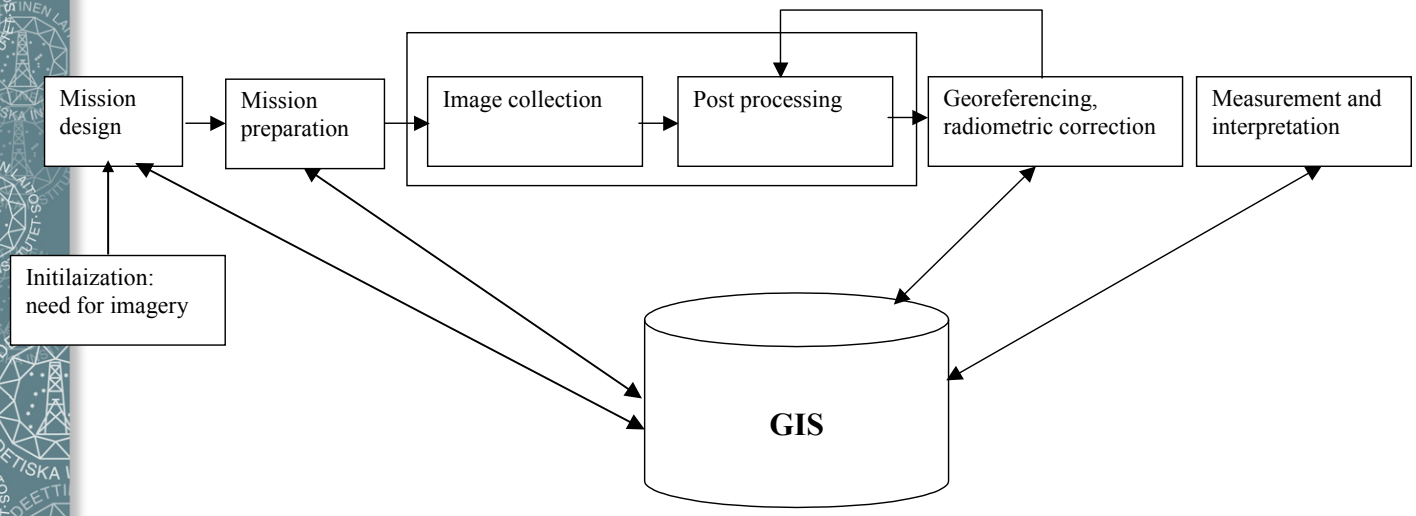
- Reflectance as the function of the wavelength



- BRDF – Bidirectional Reflectance Distribution Function: Object reflectance as the function of the illumination and observation angles

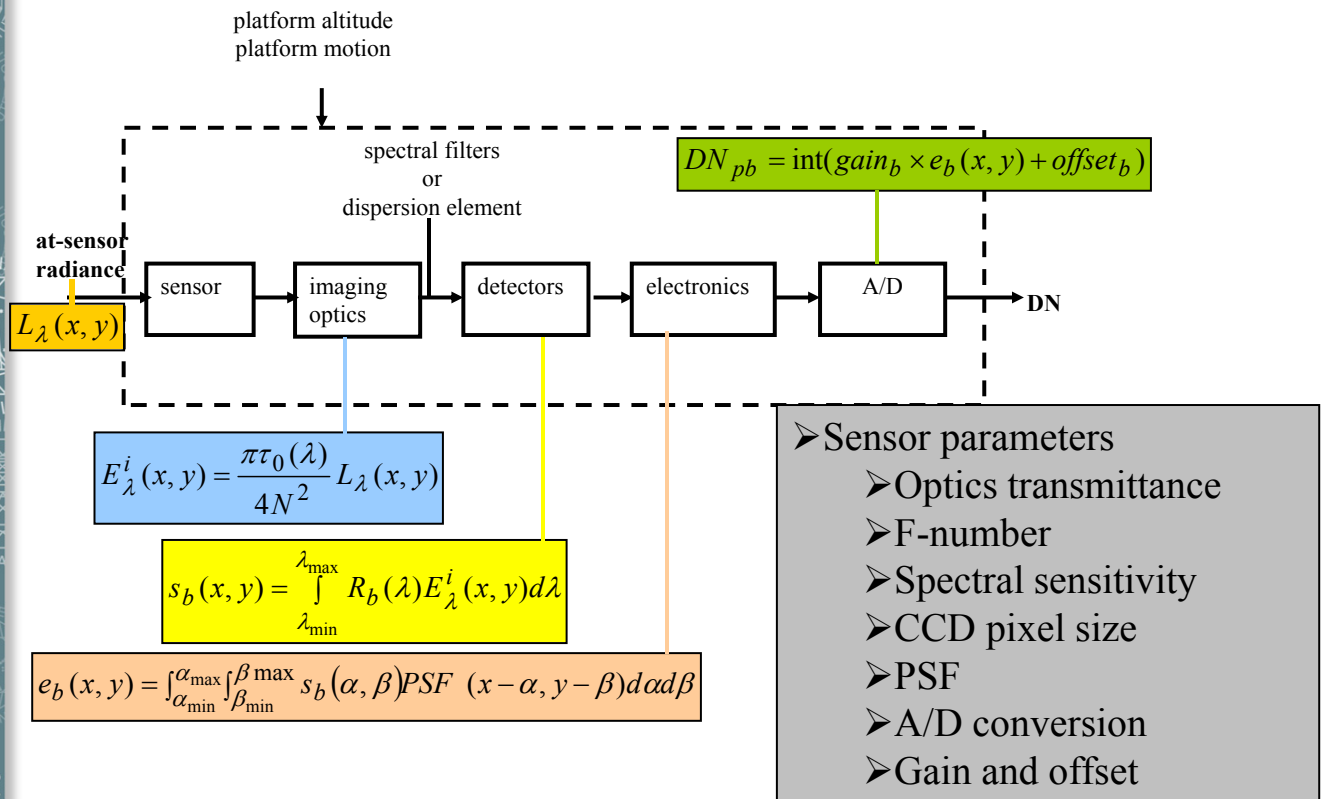


Sensor and system



- Sensor: construction, parameters, quality, calibration
- Sensor settings: exposure, aperture, …
- Post processing

Camera model



Sensor/system radiometric calibration

- Parameters
  - Relative pixel wise calibration: normalize output of all detectors to the similar level
    - sensitivity of each pixel, defect pixels, light falloff, dark current
  - Spectral response
  - Absolute calibration (radiometric response): relationship between the incoming radiance and DN

$$\text{Radiance} = cal\_gain * DN + cal\_offset$$

  - Quality evaluation (linearity, uniformity, radiometric accuracy, dynamic range, sensitivity, noise, stray light, MTF, polarization…)
- Methods
  - Laboratory calibration using Integrating spheres/flat fields, MacBeth color targets, mono-chromators, calibrated light sources
  - In-flight calibration using lamps and/or reflective panels
  - Vicarious test field system calibration using calibrated reflectance targets, atmospheric observations, …

Finnish Geodetic Institute
Eija.Honkavaara@fgi.fi

Radiometric calibration matrix

Parameter	Laboratory	(In-flight)	Test-field
Pixel sensitivity	x	x	
Light falloff	x	x	
Dark current	x	x	
Spectral response	x		
Radiometric response	x	x	x
Camera characterization	x		
System characterization			x

Finnish Geodetic Institute
Eija.Honkavaara@fgi.fi

Radiometric post processing

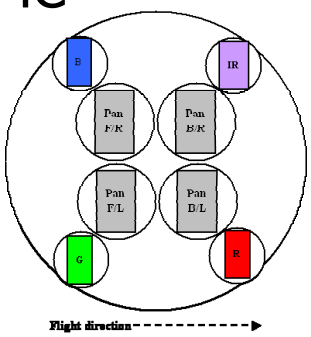
- Provide comparable DNs by eliminating effects by sensor/system, illumination, atmosphere, object anisotropy
- Image enhancement

	Visual	Classical remote sensing	BRDF
System correction -> uniform DN response to constant radiation	x	x	x
Absolute radiometric correction -> object reflectance	(x)	(x)	x
DN -> Radiance transformation	x	x	x
Atmospheric correction			
Semi-Physical	x	x	(x)
Physical	x	x	x
Reflectance calibration	x	x	x
BRDF correction	x	x	
Relative radiometric correction -> corrected DN	x	x	
Other: pan-sharpening, MTFC, noise removal, tonal adjustments (e.g. gamma correction), 16->8 bit transformations	x		

Digital photogrammetric sensors

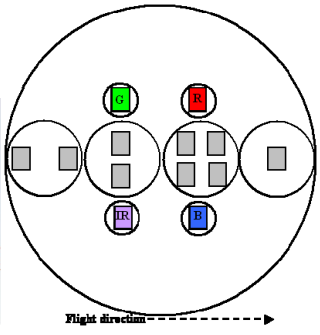
DMC

Intergraph, 2007



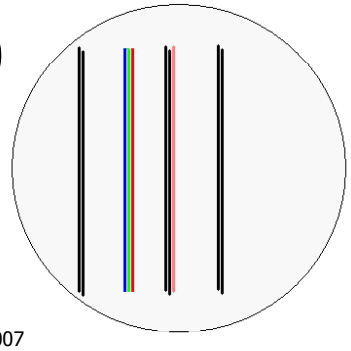
UltraCam

Microsoft, 2007

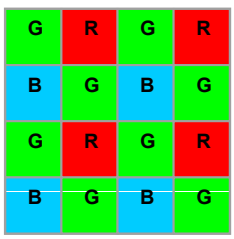


ADS40

Leica Geosystems, 2007



DSS



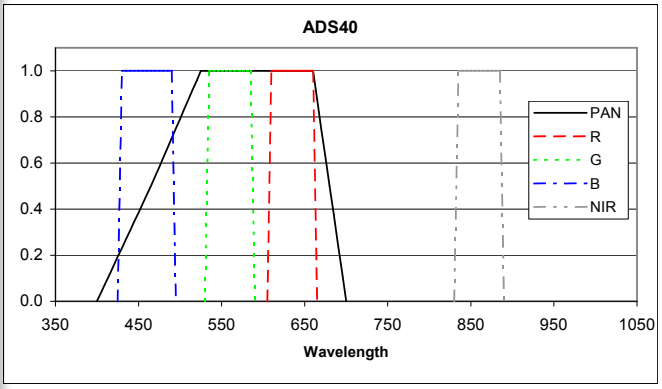
Applanix, 2007

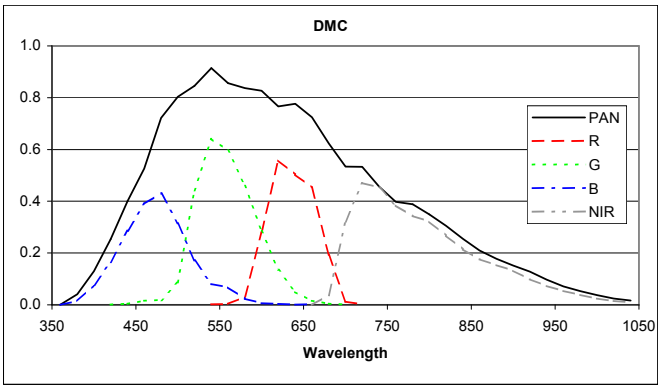
Sensor parameters

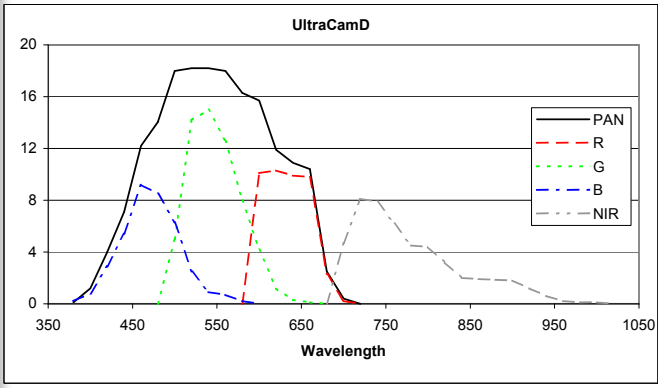
	ADS40 1st/2nd	DMC	UltraCamD/ UltraCamX	DSS 301/322/349
MS-CCD size (k)	12	3x2	4x3/ 4.8x3.1	4x4/ 5.5x4 / 7.2x5.4
Pixel size (µm)	6.5	12	9 / 7.2	9/ 9/ 6.8
A/D conversion (bit)	14	12	14 /	12
N channels	5	5	5	3
FOV (Along/accross)	64/14.2, 2	69/42	65/46	
TDI	no	yes	yes	no
Pan sharpening ratio	no	4.8	3.6 / 3	no

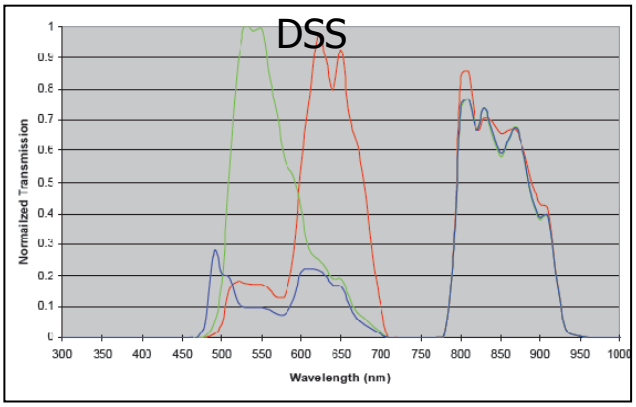
Finnish Geodetic Institute
Eija.Honkavaara@fgi.fi

Spectral response









Finnish Geodetic Institute
Eija.Honkavaara@fgi.fi

Radiometric calibration

- ADS40
  - flat field by NIST traceable Ulbricht sphere: relative calibration, radiometric response, DSNU, sensor characterization
  - NIST traceable spectral measurement unit: spectral response
  - In flight: DSNU
- DMC
  - flat field by Ulbricht sphere: relative calibration for each TDI, aperture, and temperature settings.
  - LUT generation for white balancing in post processing
- UltraCamD
  - by 60 flat field images using normal light lamps with known spectral illumination: relative calibration for each sensor and aperture setting
- DSS
  - MacBeth color targets, integrating spheres, and optimization software: pixel and column defects, dark signal, and pixel level gain corrections.

Radiometric post-processing

- ADS40: Chain for reflectance image generation
  - DN-> At-sensor radiance transformation using laboratory calibration data
  - Atmospheric correction: Modified dark pixel substraction method
  - Reflectance calibration
  - Semi empirical BRDF correction
- DMC
  - Application of laboratory calibration data
  - White balancing, 12 bit -> 8 bit conversions, pansharpening
- UltraCamD
  - Application of laboratory calibration data
  - 14 bit -> 8 bit conversions, pansharpening
- DSS
  - Application of laboratory calibration data
  - Image enhancements: image sharpening, color balance, 12 bit -> 8 bit conversions, Further processing by Inpho software

Reported problems

- ADS40
  - Limitations in dynamic range due to short integration times
  - Unrealistic colorimetric content due to separate spectral channels
  - Displacement of one of the MS-channels
- DMC
  - Color artifacts due to PAN-sharpening
  - Electronic TDI
- UltraCamD
  - Color artifacts due to PAN-sharpening
  - Color artifacts caused by the lens quality
  - Electronic TDI
- DSS
  - Reduced resolution and color artifacts due to mosaic filtering
  - Chromatic aberrations
  - Missing FMC of the DSS

Finnish Geodetic Institute
Eija.Honkavaara@fgi.fi

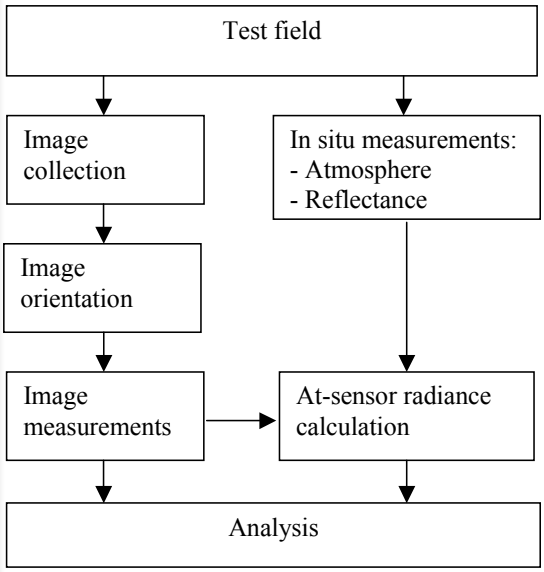
Empirical tests at Sjökulla test field

Finnish Geodetic Institute
Eija.Honkavaara@fgi.fi

Test flights

Sensor	Date	Flying height (m)
UltraCamD	11.10.2004	450
UltraCamD	14-15.10.2004	450, 900, 2800, 5600
UltraCamD	14.5.2005	450
DSS 301	12.7.2005, 17.7. 2005	1000, 3000
DMC + goniometer	31.8-2.9.2005	500, 800, 2500, 5000
ADS40	26-27.9.2005	1500, 2500
UltraCamD	1.7.2006, 5.7.2006	450, 900
Nikon D2X	1.7.2006	560

Reflectance-based test field calibration

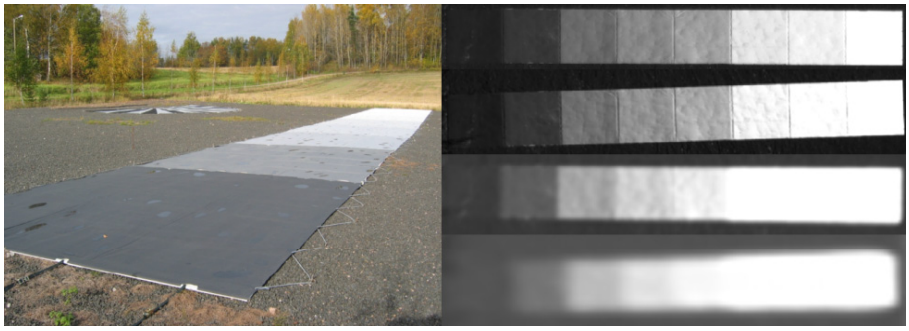


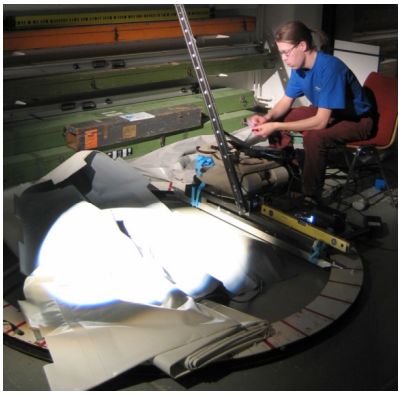
- At-sensor radiance calculation
  - Measure
    - reflectance of ground target,
    - atmospheric properties
  - Model atmosphere by using radiative transfer code.
  - Propagate the ground target radiance through the modelled atmosphere
  - Calculate at-sensor radiance by applying sensor spectral response

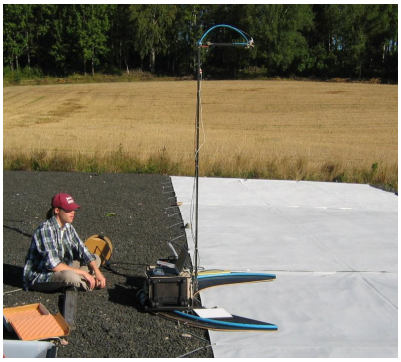
- Empirical study
  - Reference target: Portable gray scale calibrated partially at laboratory
  - Atmospheric correction using MODTRAN default models
  - Spectral response from sensor manufacturer
  - Quality evaluation by comparing the at-sensor radiances and DNs
  - Measures: linearity, sensitivity, dynamic range, absolute calibration

FGI portable grey scale

- 8 reference targets: 5 m x 5 m
- Nominal reflectance: 5% - 70%
- Reflectance measurements using ASD Field Spec Pro FR spectro radiometer at laboratory and at field

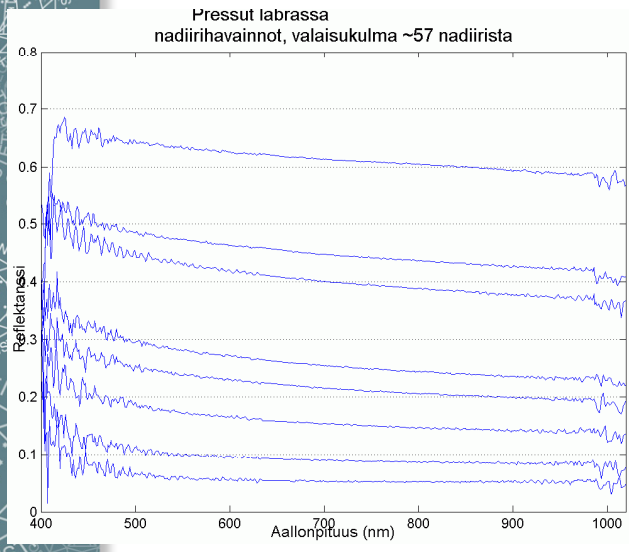




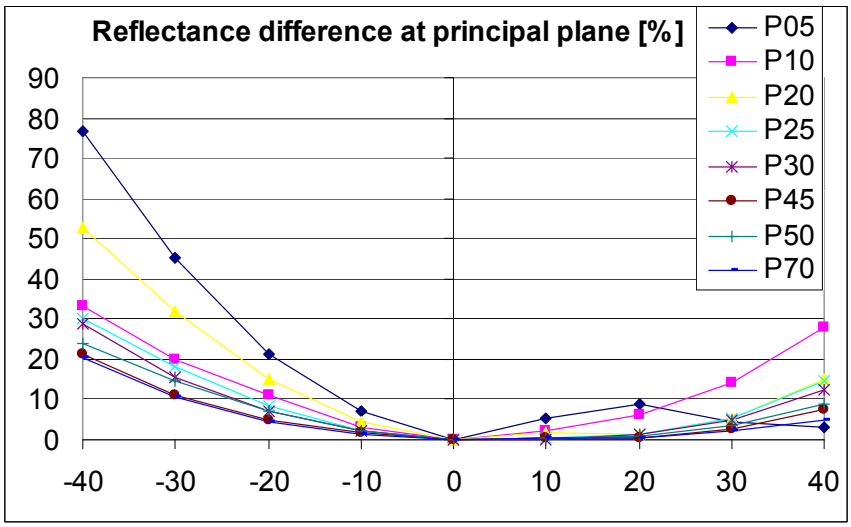


Grey scale BRDF

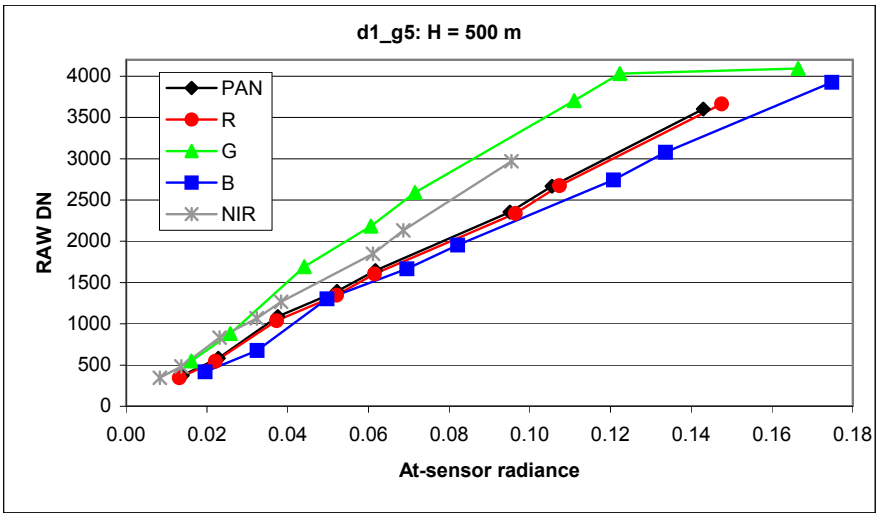
✓ Effect of wavelength

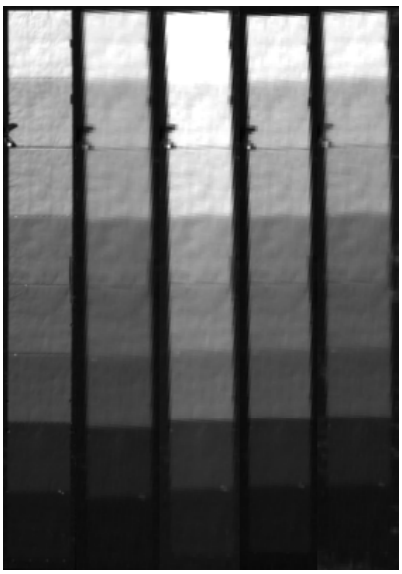


✓ Effect of observation angle



Results: DMC





PAN R, G, B, NIR

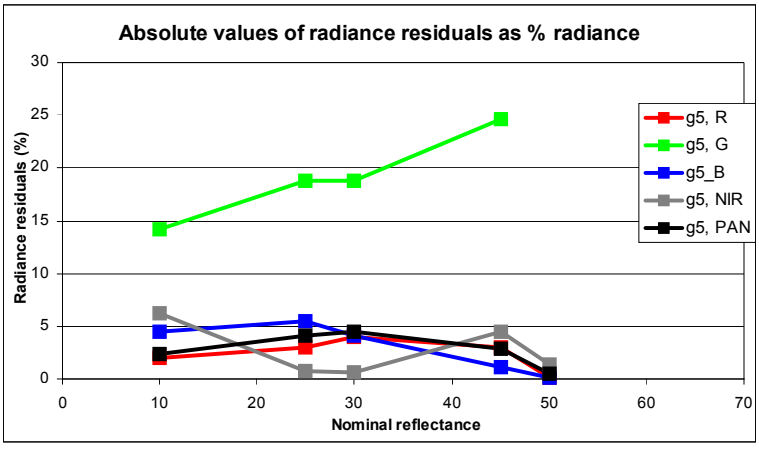
- Excellent weather, experienced operator
- Raw DNs
- Results
  - Linear
  - Over exposure and saturation at green channel
  - Dynamic range 12 bit for all channels
  - Green and NIR the most sensitive

Finnish Geodetic Institute
Eija.Honkavaara@fgi.fi

Absolute calibration, DMC

- Accuracy evaluation:
  - Calibration: 5% and 70% targets (5%, 50% for green channel) and accuracy evaluation using remaining 6 (5) targets
- Relative accuracy better than < 5 % (excluding green channel and 20% tarp)

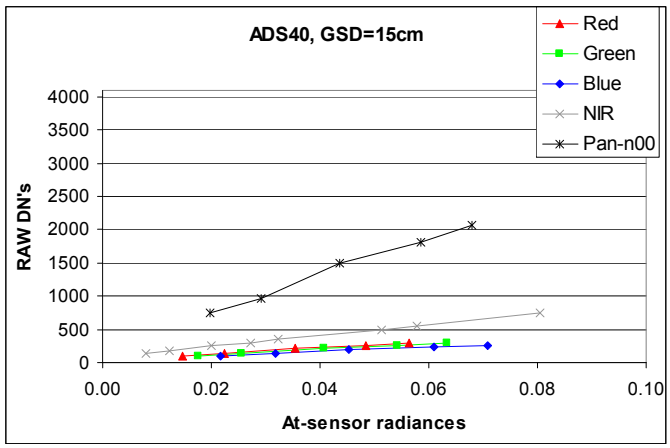
Band	param gain	offset	stdev gain	offset
PAN	2.54E-04	-	2.76E-06	-
R	2.09E-04	-	2.13E-06	-
G	1.55E-04	-	2.74E-06	-
B	2.36E-04	-	2.78E-06	-
NIR	2.16E-04	-4.69E-03	3.30E-06	8.41E-04

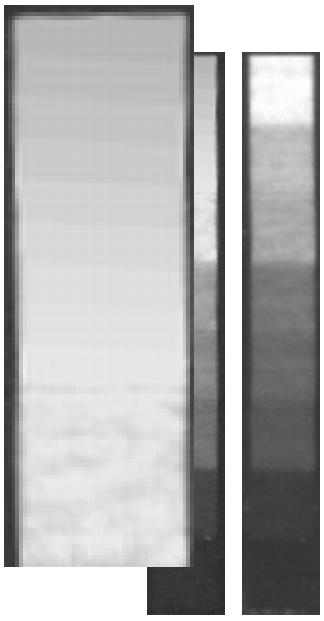


Finnish Geodetic Institute
Eija.Honkavaara@fgi.fi

Results: ADS40

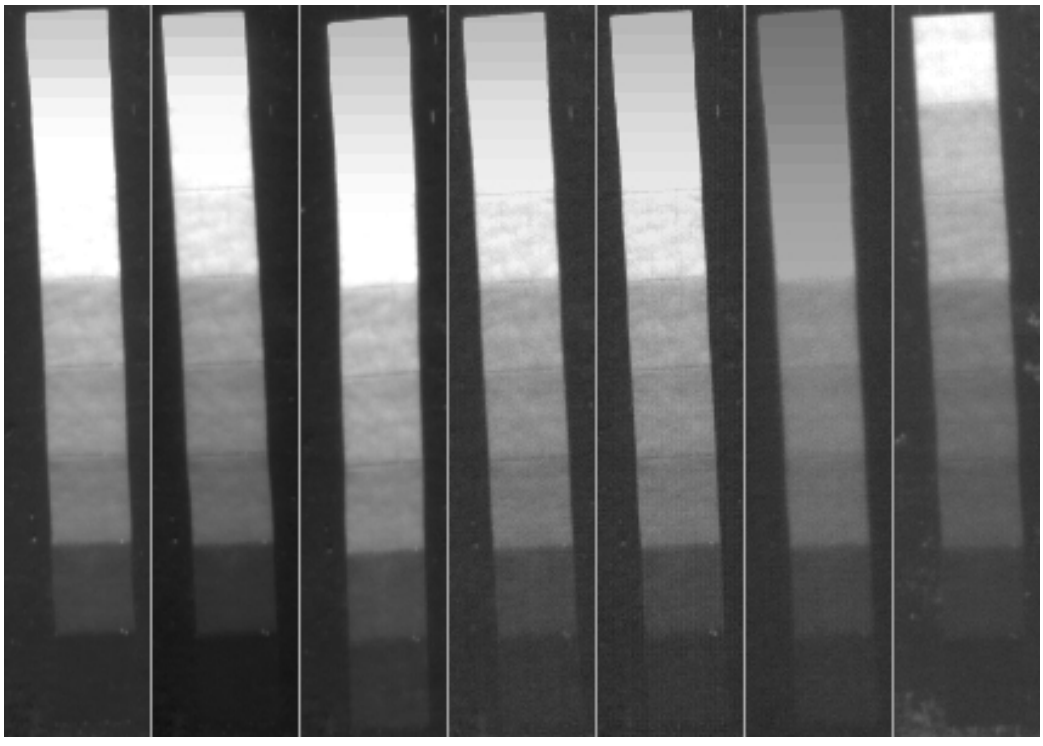
- Acceptable weather and illumination conditions, unexperienced operator
- System corrected DNs
- ”Photogrammetric” recording mode -> artifacts on 2-3 brightest taps
- Results:
  - Linear
  - Great sensitivity differences, dynamic range
    - PAN: 13 bit
    - R, G: 10 bit
    - B: 9 bit
    - NIR: 11 bit





Finnish Geodetic Institute
Eija.Honkavaara@fgi.fi

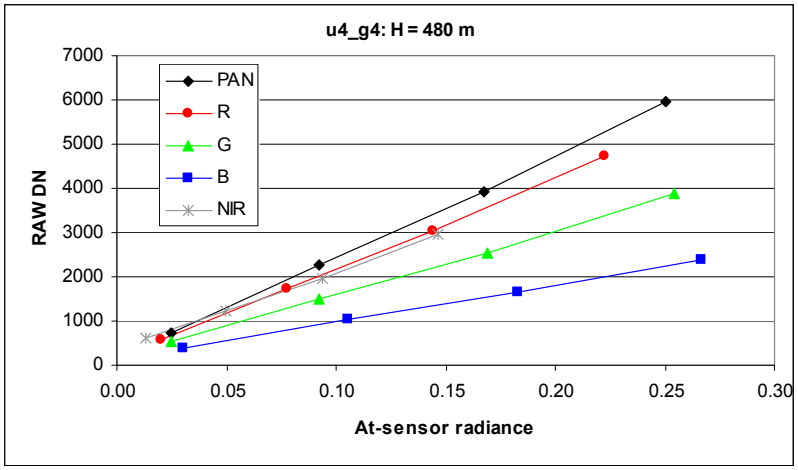
ADS40, GSD = 25 cm

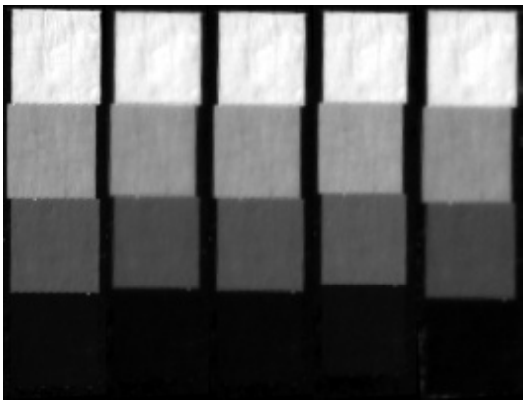


Finnish Geodetic Institute
Eija.Honkavaara@fgi.fi

Results: UltraCamD

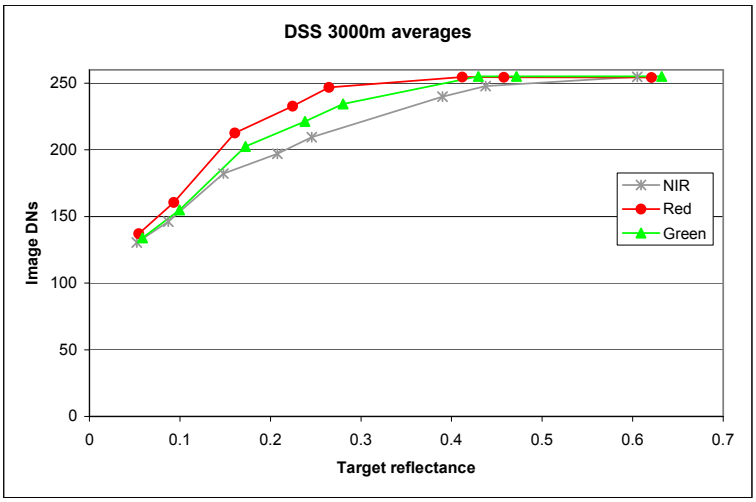
- Acceptable weather and illumination conditions, regular geometric calibration flight of a mapping company
- Raw DNs, only 4 targets
- Results:
  - Linear
  - Dynamic range 12.6 bit
  - Blue channel the least sensitive
  - Red channel saturated in 800 m flight

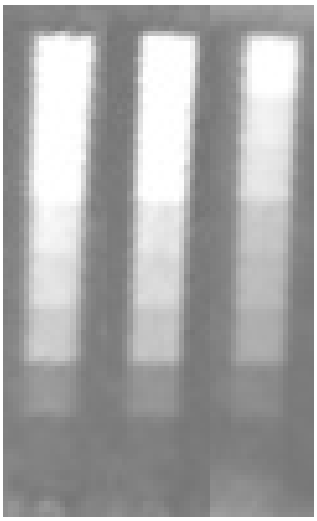




Finnish Geodetic Institute
Eija.Honkavaara@fgi.fi

Results: DSS 301 CIR mode



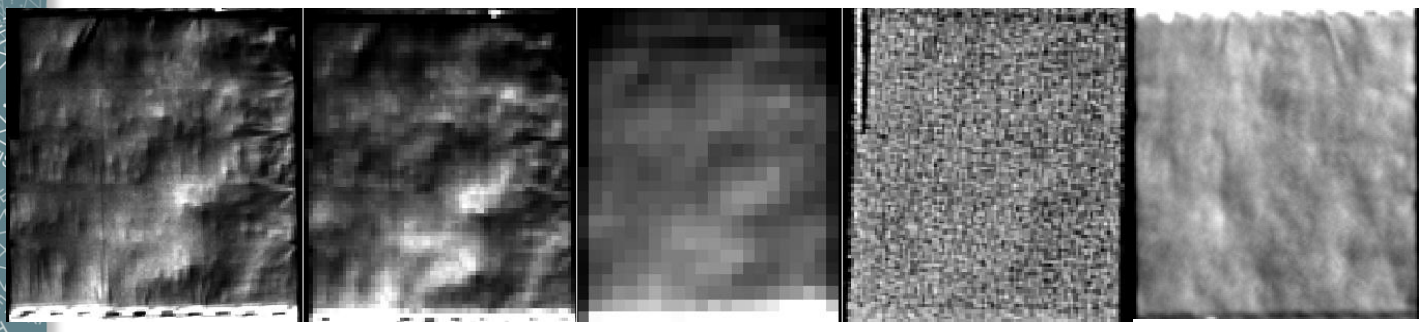


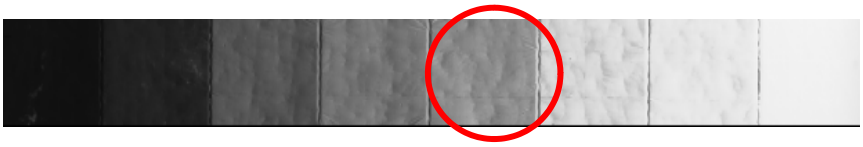
- Acceptable weather and illumination conditions, unexperienced operator
- Regular output from mapping company (8 bit/pixel/channel)
- Saturated at >20% reflectance
- Sensitivity ?

Finnish Geodetic Institute
Eija.Honkavaara@fgi.fi

Radiometric resolution, 30% reflectance target

DMC	DMC	DMC	RC20	DSS
GSD=5cm Pan, sd=5.1%	GSD=8cm Pan, sd =3.9%	GSD=25cm Pan, sd =3.4%	GSD=4 cm, Pan, sd =1.3%	GSD=3.5cm Green

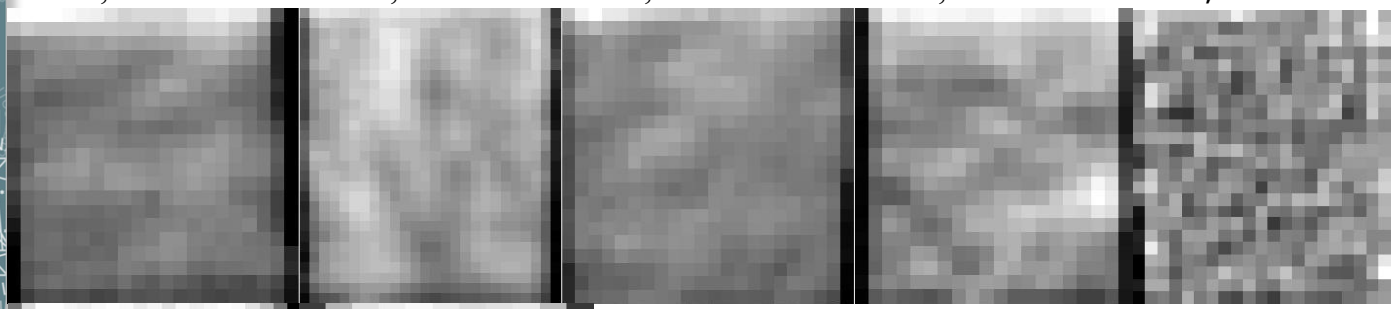


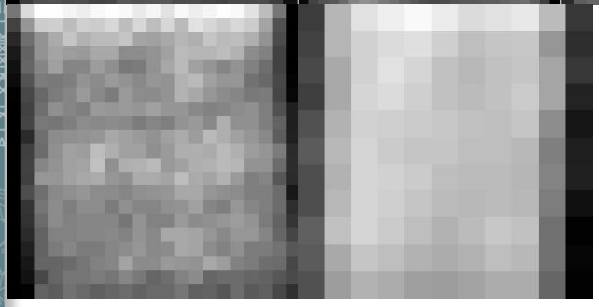


Finnish Geodetic Institute
Eija.Honkavaara@fgi.fi

Radiometric resolution, 30% reflectance target

ADS40	DSS	DMC	UltraCamD	RC25
GSD=25cm Pan, sd=2.4%	GSD=16 cm Green, sd=1.7%	GSD=25 cm Pan, Sd = 3.4%	GSD=25 cm Pan, sd=2.3%	GSD=25 cm Pan, sd=2.8%





Blue, sd=2.3%

GSD=50 cm
Green, sd=1.7%

Finnish Geodetic Institute
Eija.Honkavaara@fgi.fi

Sensor improvement

- UltraCamD->UltraCamX
  - Pansharpening ratio ->3
  - Pixel size 9 -> 7.2 µm
  - New lens
- ADS40 2nd generation
  - Perfect co-registration of all multi-spectral bands by the new Tetrachroid beamsplitter
  - 4 times increased sensitivity compared to 1st generation sensors

Finnish Geodetic Institute
Eija.Honkavaara@fgi.fi

Conclusions

- Radiometry of digital photogrammetric sensors
  - Large dynamic range (12-14 bit)
  - Linearity
  - Similar, high radiometric resolution over entire dynamic range
  - Low noise level
  - Multi-spectral data
  - Multi-angular data
- Problems:
  - DMC, UltraCamD: saturation
  - ADS40: low sensitivity of MS-channels
- Applications
  - Conventional metric and interpretative applications
  - Quantitative remote sensing, BRDF
  - Change detection
  - Historical data archives

Finnish Geodetic Institute
Eija.Honkavaara@fgi.fi

Needed

- Fluent radiometric processing chains for various applications (visual, classification, BRDF)
- Recovering raw DNs from the processed values (storing transformations or raw data)
- Radiometric concepts for photogrammetric production lines
- Information from sensor manufacturers concerning
  - Sensor parameters, radiometric stability, radiometric quality
  - Radiometric calibration
  - DN processing chains
- Sensor absolute radiometric calibration at laboratory
- Radiometric system calibration using test fields

Thank you!

eija.honkavaara@fgi.fi
lauri.markelin@fgi.fi