Metrology of image processing in spectral reflectance measurement by UAV

Eija Honkavaara, Lauri Markelin, Teemu Hakala, Jouni Peltoniemi

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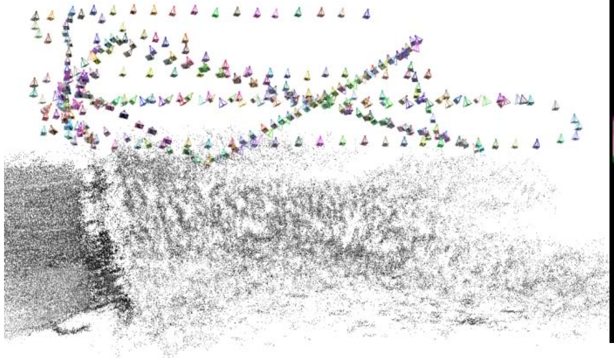
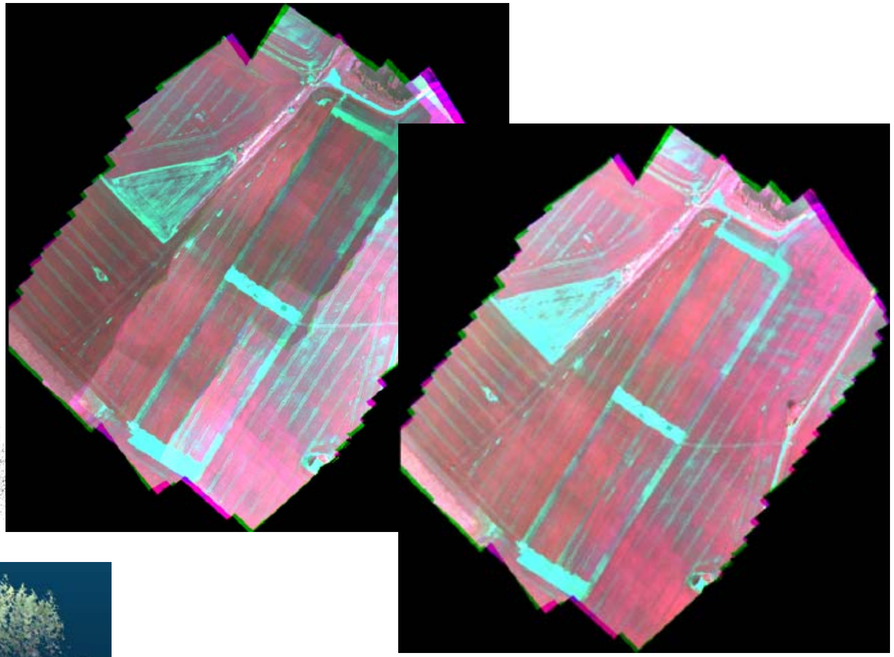
Content





?

σ_{refl}

- Background
- Approach
- Empirical investigation
- Conclusions

Metrology

- **Metrology is the science of measurement**, embracing both experimental and theoretical determinations at any level of uncertainty in any field of science and technology.
- Metrological **traceability:** Property of a measurement result whereby **the result can be related to a reference through a documented unbroken chain of calibrations**, each contributing to the measurement uncertainty
- **The level of traceability establishes the level of comparability** of the measurement: whether the result of a measurement can be compared to the previous one, a measurement result a year ago, or to the result of a measurement performed anywhere else in the world.
- Fundamental aspect when concerning quantitative utilization of spectral reflectance measurements by UAVs

MetEOC: Metrology for Earth Observation and Climate

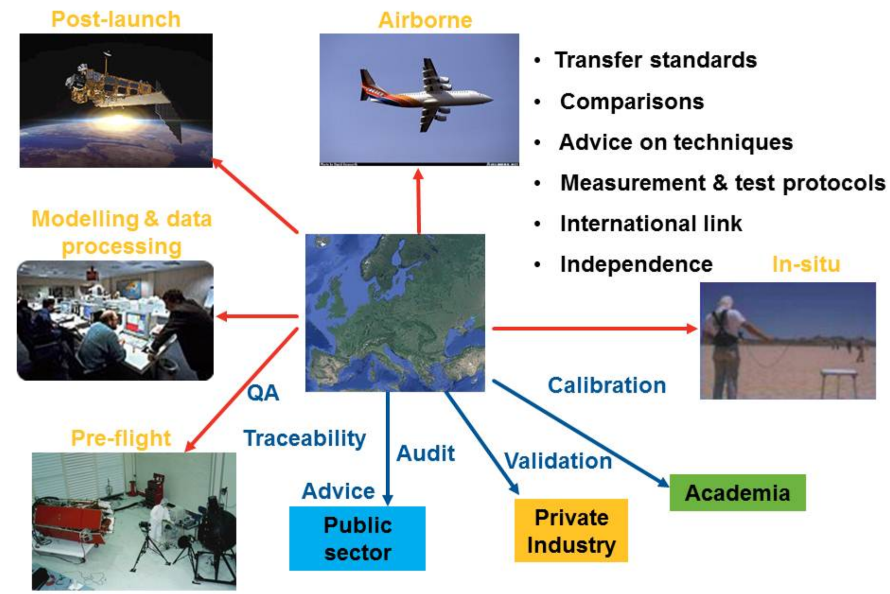
EURAMET
European Association of National Metrology Institutes

EMRP
European Metrology Research Programme
Programme of EURAMET

The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union

- Vision:
  - To establish a European centre of excellence of Metrology to support Earth Observation and Climate as a 'one-stop-shop‘
- A Joint Research project in EMRP 2011-2014
- 8 National Metrological Institutes, 4 unfunded partners, Led by Nigel Fox, National Physical Laboratory, UK
- Satellite based remote monitoring of the Earth system is crucial to
  - Enable better stewardship of the environment
  - Provide the necessary information to aid policy makers in the development of mitigation strategies to respond to climate change.
- Improvements in uncertainty and traceability are needed throughout all stages of data production: pre-flight and post-launch calibration and validation and all the intermediate processing steps.
- Meteoc II 2014 - 2017

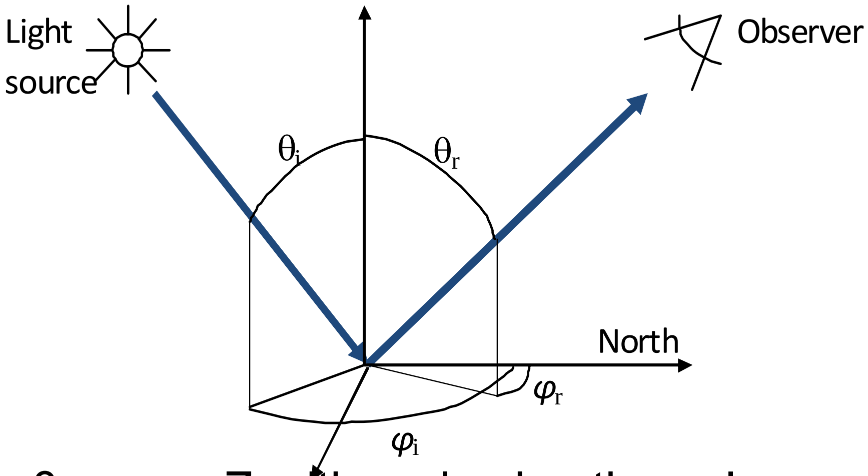
To establish a: European Metrology Centre for Earth Observation and Climate (EMCEOC)



Traceable reflectance measurement by Unmanned Airborne Vehicles (UAVs)

- Objective
  - A traceable procedure for reflectance data collection in local area applications using spectral image data collected by an UAV.
- Realization
  - Implementation of traceable reflectance in the FGI reflectance measurement chain
  - Novel UAV goniospectrometer providing reflectance data for 3D objects
- Why? Potential applications
  - Ground reference information for satellite sensor/product cal/val
  - Development of image radiometric correction methods to provide better performance of interpretation methods, e.g. new UAV hyperspectral imaging systems
  - Full utlilization of vertical/olique image data by utillizing multiview radiometry
  - E.g. interpretation methods to based on bio/geopbysical modeling
  - New Earth surface reflectance models, new spectral libraries, …
- A Researcher Excellence Grant at FGI belonging to the MetEOC project.

Fundamental challenges



θ_i, φ_i Zenith and azimuth angles of incident light

θ_r, φ_r Zenith and azimuth angles of reflected light

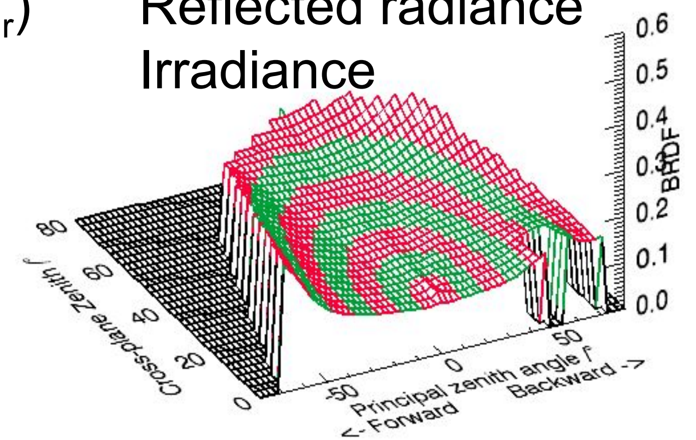
BRDF

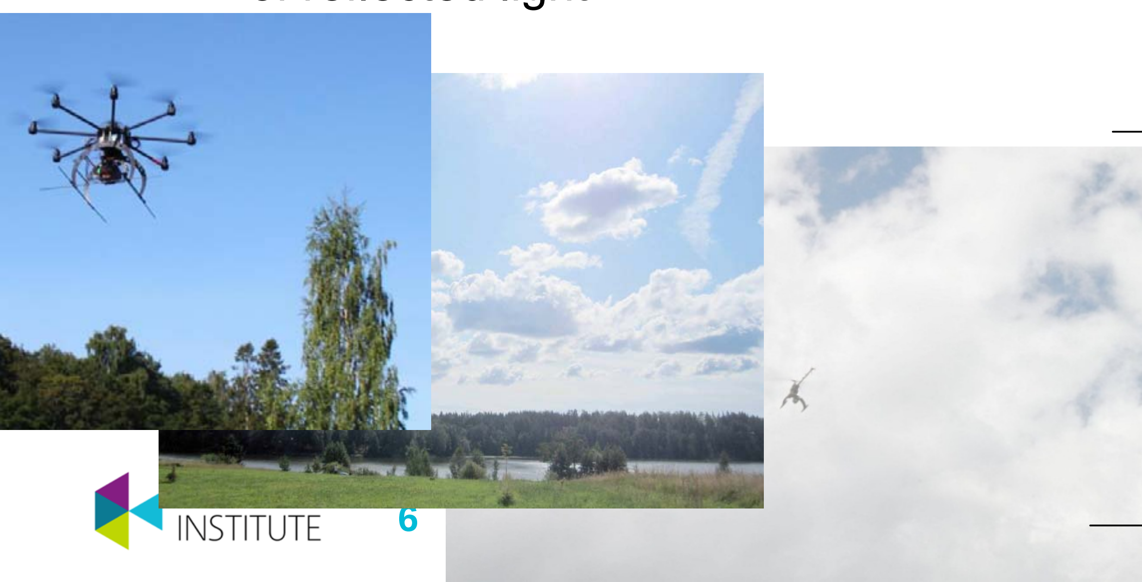
$$\rho(\theta_i, \varphi_i, \theta_r, \varphi_r) = \frac{L(\theta_i, \varphi_i, \theta_r, \varphi_r)}{E(\theta_i, \varphi_i)}$$

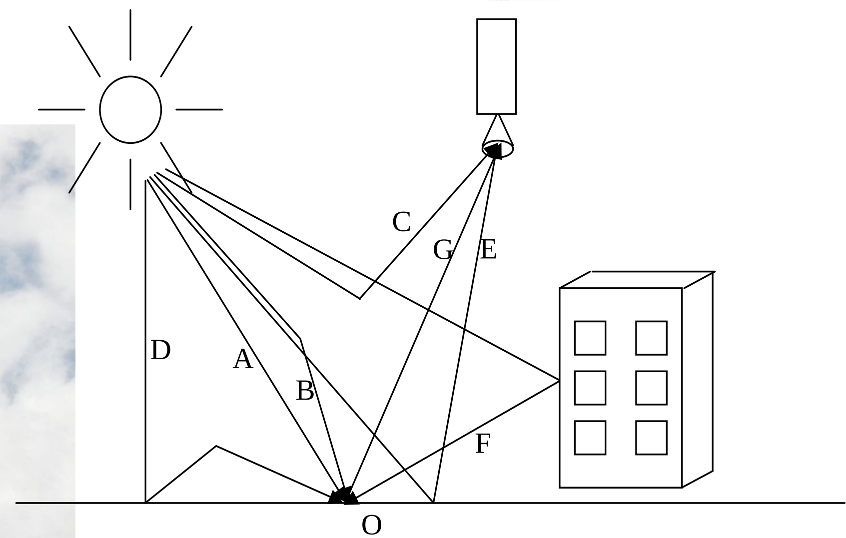
$L(\theta_i,\varphi_i,\theta_r,\varphi_r)$ Reflected radiance

$E(\theta_i,\varphi_i)$ Irradiance

BRF: Bidirectional reflectace factor







Approach

Availability of a SI-Traceable reflectance standard in a national standards laboratory

1. Transfer of the traceable reflectance to the FGI laboratory
2. Transfer of the traceable reflectance to the measurement site
3. Transfer of the traceable reflectance to the UAV output data

Aalto University MIKES

1

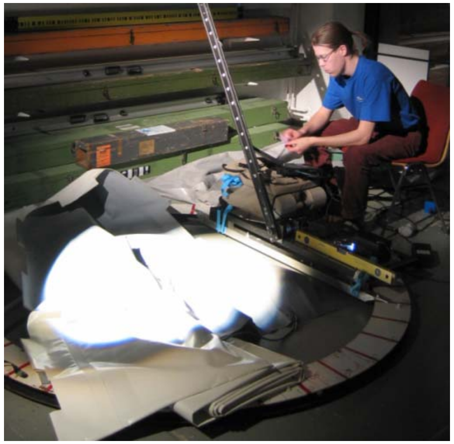
GEODEETTINEN LAITOS

2

2

3

FIGIFIGO goniospectrometer



- Finnish Geodetic Institute's Field Goniospectrometer
  - Either in field or laboratory
  - Fast BRF measurements: 10 min/target
  - ASD Field Spec Pro spectrometer
  - Spectral range 350 – 2,500 nm
  - Labsphere Spectralon reflectance standard
  - ASD calibration every two years
- Uncertainty characterized in the project
- Open spectral reflectance library
  - https://webdisk.kotisivut.com/fgi/Reflectance_Library/
  - www.specchio.ch

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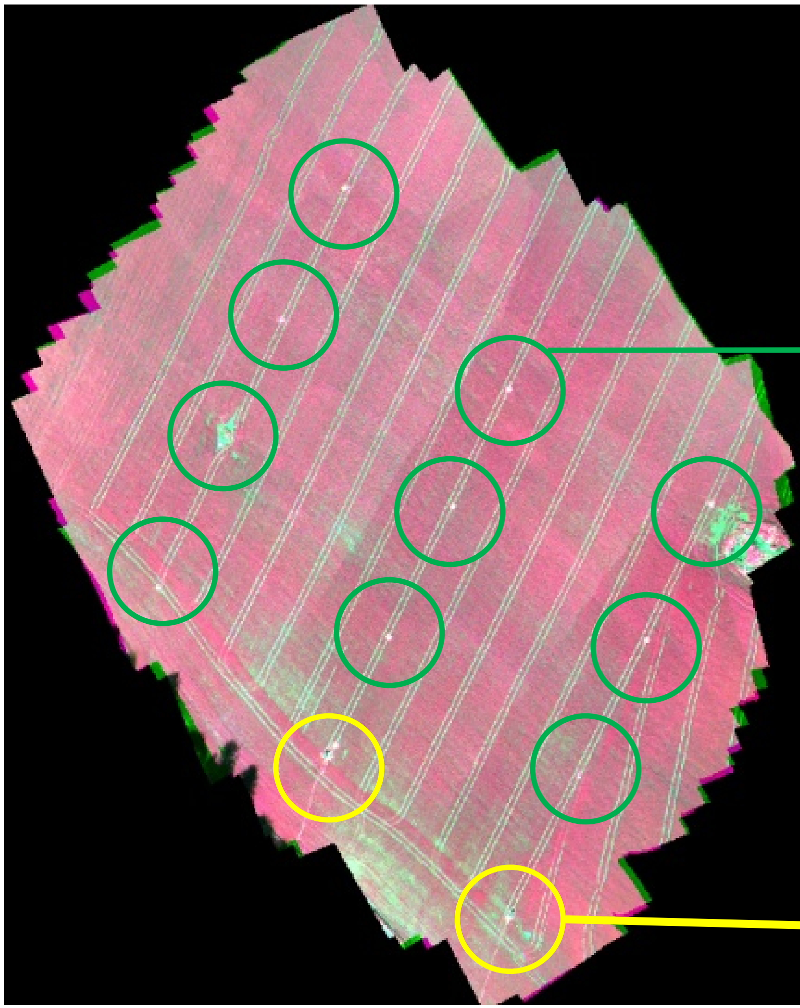
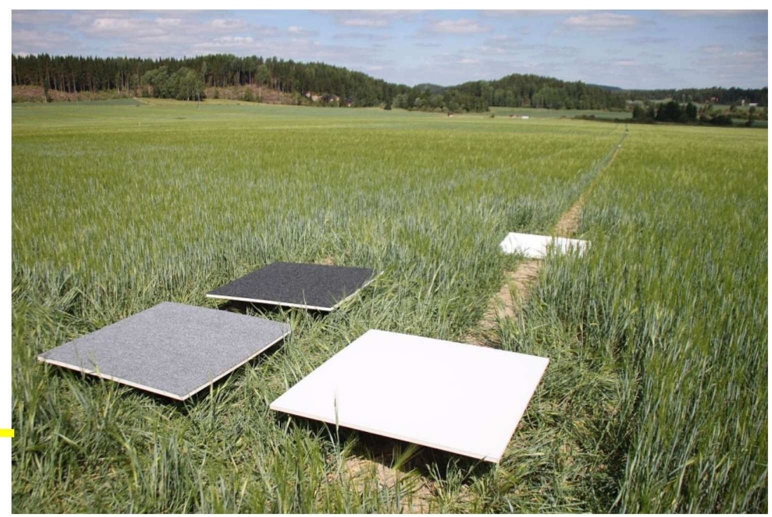
Traceable reference reflectance



- 25 cm x 25 cm field Spectralon
- 1 m x 1 m Reflectance targets
  - 12x Grey, R ~ 0.4
  - 2x Dark grey R ~ 0.12
  - 2x Black R ~ 0.04
  - 1x PTFE R ~ 0.9



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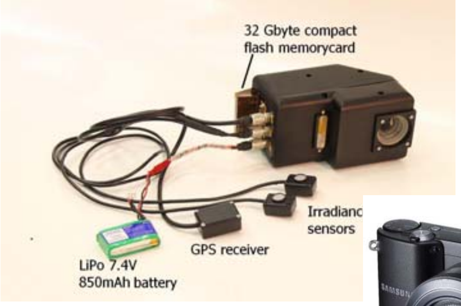
New UAV goniospectrometer

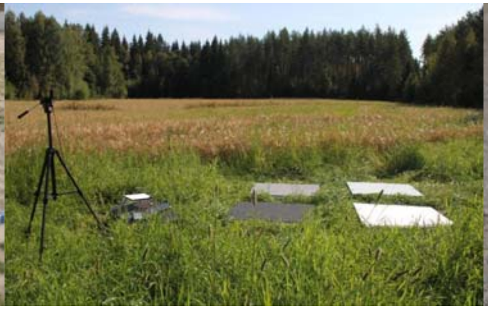
UAV measurement system

UAV
- Autopilot
- IMU
- GPS

Payload
- Spectral imager
- RGB High spatial resolution imager
- GPS
- Irradiance sensors



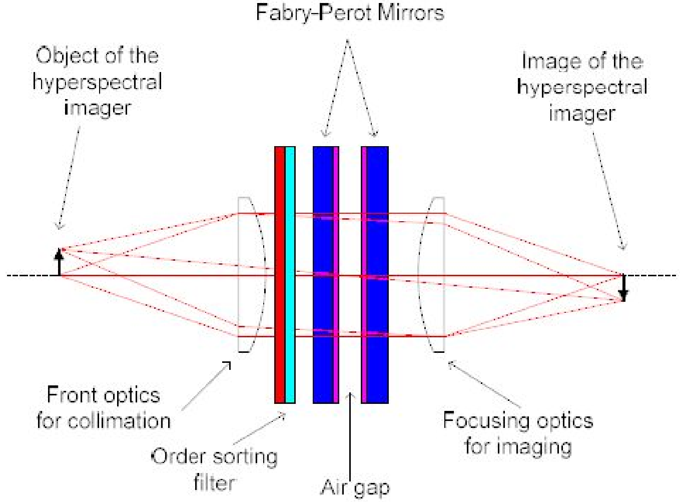
Ground control station
- Mission design and control
- Insitu reference measurements: irradiance, reflectance targets, sunphotometer

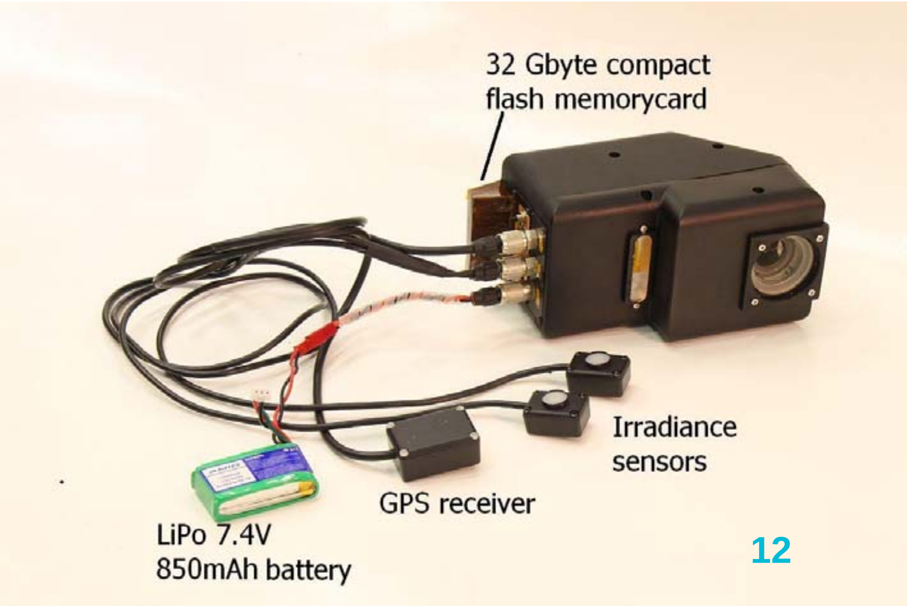


- In typical flight 100-500 data cubes with 20-40 spectral layers
- Georeferencing data
- Irradiance data
- Insitu data

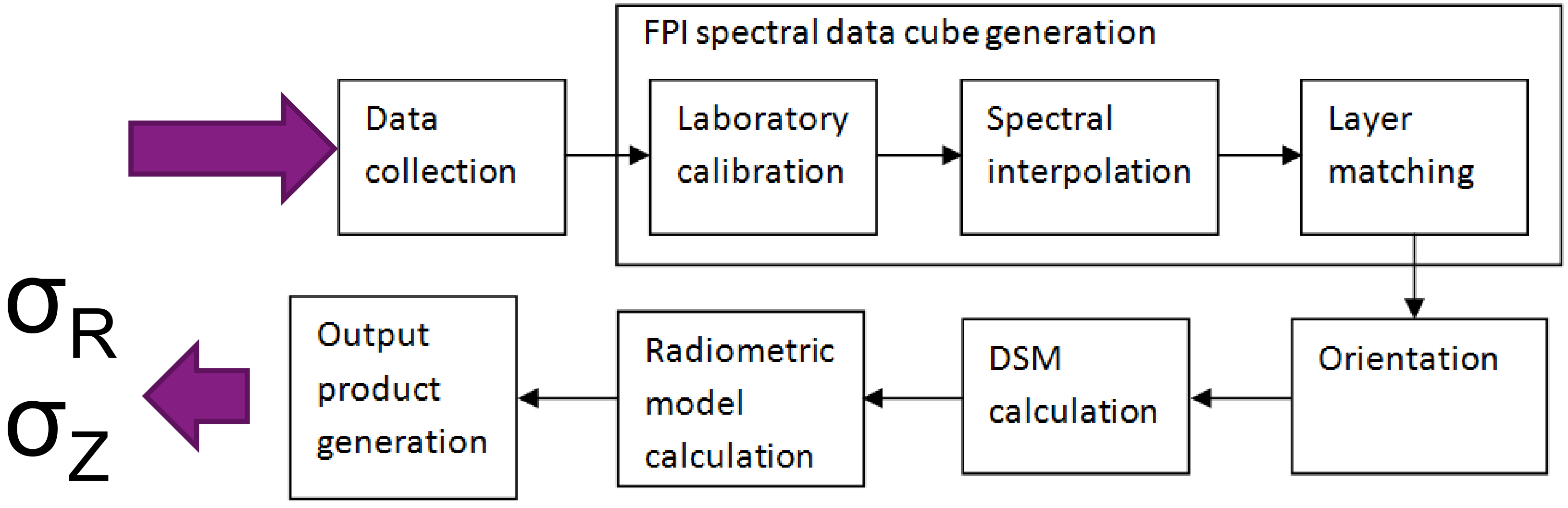
Fabry-Perot interferometer based tuneable spectral camera

- Hyperspectral imagery in frame format: stereoscopic, spectrometric data
- Weigh <700 g
- Spectral data cube by changing the width of Fabry-Perot air gap
  - Developed by VTT Technical Research Finland (Heikki Saari)
- 30-40 freely selectable spectral bands
- Custom optics: C=10.9 mm, F-number < 3.0
- CMOS detector: 1024 x 648 pixels, Pixel 11 µm
- Commercial systems by Rikola Oy



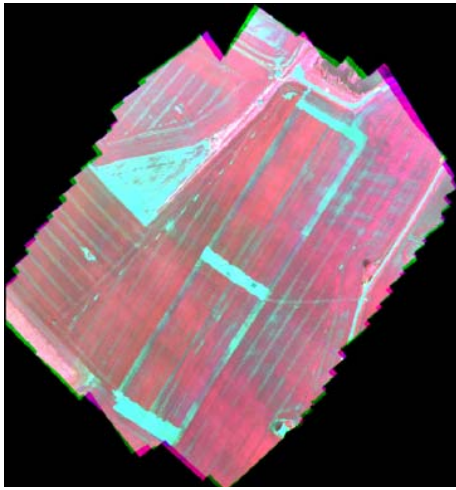


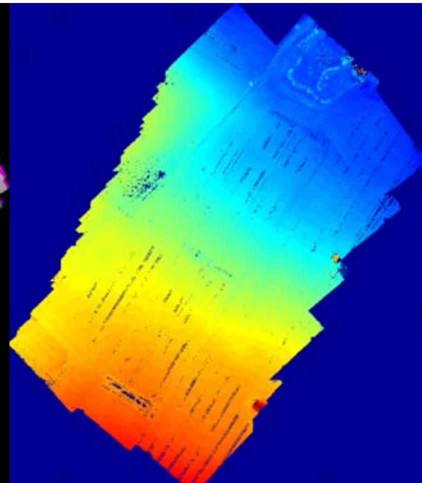
UAV image data processing

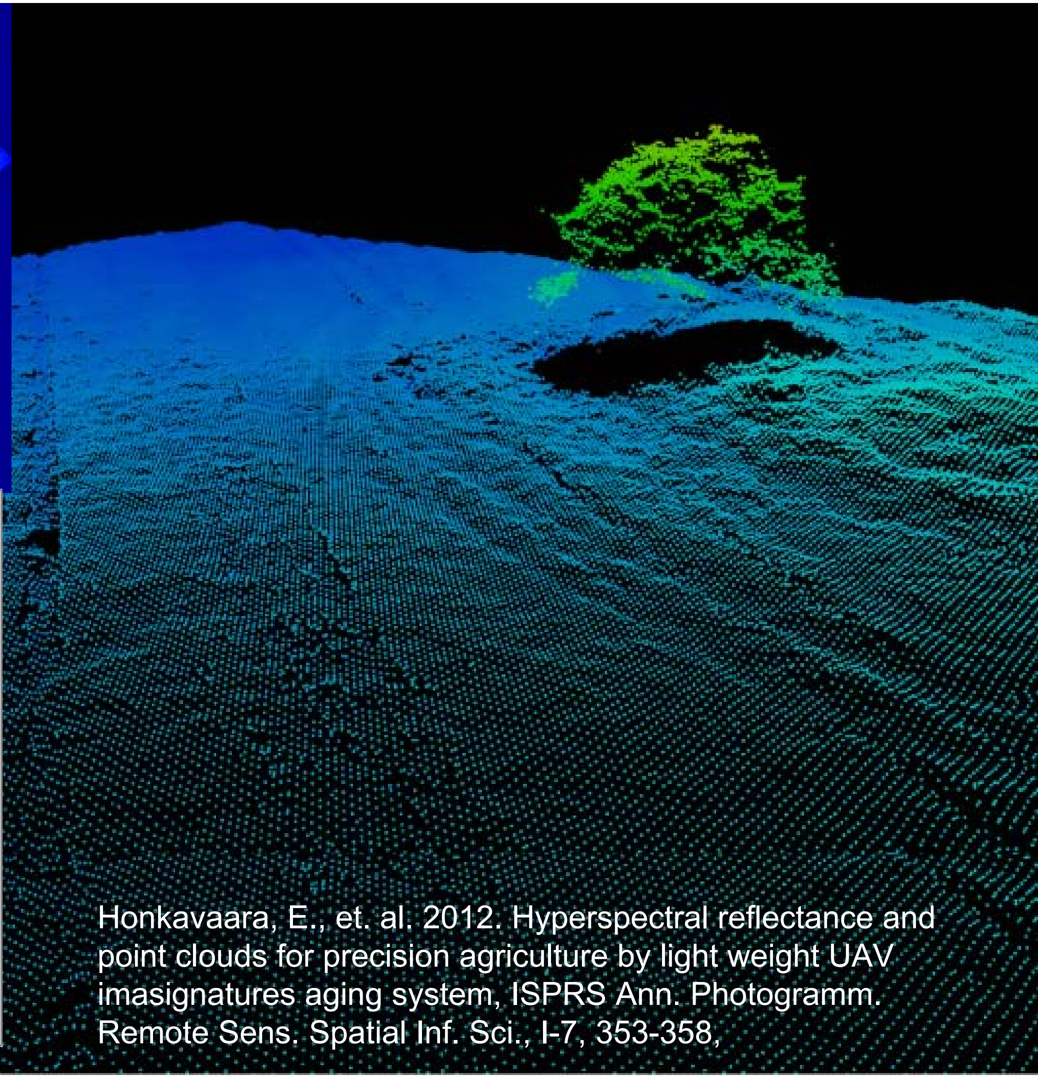


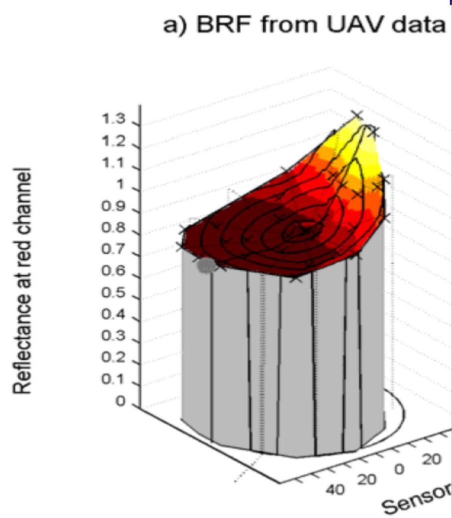
- Geometric processing
  - Image orientations, sensor calibration, digital surface model
  - Assumption: accurate enough not causing further uncertainty to output products
- Radiometric processing: Radiometric block adjustment with radiometric tie points, ground control points and direct irradiance observations
- Uncertainty propagation using measurement modeling

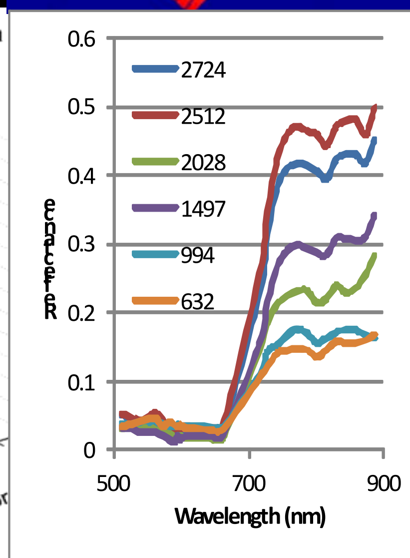
Output products: hyperspectral image mosaics, DSMs, point clouds, spectra, BRF











Honkavaara, E., et. al. 2012. Hyperspectral reflectance and point clouds for precision agriculture by light weight UAV imasignatures aging system, ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., I-7, 353-358,

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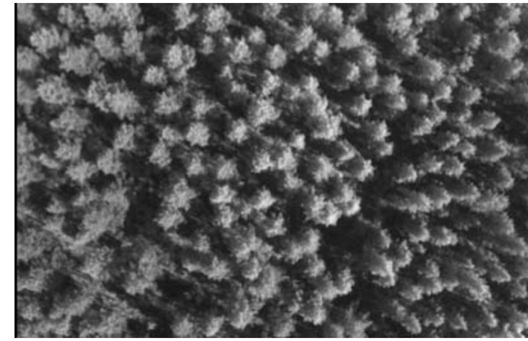
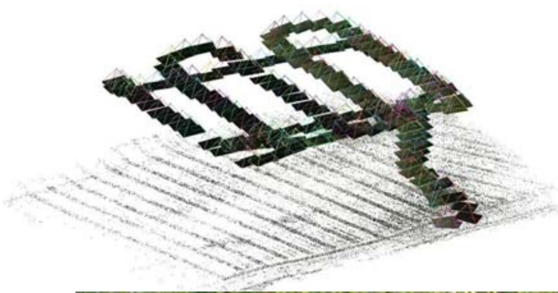
Flight paths

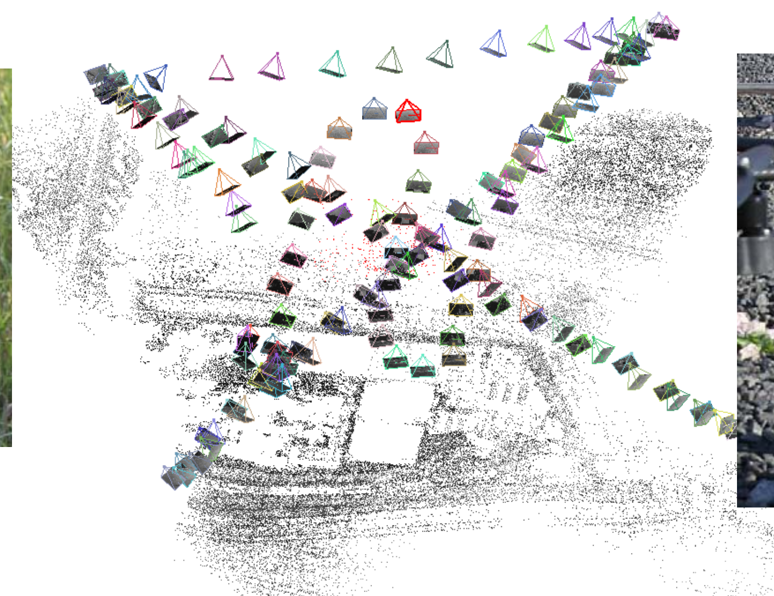
- Rectangular image format
  - Camera FOV: ±16°, ±27°, ±31°

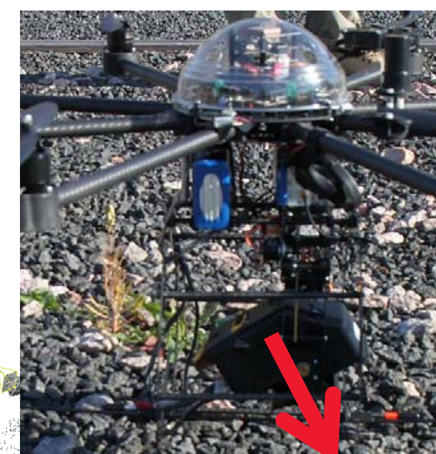


- Vertical block
  - Camera axis in vertical direction
  - BRF view angles < 31°

- Oblique BRF block
  - Bidirectional oblique flight lines
  - Camera axis tilted about 45°
  - BRF view angles up to 60°







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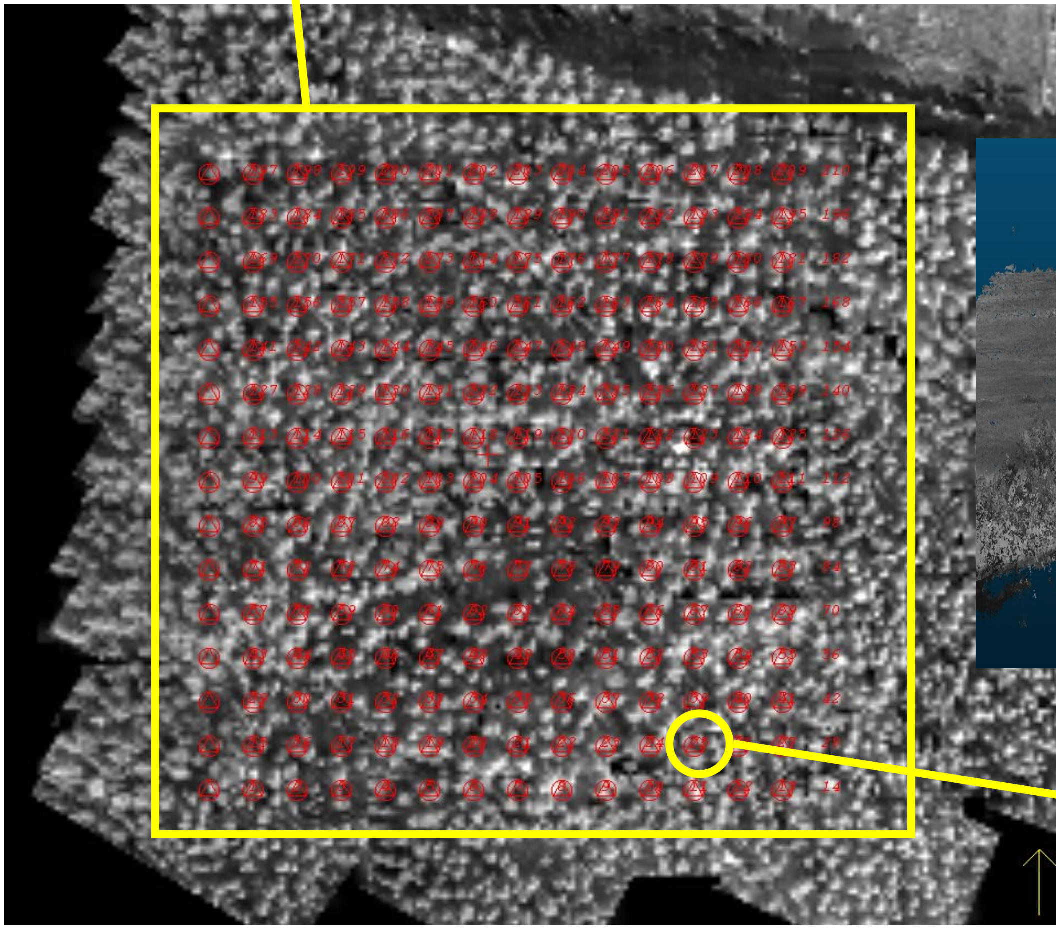
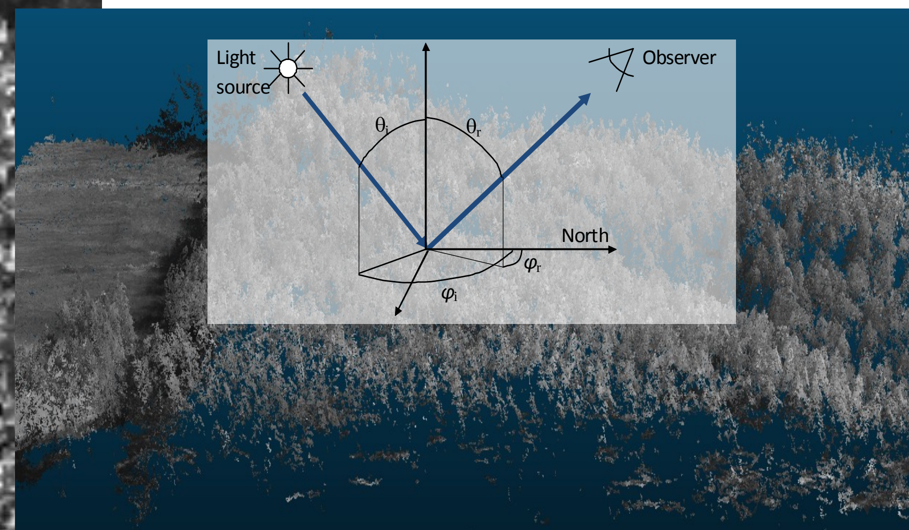
BRF sampling

Area





Single point

Uncertainty propagation

Reflectance transformation: $R(\theta_i,\varphi_i,\theta_r,\varphi_r) = f(x)$

Estimated reflectance error: $\hat{\sigma}_R = \sqrt{J_R \Sigma_{\hat{x}\hat{x}} J_R{}^T}$

Empirical line model:

$$R(\theta_i,\varphi_i,\theta_r,\varphi_r) = (DN/a_{rel} - b_{abs})/a_{abs}$$

Variance components

$\sigma_{DN} = 1/\ SNR$

σ_{a_rel}, σ_{a_abs}, σ_{b_abs}: Standard deviations of transformation parameters or measurment errors

Implementation: The reflectance uncertainty estimation is in the reflectance calculation process so that an uncertainty value is provided for each calculated reflectance value.

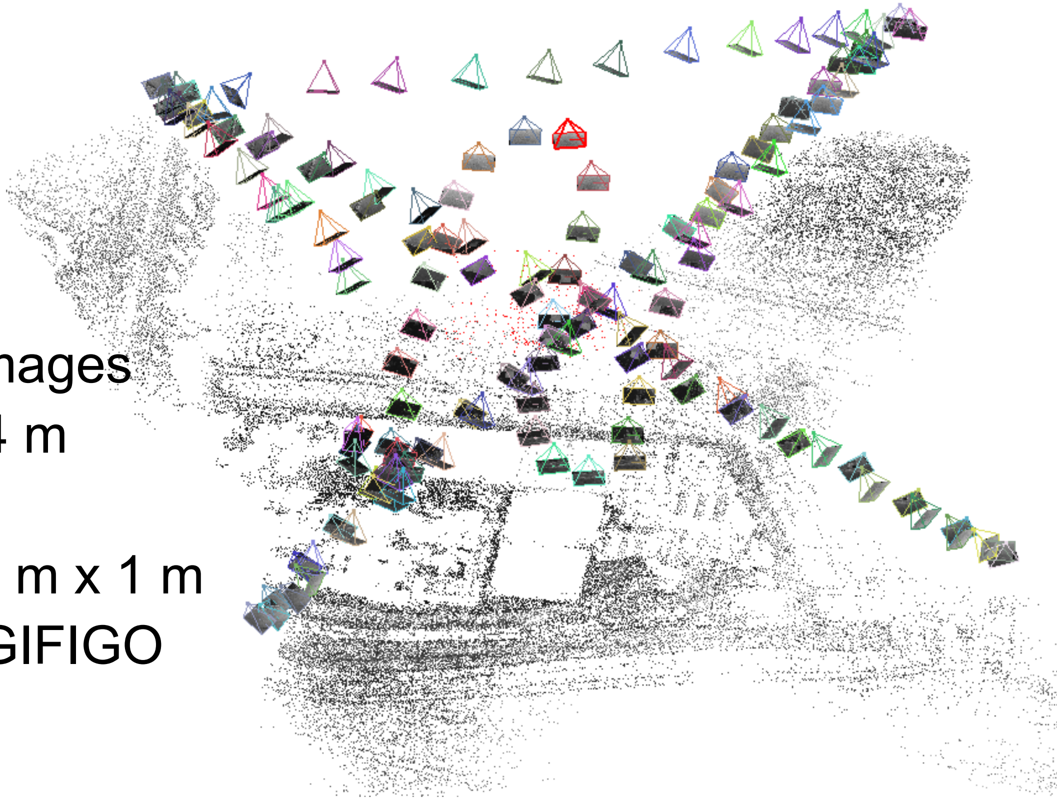
Emprical investigation

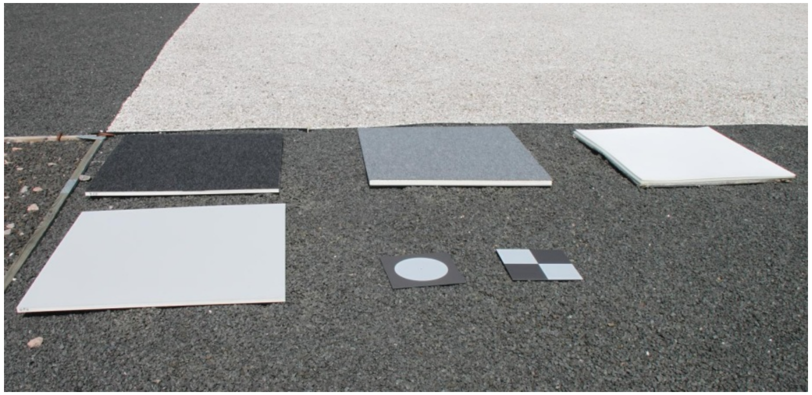
- Demonstrations of traceable BRF measurement in different objects
  - Gravels at Sjökulla remote sensing testfield
  - Barley crops in Vihti agriculture testfield
  - Pine forest in Evo forestry test site

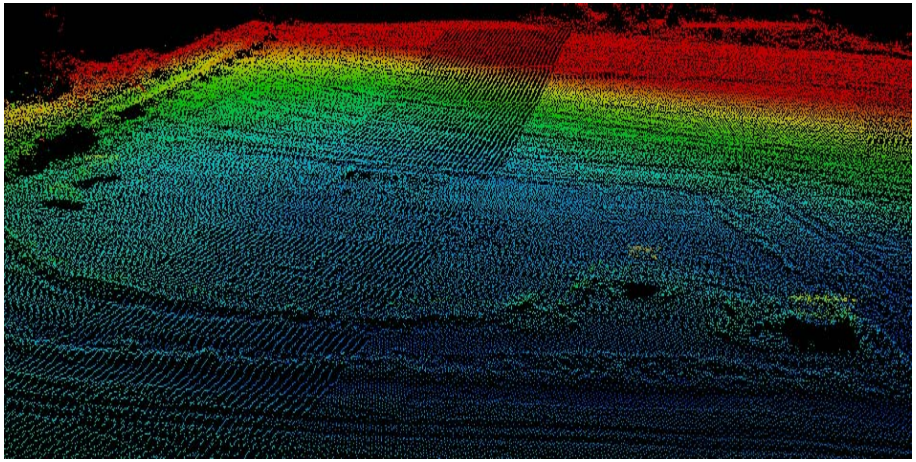
Sjökulla test field

6 August 2013

- Gravels and artificial panels
- Block with vertical and oblique images
- Flying height 400 m -> GSD 0.04 m
- Duration 10 min
- Areas of interest: 10 m x 10 m, 1 m x 1 m
- Reference measurements by FIGIFIGO
  - Gravels
  - Portable reflectance panels



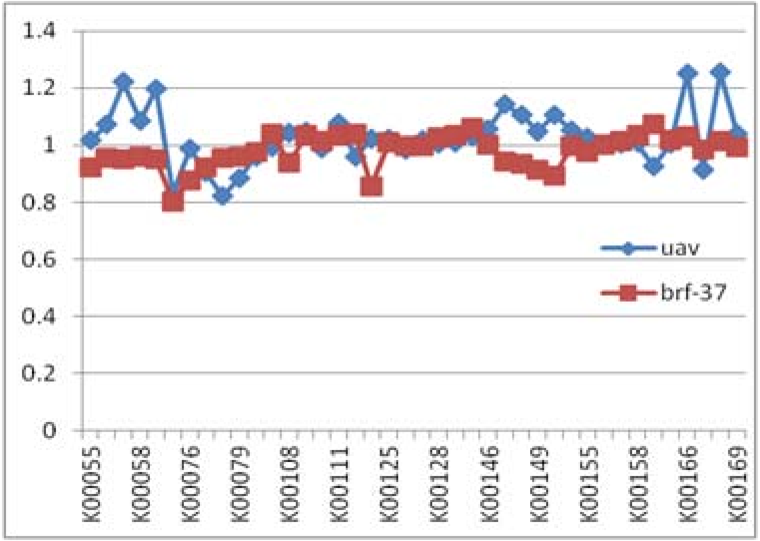




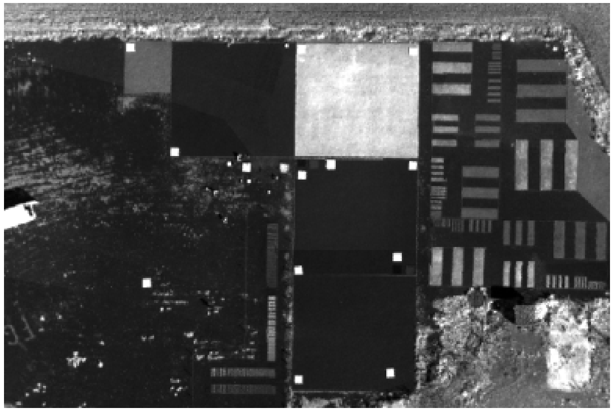
Reflectance and standard deviation mosaics

- Radiometric correction based on reflectance panels
- Theoretical standard deviations
  - Bright target R≈0.5; σ_R = 0.023
  - Dark target R≈0.03; σ_R = 0.011

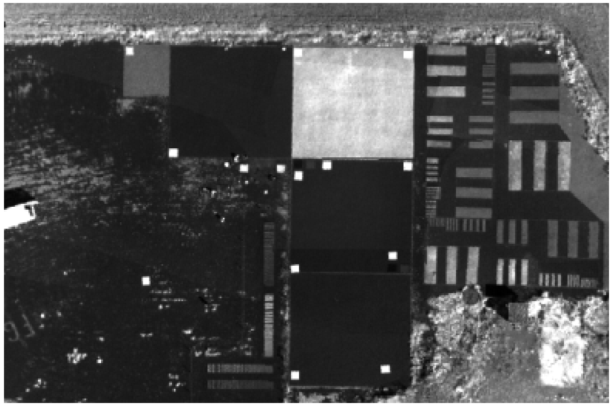
Relative image corrections
•UAV irradaince
•Reflectance panels



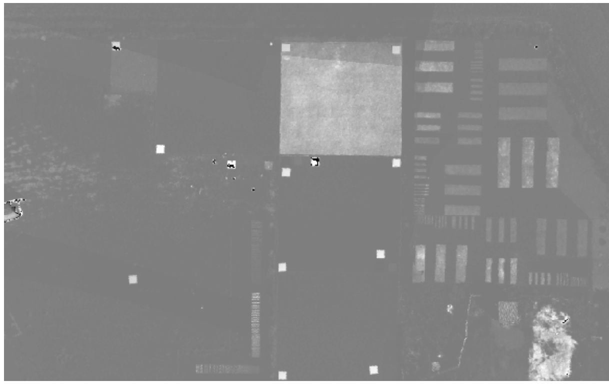
No radiometric correction



Radiometric correction



σ_R mosaic



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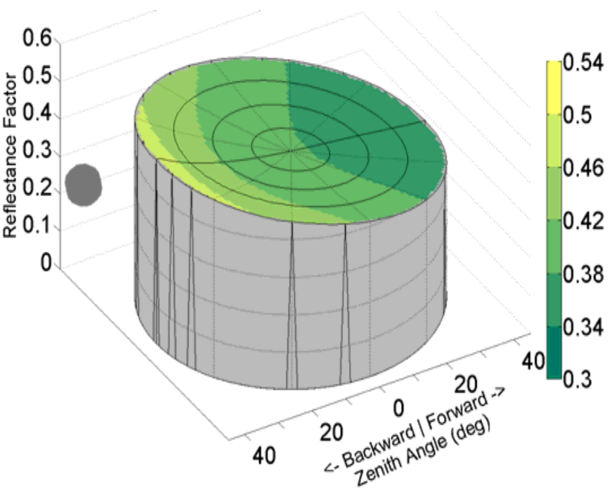
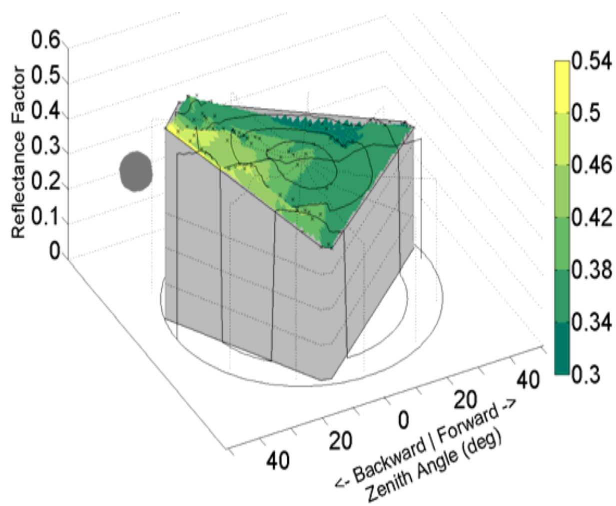
BRF of white gravel, Sjökulla

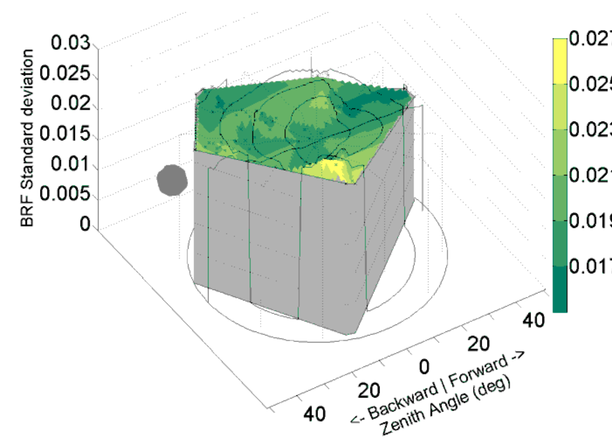
BRF FIGIFIGO



BRF UAV



Stdev UAV



- BRF followed well more accurate BRF measured by FIGIFGO

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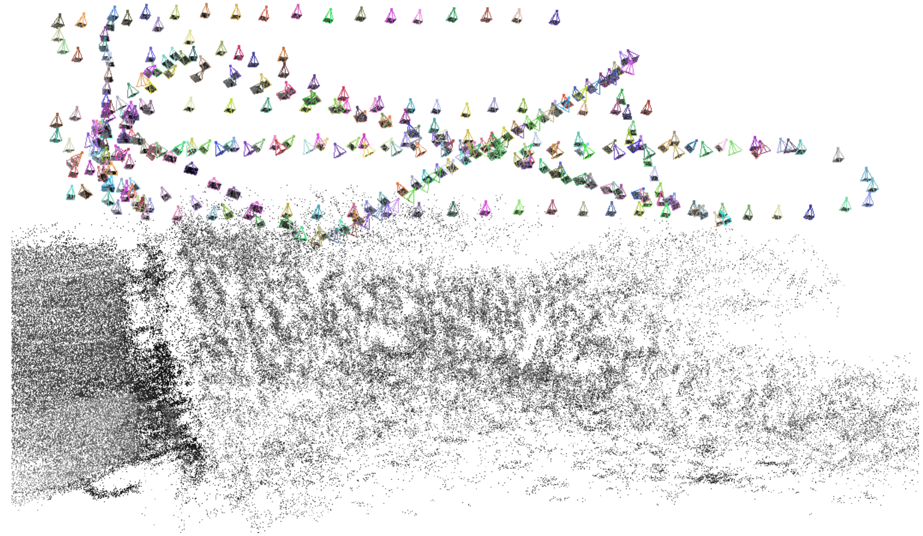
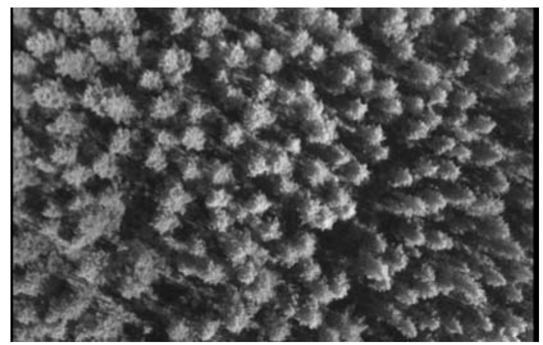
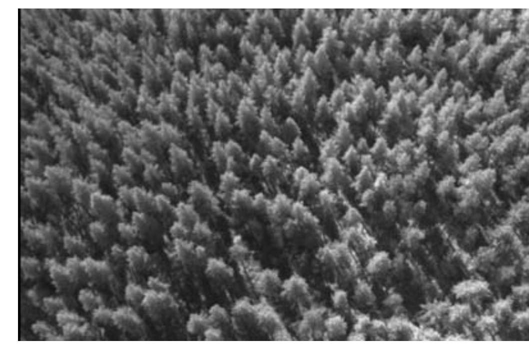
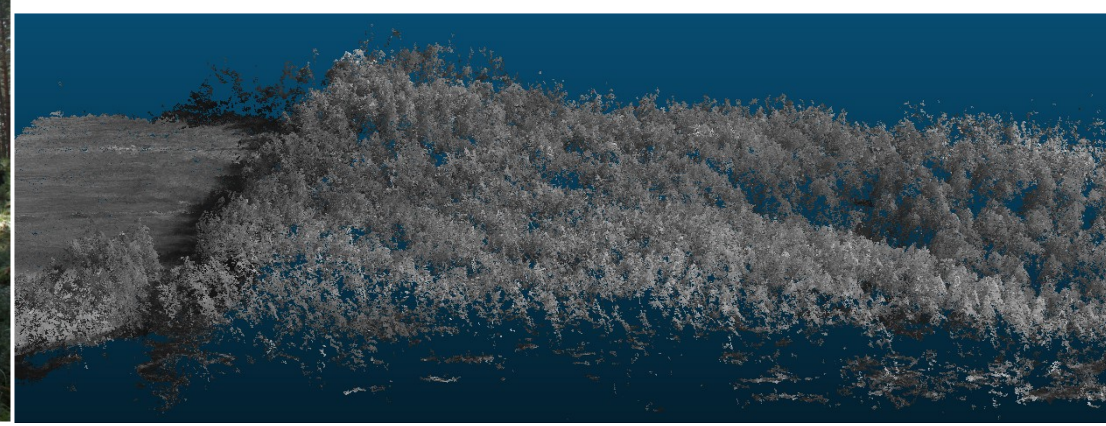
Forest at Evo, 21 August 2013

- Homogenous Scots Pine forest, with average tree height of 20 m
- Vertical and oblique blocks separately
- Flying height 100 m -> GSD 0.1 m
- Area of interest 140 m x 140 m



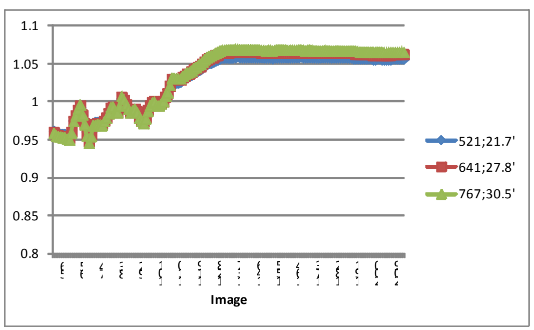


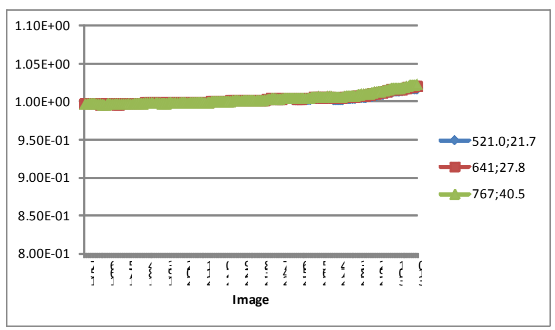


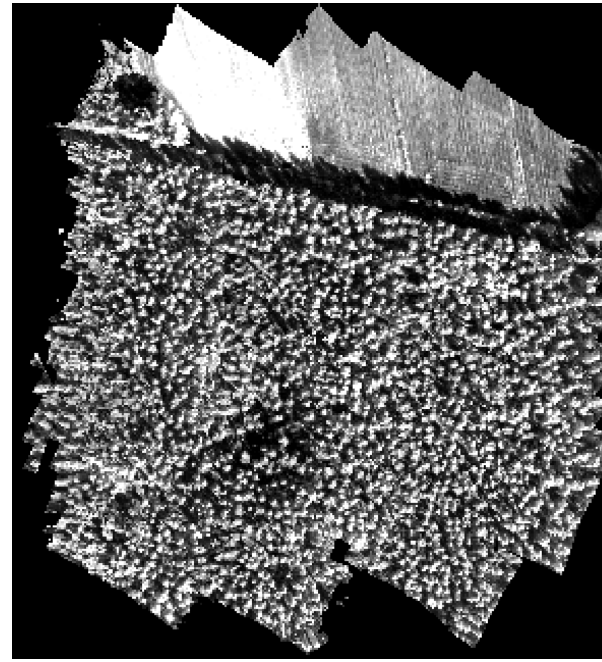


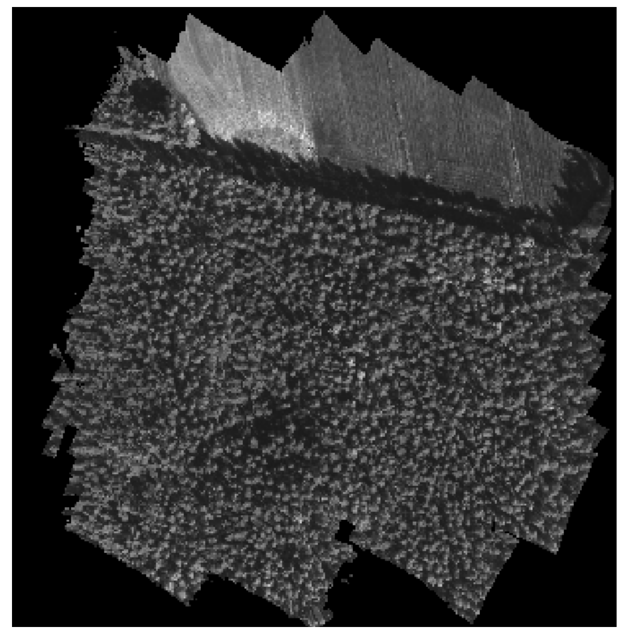
Evo reflectance mosaics

- Radiometric correction based on irradiance measurement by spectrometer ASD on ground
- Theoretical standard deviations
  - Bright target R≈0.5: $\sigma_R = 0.014$
  - Dark target R≈0.03; $\sigma_R = 0.003$









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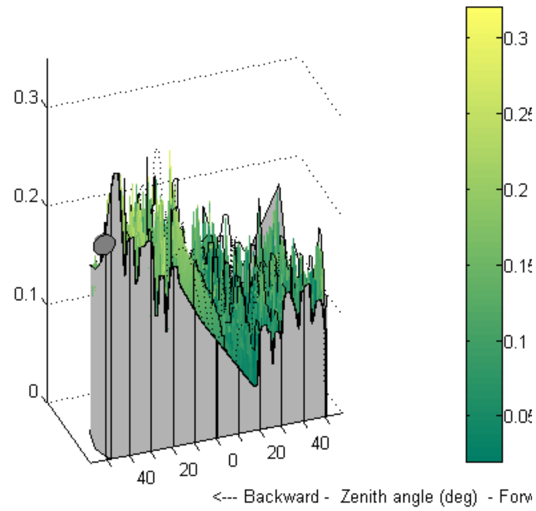
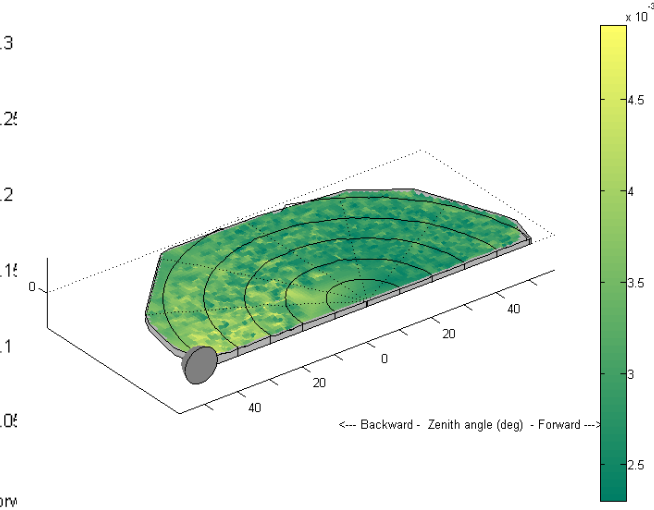
BRF of forest

- 140 m x 140 m area, 10 m point interval
  - 2700 observations
  - NIR: σ_R=0.003

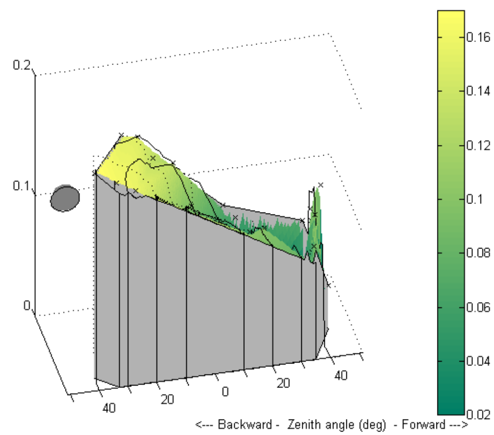
BRF by UAV, pine forest, NIR-band



BRF stdev by UAV, pine forest, NIR-band



- 5 m x 5 m object area
  - 32 observations



Conclusions

- New technology:
  - Traceable transfer of reflectance from national standards laboratory to field measurements
  - New UAV goniometer based on spectrometric camera
  - Uncertainty propagation to provide uncertainty estimates
- Demonstrations with gravel, barley field and pine forest
- Theoretical standard deviations about 0.01 and more
- Emprical accuracy results 0.02-0.04 in reflectance
- Riogorous approach for utlization of radiometric observations by vertical/oblique imaging systems

Thank you!

- We acknowledge EMRP for funding of the project. The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union
- Metrology Research Institute of Aalto University

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- Visual structure from motion
  - Wu, C., Agarwal, S., Curless, B., Seitz, S.M. 2011. Multicore Bundle Adjustment, CVPR 2011.
- SURE
  - Rothermel, M., Wenzel, K., Fritsch, D., Haala, N. (2012). SURE: Photogrammetric Surface Reconstruction from Imagery. Proceedings LC3D Workshop, Berlin ,December 2012

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  - Honkavaara, E., Markelin, L., Hakala, T., Peltoniemi, J.. Metrology of image processing in spectral reflectance measurement by UAV. Submitted to PFG special issue of EuroCOW
  - …