3D hyperspectral reflectance signatures by light-weight UAVs for the monitoring and measuring the environment

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GEODEETTINEN LAITOS

In co-operation

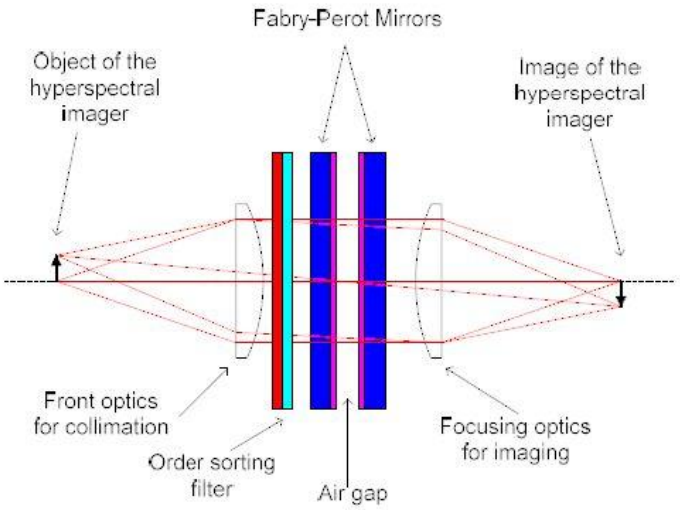
- VTT Technical Research, Finland: Heikki Saari, Jussi Mäkynen ym.
- MTT Agrifood Research, Finland: Jere Kaivosoja, Liisa Pesonen
- University of Jyväskylä: Ilkka Pölönen, Heikki Salo
- CLEEN MMEA Research Program
  - Lentokuva Vallas Oy: Pentti Ruokokoski, Jussi Kirjasniemi, Hannu Vallas ym.
  - Luode Oy: Antti Lindfors ym.

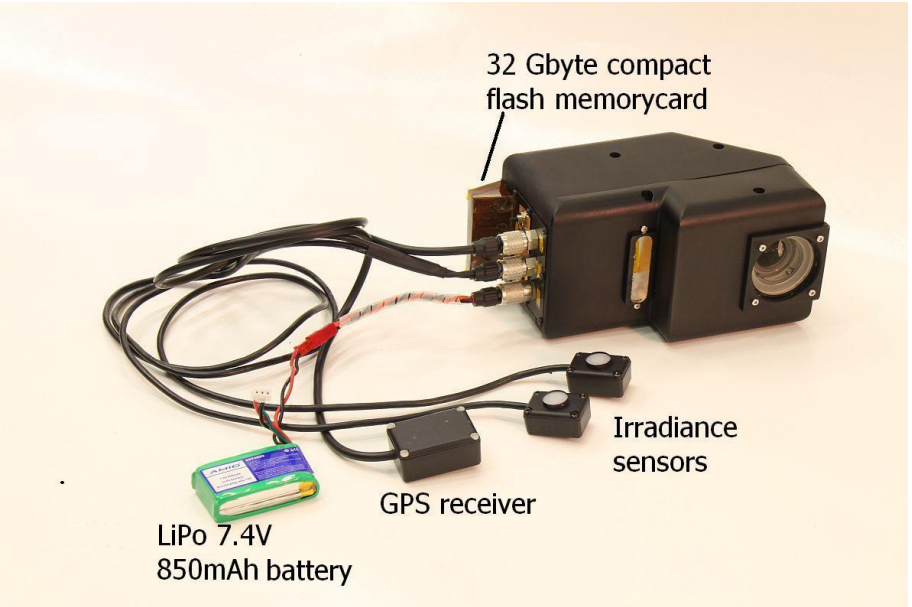
Introduction

- Objective
  - To develop new, rigorous approaches for UAV and small aircraft based remote sensing, for environmental monitoring and assessment
  - Rapid response situation picture, rigorous processing
- A novel imaging concept
  - High spatial resolution image block
  - Lower spatial resolution spectral data cube block by a novel Fabry-Perot interferometer based hyperspectral imager (VTT)
  - Frame sensors, weigh less than 500-600 g -> operation using light UAVs (1-2 kg payload)
- Novel data processing
  - Utilizing image block structure with multiple overlaps and redundancy in geometric and radiometric processing
- Primary outputs of data processing:
  - High density point clouds and digital surface models (DSMs)
  - Hyperspectral object reflectance signature images
  - Bidirectional reflectance factor information
- Novel analysis techniqes
  - Integrating **quantitative** geometric, textural and spectral features from images and DSMs

VTT Fabry-Perot interferometer based hyperspectral imager, 2012 prototype

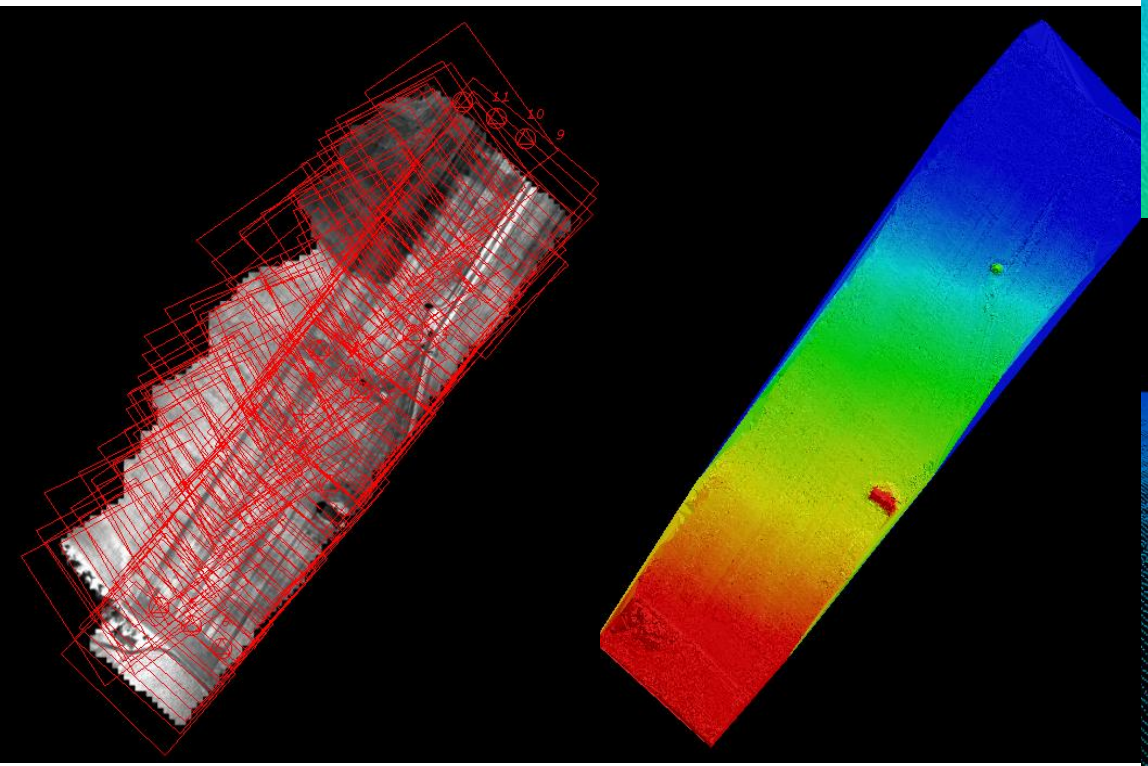
- Fabry-Perot Interferometer: spectral data cube is by changing the width of Fabry-Perot air gap by VTT
- Custom optics, CMOS detector
- Image size: 1024 x 648 pixels (2xbinned), Pixel 11 µm
- C=10.9 mm, F-number < 3.0
- Application based filter selection: 500-900, 450-700, 600-1000 , 400-500, … nm, Spectral resolution 10-40 nm @ FWHM

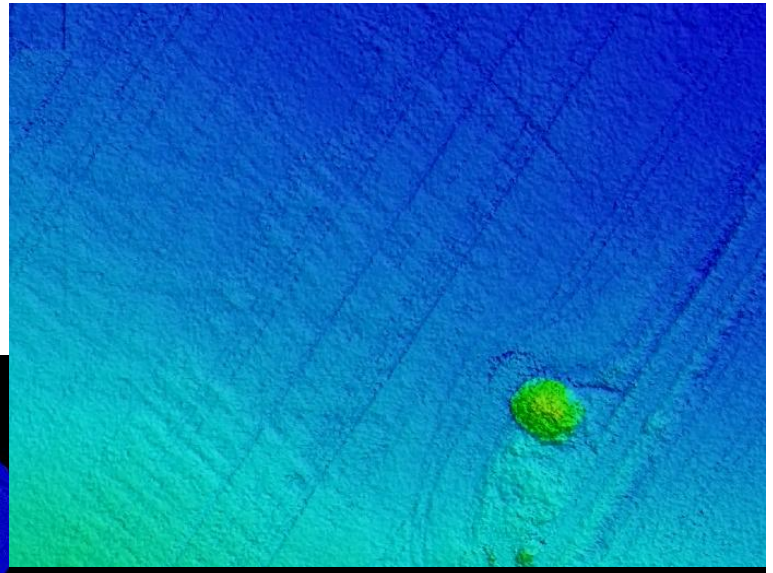


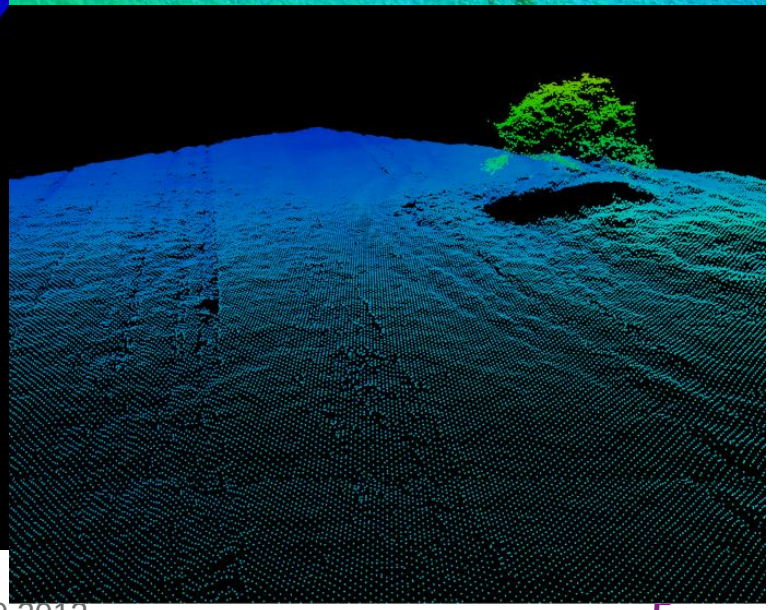


Dense point cloud technology

- High quality point clouds by automatic image matching from frame image block

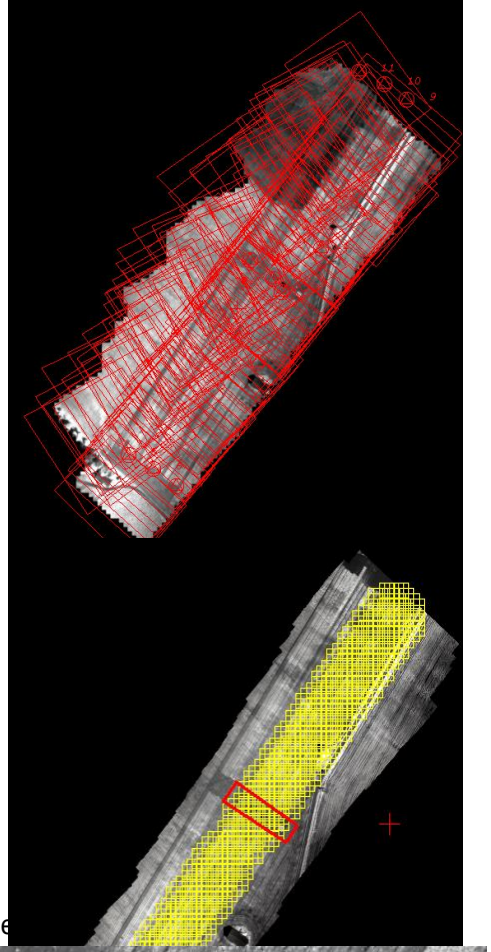


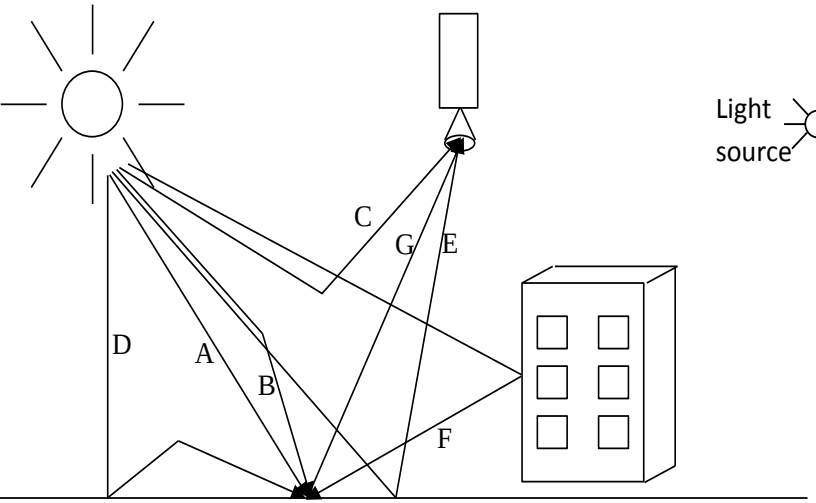


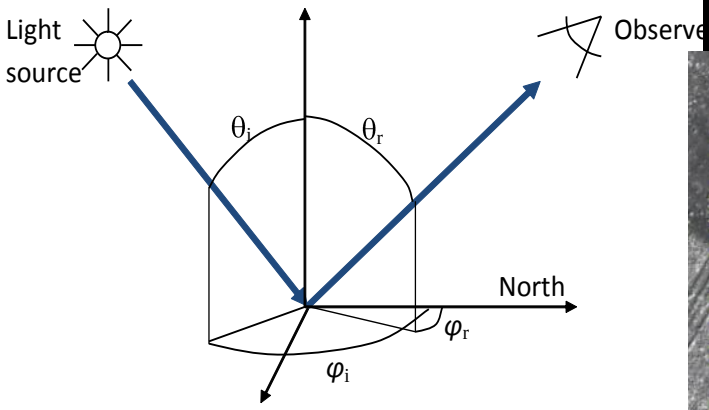


Hyperspectral reflectance signature generation

- Tasks
  - Eliminate radiometric differences caused by sensor instability and illumination/atmospheric
  - BRDF compensation
  - Reflectance calibration
- Approach
  - Radiometric block adustment using a network of radiometric tie points
    - Relative adjustment of images
    - BRDF-effect elimination
  - Reflectance images using reflectance targets







FGI Process

1. Geometric and radiometric laboratory calibration of sensors
2. Applying radiometric laboratory calibration to images
3. Processing of high spatial resolution stereoscopic data
   - Orientation using self-calibrating bundle block adjustment
   - Dense point clouds by automatic image matching
   - Radiometric block adjustment, reflectance transformation

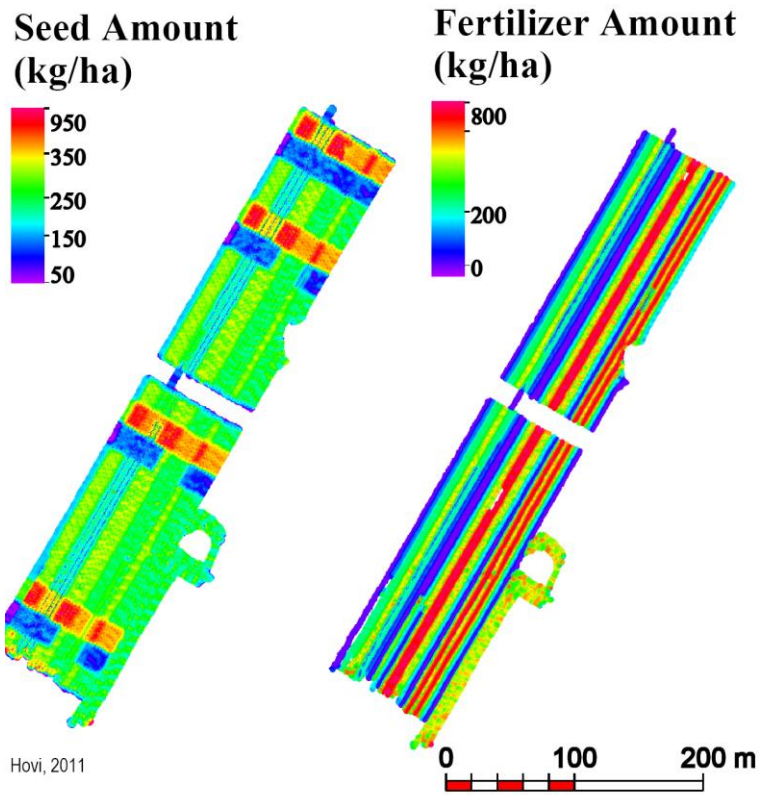
   ⇒ DSMs, point clouds, High spatial resolution orthophoto mosaic
4. Processing of FPI hyperspectral images
   - Band matching
   - Orientation of reference channels by self-calibrating bundle block adjustment
   - Radiometric block adjustment, reflectance transformation

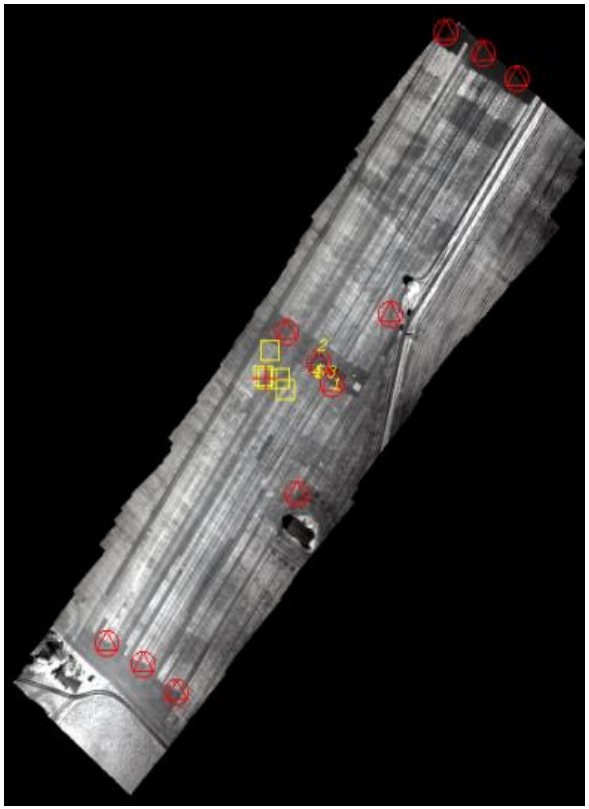
   ⇒ Lower spatial resolution hyperspectral data cube orthophto mosaic
5. Applications

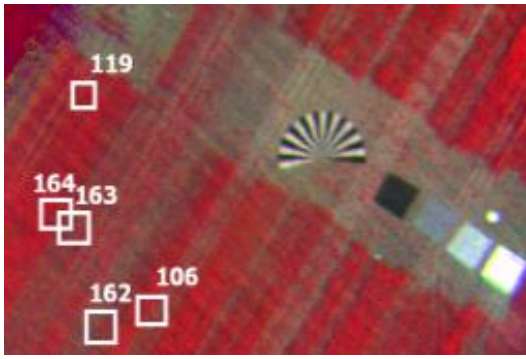
Empirical investigations

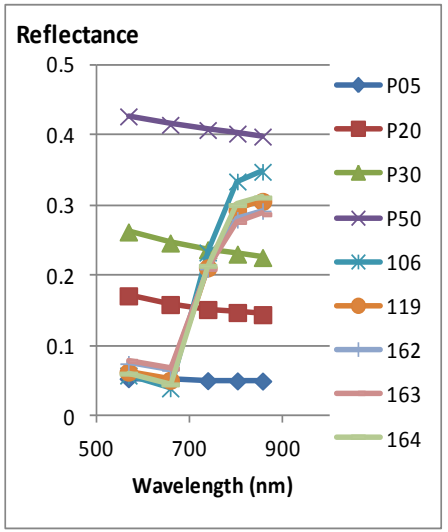
Example 1: Precision agriculture

- Co-operation: VTT, MTT, University of Jyväskylä
- Campaign at Vihti test site of MTT Agrifood Research Finland in 6.7.2011









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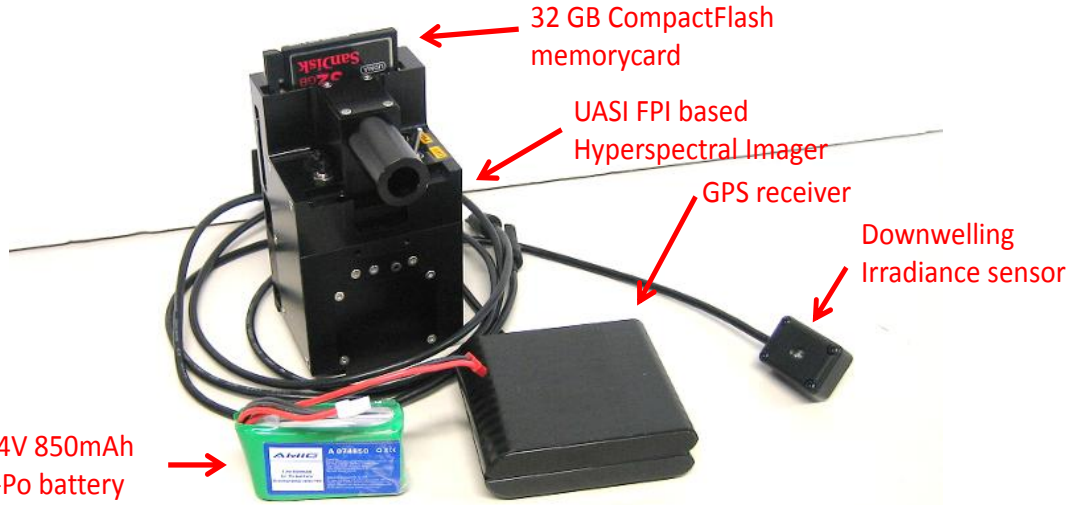
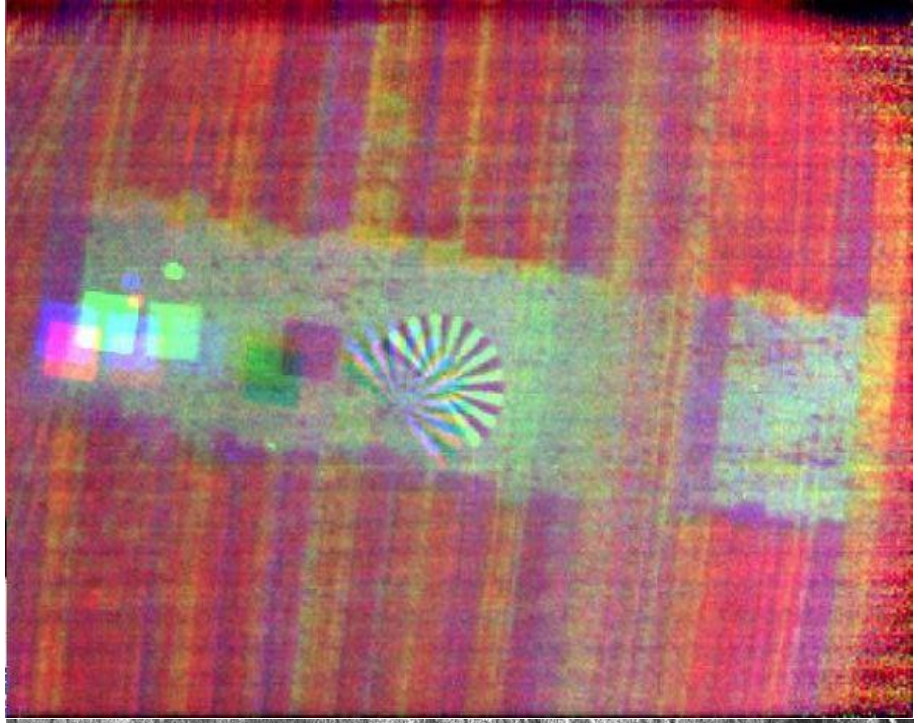
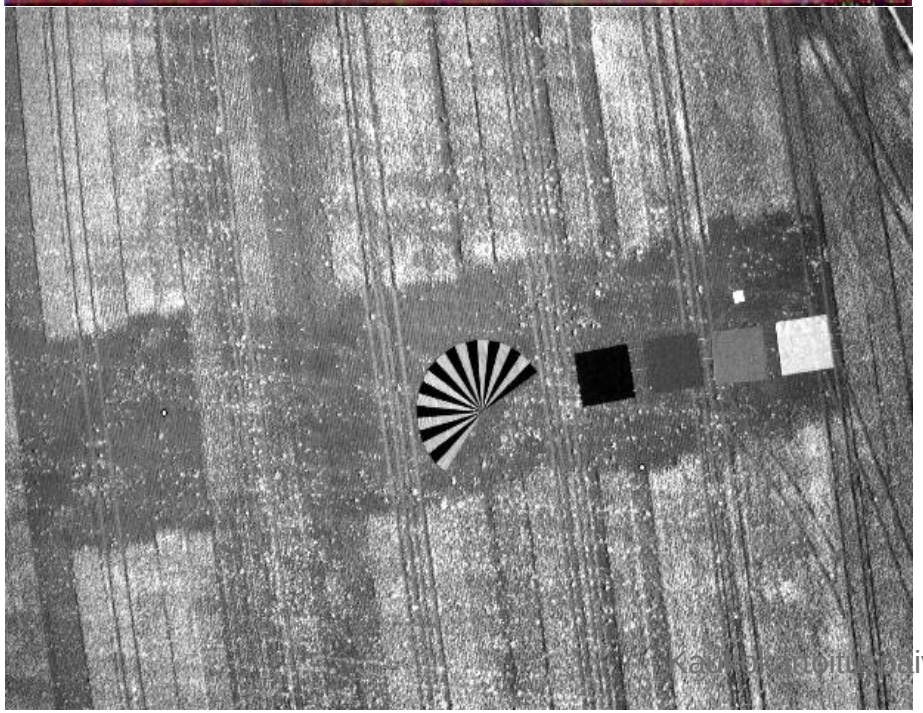
UAV imaging system 2011

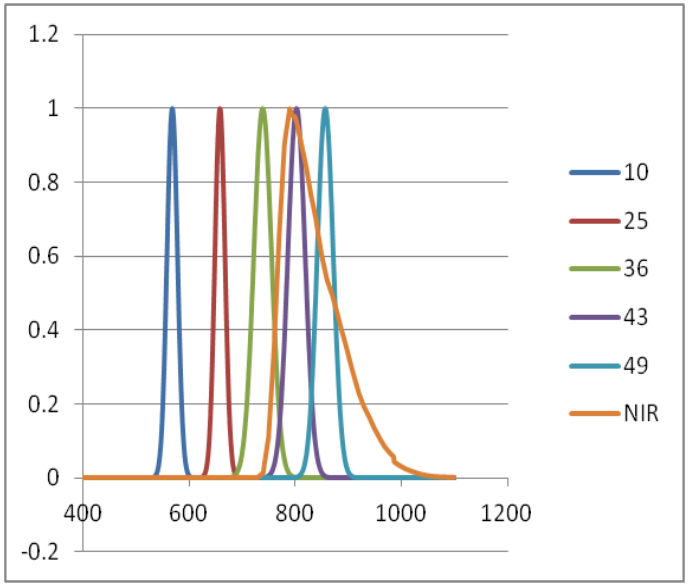
- Co-operation: VTT, MTT, University of Jyväskylä
- Microdrones MD4-1000 quadrocopter UAV, 1000 g payload
- Hyperspectral imaging: Fabry-Perot interferometer based camera prototype by the VTT Technical Research Finland
  - 640x480 pixels, Pixel size: 8.8 µm, F=9.3 mm, Fov: 36º, 26º, fstop < 7
  - Desired spectral channels by changing the FPI interferometer air gap during a short time interval (50 channels in 1.5 s)
- High spatial resolution imaging: Commercial Panasonic Lumix GF1 camera
  - 4000x3000 pixels, Pixel size 5.5 µm, F=20 mm, FOV: 48º, 37º



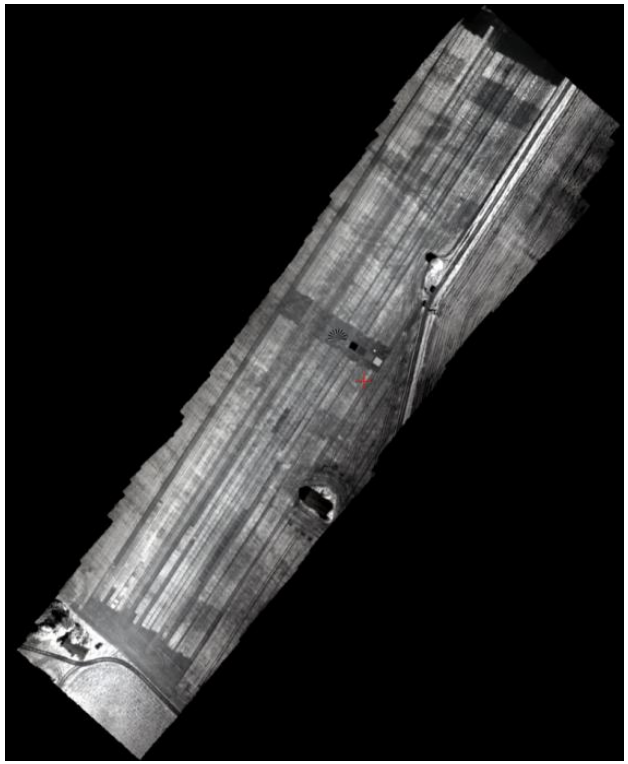




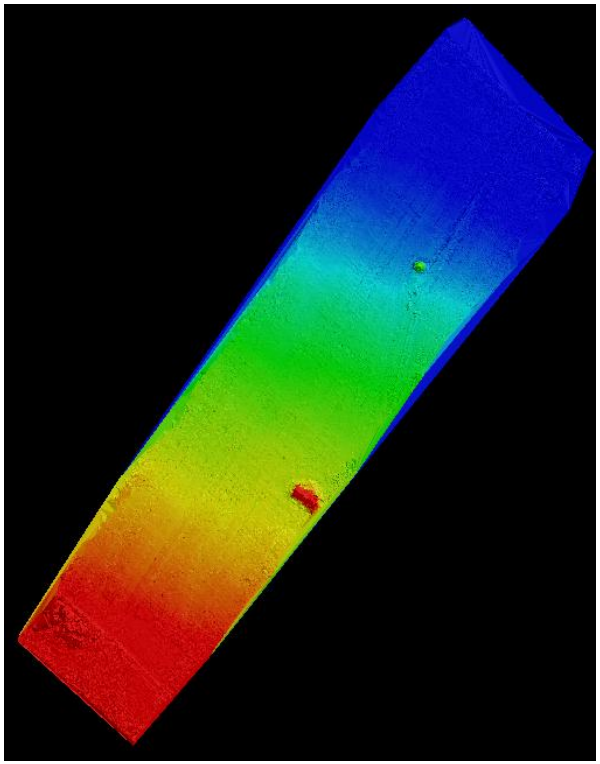
- Data collection, separately with both sensors
  - Flying height 140 m
  - UASI:GSD 13 cm, 5 selected channels
    - Center, FWHM
    - G: 568, 23
    - R: 658, 22
    - Red-edge: 739, 29
    - NIR-1: 803, 38
    - NIR-2: 857, 35
  - GF1: GSD 3 cm
- Sunny weather



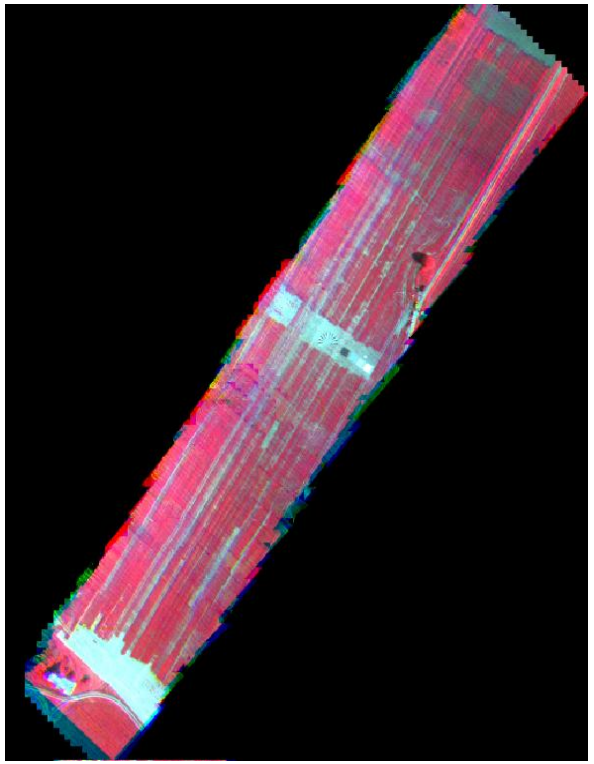
Results - Mosaics and DSMs



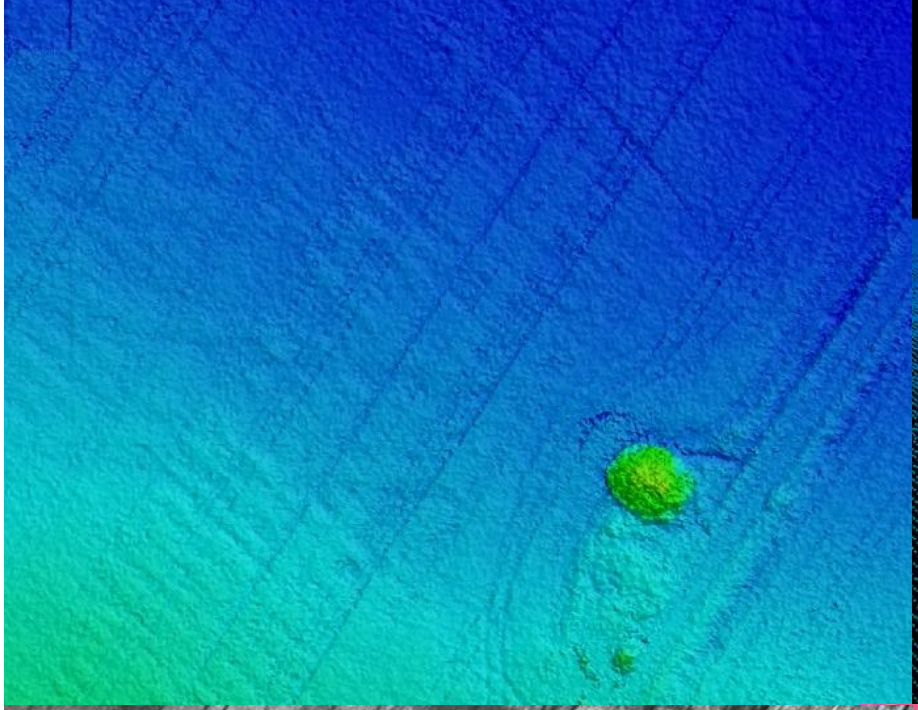
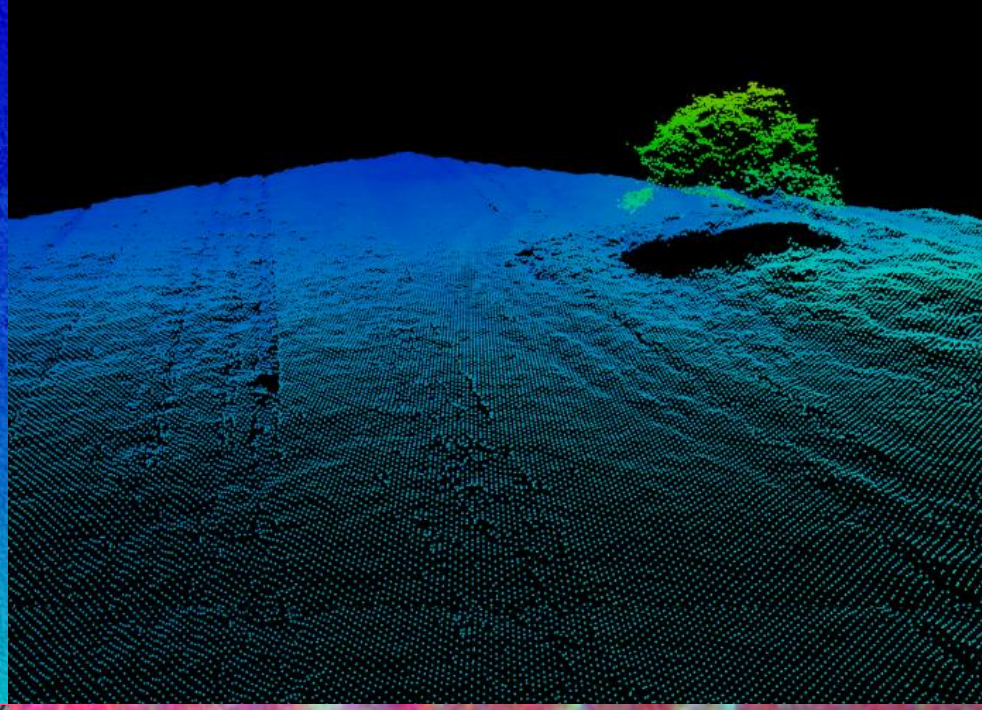
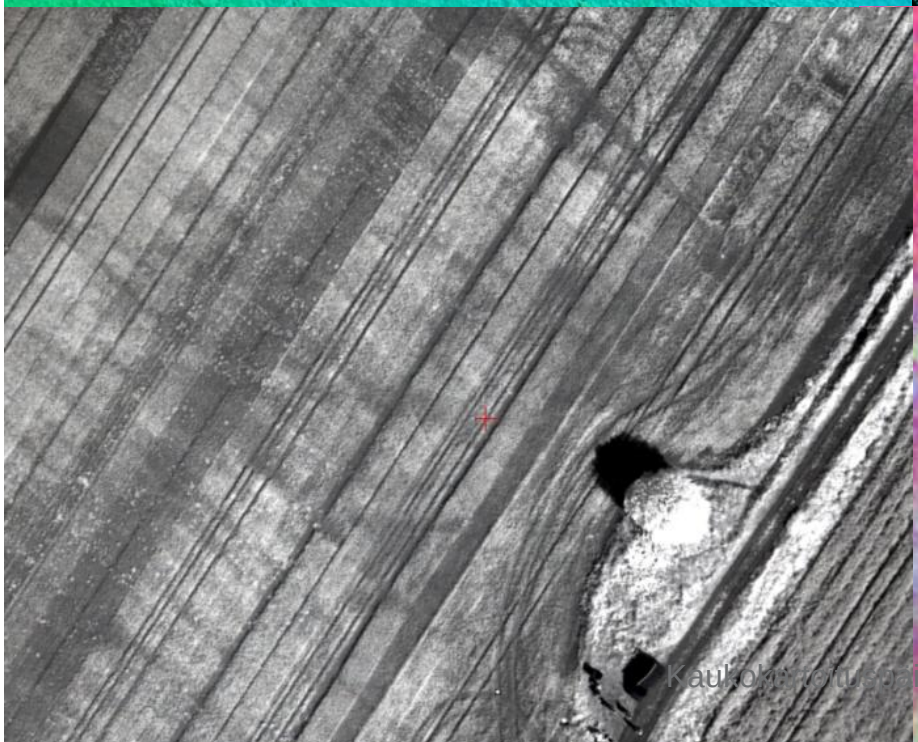
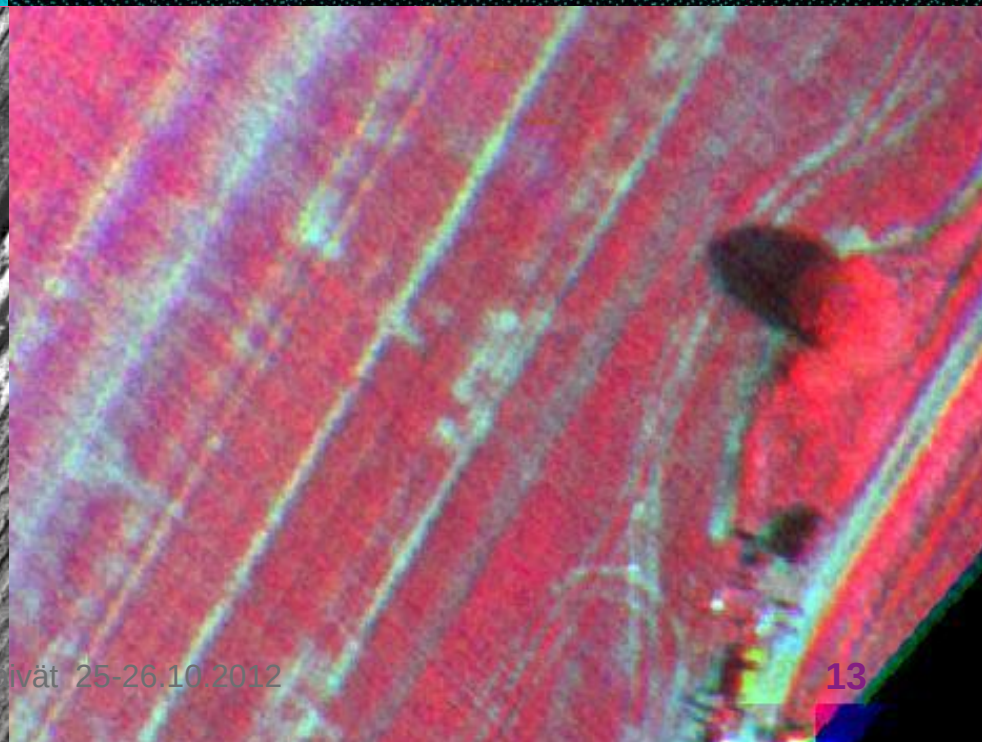
GF1 orthophoto mosaic
•GSD: 3 cm
•dX,dY:10-20 cm



GF1 point cloud
•Point interval 10 cm
•dZ: 10-20 cm



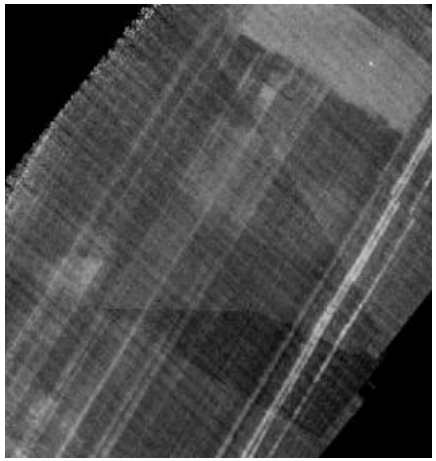
Hyperspectral orthophoto mosaic
•GSD: 10 cm
•dX,dY: 20-50 cm

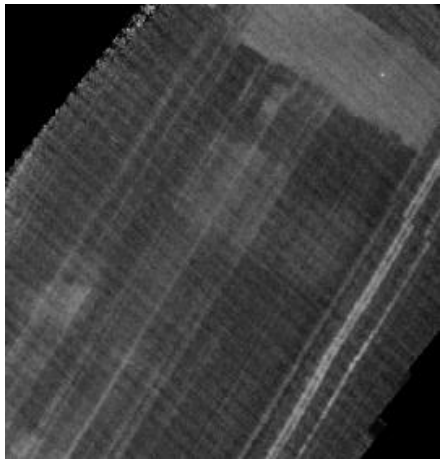
Results – Radiometric block adjusment

- Relative adjustment

No relative correction

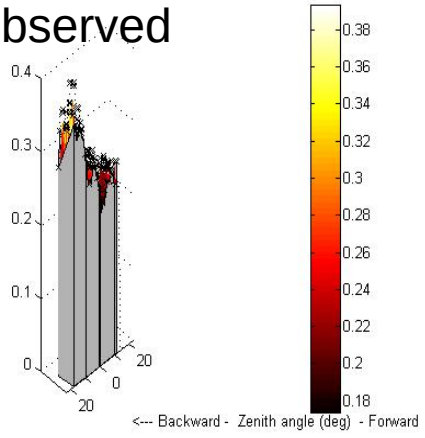


Relative correction

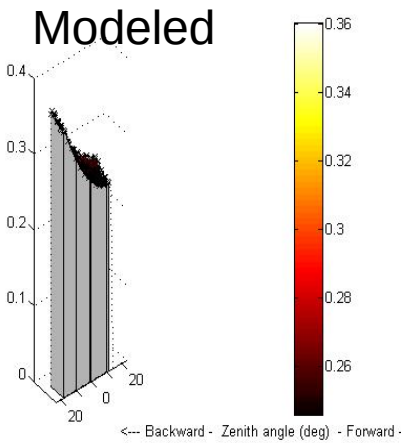


- BRDF correction

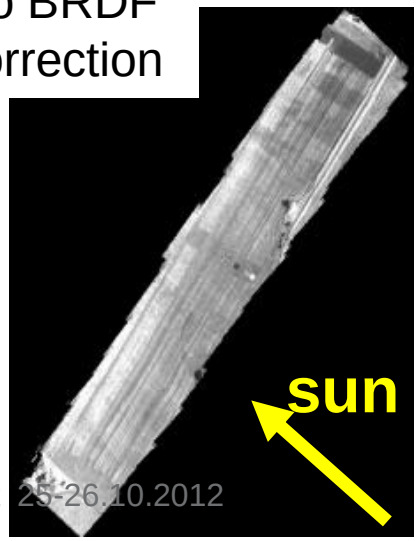
Observed



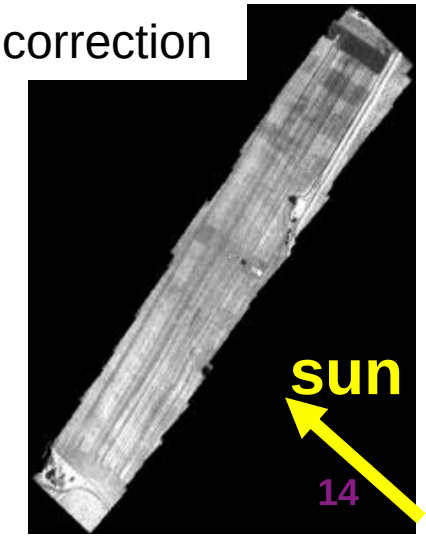
Modeled



No BRDF correction

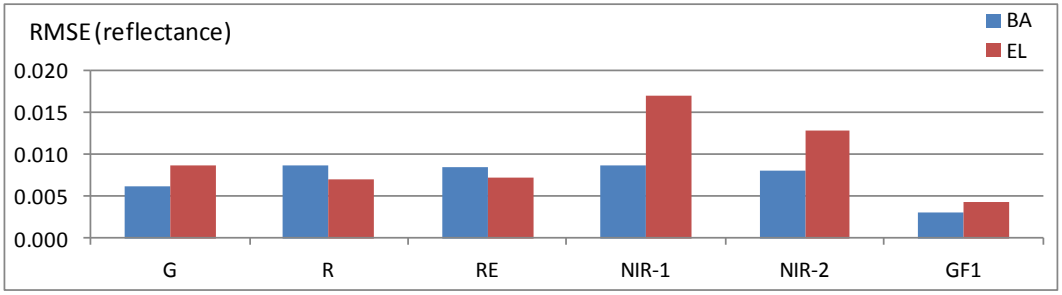


BRDF correction



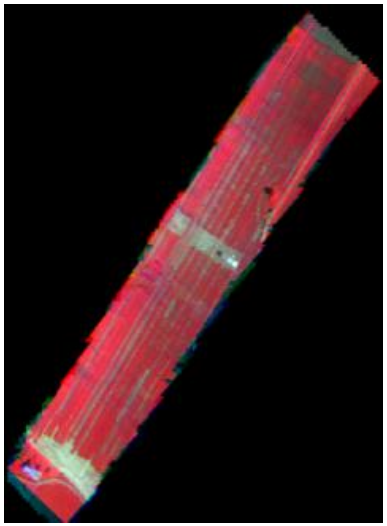
Results: Reflectance error

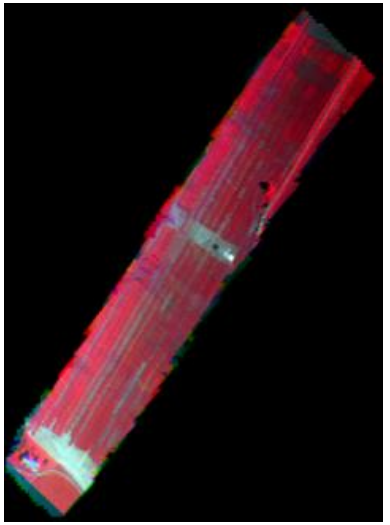
- Methods:
  - Empirical line method with one image
  - Radiometric block adjustment
- Reflectance errors by radiometric check targets
  - On the level of 0.005-0.008 or 5%
- Empirical line method based on single image provided mostly worse result than the block adjustment

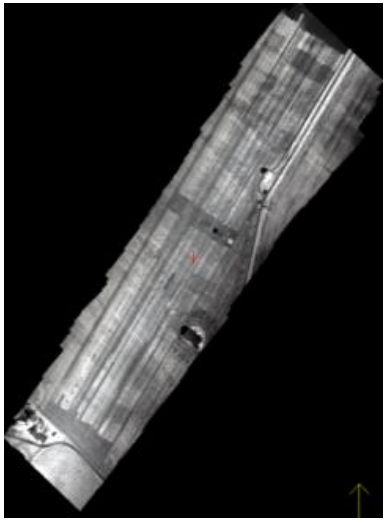


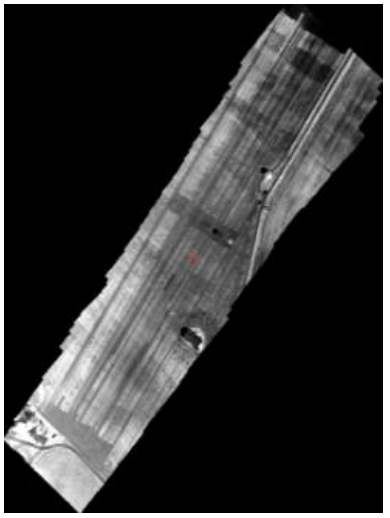
Original data

Reflectance data



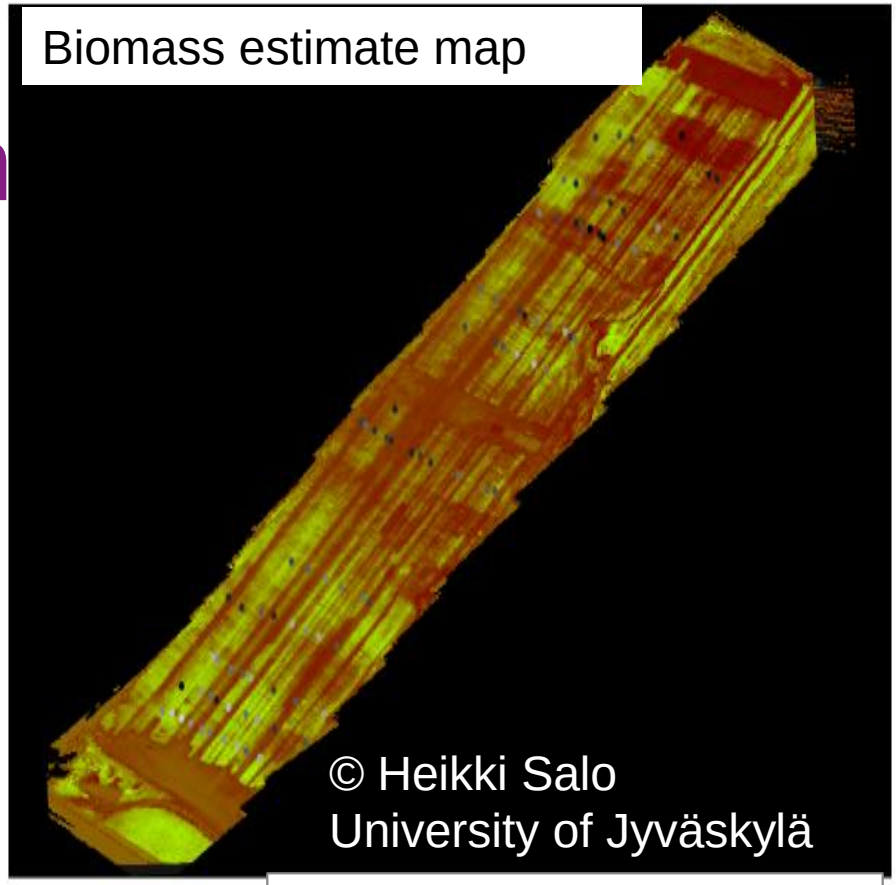


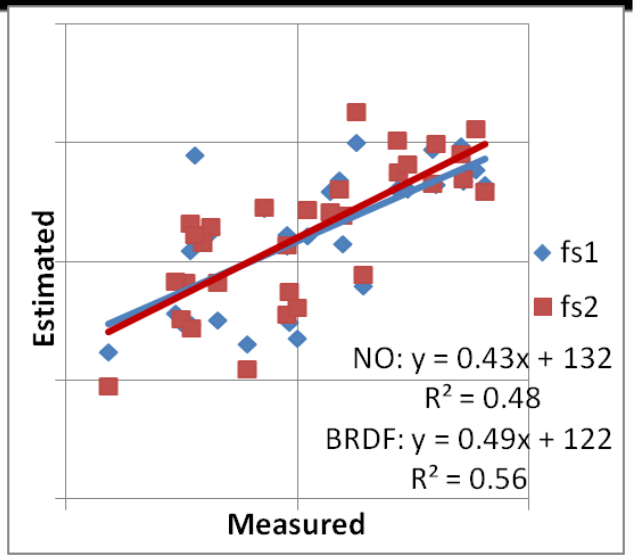




Biomass estimation

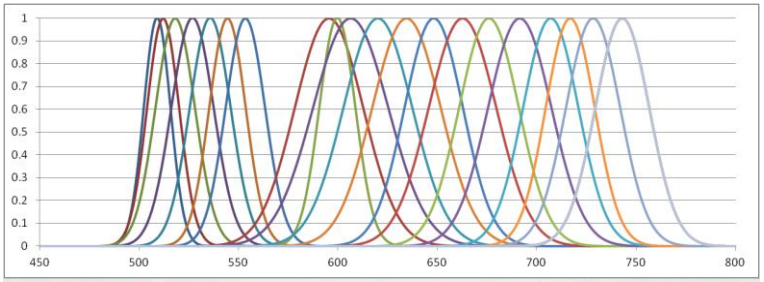
- Support Vector Regressor-based biomass estimation using radiometric features, with and without BRDF correction.
- Biomass estimates in g/m^2
- R^2
  - NO-BRDF: 0.48
  - BRDF: 0.56
- Estimate quality is dependent on the radiometric and geometric quality of the input data
- Results are promising

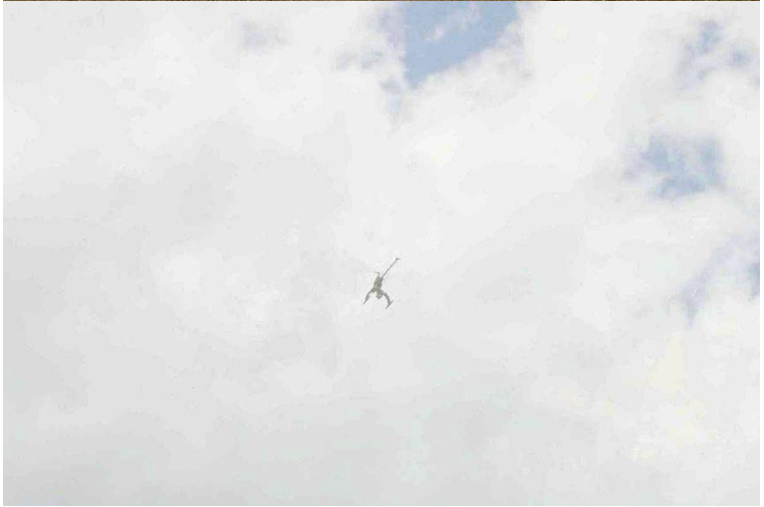




Vihti campaigns 2012

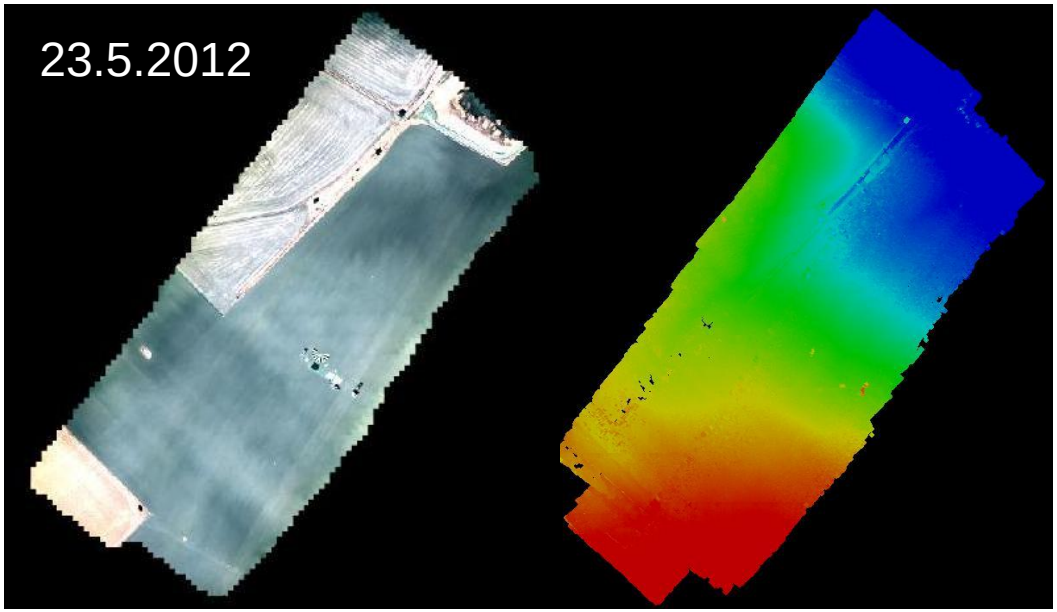
- In co-operation: VTT, MTT, University of Jyväskylä, FGI
- Three campaigns
  - Bare ground/soil: 21.5.2012
  - Weeds: 14.6.2012
  - Vegetation: 2.7.2012
- Sensors
  - VTT FPI Proto 1, 2011
  - VTT CIR UAV camera, 2012
  - VTT FPI Proto 2, 2012
- Insitu
  - MTT biomass and vegetation measurments
  - FGI reflectance reference, irradiance measurement

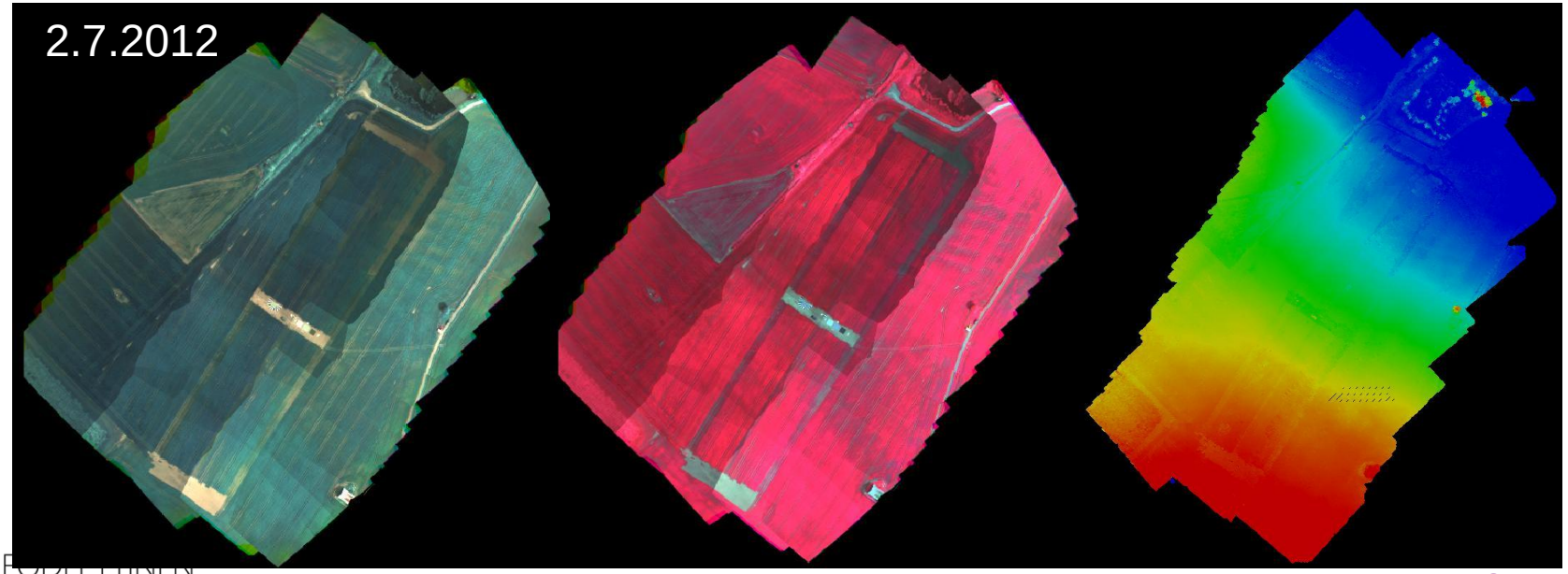




Results

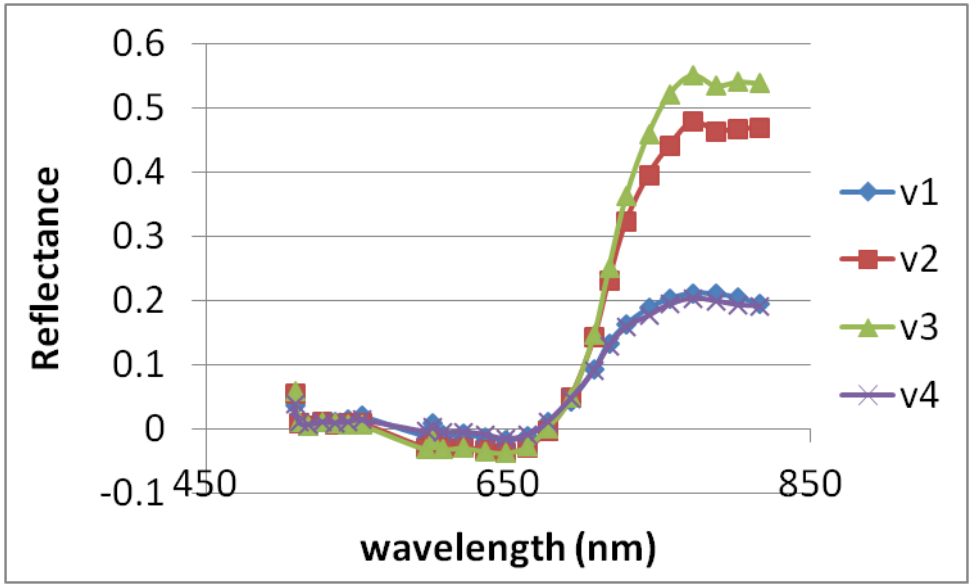
- High quality DSMs from CIR camera
- Varying illumination conditions cause radiometric challenges in 2.7.2012





Reflectance

- First experiments: Empirical line method using unadjusted image data
- Good spectrums: areas with high amount of biomass are clearly separable
- But: the entire image block has to be radiometrically balanced rigorously to get correct reflectance signatures



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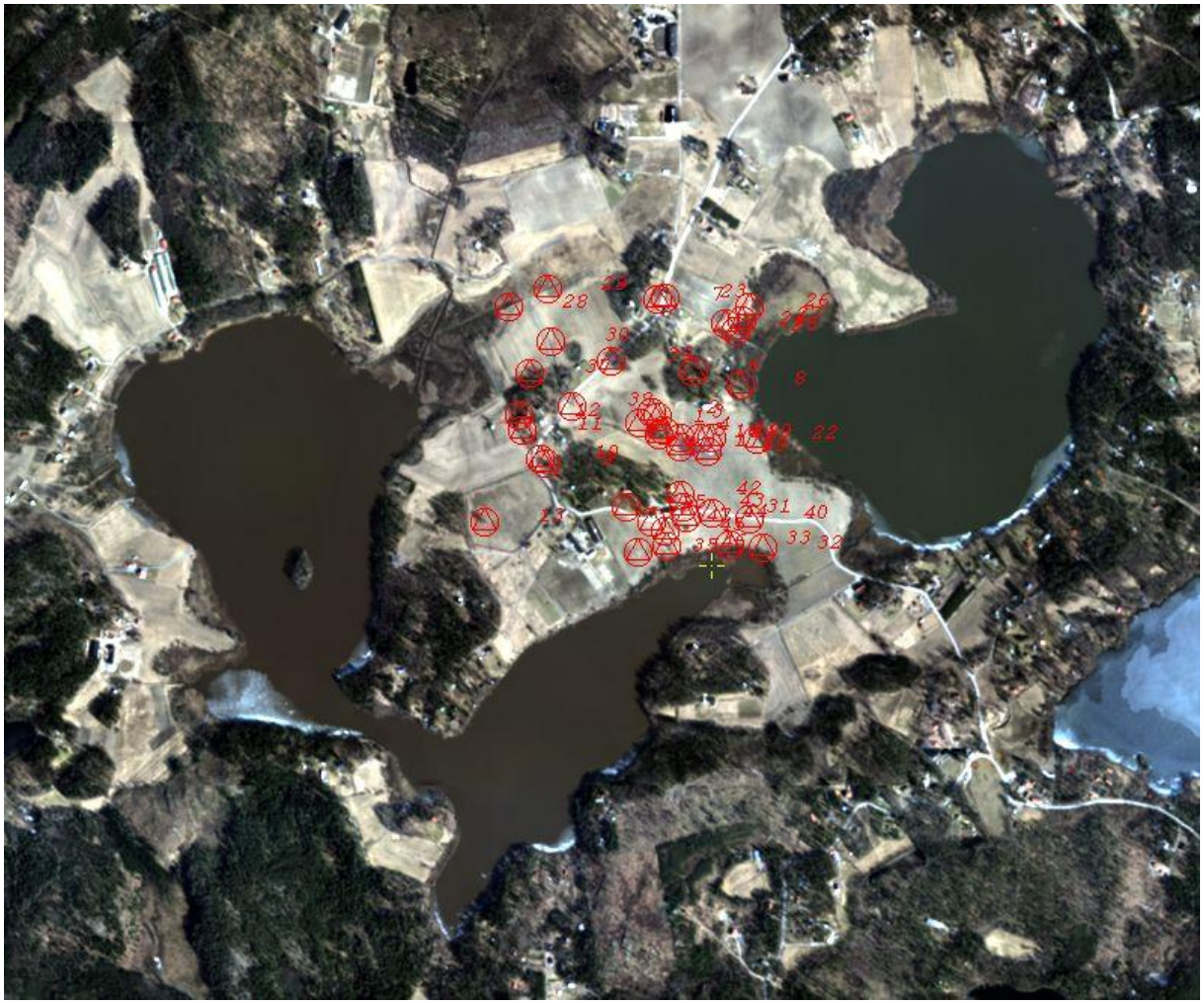
Example 2: Water quality monitoring

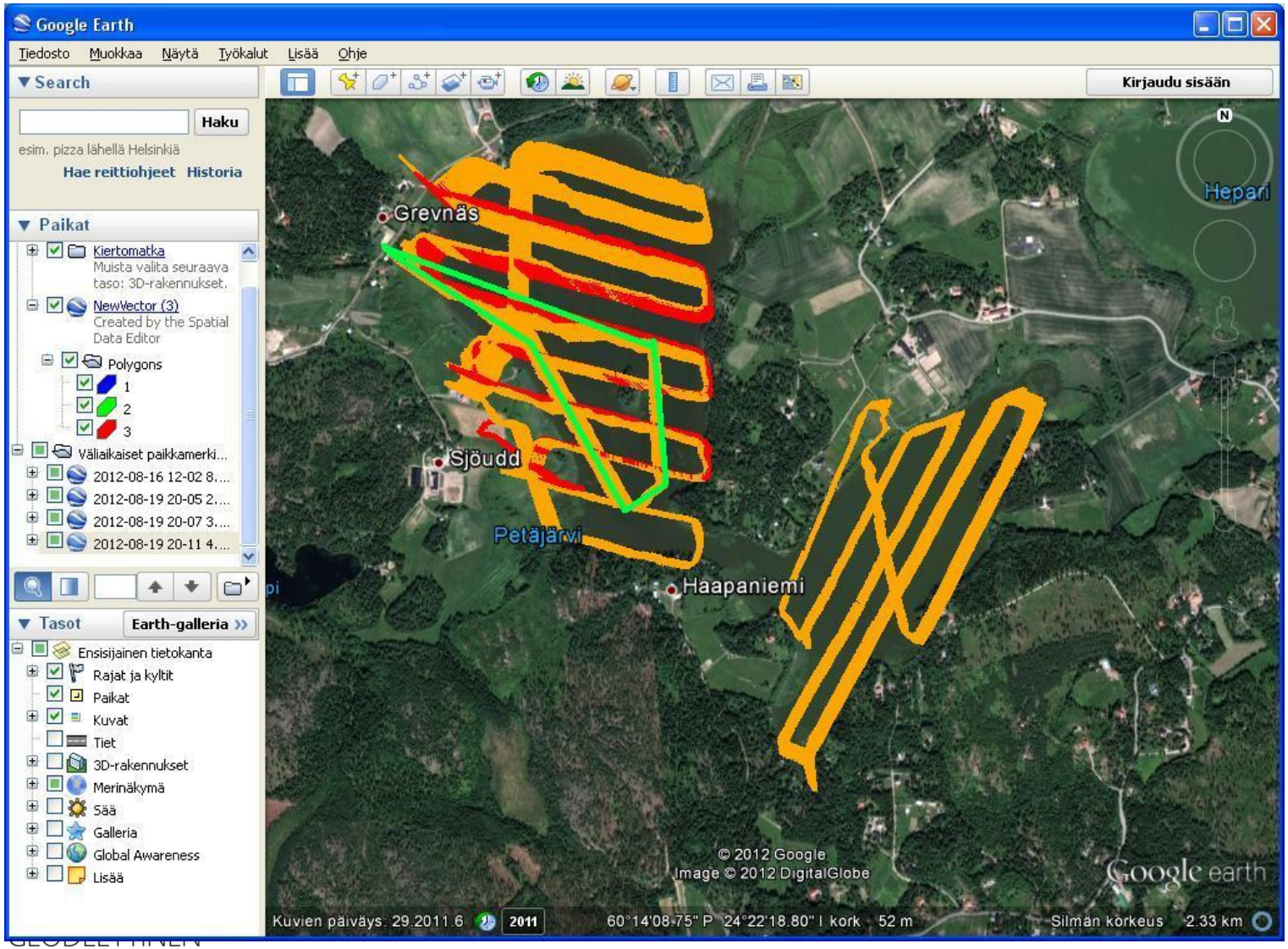
- Co-operation
  - Lentokuva Vallas Oy
  - Luode Oy
  - VTT
  - CLEEN SHOK MMEA Program
- Platforms
  - UAV
  - Manned small aircraft



UAV Campaign at Sjökulla Petäjärvi 16.8.2012

- VTT spectral camera with filters 500-900 nm and 400-500 nm
- Flying height 150 m, GSD 15 cm
- Reference
  - Water quality measurements by Luode Oy
  - Spectral reference targets and measurements by FGI

UAV Campaign at Sjökulla/Petäjärvi 16.8.2012



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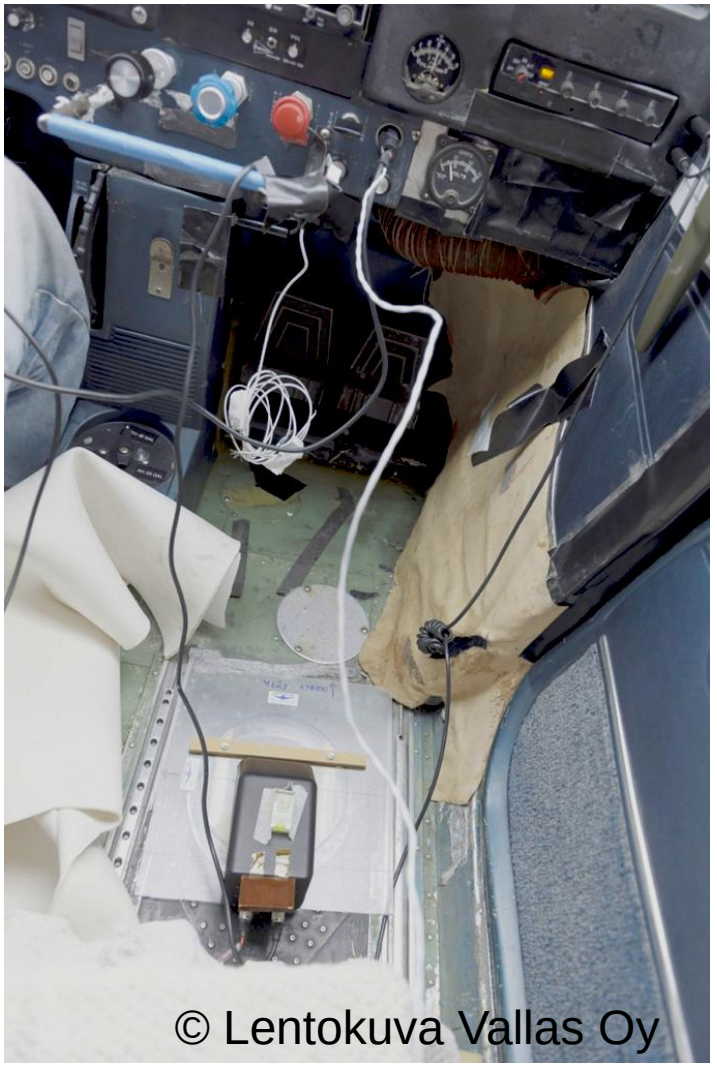
Spectral camera installation in single-engine aircraft of Lentokuva Vallas Oy

© Lentokuva Vallas Oy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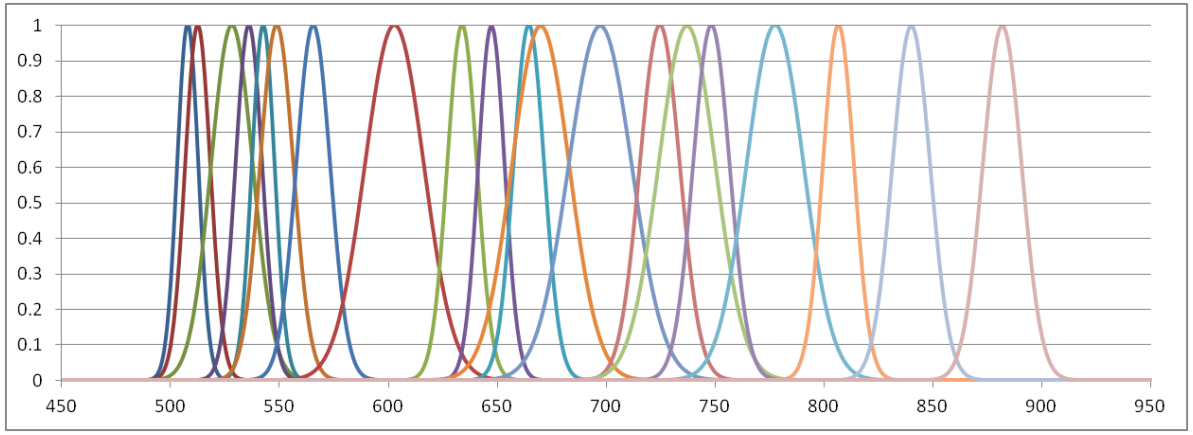
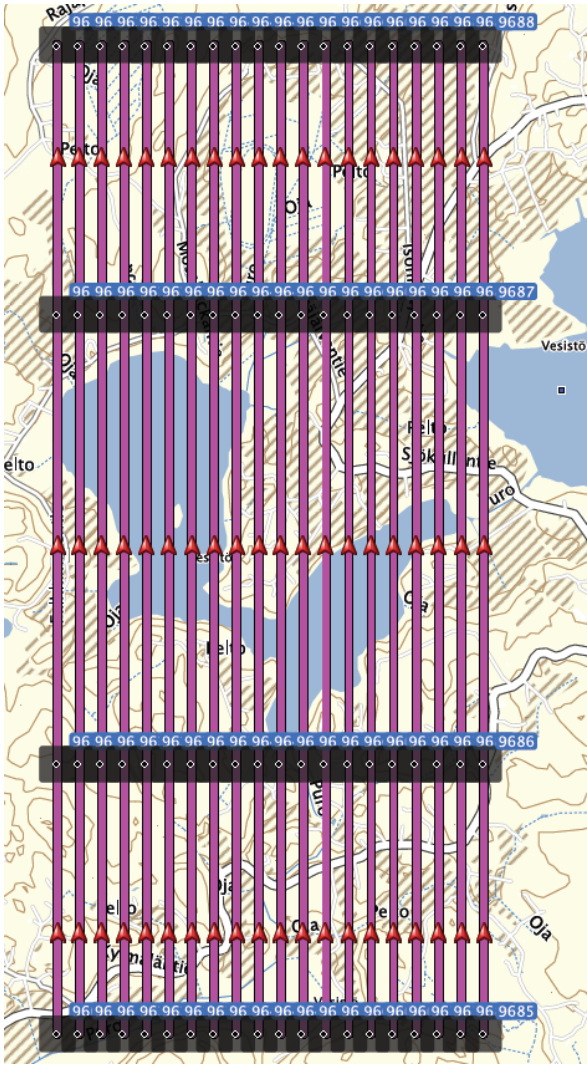
Data collection

- Flight campaign over Sjökulla test field 25.9.2012 by Lentokuva Vallas Oy, OH-CNU, Cessna 172 Reims Rocket
- Instruments:
  - VTT spectral camera proto 2B
  - Lentokuva Vallas Nikon D3X, Zeiss Planar 50 mm/1.4
- Weather: Cloudy, some rain
- Block
  - Height: 440 m over terrain, Speed 39 m/s,
  - 2 km x 4 km = 8 km^2 , 20 lines, 200 m Flight line spacing,
  - GSD 50 cm
- Two flights with spectral camera, with 8 ms and 14 ms integration times , Image interval > 2 s, 20 channels
- Insitu data
  - Sjökulla test site
  - Ground reflectance reference data with Avantes hand held spectrometer
  - Water measurements by Luode Oy





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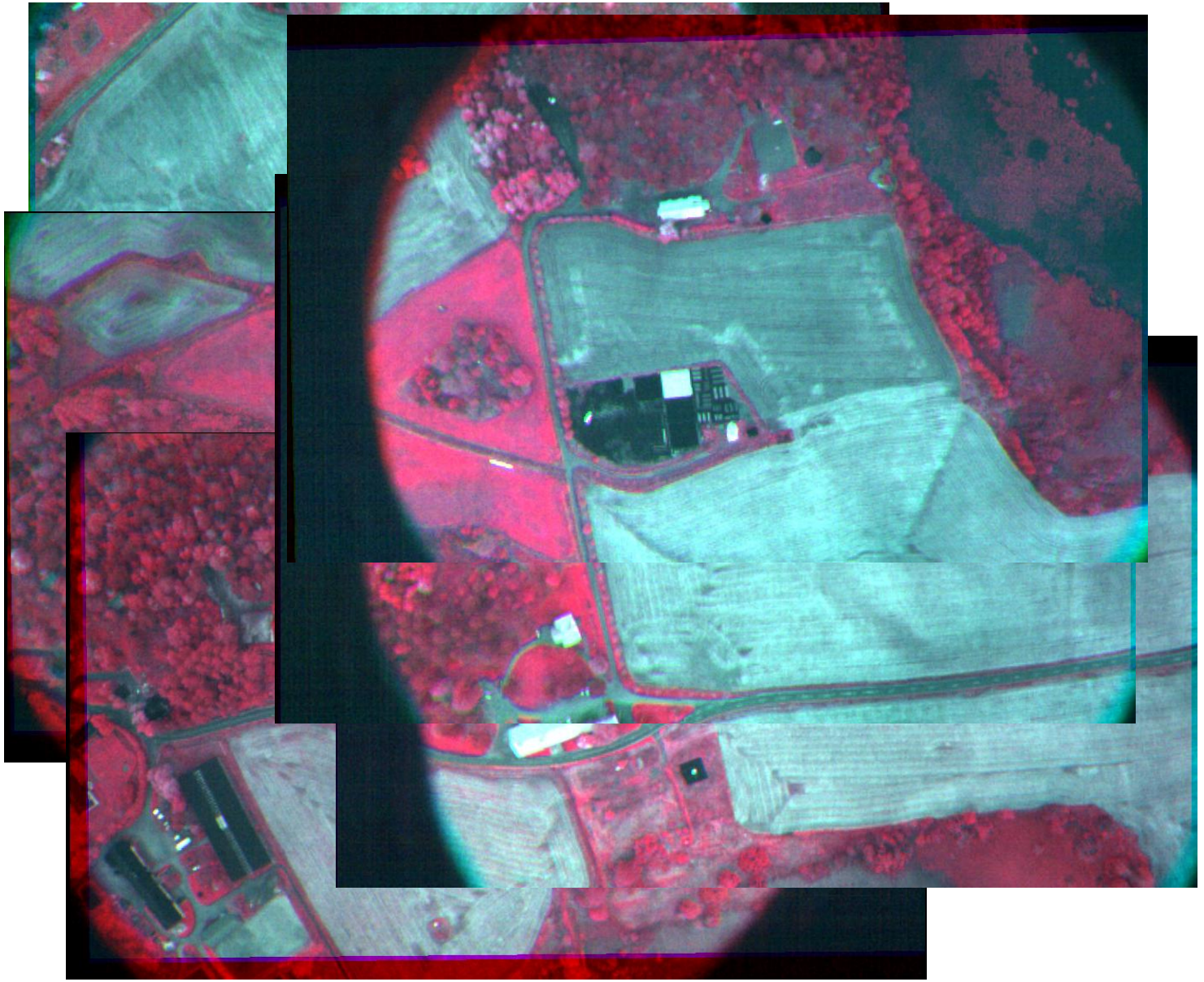

Conclusions

Conclusions

- Spectrophotogrammetry: stereoscopic, 3D, hyperspectral, spectrodirectional remote sensing
- Image block with high overlaps is the key for reliable processing of remote sensing image data
  - Provides strong geometric and radiometric constraints
  - Redundancy
  - Especially important in dynamic environments, e.g. low-weight UAV imaging systems
  - Well-known in geometric processing: Bundle block adjustment, Point determination by intersection, DSM/point cloud generation
  - Block utilization in radiometric processing need to be improved
- FPI spectral camera demonstration with UAV and manned platform
  - UAVs: areas < 1 km^2
  - Manned platforms: areas >> 1 km^2
- Many potential environment related measurement applications: agriculture, forestry, water, climate parameters

Thank you !

- http://www.fgi.fi/fgi/research/researchgroups/spectrophotogrammetry