New light-weight stereoscopic spectrometric airborne imaging technology for high-resolution environmental remote sensing – Case studies in water quality mapping

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Introduction

- New light-weight Fabry-Perot interferometer based camera technology
  - Data cubes with adjustable spectral properties in a rectangular image format
  - Weigh 600 g -> suitable for light Unmanned Airborne Vehicles (UAVs) and light Manned Airborne Vehicles (MAVs)
- Objective: To investigate and develop processing and use of the FPI imaging technology in environmental remote sensing and monitoring applications
  - 3D-geometry, object reflectance signatures
  - Measurement and processing in all weather conditions
- Previous studies in precision agriculture using 2011 and 2012 prototypes
- Case studies in water quality mapping
  - Objective is to develop a fast and cost-efficient method to provide high-resolution data from complex environments where the use of traditional sampling methods is limited, such as lakes, rivers and harbour areas
  - Assessment of its potential in measurement and monitoring of various water quality parameters algae blooms, turbidity, organic carbon, total phosphorus concentrations, chlorophyll-a
FPI spectral camera technology
Fabry-Perot interferometer based tuneable spectral imager, 2012 prototype

- Hyperspectral imagery in frame format
- Spectral data cube by changing the width of Fabry-Perot air gap
  - Developed by VTT Technical Research Finland (Heikki Saari et al.)
- 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 between 400-1000 nm
  - 500-900, 450-700, 600-1000, 400-500, … nm
  - Spectral resolution 10-40 nm @ FWHM
UAV operation

**UAV**
- Autopilot
- IMU
- GPS

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

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

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

- Desired output product: water leaving spectral reflectance mosaic
- Rigorous FPI spectral data cube generation is the basis for further processes
- Geometric processing with standard photogrammetric methods: orientations, DSMs
- New processing is developed for radiometric model calculation using frame format images
- Output products: DSMs, spectrometric point clouds, spectrometric image mosaics, spectrometric stereoscopic data
Spectral data cube generation

- Sensor radiometric and spectral calibration in laboratory using an integrating sphere and monochromator by VTT
- Spectral smile correction
- Layer matching
  - Geometric transformation by using feature based matching to a single reference layer.
  - Affine or projective transformation.
  - Strategy: Reference layer for each spectral region, apriori matching in layer order
  - Quality statistics: Standard deviations of model parameters, magnitudes of parameters, residuals
A new method for reflectance image generation of frame images

- **Data**
  - Overlapping spectral rectangle format data cubes

- **Tasks**
  - Eliminate radiometric disturbances caused by sensor instability and illumination/atmosphere
  - BRDF compensation
  - Reflectance calibration

- **Approach**
  - Radiometric model parameters using radiometric block adjustment with a network of radiometric tie points
  - Optional in situ irradiance measurements
  - Reflectance images using reflectance targets
Output products: DSMs, hyperspectral image mosaics, hyperspectral point clouds

Empirical study

- Campaigns by UAV and MAV in lake Petäjärvi, Sjökulla
- Shallow lake in agricultural area extending to an area of 2 km by 2 km
UAV Campaign, 16.8.2012

- Helicopter UAV, 4 kg payload, autopilot
- Flight parameters according to legislation in Finland: Flying height 150 m, GSD 15 cm; Visual control by UAV pilot
- FPI spectral camera
  - Filters 500-900 nm, 600-750 nm and 400-500 nm, 29-42 spectral bands
  - Continuous interval mode
- Weather: Fluctuating cloudiness
- In situ data
  - Water quality measurements by Luode Consulting Oy
  - Spectral reference targets and measurements by FGI

- By Lentokuva Vallas Oy, OH-CNU, Cessna 172 Reims Rocket
- Block
  - Height: 440 m over terrain, Speed 39 m/s,
  - 2 km x 4 km = 8 km², 10 lines, 200 m Flight line spacing
  - Overlaps: 63%, 56%
  - GSD: 45 cm
- 14 ms integration times, image interval > 2 s, Filter 500-900 nm, 20 channels
- Weather: Cloudy, rainy
- Insitu data
  - Sjökulla test site
  - Ground reflectance reference data with Avantes hand held spectrometer
  - Water quality measurements by Luode Oy
UAV and MAV campaigns at Sjökulla/Petäjärvi in 2012

UAV

MAV
Results
Signal-to-noise ratio

MAV
45 cm

UAV
15 cm

ISPRS Hannover Workshop 2013, 21 – 24 May 2013, Hannover, Germany
Georeferencing using national open topographic orthophotos and DSMs

- Georeferencing a block with a three-layer image, apply the orientations to layer matched datacubes
- Ground reference: national open digital surface models and orthophotos, 90 GCPs
  - GPS data was not used
- Orientations for images containing only water by interpolation from adjacent images
- Bae Systems Socet Set environment
  - Automatic tie point measurement
  - Self-calibrating bundle block adjustment
  - $\sigma_0 = 0.5$ m
  - RMS at GCPs:
    - X: 0.69 m, Y: 0.70 m, Z: 0.18 m

Reflectance images of MAV data

- Extensive illumination variations during the flight, water shower in the middle of the flight
- Radiometric block adjustment
  - Relative shift correction or relative multiplicative correction
  - Reflectance transformation using empirical line method
- Coefficient of variation in radiometric tie points
  - 0.1-0.14 without corrections, 0.06-0.1 with corrections
  - Potential shadowing by the floor hole was uncorrected

- No correction

- Relative multiplicative

[Graph showing coefficient of variation across different wavelengths, with labels and axes provided.]
Vegetation and soil reflectance

- Insitu measurement: rain seriously descreased reflectance
- The FPI reflectance followed quite well the reference reflectance
Lake reflectance from MAV data

- Reflectance in 3 m x 3 m image window
- Reflectance is influenced by algae blooms and turbidity
- Further analysis is in operation
MAV and UAV spectral data cube mosaics

- MAV mosaic, GSD 1 m
- 25.9.2012, rainy weather
- UAV mosaic, GSD 20 cm
- 16.8.2012, sunny weather
Conclusions

• Preliminary results of the FPI spectral camera in water quality mapping application were presented. Data analysis will continue.
• Very promising technology
  • High spatial resolution, stereoscopic, spectrometric image data
  • FPI camera is operational from dynamic, light-weight, UAV platforms, suitable also for operation from MAV platform
• Can be operated in difficult illumination conditions: under clouds, rain
  • Well suited for time-critical and monitoring applications, such as water quality, agriculture, mining environments, disasters
• UAV operation best suited for areas <25 ha (depending on legislation), MAV for larger areas
• Radiometric processing technology for images collected in diverse weather conditions is needed, radiometric aspects need to be carefully considered
• Ongoing studies at FGI
  • Improving radiometric and geometric processing
  • Procedure for SI-traceable UAV reflectance measurements
  • Analysis in forests, agriculture, water environment, mining environment
Thank you!