Low-altitude / high-resolution remote sensing – from theory to application

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PhenoFly mission statement

- The **PhenoFly team** develops sensing systems and analysis procedures that deliver quantitative data to capture reliable information about vegetation.
- Our **vision** is to bring (high-throughput) phenotyping approaches from large facilities to the landscape.
- We **aim** to understand the interaction of plants with their environment to facilitate a more sustainable use of resources.

Understanding the data:

- Flight planning, setup and flight
- Data processing
- Plant trait extraction
- Database
- $P = G \times E$
Outline

Flight planning, setup and flight -> Data processing -> Plant trait extraction -> Database

Understanding the data

\[ P = G \times E \]
Outline

Flight planning, setup and flight → Data processing → Plant trait extraction → Database → $P = G \times E$

Understanding the data
Mission planning

- Selection of equipment
- Flight planning
- (Legislation, weather, security & health measures)

➢ Can be quite complex
  - Data product (point cloud, digital surface model, orthophoto)
  - Sensor (point, line or 2d imager)
  - Data type (RGB, spectral, thermal …)
  - Coverage (flight time, flight speed, altitude)
  - Ground sampling distance (altitude, resolution, motion blur ~ flying speed + integration time)
  - Focus distance depth of field
  - GCP placement
Mission planning

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  - Focus distance and depth of field
  - GCP placement
Flight planning

Ground sampling distance $\sim$ altitude + sensor motion blur $\sim$ flying speed + shutter speed

Flight planning

focus distance ~ lens configuration

➢ During our literature review we found only a few publications are stating these quality indicators

Flight parameter quality assurance

http://phenofly.net/PhenoFlyPlanningTool

Flight planning

http://phenofly.net/PhenoFlyPlanningTool

L. Roth, A. Hund, and H. Aasen, 2018 “PhenoFly Planning Tool - Flight planning for high-resolution optical remote sensing with unmanned areal systems,” Plant Methods,
Mission planning

- Selection of equipment
- Flight planning
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Think of it even before you by your equipment
Spectral sensors for UAS RS

- **TetraCam mini-mca**: Multispectral 2D imager (Berni et al., 2009) (Kelcey and Lucieer, 2012)
- **Cubert UHD 185**: 2D Hyperspectral snapshot imager (Aasen et al., 2015)
- **Rikola FPI – VNIR**: 2D Hyperspectral sequential imager (Honkavaara et al., 2013)
- **Imec filter-on-chip**: Hyperspectral snapshot 2D
- **Headwall micro-HyperSpec**: Hyperspectral line-scanner (Zarco-Tejada et al., 2012) (Lucieer et al., 2014)
- **OceanOptics STS**: Hyperspectral points-pectrometer (Burkart et al., 2014, 2015)
- **Headwall Nano-Hyperspec **

Simple consumer oriented systems

- **Parrot Sequoia / Micasense Red-Edge**: Mutli-spectral 2D imager

High-quality systems

- **Rikola FPI – NIR/SWIR (1100 – 1600 nm)**: 2D Hyperspectral sequential 2D imager (Honkavaara et al., 2016)
- **HySpex Mjolnir**
- **SPECIM FX10**

**Spectral sensor types for UAS RS**

- **imu + gnss**
- (or machine vision)
- SfM + GCPs

Drawings kindly provided by Stefan Livens (VITO)

Spectral sensor types for UAS RS

**Point**

- $I(\lambda)$
- Footprint

**Pushbroom**

- $I(x, \lambda)$
- Across-track
- Along-track

<table>
<thead>
<tr>
<th>imu + gnss</th>
<th>imu + gnss</th>
</tr>
</thead>
<tbody>
<tr>
<td>(or machine vision)</td>
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</tr>
<tr>
<td>SfM + GCPs)</td>
<td>SfM + GCPs)</td>
</tr>
</tbody>
</table>

Orthorectification via

imu + gnss
(or machine vision
SfM + GCPs)

imu + gnss
(or machine vision
SfM + GCPs)

Drawings kindly provided by
Stefan Livens (VITO)

Spectral sensor types for UAS RS

**Point**

- $I(\lambda)$
- Footprint

**Pushbroom**

- $I(x,\lambda)$
- Across-track
- Along-track

**2D imagers**

- $I(x,y,\lambda)$

-- imu + gnss (or machine vision)
  - SfM + GCPs

-- imu + gnss (or machine vision)
  - SfM + GCPs

-- SfM + GCPs
  - (and/or imu + gnss)

Drawings kindly provided by Stefan Livens (VITO)

A spectral digital surface model is a representation of the surface in 3D space linked with spectral information emitted and reflected by the objects covered by the surface.
Track plant growth with 3D information

Tracking biochemical traits with spectral data

Outline

Flight planning, setup and flight → Data processing → Plant trait extraction → Database → $P = G \times E$

Understanding the data
Single image

Mosaic, blending: disabled

Mosaic, blending: average

Influence of the SFOV

Aasen, H., Bolten, A., 2018. Multi-temporal high-resolution imaging spectroscopy with hyperspectral 2D imagers – from theory to application. RSE
Influence of the SFOV

Aasen, H., Bolten, A., 2018. Multi-temporal high-resolution imaging spectroscopy with hyperspectral 2D imagers – from theory to application. RSE
The **specific field of view** is the composition of pixels and their angular properties within a scene used to characterize a specific AOI on the ground.
Hemispherical conical reflectance factor (HCRF)  

Hemispherical directional reflectance factor (HDRF)  

Hemispherical conical reflectance factor (HCRF)  

Field spectrometer  
A: single image  

C: blending: disabled (HS DSM_{dis})  

D: blending: average (HS DSM_{avg})  

Influence of the SFOV on retrievals (VIs)

… a comment on UAV radiometric calibration procedures
Radiometric calibration protocol

Not suited for radiometric calibration

Aasen, H., Bolten, A., in review. Multi-temporal high-resolution imaging spectroscopy with hyperspectral 2D imagers – from theory to application..
## Metadata and standardization

Table 5. Numeric (n) or qualitatively (q) mandatory (m), and advised (a) auxiliary and metadata for spectral data processing. Although the direct and diffuse illumination ratio is important, it is set to advised, since it is not easy to measure.

<table>
<thead>
<tr>
<th>Pixel</th>
<th>Image</th>
<th>Scene</th>
</tr>
</thead>
<tbody>
<tr>
<td>signal-to-noise ratio (n, m)</td>
<td>capturing position (n, m)</td>
<td>sensor description (q, m)</td>
</tr>
<tr>
<td>radiometric resolution (n, m)</td>
<td>illumination (q, m)</td>
<td>(including version)</td>
</tr>
<tr>
<td>viewing geometry (n, m)</td>
<td>conditions</td>
<td>band configuration (n, m)</td>
</tr>
<tr>
<td></td>
<td>direct and diffuse illumination ratio (n, a)</td>
<td>(FWHM, band center)</td>
</tr>
<tr>
<td></td>
<td>capturing time (n, m)</td>
<td>geometric processing (q, m)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>procedures and accuracies (including software version and parameters)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>top-of-canopy (q, m)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>reflectance calculation method</td>
</tr>
<tr>
<td></td>
<td></td>
<td>reflectance uncertainty (n, a)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>environmental conditions during measurement</td>
</tr>
</tbody>
</table>

PhenoFly
Low-altitude / high-resolution remote sensing
Low-altitude / high-resolution remote sensing at PhenoFly

Low-altitude remote sensing
- Close range
- Proximal

FIP¹
- LS, hyper-spec, thermal, RGB

Multi-rotor UAVs
- Hyper-spec, thermal, RGB

Multi-spec, RGB

Fixed-wing UAVs

Leaf, plant, plot
- Plot to field (<2 ha)
- Field to region (<50 ha)

Multi-sensor pack

Thermal camera
FLIR A65

VIS spectral camera
IMEC SNm4x4
460-630 nm

NIR spectral camera
IMEC SNm5x5
600-1000 nm

RGB camera
Point gray 12 mpix
Plant research station Eschikon, ETH Zurich

FIP field 360°
Example 2: Radiometric calibration protocol

Aasen, H., Bolten, A., 2018. Multi-temporal high-resolution imaging spectroscopy with hyperspectral 2D imagers – from theory to application. RSE
FIP field – plant research station Eschikon
• RGB orthophoto and DSM (> 0.003 m)
• Mapped 1-3 times a week
Extracting leaf area index using viewing geometry effects

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Extracting leaf area index using viewing geometry effects

\[ \theta = 0^\circ, p_p = 0.60 \quad \theta = 20^\circ, p_p = 0.68 \quad \theta = 30^\circ, p_p = 0.72 \]

Original

Segmented

Plants \((p_p)\)

Soil \((p_s)\)

Fig. 7. Prediction performance of the CC/LC viewing geometry model for soybean growth simulation data for canopy cover (CC, a), lateral cover (LC, b) and apparent plant area fraction \((p_{app})\) versus leaf area index \((LAI)\) (c). Black lines show an implied 1:1 relationship (a and b) respectively a negative exponential relationship (c).

Extracting leaf area index using viewing geometry effects

Conclusions

➢ You need to know what you are doing
  ▪ It is your reasonability to generate reliable data
  ▪ Know your sensing system and your flight parameters
  ▪ Think of what you want to measure – and what you are measuring

➢ UAS remote sensing is ready
  ▪ Provide reliable data
  ▪ New approaches beyond classical approaches

➢ What is next…
  ▪ Multi-modal remote sensing - combining 3D, spectral, thermal data


Multi-modal remote sensing: Combining different data types

- **Segmentation approach**: either uses spectral (or color) information or 3D information for a pre-segmentation or classification.

- **Complementation approach**: uses spectral and 3D data as complementary data to estimate different traits from both type of data.

- **Combination approach**: combines 3D and spectral data to estimate one trait.

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Conclusions

➢ You need to know what you are doing
  ▪ It is your reasonability to generate reliable data
  ▪ Know your sensing system and your flight parameters
  ▪ Think of what you want to measure – and what you are measuring
  ▪ State quality parameters

➢ UAS remote sensing is ready
  ▪ Provide reliable data
  ▪ New approaches beyond classical approaches

➢ What is next…
  ▪ Multi-modal remote sensing - combining 3D, spectral, thermal data
  ▪ From pixel to object base image analysis - Exploring the high spatial resolution

Thank you for your attention and special thanks to:
SENSECO: Optical synergies for spatiotemporal sensing of scalable ecophysiological traits (COST Action CA17134)

The main objectives:

- To tackle the scaling gap between leaf and satellite measurements in order to link driving mechanisms at the leaf scale to photosynthesis at the global scale.
- To improve the time-series processing of satellite sensor data for modelling vegetation processes related to seasonal productivity.
- To improve synergies between passive optical EO domains.
- To ensure measurements comparability across different scales, space and time.