

Plant physiological traits from high resolution hyperspectral and thermal imagery: models and indices for early stress detection

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European Commission Joint Research Centre (JRC) Directorate D – Sustainable Resources







Plant-trait retrievals for stress detection







"these guys are playing with toys..."



What do you do ?

"I work in remote sensing using unmanned vehicles"





1. Conceptual

2. Technical

3. Self-imposed requirements









1. Conceptual

2. Technical

3. Self-imposed requirements

CASI Hyperspectral Imager

Year 2000

Computer for imagery acquisition

Storage device

Inertial navigation system

Hyperspectral imager

Year 2011







Micro-hyperspectral imager on board a 6 kg platform



















1000 ha flight 260 bands @ 6 nm FWHM 400-1000 nm 50 cm pixel size

It was a flight test during a cloudy day \rightarrow radiometric changes due to changing atmospheric conditions

Radiometric calibration







Hyperspectral 45 cm







1. Conceptual

2. Technical

3. Self-imposed requirements

Some dreams ... as of 2005

- VHR in thermal + multi(hyper)spectral (sub-meter) to identify pure crowns / avoid mixed pixels
- Canopy temperature maps with errors below 1 K (absolute, not only relative)
- Processing capabilities for 1-day turn-around times -> decision making
- Imagery & products through simpler tools for GIS-unexperienced end-users / technicians
- Acceptable cost







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Cameras for stress detection

→ RGB / CIR cameras → pNDVI & DSM generation

→ Thermal Cameras → Water stress detection / irrigation

→Multispectral cameras

- \rightarrow Nutrient stress detection (C_{ab}, C_{x+c})
- → Physiological indices (PRI, F)
- → Canopy structure (NDVI, EVI)

→ Hyperspectral imagers
→ New indices / methods
→ Combined spectral indices



















Remote Sensing Indicators of Vegetation Stress

Visual

Pigments-traits C_{ab} / C_{ar}

Nutrient deficiencies / effects of diseases → less absorption at specific bands → captured by RT model inversion methods & sensitive indices

Nutrient / water stress & effects of diseases → affects canopy growth → effects in the near infrared → captured by indices sensitive to canopy structure

Pre-visual

> Xanthophyll cycle pigments (V+A+Z) & $A_{nth} \rightarrow rapid changes phot.$ Efficiency & photoprotective roles \rightarrow PRI: Indicator of the epoxidation state (EPS) of the xanthophyll pigments \rightarrow under stress V+A+Z $\uparrow \rightarrow R530 \downarrow \rightarrow PRI \uparrow$

\succ Chlorophyll Fluorescence (CF) \rightarrow F emission \rightarrow Photosynthesis

- Excess energy \rightarrow function of the photosynthetic state
- 3% 4% of the radiance levels
- Main interest to monitor remotely photosynthesis & stress condition
- > Temperature: $T_c \rightarrow T_c-T_a \rightarrow CWSI$
 - Stomata closure → Reduction in transpiration and CO₂ uptake → Decreased photosynthesis → Temperature increase







Structure














Thermal

Single-crown temperature for stress detection (40 cm resolution thermal image)







Gonzalez-Dugo et al. (AgForMet, 2012)

CWSI map from UAV



Bellvert et al. (2013)



Map of CWSI – thermal-based indicator of stress from UAV

CWSI 0.0

1.0

Gonzalez-Đugo et al. (2013)



SIF & Pigments



Understanding the retrieval of SIF from broad-band (2-6 nm) hyperspectral imagers on board UAVs





Assessment of SIF retreival using a 3D model (FluorFLIGHT)

Hyperspectral data

FluorFLIGHT simulations



Hernández-Clemente et al. (2017)

Assessment of SIF retreival using a 3D model (FluorFLIGHT)



6.5 nm FWHM

1 nm FWHM

Hernández-Clemente et al. (2017)

Assessment of SIF retrieval using a 3D model (FluorFLIGHT)

6.5 nm FWHM

1 nm FWHM



6.5 nm FWHM & oversampling at 1.85 nm / band

Hernández-Clemente et al. (2017)

Using SIF for water stress detection in precision agriculture



Using SIF for water stress detection in precision agriculture



Zarco-Tejada et al. (2017)

Chlorosis detection



Chlorophyll & Car content maps → *nutrient stress*



Zarco-Tejada et al. (2013)

Chlorophyll & Carotenoid content estimation



C_{a+b}

 C_{x+q}



Disease detection

VHR hyperspectral & thermal indices for disease detection





Lopez-Lopez et al. (2016)

Calderon et al. (2013; 2015)



Gallipoli, Ottobre 2013





European Commission

Gallipoli, 9 Luglio 2015



European Commission

Hyperspectral 45 cm







Hyperspectral 45 cm















Thermal 60 cm





Thermal 60 cm



Model-retrieved Plant Traits

Haked Leaf-Campy models

Index-based Plant Traits

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Spectral bandset Traits available



Tree by tree physiological assessment



Chlorophyll degradation (Pheophytinization)



Xanthophyll cycle (Epoxidation state)





Sensitivity of Plant Traits to Xf symptoms



European Commission





Overall accuracy – 2 year dataset











Final remarks



→ Tremendous progress in the past 15 years: from "toys" to science: scientific papers are critical

- → Proved that we are not collecting *just* pretty pictures: quantitative RS is possible
- → Calibration / atm. correction is still a weakness for some RS users / vendors of drones
- → Progress is needed on hyperspectral use from drones: good quality spectra still hard to get
- → More studies demonstrating larger scale RS from drones are needed to convince at other levels



Do you remember the definition of remote sensing in the 1980s?

"A solution looking for a problem"






I have a drone. What can I use it for ?



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HELICOPTER

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CSIC

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CROPSIGHT

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PILATUS

Benzin

(17' endurance)



Benzin

(17' endurance)





CropSight (1 h endurance)









(1.5-3 h endurance)















CASI hyperspectral imager – 228 spectral bands @ 2 m spatial resolution







AVIRIS NASA-JPL hyperspectral sensor - 224 contiguous spectral channels















MIVIS / AHS / Daedalus - INTA

- INTA (Spain)
 DLR (Germany)
 NERC (UK)
- > NERC (UK)

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Low-cost UAV platforms









800 ha flight 7 flightlines 260 bands @ 6 nm FWHM 400-1000 nm 40 cm pixel size