ESALQ
Escola Superior de Agricultura "Luiz de Queiroz"

Tools and their applications

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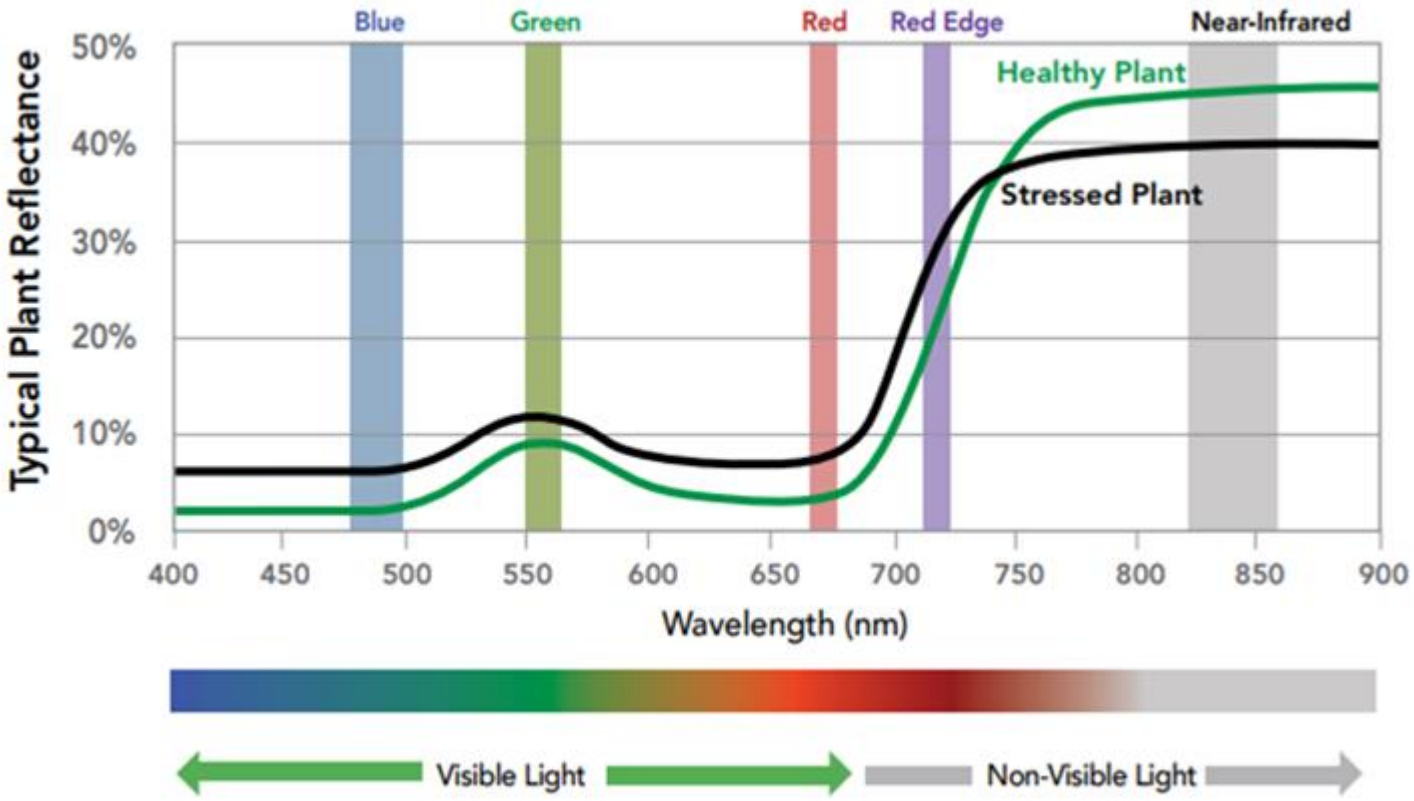
Summary

1. ***Single-imager Multispectral Camera***
   - ✓ *Survey2 and Survey3*
2. ***Multi-imager Multispectral Camera***
   - ✓ *MicaSense RedEdge™*
3. ***Hiperspectral Camera***
   - ✓ *SOC710-GX*
4. ***Thermal radiometric Camera***
   - ✓ *Workswell WIRIS*
5. ***Light Detection and Ranging - LiDAR***
   - ✓ *RIEGL VUX-1UAV*
6. ***Best Practices for Collecting Data***
7. ***Vehicle-based high-throughput systems***
8. ***High-Tech Robot***
   - ✓ *TERRA-MEPP*

1. Single-imager Multispectral Camera

Plant Reflectance



Mapir Cameras

Survey2

Turn-Key Survey Camera

Survey3

Turn-Key GPS Survey Camera

Kernel

Professional Array Camera

Survey2

Turn-Key
Survey Camera

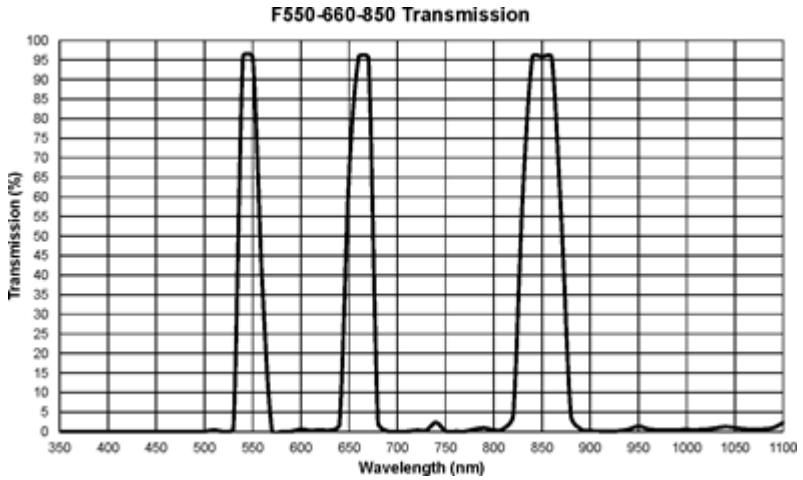
Survey3

Turn-Key GPS Survey
Camera

Survey2	Survey3
16MP	12MP
1440p30	2160p24
Up to 0.28fps (RAW)	Up to 0.36fps (RAW)
Up to 0.51fps (JPG)	Up to 0.67fps (JPG)
82° HFOV (23mm) Lens	87° or 41° HFOV (19mm/47mm) Lens
6 Filter Options	4 Filter Options
No GPS Tags	External GPS Tags (Included)
No IMU	IMU
59 x 41 x 30 mm	59 x 41.5 x 36 mm
47g+	50g+
Max 64GB Storage	Max 128GB Storage
Starts at $400	Starts at $400

Survey3

- ✓ **Triple-band multispectral filters**
  - ✓ Red+Green+NIR (RGN)
    - ✓ Most popular for plant phenotyping (Survey3W)
    - ✓ Indices such as NDVI, GNDVI, OSAVI, TVI, CVI, etc.
  - ✓ NIR+Green+Blue (NGB).
    - ✓ ENDVI index.



Survey3

- ✓ USB GPS Receiver
- ✓ **Battery** (Removable Li-ion 1200mAh)
  - – Optional micro USB
- ✓ **Micro SD:** Up To 128GB Card
  - ≈ 30,000 JPG, 4,400 RAW+JPG
- ✓ **Speed photo trigger:**
  - ✓ RAW+JPG: 2.75 Seconds / Photo.
  - ✓ JPG: 1.5 Seconds / Photo
- ✓ **Video Resolution**: 2160p24, 1440p30, 1080p60, 720p60
- ✓ **Image Resolution**: 12 MegaPixel (4032 x 3024 px).

Price

Survey2 Camera - Visible Light RGB
$400.00

Survey2 Camera - NDVI Red+NIR
$400.00

Survey2 Camera - Near Infrared (NIR)
$400.00

Survey3W Camera - Visible Light RGB
$400.00

Survey3W Camera - Red+Green+NIR (RGN, NDVI)
$400.00

Survey3W Camera - NIR+Green+Blue (NGB, ENDVI)
$400.00

Survey2 Camera - Red
$400.00

Survey2 Camera - Green
$400.00

Survey2 Camera - Blue
$400.00

Survey3W Camera - Near Infrared (NIR)
$400.00

Survey3N Camera - Near Infrared (NIR)
$400.00

Survey3N Camera - Visible Light RGB
$400.00

Survey3N Camera - Red+Green+NIR (RGN, NDVI)
$400.00

Survey3N Camera - NIR+Green+Blue (NGB, ENDVI)
$400.00

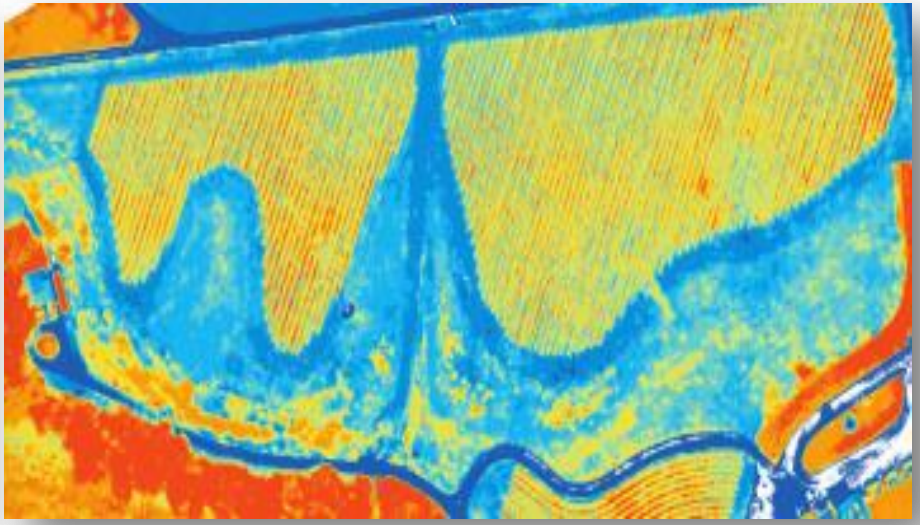
Sensor Câmera MAPIR Survey 2 NDVI RED+NIR

A linha de câmeras da MAPIR foi desenvolvida e pensada para utiliz
agricultura de precisão e meio ambiente. A MAPIR Survey 2 I
infravermelho próximo, possibilitando uma serie de cálculos diferen
normalizada (NDVI). Com pequenas dimensões e peso de apenas 64
RGB é de fácil integração em praticamente todos os Veículos Aéreos N

Preço: R$3.850,00

Tudo sobre o Sensor Câmera MAPIR Survey 2 NDVI RED+NIR >>>

NDVI analysis of an Vineyard

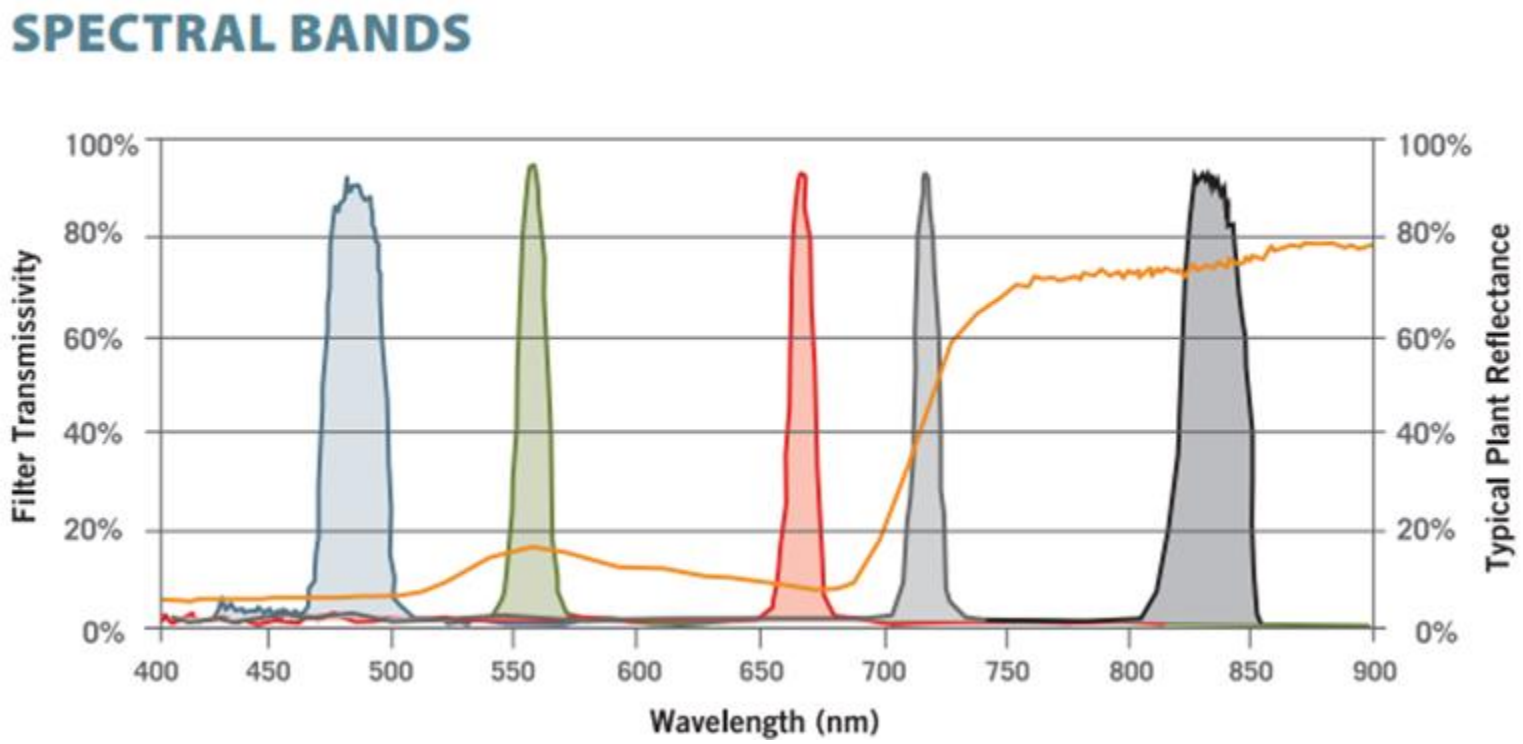


2. Multi-imager Multispectral Camera

MicaSense RedEdge™

- ✓ Multispectral camera optimized for use in small unmanned aircraft systems.
  - ✓ Also works unplugged.
  - ✓ An integrated shutter button maintain geo-tagging and timestamping.

MicaSense RedEdge™ Spectral Bands

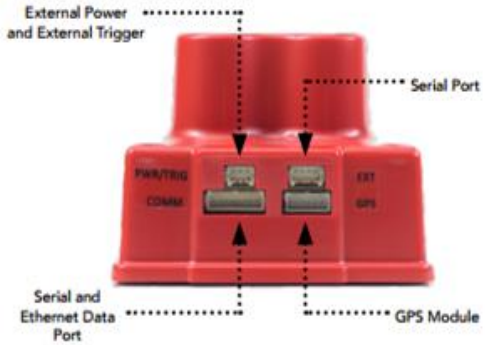


- ✓ One camera allows to perform many vegetation indices.

MicaSense RedEdge™

- ✓ Fast capture rate
  - – faster flight speeds and lower flight altitudes
- ✓ Single SD card stores all images with geotags

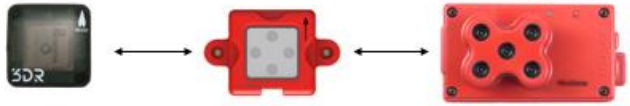
- ✓ Calibrated
- ✓ Rugged design



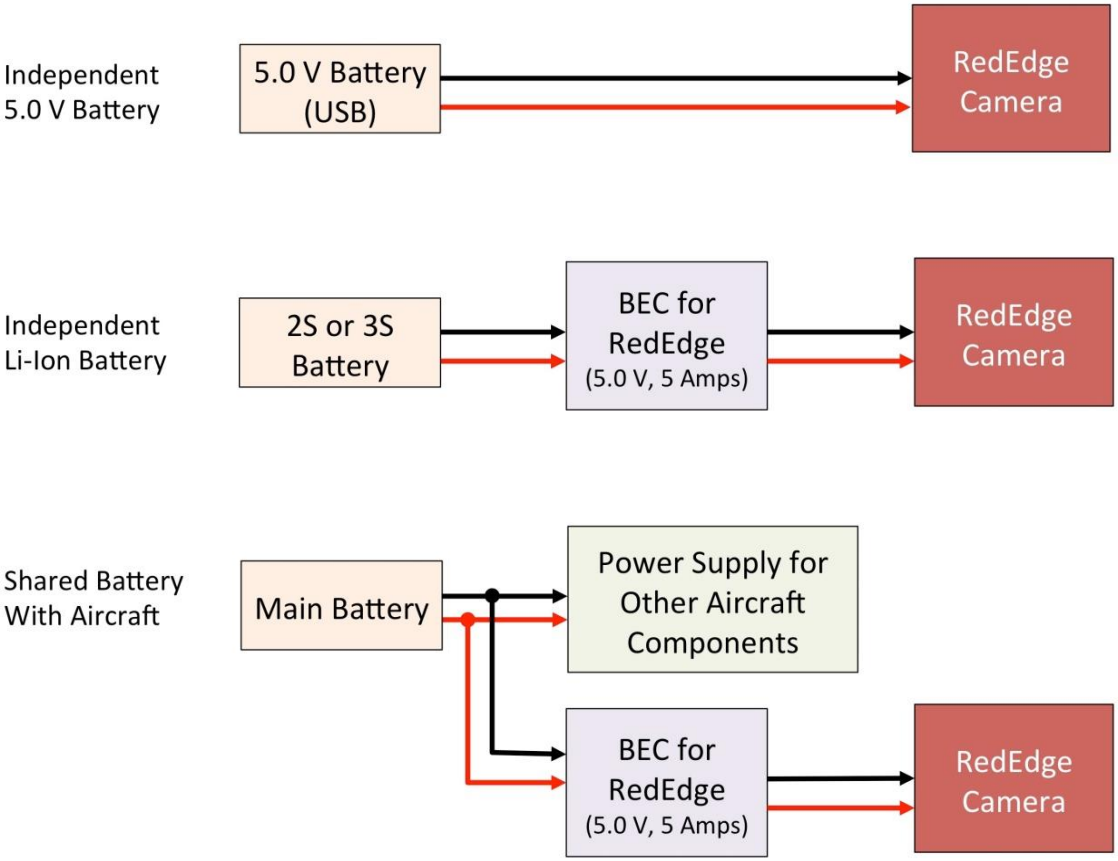
GPS and DLS

- ✓ **Two GPS options:**
  - Included module
  - Use custom GPS data

- ✓ **DLS - Downwelling Light Sensor**: Measures the ambient light during a flight for the five bands (metadata),
  - specialized processing tools (Atlas) to correct lighting changes.
  - Installed on **top of the aircraft**, facing up towards the sky
  - Used in **conjunction** Calibrated Reflectance Panel (CRP)
- ✓ Multiple options for integration



Powering


Independent
5.0 V Battery
5.0 V Battery
(USB)
RedEdge
Camera
Independent
Li-Ion Battery
2S or 3S
Battery
BEC for
RedEdge
(5.0 V, 5 Amps)
RedEdge
Camera
Shared Battery
With Aircraft
Main Battery
Power Supply for
Other Aircraft
Components
BEC for
RedEdge
(5.0 V, 5 Amps)
RedEdge
Camera

Technical Specification

Weight:	180 grams (6.3 oz.) (including DLS and cable)
Dimensions:	12.1 cm x 6.6 cm x 4.6 cm (4.8 in x 2.6 in x 1.8 in)
External Power:	5.0 V DC, 4 W nominal (8 W peak)
Spectral Bands:	Blue, green, red, red edge, near IR (global shutter, narrowband)
RGB Color Output:	3.6 MP (global shutter, aligned with all bands)
Ground Sample Distance (GSD):	8 cm per pixel (per band) at 120 m (~400 ft) AGL
Capture Rate:	1 capture per second (all bands), 12-bit RAW
Interfaces:	Serial, Ethernet, WiFi, External Trigger, GPS
Field of View:	47.2° HFOV
Custom Bands:	400nm - 900nm (QE of 10% at 900nm)

Wavelength

Band Name	Center Wavelength (nm)	Bandwidth (nm)
Blue	475	20
Green	560	20
Red	668	10
Red Edge	717	10
Near IR	840	40

Price

USA

MicaSense RedEdge Kit

$5,195.00

RedEdge and Pix4Dag: Yearly

$6,594.00

RedEdge and Pix4Dag: Perpetual

$8,435.00

RedEdge and Pix4Dmapper Pro: Yearly

$8,445.00

RedEdge and Pix4Dmapper Pro: Perpetual

$12,895.00

Brazil

Sensor Câmera Multispectral Micasense RedEdge

A Micasense RedEdge é um sensor multispectral de altíssima pe precisão. Com ele é possível gerar mosaicos com até 8cm por pixel d é composta por 5 espectros, azul, verde, vermelho, vermelho próxi 150 gramas, pode ser integrada a grande parte dos Veículos Aéreo interface da RedEdge permite que ela seja integrada a grande part PWM, ou simplesmente funcionar independente da controladora.

Preço: R$38.800,00

Tudo sobre o Sensor Câmera Multispectral Micasense RedEdge >>>

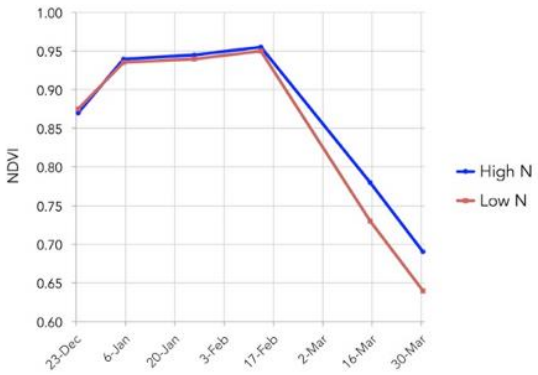
Detecting Weeds with MicaSense Atlas and RedEdge

- ✓ Using the *Weeds1* layer, which identifies variation in chlorophyll content.
  - – Manually identifying - $525,
  - – RedEdge - $250.

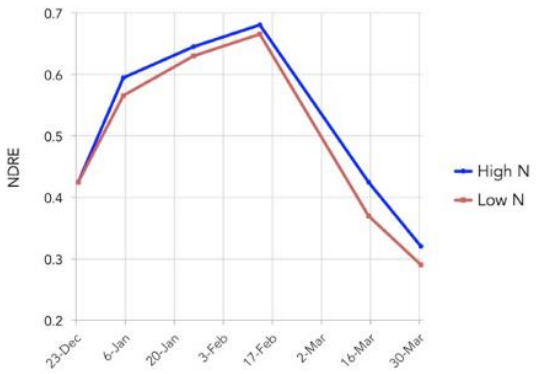
Monitoring Urea Application in Rice

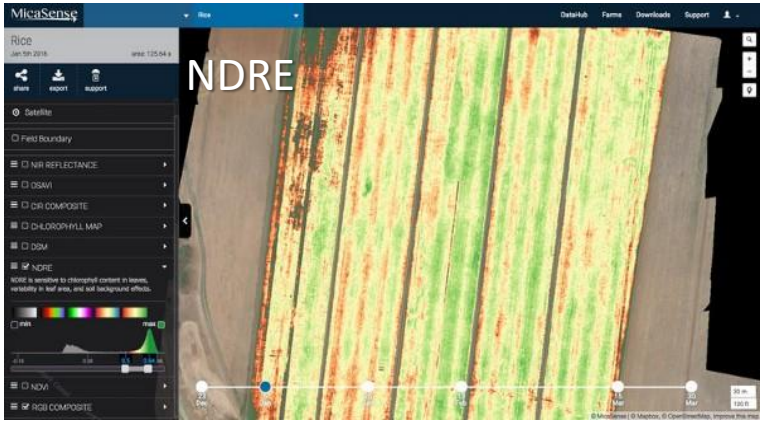
✓ Six different flights over a three-month

$$\mathrm{NDVI} = \frac{(\mathrm{NIR} - \mathrm{Red})}{(\mathrm{NIR} + \mathrm{Red})}$$



$$\mathrm{NDRE} = \frac{(\mathrm{NIR} - \mathrm{RE})}{(\mathrm{NIR} + \mathrm{RE})}$$

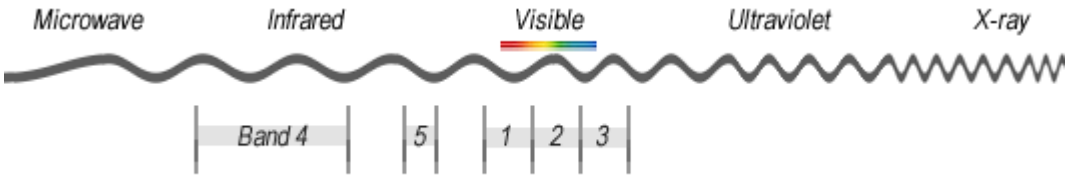




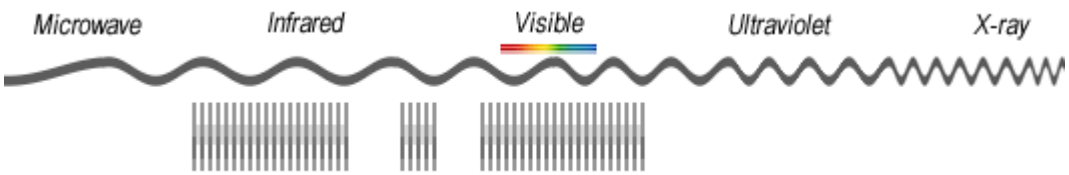
3. Hyperspectral Camera

Multispectral vs Hyperspectral

- ✓ Multispectral
  - 3 to 10 bands

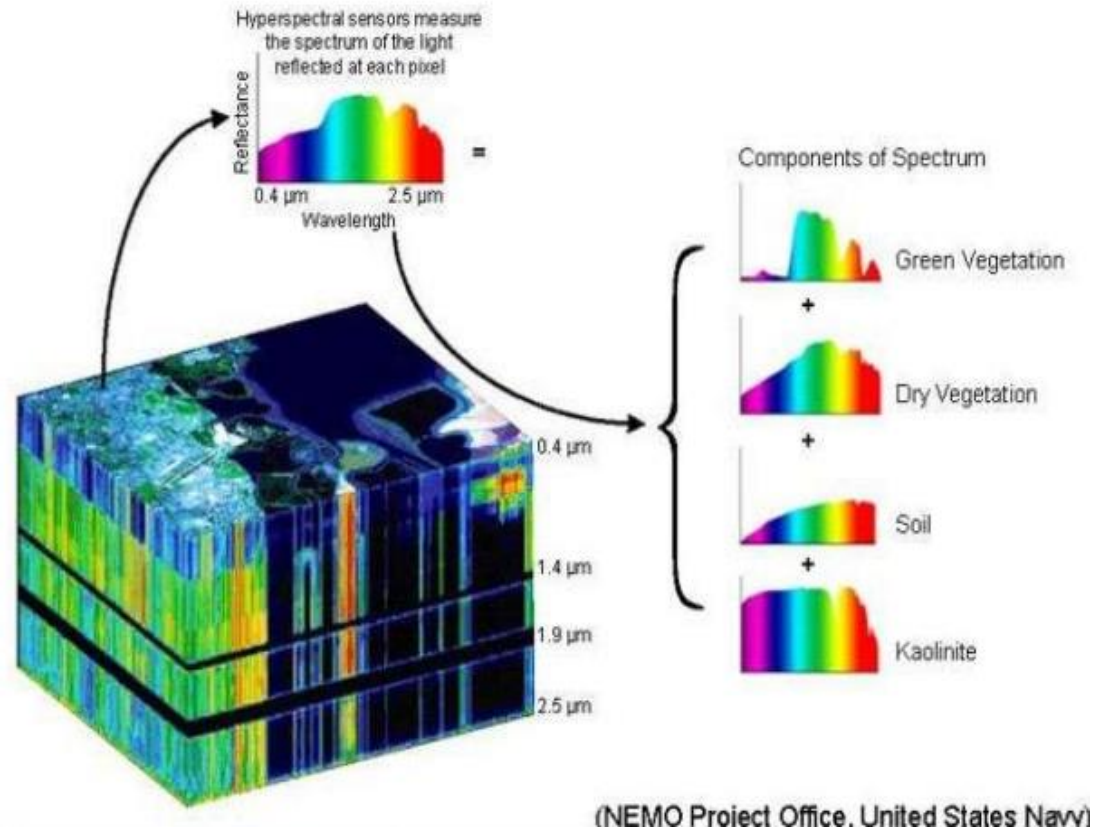


- ✓ Hyperspectral
  - **Hundreds or thousands of bands**



Hyperspectral Camera

✓ Much more detailed information.



SOC710-GX Airborne Hyperspectral Imager

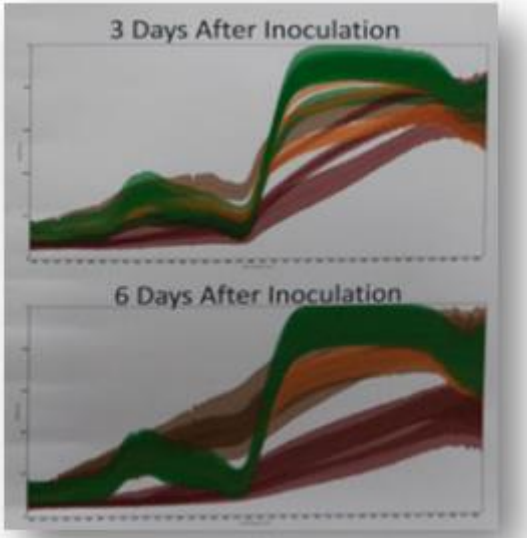
- ✓ Designed for UAV or small aircraft.
- ✓ Delivers **real-time results**
- ✓ **Compact:** 20 cm and less than 1,5kg
- ✓ Continuous data collection for **over an hour**.

Technical Specification

- ✓ **Spectral Coverage:** 400-1000nm
- ✓ **Spectral Resolution:** 4.2nm
- ✓ **Bands:** 120
- ✓ **Focal Length:** Configurable
- ✓ **Power:** 12-VDC / 10 Watts
- ✓ **Pixel size:** 9.9µm x 9.9µm
- ✓ **Operating Temp:** 0°C … +50°C

Hyperspectral disease signatures for detection of charcoal rot in soybean

- ✓ Charcoal rot (*Macrophomina phaseolina*),
- ✓ Hyperspectral imaging
  - Precise and accurate phenotypes
  - Minor differences in disease expression.
- ✓ Spectral reflectance signatures using HSI.
- ✓ HSI successfully differentiated symptoms not distinguishable through visual assessment.

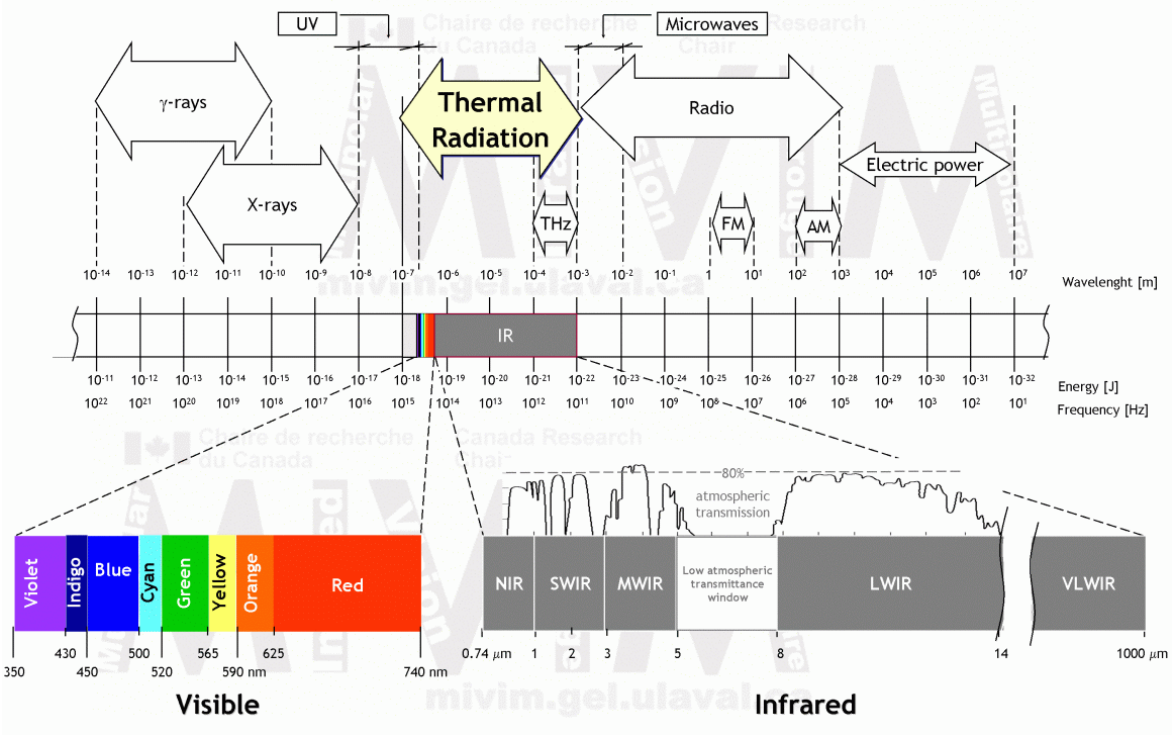


Jones et al., 2016

4. Drone Radiometric Thermal Camera

Radiometric thermal camera

- ✓ Thermal infrared region **7 – 15 microns**
- ✓ Measure the **emitted** radiation.
- ✓ Temperature of a surface (individual pixels)

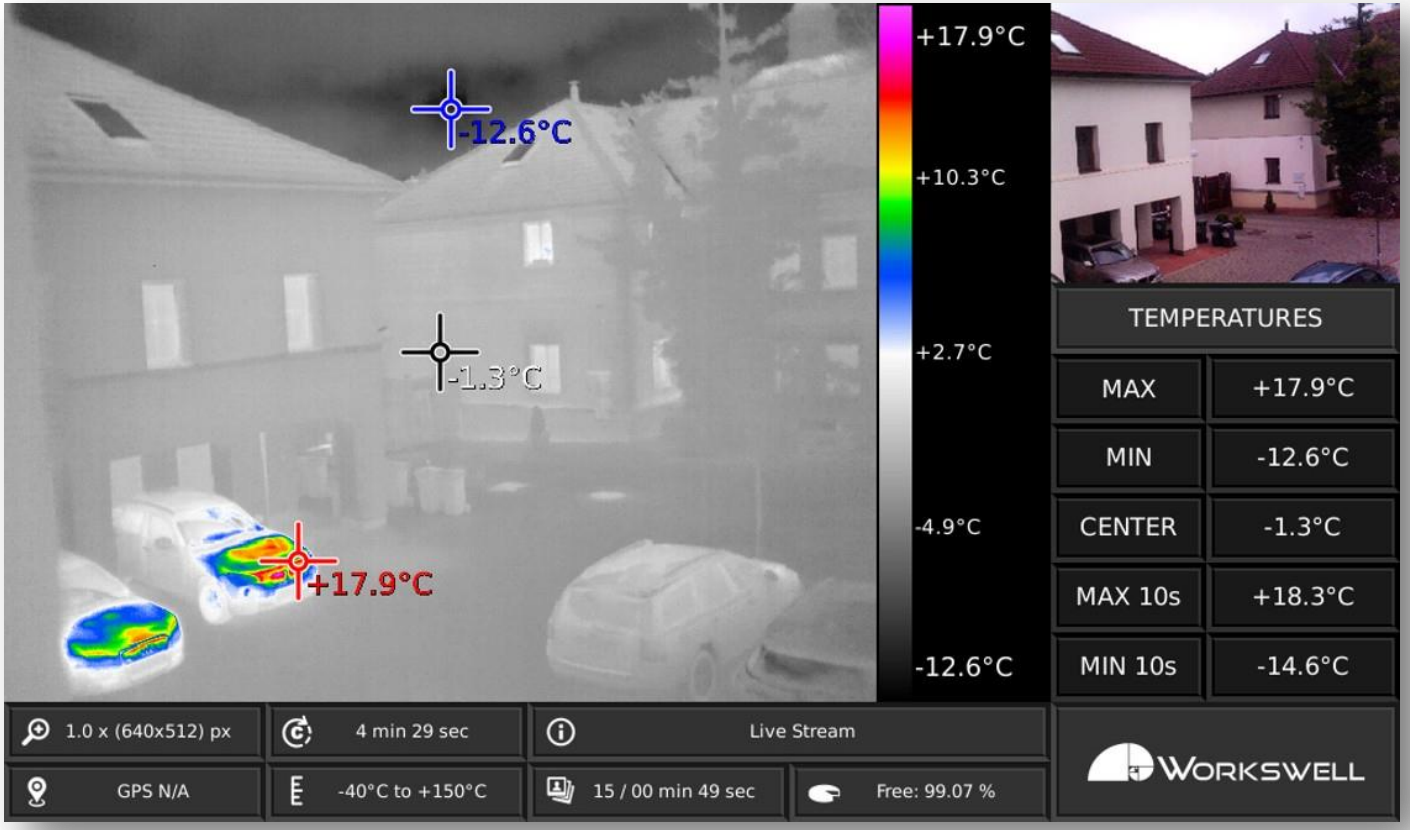


Drone Thermal Camera

- ✓ *Workswell WIRIS*
  - ✓ Thermal camera,
  - ✓ Digital camera,
  - ✓ Processor unit to record radiometric data.

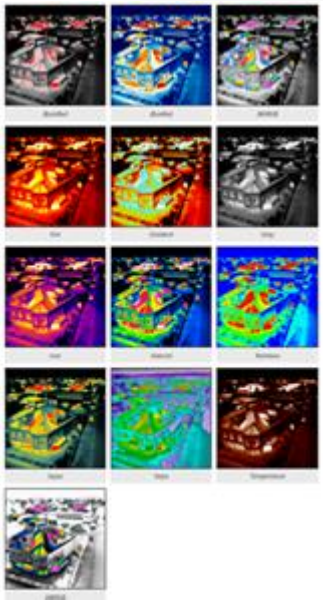
- ✓ Intensity of the thermal radiation
  - ✓ **Workswell CorePlayer**.
- ✓ Also records radiometric video.

Temperature Measurement



Other functions

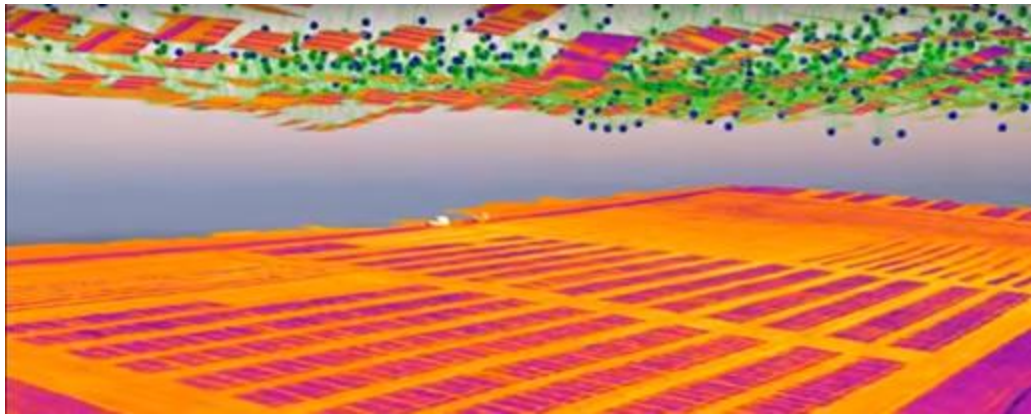
- ✓ Zoom
  - – Digital camera - 16x
  - – Thermal camera - 14x
- ✓ Palettes
  - – 18 colour palettes
  - – Isotherms



Other functions

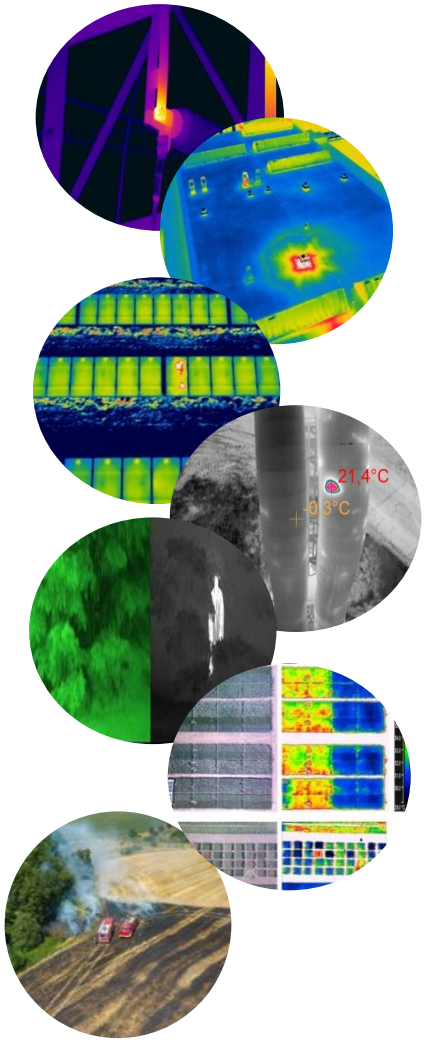
- ✓ GPS navigation - **optional** accessory.
  - ✓Coordinates, Speed, Number of satellites, Altitude, META data.

- ✓Allows the creation of a 3D model.
  - ✓(Pix4D)



Potential Applications

- ✓ Power engineering sector
- ✓ Flat roofs
- ✓ Photovoltaic power plants
- ✓ Security system
- ✓ Searching people and animals
- ✓ Pipelines
- ✓ Cultivation and Phenotyping
- ✓ Detect water stress
- ✓ Fight fires



Technical Specification

	Workswell WIRIS 2nd 640	Workswell WIRIS 2nd 336
Thermal Imaging Camera		
Resolution	640 x 512 pixels	336 x 256 pixels
FPA active sensor size	1.088 x 0.8705 cm	0.5712 x 0.4351 cm
Temperature ranges	-25 °C to +150 °C -40 °C to +550 °C, optional temperature range 400 °C to 1 500 °C (filter)	
Temperature sensitivity	0.05 °C (50 mK) 0.03 °C (30 mK) available on request	
Accuracy	±2 % or ±2 °C (in high temperature range 0 °C to +550°C)	
Spectral range	7.5 – 13.5 µm	
Calibration	Yes, the package includes the calibration certificate	
Detector type	Uncooled VOx microbolometer	
Lenses	Interchangeable and focusable, various field of view	
Available lenses	18°, 32°, 45°, 69°	17°, 25°, 35°, 45°
Focus	Manual (focused on infinity, Min focus distance depends on lens)	
Digital zoom	1 – 14x continuous	1 – 11x continuous
Digital Camera		
Resolution	1 600 x 1 200 pixels	
Focus	Fixed	
Digital zoom	1 – 16x continuous	

Technical Specification

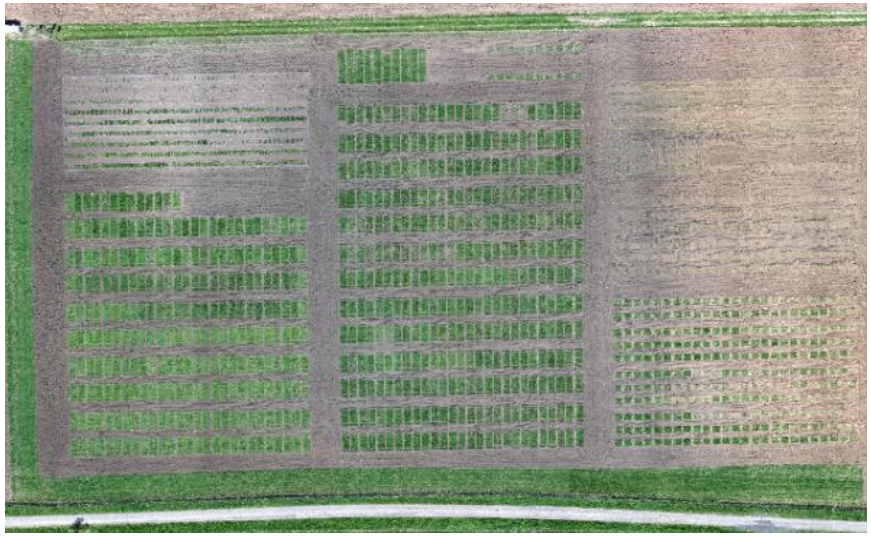
Memory and Data Recording	
Memory	Internal: 32 GB (up to 80 000 images or 200 minutes of video) External: recording directly on USB stick
Image recording	Radiometric image and digital JPEG image can saved by trigger Radiometric image format: JPEG or TIFF
Video recording	Radiometric video recording can be start/stop by trigger
Periodic image capturing	Yes, adjustable interval between 1 to 60 s (IR and digital saved on trigger)
GPS location info	GPS data is stored in EXIF when external GPS is connected
Remote control	Data are recorded by PWM, SBus or External (TTL) trigger
File management	Images and video from each flight are stored in separate folders
File transfer	Selected folders are transferred to USB flash disk
Measurement Functions	
Measurement functions	Center spot, Hot/Cold spot detection, Peak Max/Min spot detection
Alarm mode (isotherm)	Above, Below, Between, Above & Below
Hot/Cold spot detection	Auto hot and cold spot detection with temperature values
Peak Max/Min detection	Measurement interval 1 to 100 s
Temperature unit	Celsius, Fahrenheit, kelvin
Emissivity correction	Adjustable in WIRIS directly or in Software
Other corrections	Reflected ambient temperature, atmospheric temperature

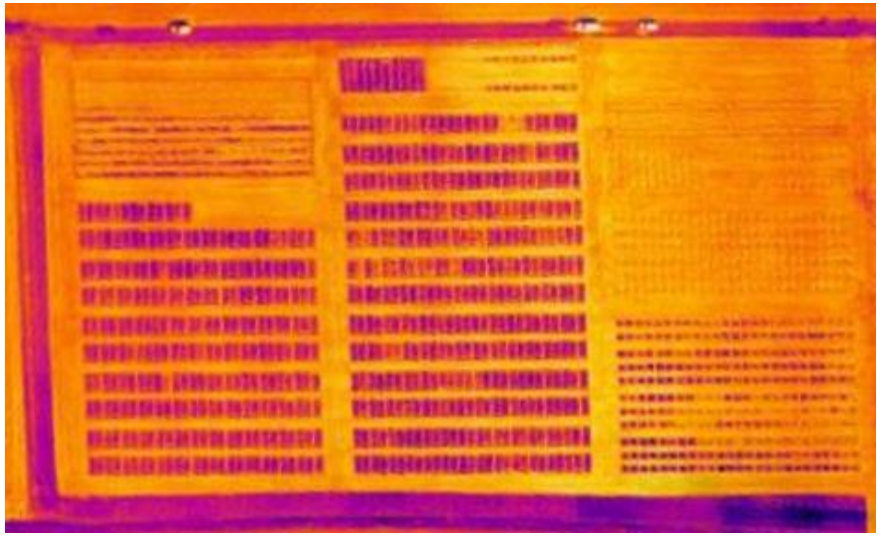
Technical Specification

Power Supply	
Input supply voltage	6 to 36 V DC
Power dissipation	< 6 W (max. 8 W during calibration event of approx. 0.5 seconds)
Power connector	Coaxial 2.1 x 5.5 mm, outer shell - GND
Dimensions/Weight	
Dimensions	135 x 77 x 69 mm
Weight	< 390 g
Mounting	4x 1/4-20 UNC thread (2x bottom side and 2x top side)
Operating Environment	
Operating temperature	-15°C to +50°C
Storage temperature	-30°C to +60°C
Humidity	5% to 95% non-condensing
List of contents	
	WIRIS head with chosen lens, Calibration certificate, USB Flash drive 32 GB, HDMI cable, Servo connectors (PWM), Power supply cable, Software license CorePlayer, Hard transport case

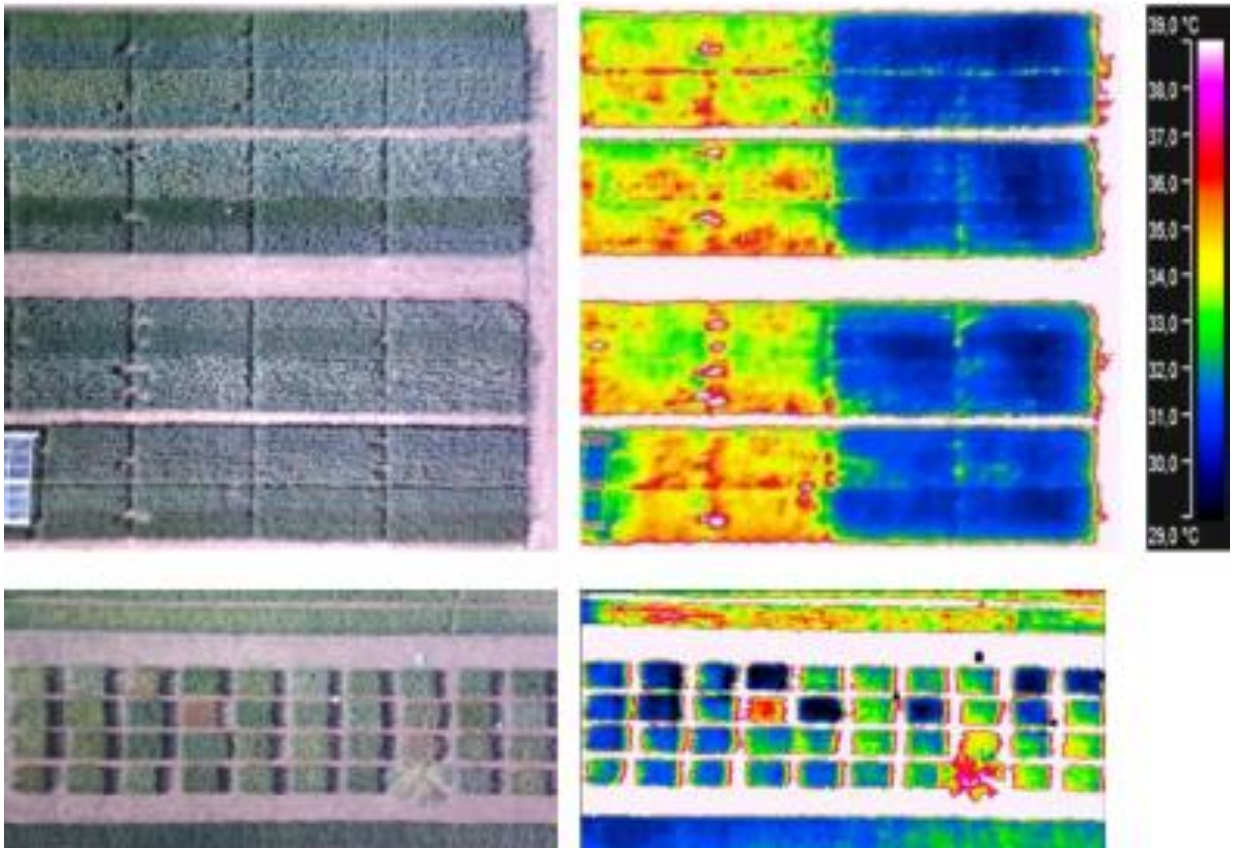
Using the UAV Thermography for Cultivation and Phenotyping of Cereals

- ✓549 genotypes of wheat, 82 genotypes of barley and 70 genotypes of triticale





Detection of Water Stress in Cereals Using the UAV Thermography



Price

Product Categories

- Camera gimbals
- Infrared Cameras
  - Workswell Thermal Vision Light
  - Workswell Thermal Vision Pro
  - Workswell WIRIS
- Multi-spectral cameras
  - ADC Multi-spectral Imaging Systems
  - GEMS Sensor Payload
- Multispectral systems
- Parts & Spares
  - Parts & Spares for XYRIS 6
- Rescue Systems
- UAV Mapping

Workswell WIRIS (336 x 256 resolution)
Workswell WIRIS
€6.995

Workswell WIRIS (640 x 512 resolution)
Workswell WIRIS
€9.995

Cautions

- ✓ Do not point at strong energy sources (laser radiation or sun).
  - ✓ Effect on the accuracy
  - ✓ Damage to the detector

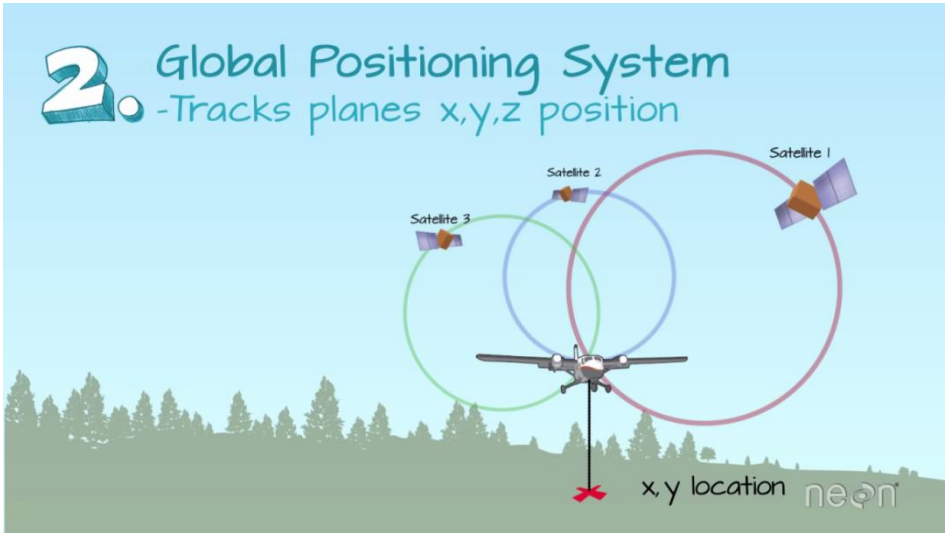
- ✓ Do not use the camera in temperatures higher than +50°C or lower than -15°C.
- ✓ Maximum irradiance 100W/cm2
- ✓ Air Displacement

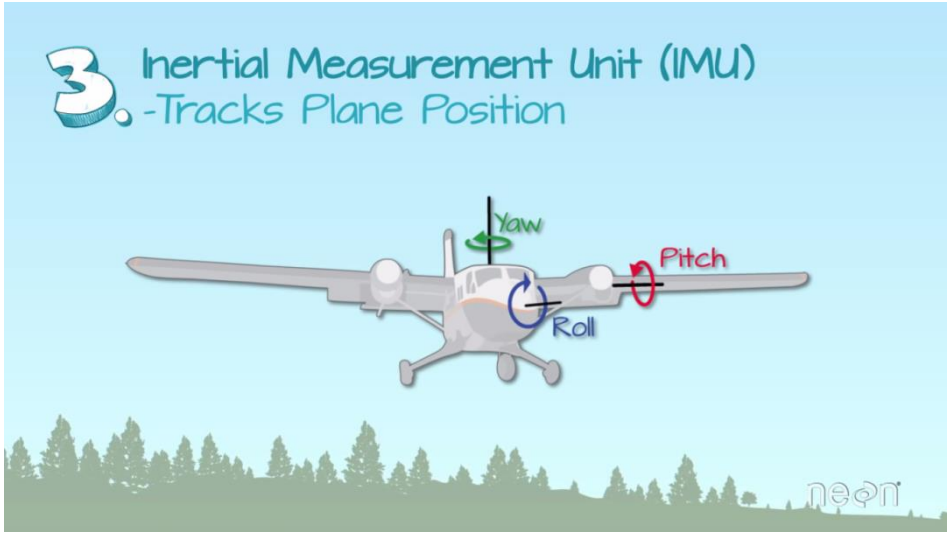
5. Light Detection and Ranging - LiDAR

Light Detection and Ranging - LiDAR

- Pulsed laser beam and the reflection time of the signal from the object back to the detector is measured.

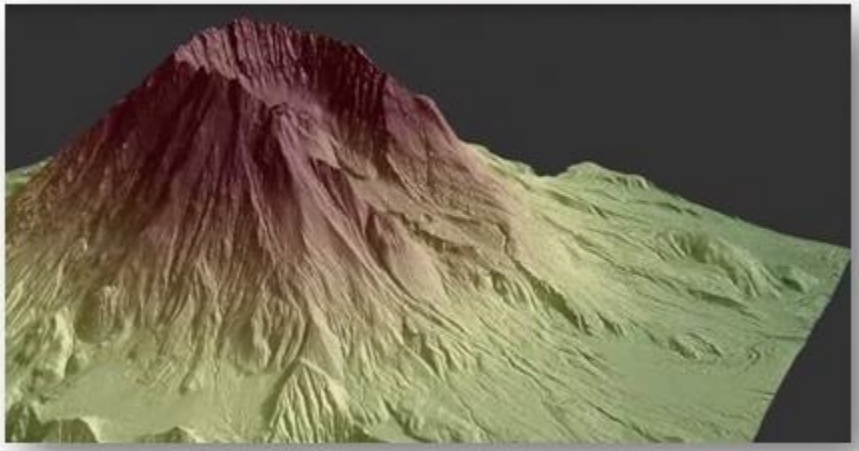
Light Detection and Ranging - LiDAR



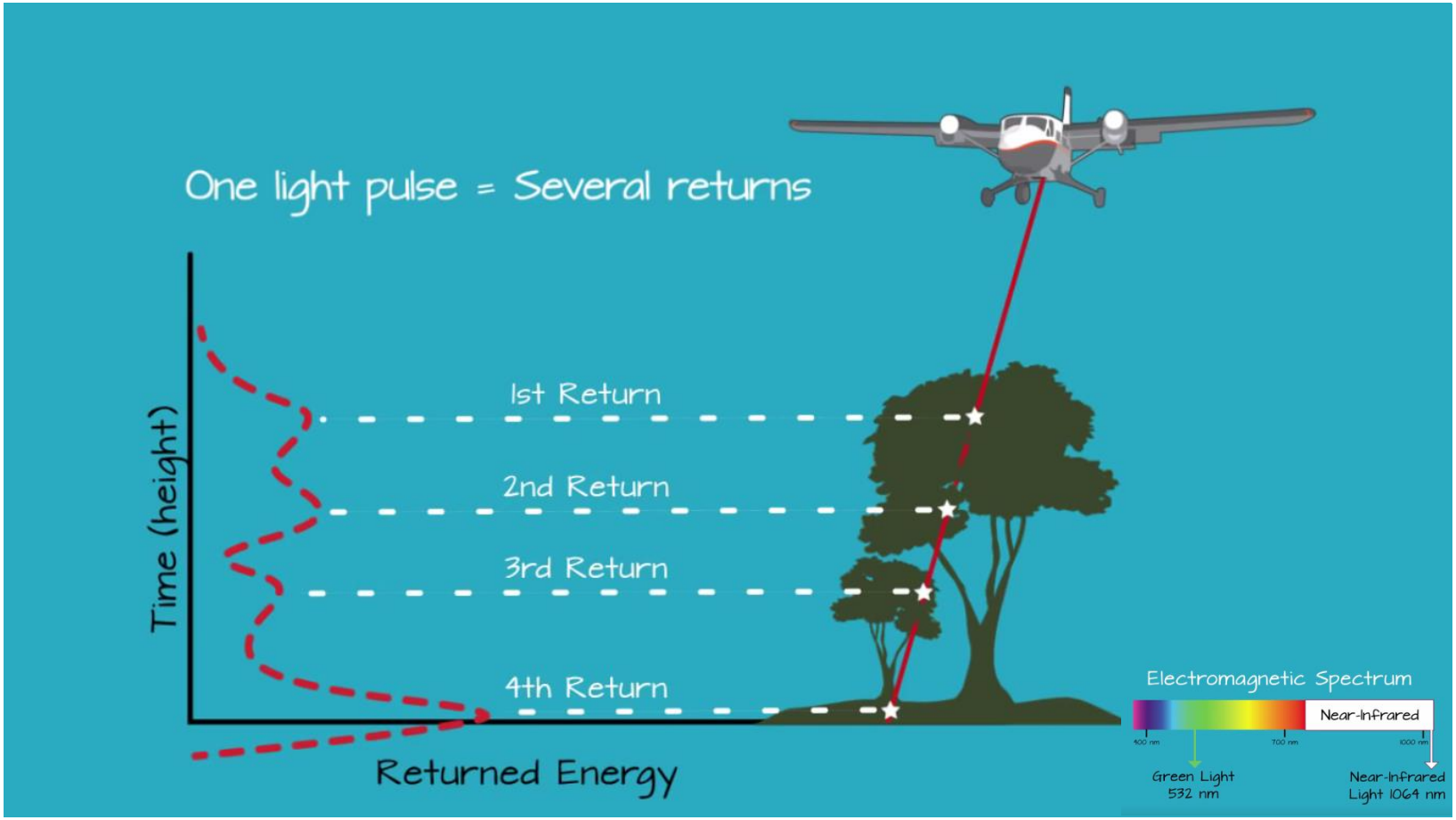


UAV LiDAR

- ✓ Relatively new technique.
- ✓ Inicially - High resolution elevation maps
  - – Vegetation was considered noise



Vegetation measurement



LiDAR - Riegl

- ✓ ***RIEGL* VUX-1**
  - UAS/UAV/RPAS, gyrocopter, and ultra-light aircraft.
  - Modest power consumption.
  - Data set is stored - 240 GByte SSD or real-time line (LAN-TCP/IP)
- ✓ ***RIEGL* VUX-1 HA (High Accuracy)**
  - Terrestrial mobile data acquisition
  - Field of View of 360°
  - accuracy of 5 mm
- ✓ ***RIEGL* VUX-1 LR (Long Range)**
  - Helicopter, gyrocopter, and other small aircraft.
  - Max. measurement range of 1,350 m
  - up to 750,000 measurements/sec.,
  - Flight altitude of up to 530m.

RIEGL
LASER MEASUREMENT SYSTEMS

VUX-1UAV Lidar Sensor Main Features:

Technical Data *RIEGL* VUX®-SYS

Scanner Performance (for details refer to the corresponding info sheets and data sheets)

RIEGL VUX-1 Series Sensor	VUX-1LR	VUX-1UAV	VUX-1HA [1]
Maximum Range	1,350 m [2]	920 m [2]	420 m [3]
Minimum Range	5 m	3 m	1.2 m
Accuracy / Precision	15 mm / 10 mm	10 mm / 5 mm	5 mm / 3 mm
Laser Pulse Repetition Rate	up to 750 kHz	up to 550 kHz	up to 1017 kHz
Max. Effective Measurement Rate	up to 750,000 meas./sec.	up to 500,000 meas./sec.	up to 1,000,000 meas./sec.
Field of View (selectable) [4]	up to 330°	up to 330°	up to 360°
Max. Scan Speed	200 scans/sec	200 scans/sec	250 scans/sec

- ✓ Operating flight altitude up to 300m
- ✓ Compact (227 x 180 x 125 mm), lightweight (3.5 kg) and rugged
- ✓ Easily mountable on professional UAS / UAV / RPAS

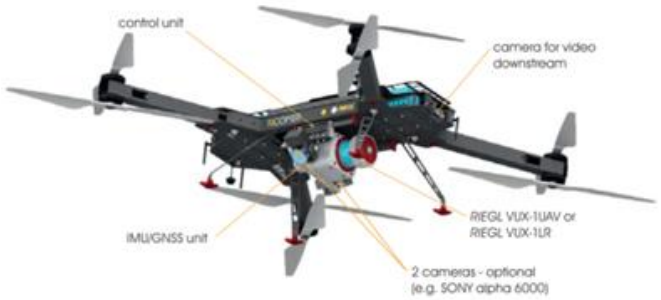
RIEGL RiCOPTER with VUX-SYS

- ✓ Complete miniaturized airborne laser scanning system.
- ✓ The system consists of:
  - the *RIEGL* VUX-1UAV laser scanner,
  - IMU/GNSS system,
  - control unit
  - up to 4 optional high-resolution cameras.

RIEGL RiCOPTER with VUX-SYS

RIEGL VUX-SYS Sensor System Technical Data

System Components	• *RIEGL* VUX-1UAV LiDAR sensor • IMU/GNSS unit with antenna • control unit • up to 2 cameras (optional)
***RIEGL* VUX-1UAV Scanner Performance when integrated in RiCOPTER** Field of View (FOV) max. effective measurement rate max. range @ target reflectivity 20 % minimum range	 230° up to 350,000 meas./sec 550 m 3 m
range accuracy Laser Safety Class according to IEC60825-1:2007	10 mm Laser Class 1 (eye safe)
IMU/GNSS Unit accuracy Roll, Pitch / Heading IMU sampling rate position accuracy (typ.)	 0.015° / 0.035° 200 Hz 0.05 m - 0.3 m
Camera Interfaces	2x trigger and event marker



RIEGL RiCOPTER Aircraft Technical Data

Specifications and Performance:

Main Dimensions ready to fly arms folded for transportation & storage	 1,920mm x 1,820mm x 470mm 624mm x 986mm x 470mm
MTOM (Maximum Take-Off Mass)	< 25 kg
Max. Payload (batteries & sensor load)	up to 16 kg [1]
Empty Weight	8 kg
Max. Operating Altitude AMSL [2]	up to 4000 m (12,000 ft) [3] [4] (under ISA[5] conditions)
Max. Flight Endurance	with 8 kg sensor load: up to 30 min with 5 kg sensor load: up to 40 min
Cruise Speed	typ. 20 - 30 km/h
Take-off / Landing	VTOL (Vertical Take-off and Landing)
RiOPTER Transportation Case dimensions empty weight	 1,220mm x 810mm x 540mm approx. 20 kg
RiCOPTER Ground Station (optional) dimensions weight components	 600mm x 400mm x 400mm approx. 19 kg • monitor for video downstream • video receiver with two antennas • ground station PC (flight planning, mission guidance) • internal batteries for power supply

Proceedings of SilviLaser 2015 - September 28-30, 2015 - La Grande Motte, France

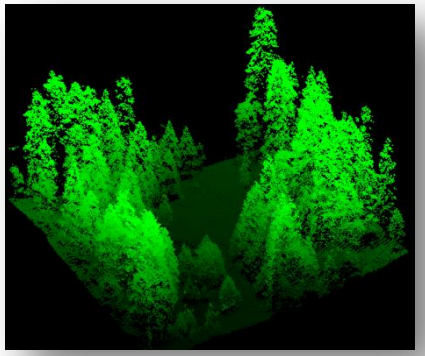
First examples from the RIEGL VUX-SYS for forestry applications

Mandlburger Gottfried[1], Markus Hollaus[1], Philipp Glira[1], Martin Wieser[1], Milutin Milenković[1], Ursula Riegl[2] and Martin Pfennigbauer[2]

[1]*Vienna University of Technology, Department of Geodesy and Geoinformation, Research Group Photogrammetry, Gußhausstraße 27-29, A-1040 Vienna, Austria (gottfried.mandlburger, markus.hollaus, philipp.glira, martin.wieser, milutin.milenkovic@geo.tuwien.ac.at)*
[2]*RIEGL Research Forschungsgesellschaft mbH, Riedenburgerst. 48, 3580 Horn, Austria (uriegl, mpfennigbauer@riegl.com)*

Highlights: Very high point density UAS-based laser scanner point clouds of an alluvial forest acquired with the RIEGL VUX-SYS were analyzed w.r.t. forestry applications. With point densities >1500 points/m² and accuracies <2 cm the study shows that individual stems and branches, understory, lying deadwood, and the terrain are clearly represented in the 3D point clouds.

Keywords: *UAS, LiDAR, forest, single trees, understory, deadwood, terrain roughness*



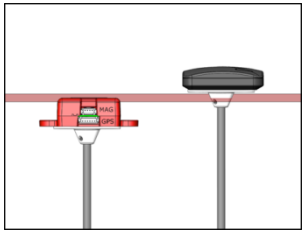
- ✓ 3D data acquisition of a alluvial forest area.
- ✓ An average point density of 1500 points/m2
  - Point spacing of 2.5 cm
- ✓ Quality control confirmed an accuracy of less than 2 cm.

6. Best Practices for Collecting Data

UAV Considerations

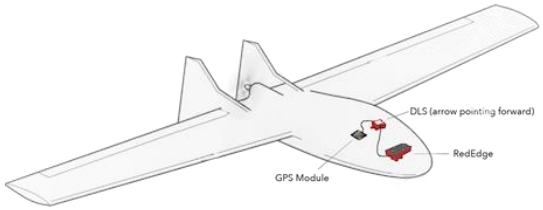
Multicopter Mounting Considerations

- ✓ Gimbal
  - – Keep vibration to a minimum
  - – Ensure the nadir.
- ✓ DLS and GPS on top of the aircraft
  - – clear view of the sky.



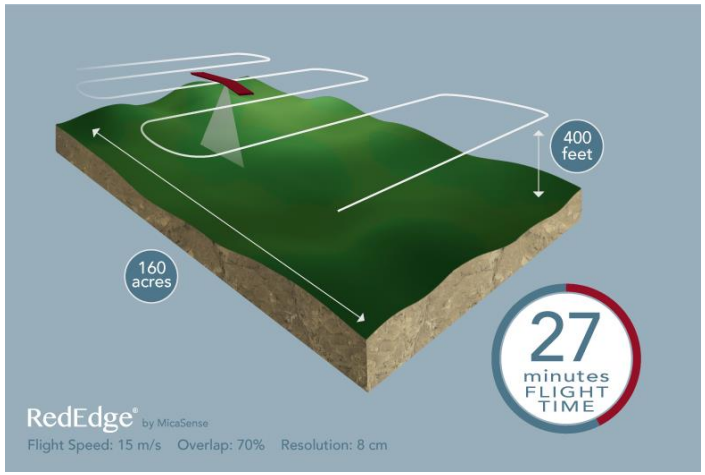
Fixed-Wing Mounting Considerations

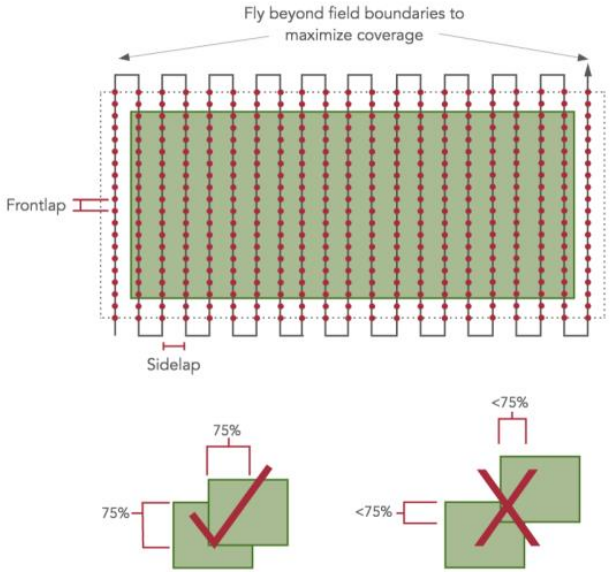
- ✓ Airflow around the camera
  - – cooling.
- ✓ Protected during landing.



Mission Planning

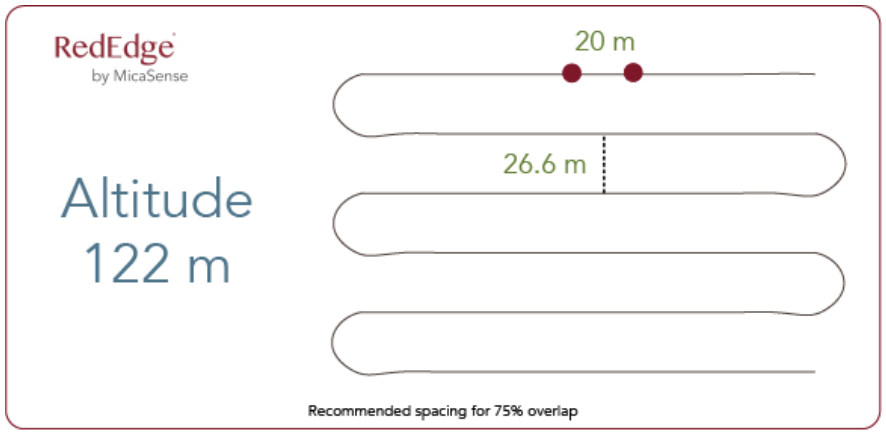
- ✓ The area should be larger than the field.
  - One additional flight track.
  - Sufficient space at the end of each flight track (critical for fixed-wing).

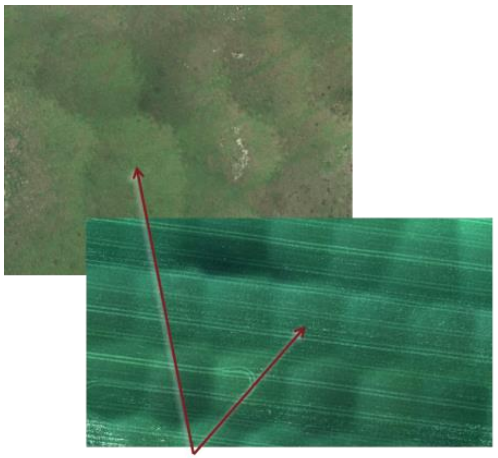




Overlap

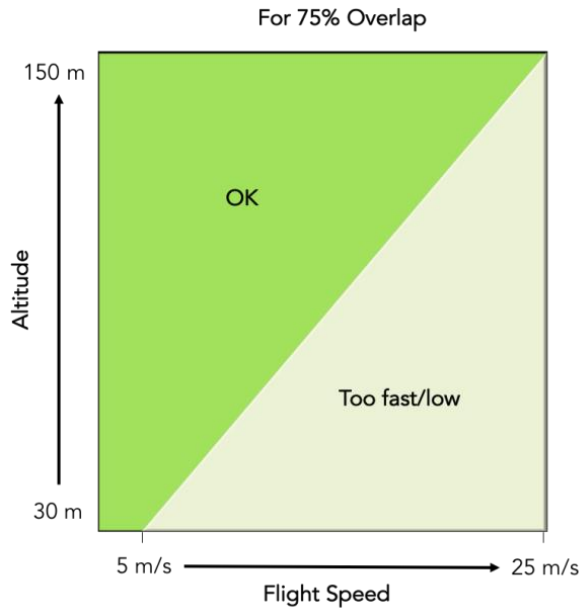
- ✓ **Sidelap:** Distance between tracks,
- ✓ **Frontlap:** Distance between successive captures.
- ✓ Both of these should be configured to yield a **75% overlap**.




"Blotchy" Artifacts

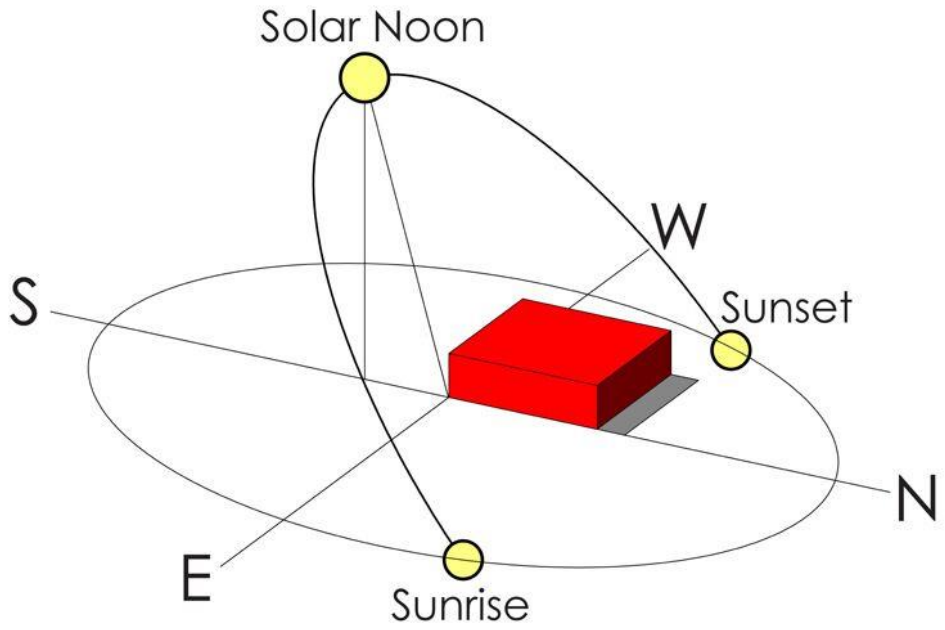
Speed and Altitude

- ✓ Frontlap also depends on the **flight speed** and **altitude**.
- ✓ The flight tracks should be oriented perpendicular to the rows.



Best Time for Capture

- Flights should be performed within **two and a half hours of local solar noon**.



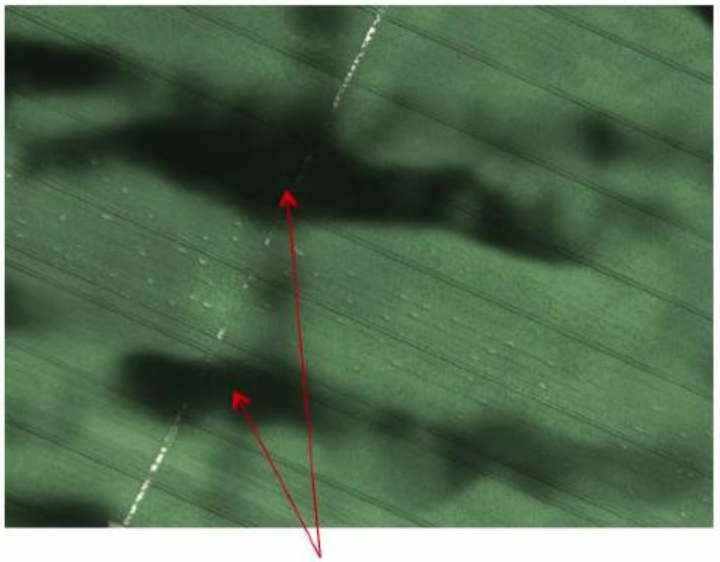
Calibrated Reflectance Panels

- Reflectance-compensated outputs
  - immediately before and after each and every flight
- Panel placed flat on the ground, far away from any objects
- Hold the aircraft at chest level and point the camera to the panel

Ambient Light Conditions

- ✓ Consistent throughout any one flight.
- ✓ Clear sunny days as well as light overcast days in which the ambient light is not changing are best.

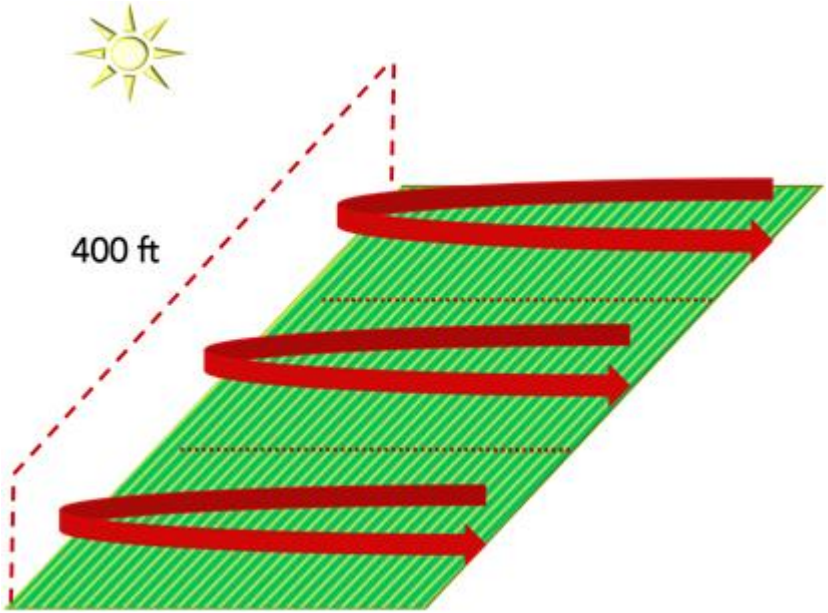
Clouds



Clouds Passing By

Sloped Terrain

- Maintain altitude constant relatively to the slope.
- If "terrain following" is not possible, split the field into multiple flights.



7. Vehicle-based high-throughput systems

Vehicle-based high-throughput systems

CSIRO PUBLISHING
Functional Plant Biology, 2014, **41**, 68–79
http://dx.doi.org/10.1071/FP13126

Development and evaluation of a field-based high-throughput phenotyping platform

Pedro Andrade-Sanchez[A,E], *Michael A. Gore*[B,C], *John T. Heun*[A], *Kelly R. Thorp*[B], *A. Elizabete Carmo-Silva*[B,D], *Andrew N. French*[B], *Michael E. Salvucci*[B] *and Jeffrey W. White*[B]

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[E]Corresponding author. Email: pandrade@ag.arizona.edu

Evaluation of a field-based HT phenotyping plataform

- ✓ Measuring morphological and physiological responses of Pima cotton (Gossypium barbadense L.)

- ✓ Well watered and water-limited conditions
- ✓ **Phenotyping plataform** x **aerial imagery** x **manual phenotyping**.

Vehicle-based high-throughput system

- LeeAgra 3434 DL open rider sprayer.
- Height clearance of 1.93 m,
  - minimal disturbance to the plants.

Vehicle Components

- ✓ Three types of sensors for measuring plant canopy height, temperature and reflectance.

a) Front view of the phenotyping system,

b) Sonar proximity sensor,

c) Infrared radiometer sensor,

d) GPS-RTK receiver-antenna ,

e) Multi-spectral crop canopy sensor.

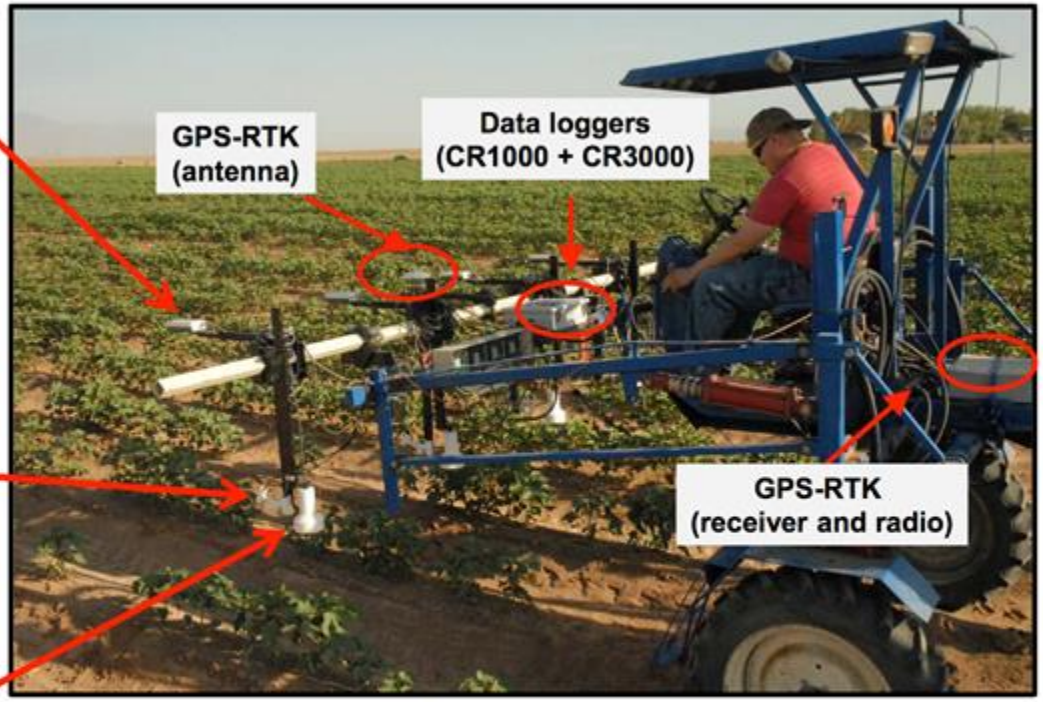
Vehicle-based high-throughput system

Vegetation Indices

Active, multi-spectral crop canopy sensor

Infrared thermometer

Ultrasonic Transducer



High-clearance tractor
Average speed of 2.82 km/h; 1-4 data point/meter (1-4 Hz)

Andrade-Sanchez, Gore et al. 2014. *FPB* 41:68-79

Performance

1. Field efficiency:

$$\frac{Productive\ time\ under\ field\ conditions}{Total\ time\ in\ the\ field}$$

2. Ability of the system to generate data on a time and area basis:

$$Size\ of\ eletronic\ data\ files\ (MB)$$

Correlations from Aerial and phenotyping system

- ✓ **Temperature**
  - r^2= 0.75-0.82
- ✓ **NDVI**
  - r^2 = 0.61–0.62 (4 and 18 August)
  - r^2 = 0.35 (21 july)
- ✓ **Canopy height**
  - r^2 = 0.76–0.79

Conclusions

- ✓ The tractor-based phenotyping system
  - Reliably acquiring and recording data
  - Much higher rates
- ✓ Opportunities to improvement.
  - Data acquisition rate
  - Number of rows monitored
- ✓ Experimental design
  - Plots are arranged in longer runs
- ✓ Data loggers have much higher sampling frequencies (100 Hz) than sensors (2 Hz).

8. High-tech Robot

TERRA MEPP

Transportation Energy Resource
from Renewable Agriculture -
Mobile Energy-Crop Phenotyping Platform

Project

$3.1 million in funding - U.S. Department of Energy Advanced Research Projects.

Robot

Visual and microclimate sensors plant growth and physiological traits.

Genomics

500 varieties of sorghum

Market

A cost-benefit analysis

Software

Manage the robot's data and construct a 3D image of each plant to predict biomass yield

Genetics team

ILLINOIS

Carl Bernacchi
Associate Director
University of Illinois
> more

Patrick Brown
Professor
University of Illinois
> more

Cornell University

Edward Buckler
Professor
Cornell University
> more

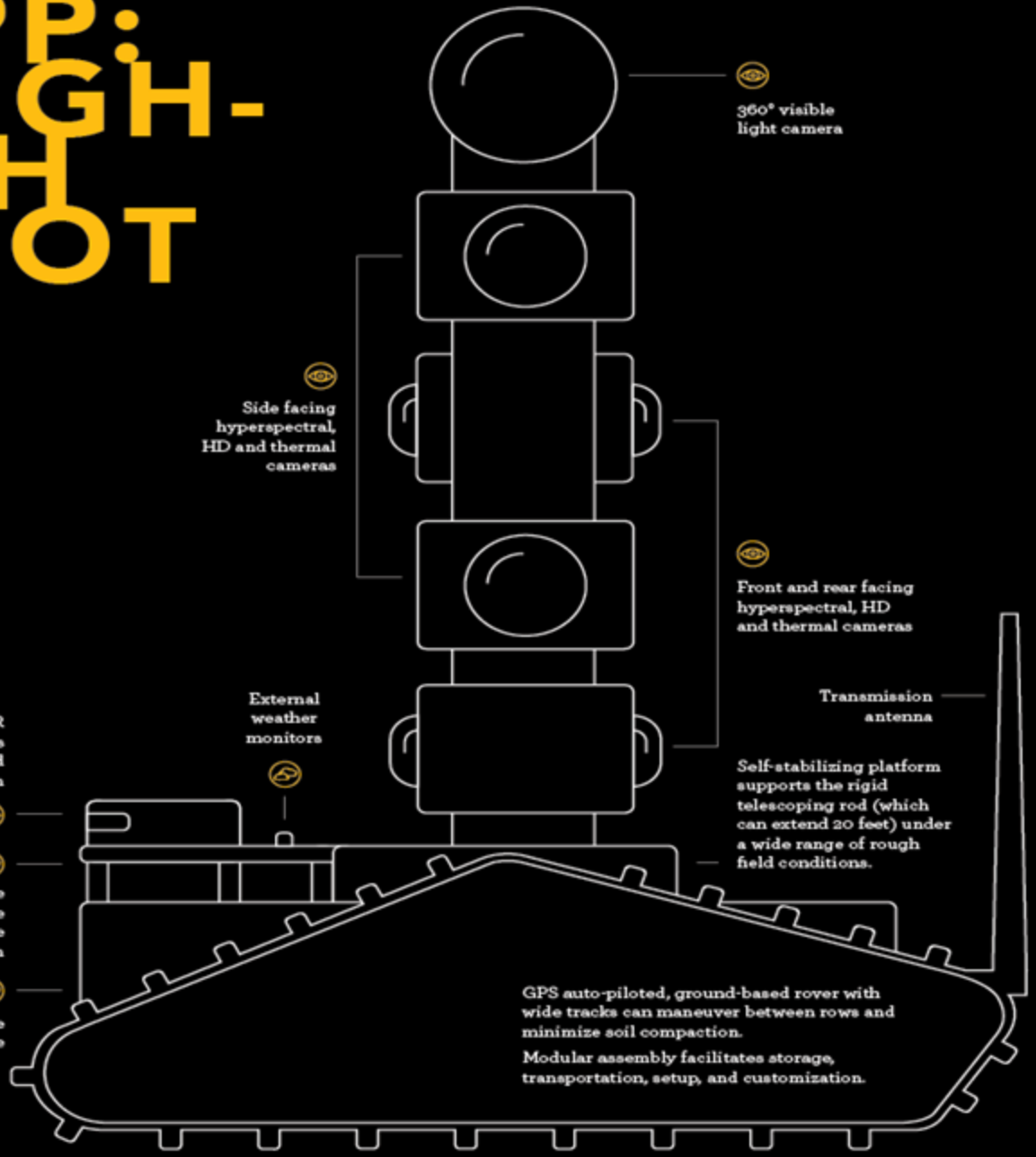
Samuel Fernandes
Postdoctoral Researcher
University of Illinois
> more

Signetron

Elodie Gazave
Research Associate
Cornell University
> more

Michael Gore
Professor
Cornell University
> more

TERRA-MEPP: A HIGH-TECH ROBOT



VISUAL SENSORS

Visual sensors, i.e. cameras, will capture each plant from above and below, using a fine-tuned spectrum, parts of which are not visible to the human eye, to characterize each plant.

- HEIGHT
- GREENNESS
- STEM DIAMETER
- LEAF AREA INDEX
- BIOMASS GROWTH RATE
- BIOMASS QUALITY
- PHOTOSYNTHESIS

MICROCLIMATE SENSORS

Microclimate, i.e. environmental, sensors will evaluate several environmental factors that affect plant growth and biomass yield.

- TEMPERATURE
- HUMIDITY
- CO_2 LEVELS
- SOIL MOISTURE
- LIGHT PENETRATION
- TRANSPIRATION
- WATER USE EFFICIENCY

DIGITAL PHENOTYPE

Imaging and microclimate sensor data will be used to construct a 3D image of each plant, which can be used to calculate production throughout the growing season.

TERRA-MEPP

- ✓ Twice each day - **more than 2,500 plots**
  - Operates at high speeds
  - Operates in hard conditions
- ✓ Evaluates both row sides
- ✓ Capture each plant, from above and below.

Process of development

*commercial version by 2021.

Commercial robot

- ✓ TerraSentia
  - 2 visual cameras,
  - Tablet app,
  - secure cloud software to store data and teach the robot.
  - At 8.5 hours charge - full workday.
- ✓ Further customized
  - ✓ **GPS** to enable autonomous navigation,
  - ✓ **Multi-spectral cameras,**
  - ✓ **Hyperspectral cameras**,
  - ✓ **Stereoscopic,**
  - ✓ **Structured light cameras**,
  - ✓ **LIDAR**.

Price

- ✓ Small version (3D-printing) ~$4,999
  - 6,3 Kg,
- ✓ TERRA-MEPP rover ~ $20,000 or less,
  - operating cost ~$13,000 per year,
  - return ~$38.4 million in ten years.

Application

- ✓ "Our philosophy is **growers first**," Chowdhary
- ✓ "We are starting to do **disease detection** as well," added Soman, noting the robot's ability to be **inside the canopy**.
- ✓ "Our long-term dream is for several robots that would **stay out in the fields**. There would be a charging station. And they would report data to you," Chowdhary concluded.

By Kay Shipman Archives

Email Author

Follow @farmweeknow

U of I scientists envision robot crop scouts doing farm dirty work

The device can roll between crop rows, counting plant populations and reporting on stalk sizes, uniformity and vigor.

Girish Chowdhary, University of Illinois assistant professor in agricultural and biological engineering, explains the benefits of a robotic crop scout positioned in front of him during U of I Agronomy Day. (Photo by Kay Shipman)

Published on: Aug 30, 2017

Thank you!

Willian Giordani
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