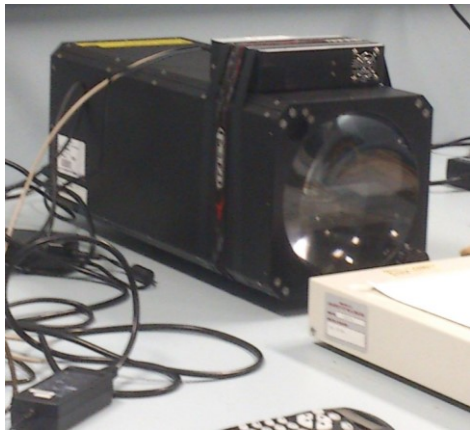
Unmanned aircraft observations of solar induced chlorophyll fluorescence with high accuracy georeferencing



Arko Lucieer, Juliane Bendig, Deepak Gautam, Darren Turner, Zbyněk Malenovský, Iain Clarke, Chris Watson (School of Land & Food, UTAS)

Sharon Robinson, Rhys Wyber, Zbyněk Malenovský, Michael B. Ashcroft, Barry Osmond (School of Biological Sciences, UOW)

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Australian Government
Australian Research Council

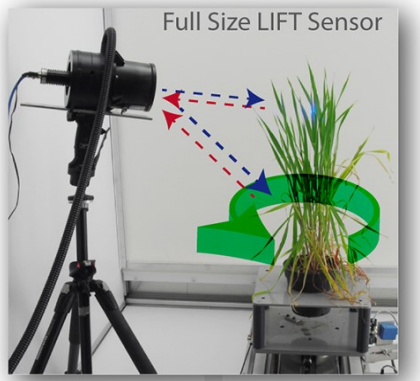
UNIVERSITY OF WOLLONGONG

UNIVERSITY of TASMANIA

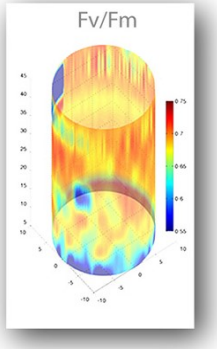
AirLIFT: an Australian Research Council (ARC) Discovery Project

Leaf & Plant Scale LIFT CF

WP1: Comprehensive evaluation of leaf & plant scale CF

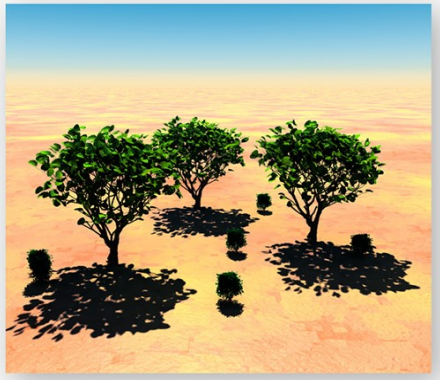


360* Lab Scan of Wheat Canopy CF yield



Canopy Scale LIFT CF

WP2: Discrete Anisotropic Radiative Transfer (DART)



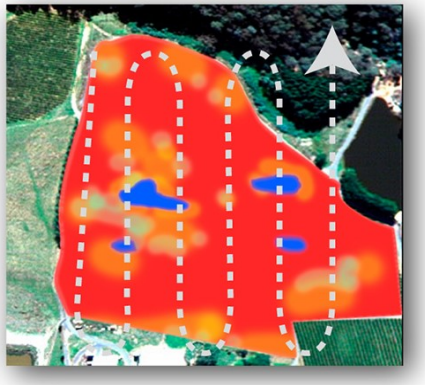
Simulation of 3D canopy light environment enabling conversion of airLIFT CF data into real time photosynthetic yield information

Linking LIFT & SIF

AirLIFT CF

WP3: Miniature airLIFT on OktoKopter

WP4: CF map at field scale



Oktokopter flies programmed path scanning crop CF

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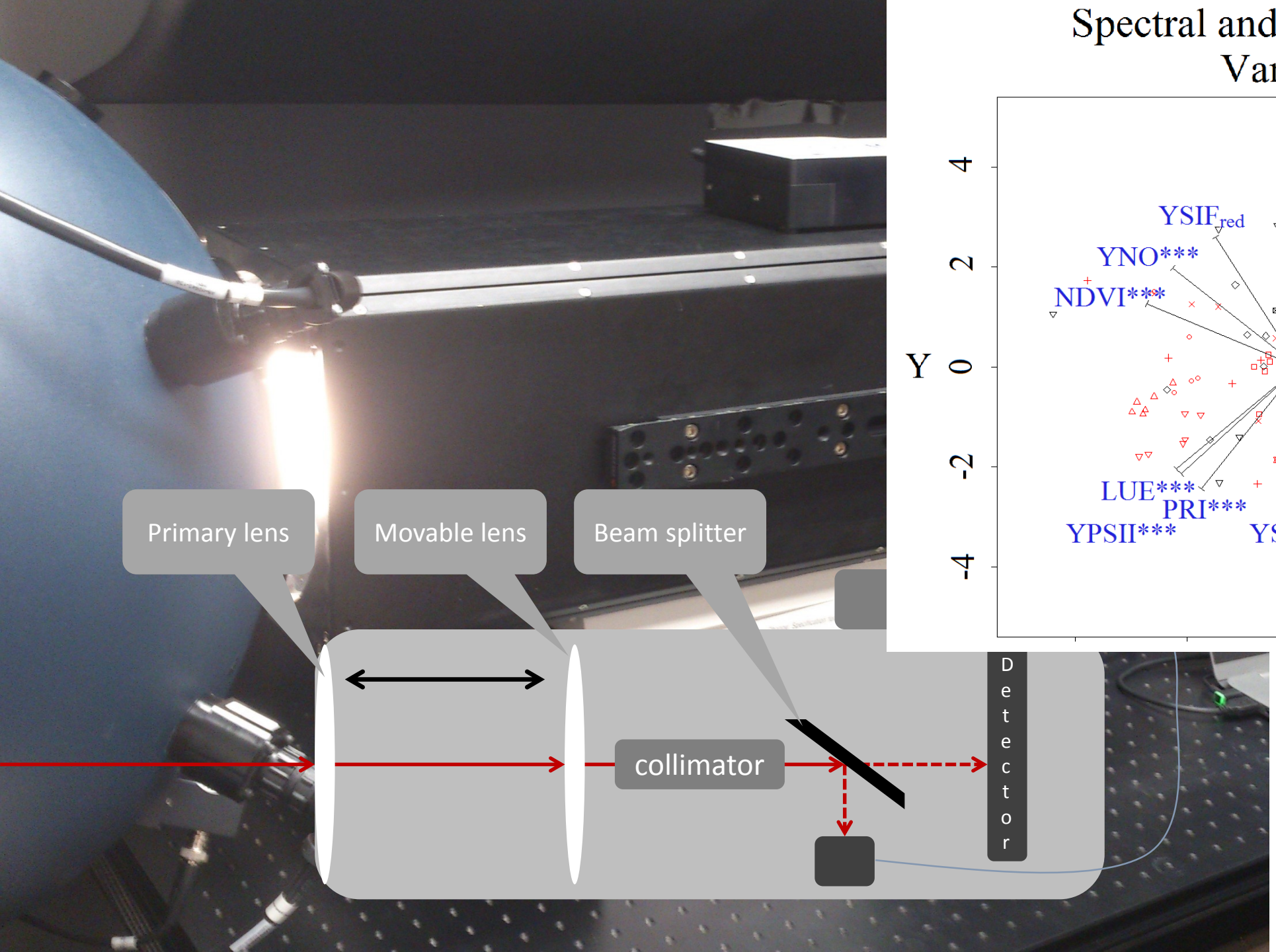

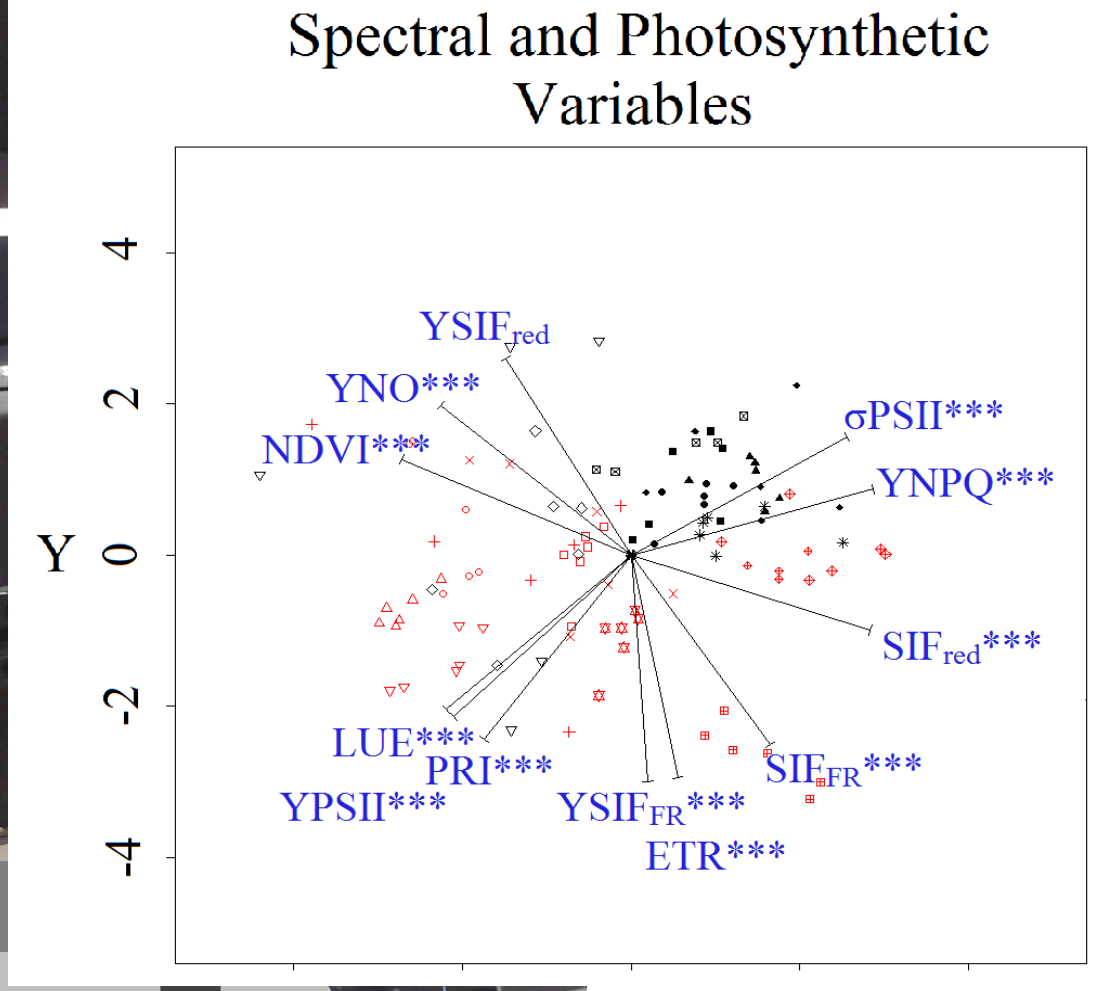

Courtesy of Rhys Wyber

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Linking and scaling LIFT to UAS SIF

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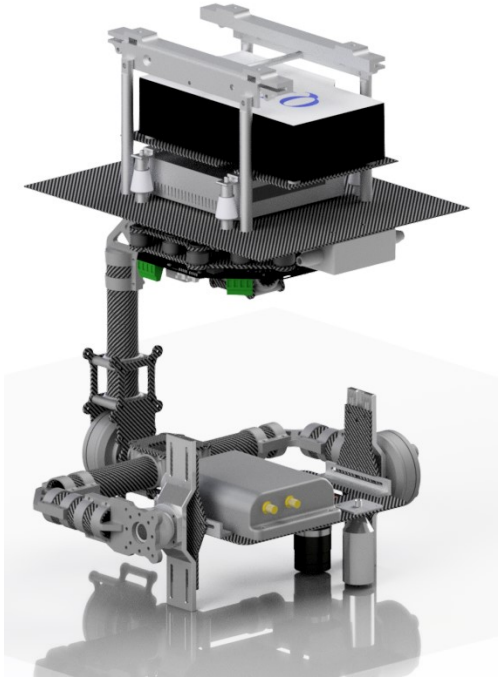
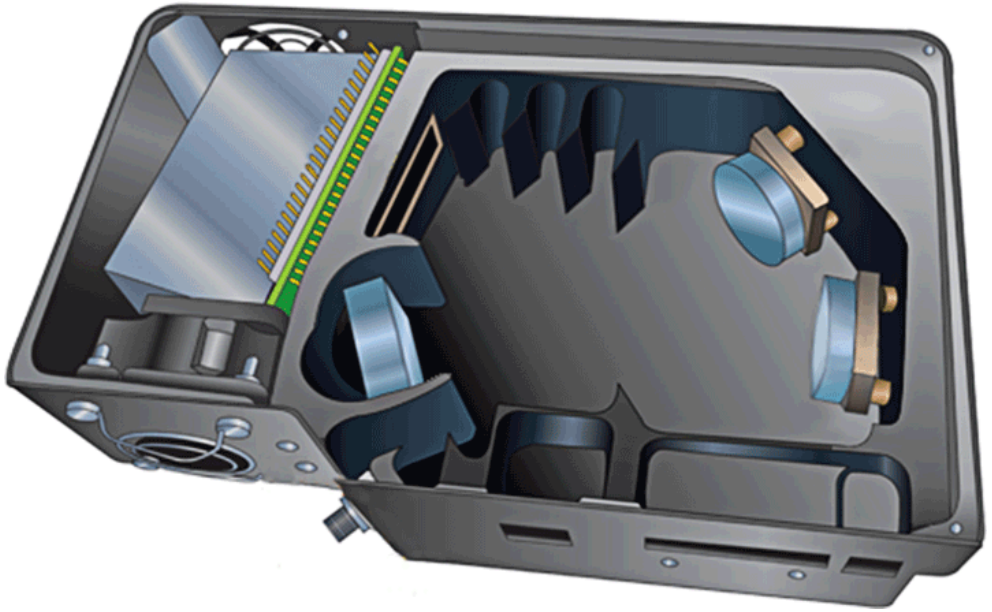
HyperUAS (version III) – 2016

HyperUAS (version IV) - 2016

Sun-induced chlorophyll fluorescence (SIF) payload

- Ocean Optics spectrometer QE Pro with spectral range 500–850 nm FWHM ~ 0.7 nm.
- Bifurcated cable with inline shutters: downward looking Gershun tube (1-14° FOV) and upward looking cosine receptor.
- Gimbal with tightly-coupled GNSS/IMU synchronised with QE Pro acquisitions.
- Machine vision camera (Grasshoper 3) for orthophoto and Structure from Motion products (e.g. DSM).





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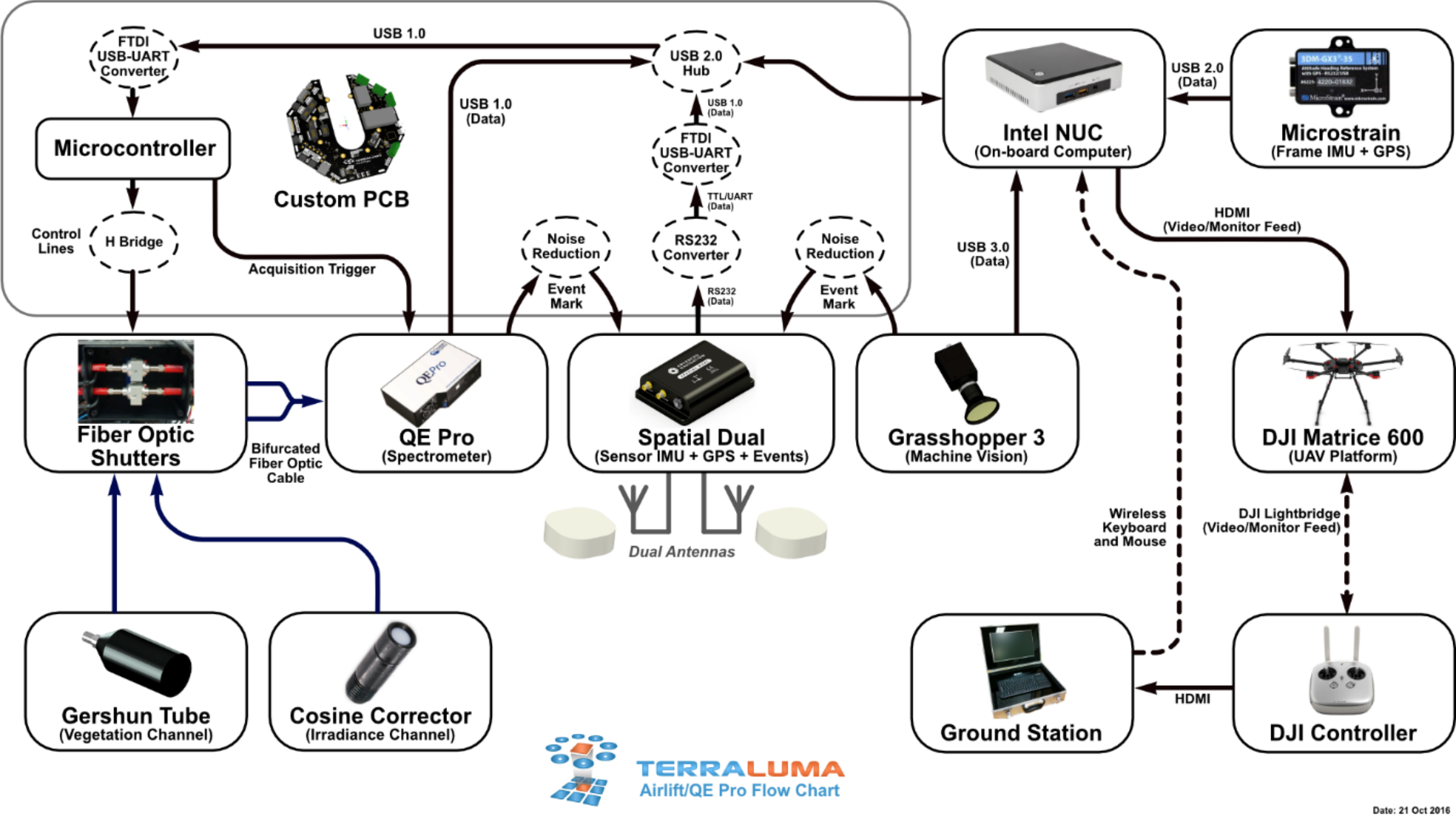
USB 1.0
FTDI USB-UART Converter
USB 2.0 Hub
Microcontroller
Custom PCB
USB 1.0 (Data)
USB 1.0 (Data)
FTDI USB-UART Converter
TTL/UART (Data)
Control Lines
H Bridge
Acquisition Trigger
Noise Reduction
RS232 Converter
Noise Reduction
Event Mark
RS232 (Data)
Event Mark
Intel NUC
(On-board Computer)
USB 2.0 (Data)
Microstrain
(Frame IMU + GPS)
HDMI (Video/Monitor Feed)
USB 3.0 (Data)
Fiber Optic Shutters
Bifurcated Fiber Optic Cable
QE Pro
(Spectrometer)
Spatial Dual
(Sensor IMU + GPS + Events)
Grasshopper 3
(Machine Vision)
DJI Matrice 600
(UAV Platform)
Dual Antennas
Wireless Keyboard and Mouse
DJI Lightbridge (Video/Monitor Feed)
Gershun Tube
(Vegetation Channel)
Cosine Corrector
(Irradiance Channel)
Ground Station
HDMI
DJI Controller
TERRALUMA
Airlift/QE Pro Flow Chart
Date: 21 Oct 2016

Accurate spectrometer footprint geocoding

Courtesy of Deepak Gautam

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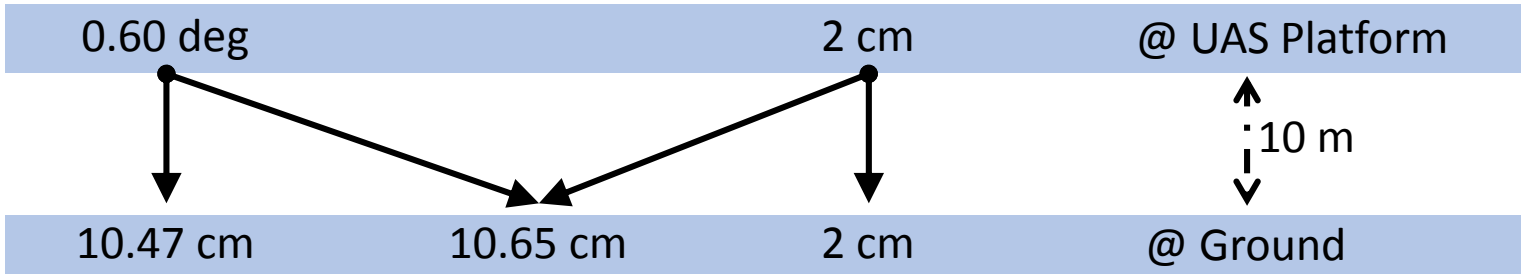
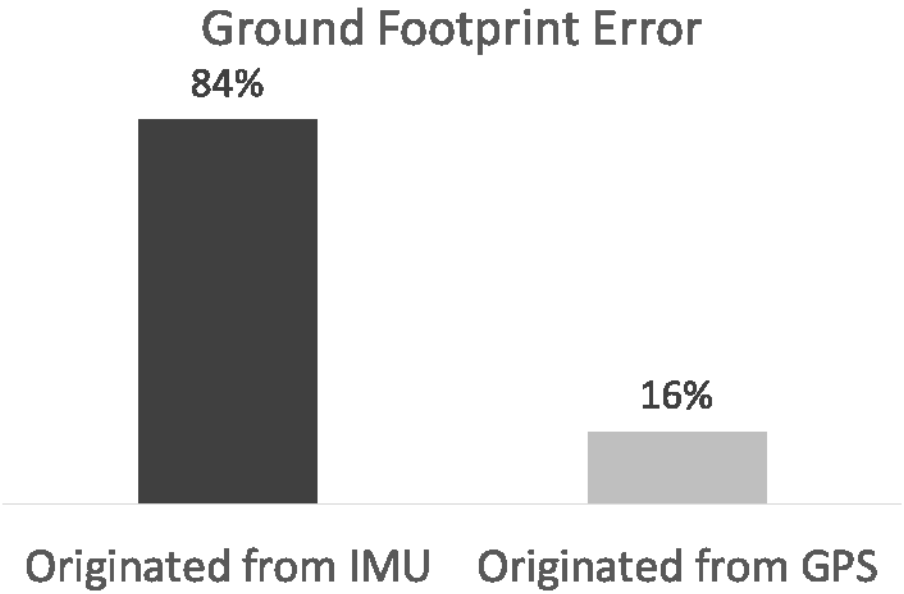
MEMS-based IMU:
Spatial Dual

GNSS Antenna:
G5Ant-53A4T1





Wallace, L., Lucieer, A., Turner, D., Watson, C., others, 2011. Error assessment and mitigation for hyper-temporal UAV-borne LiDAR surveys of forest inventory. Proc. Silvilaser.

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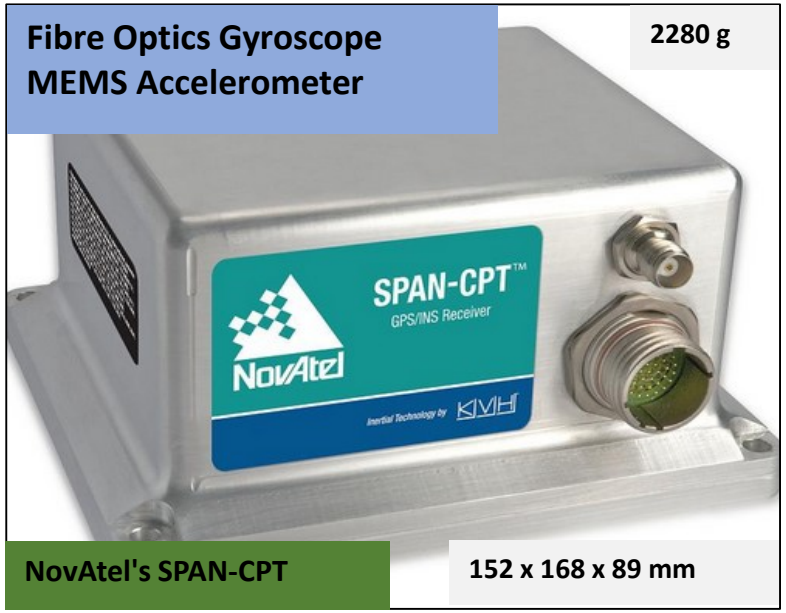
Comparison of GPS/IMU sensors

Reference (SPAN)



Tested (SD & MTi-G)

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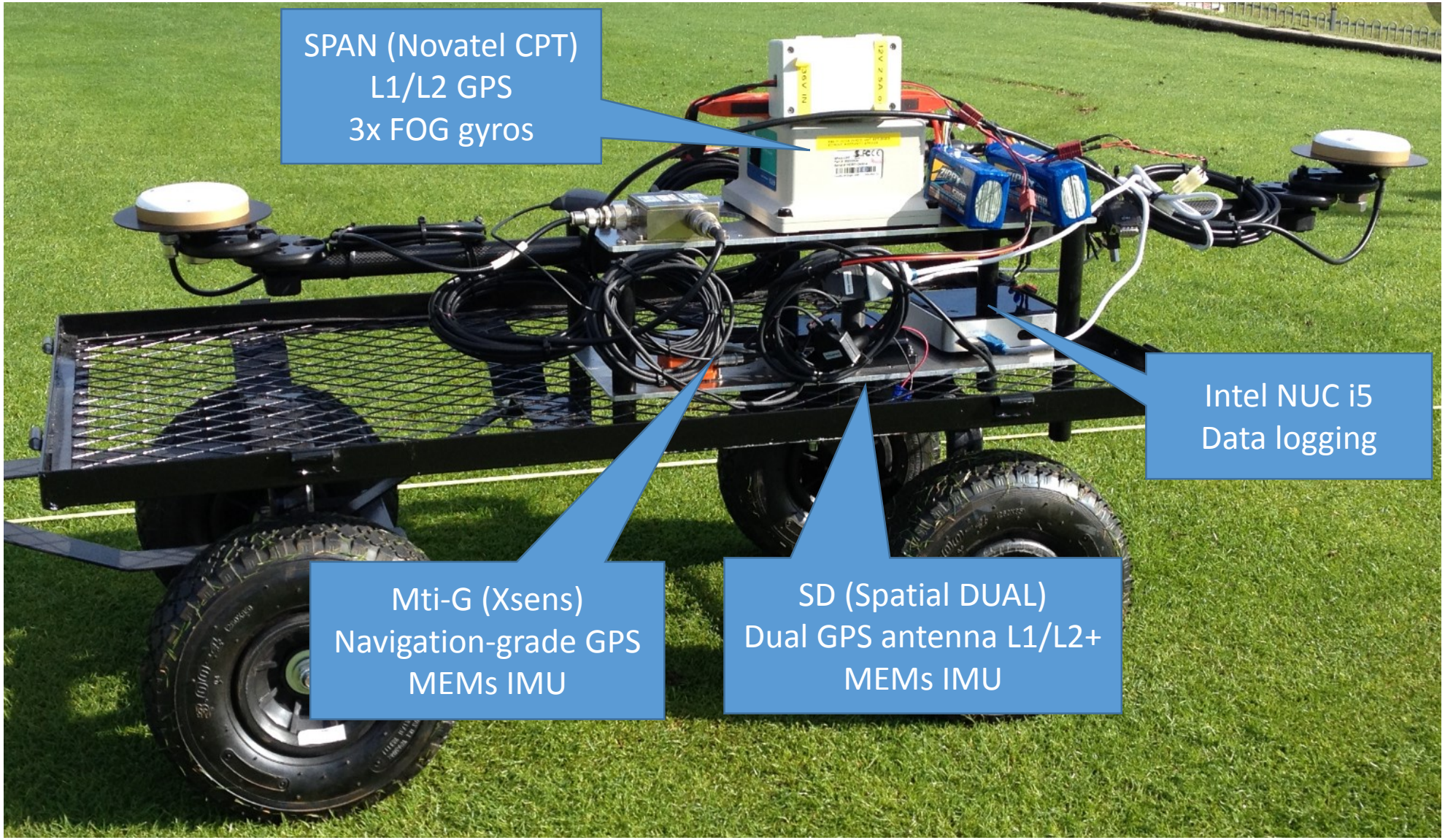
IMU/GNSS error assessment



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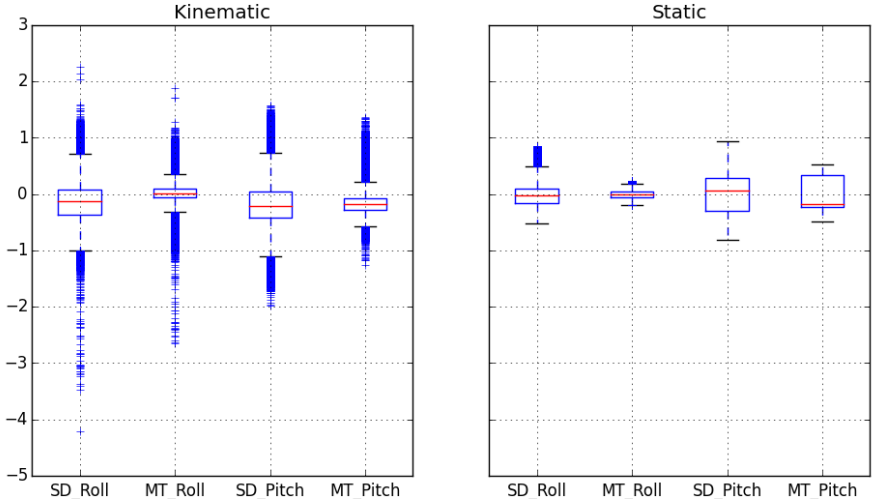
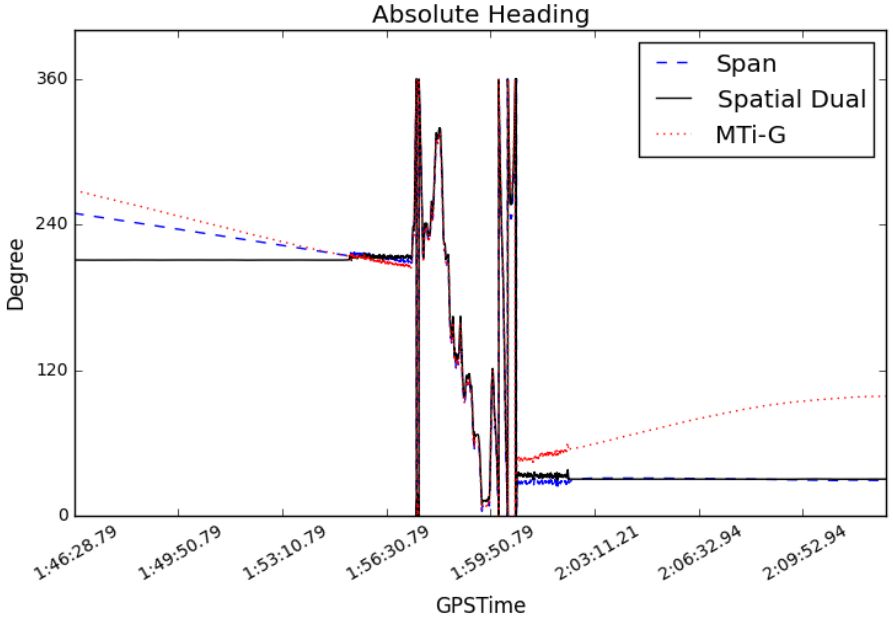
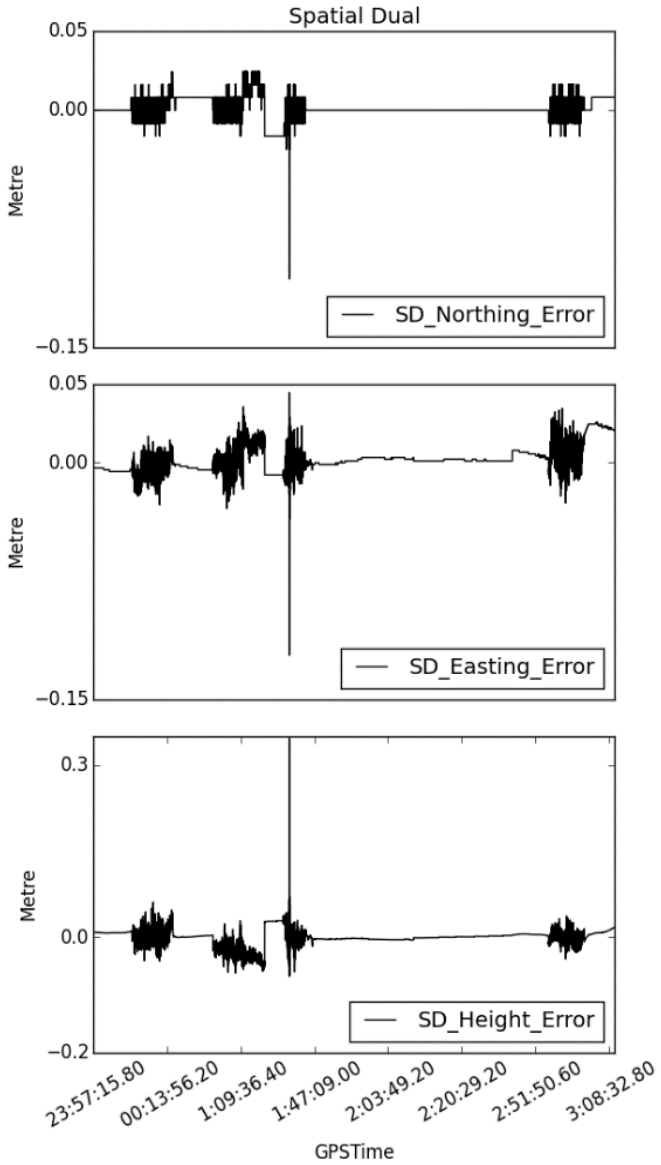
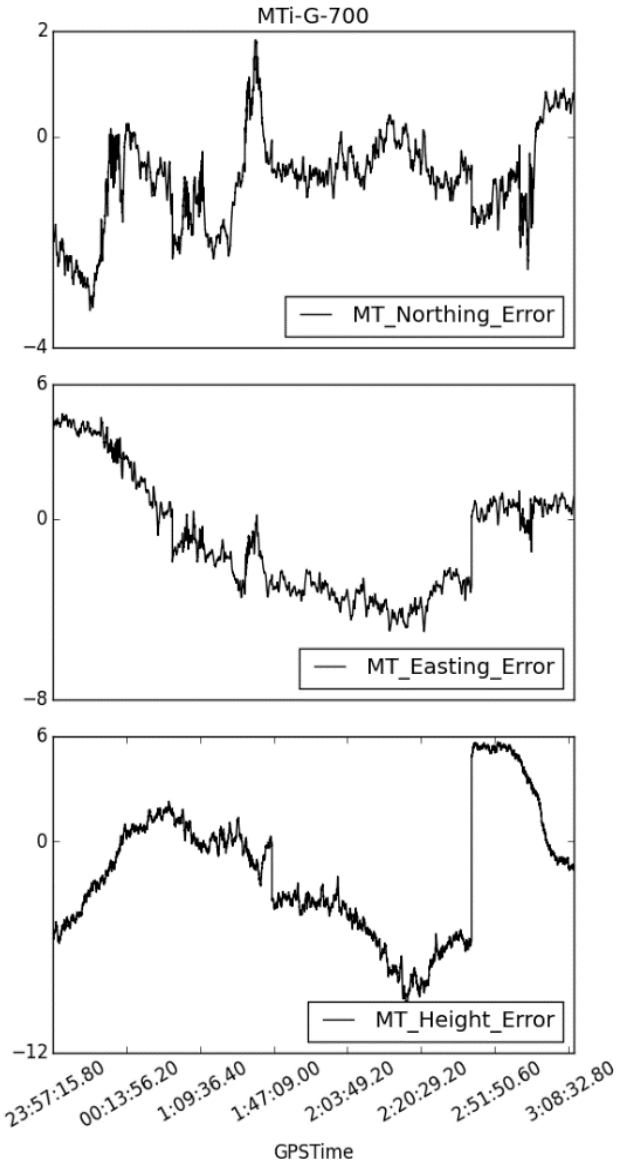
Experimental results









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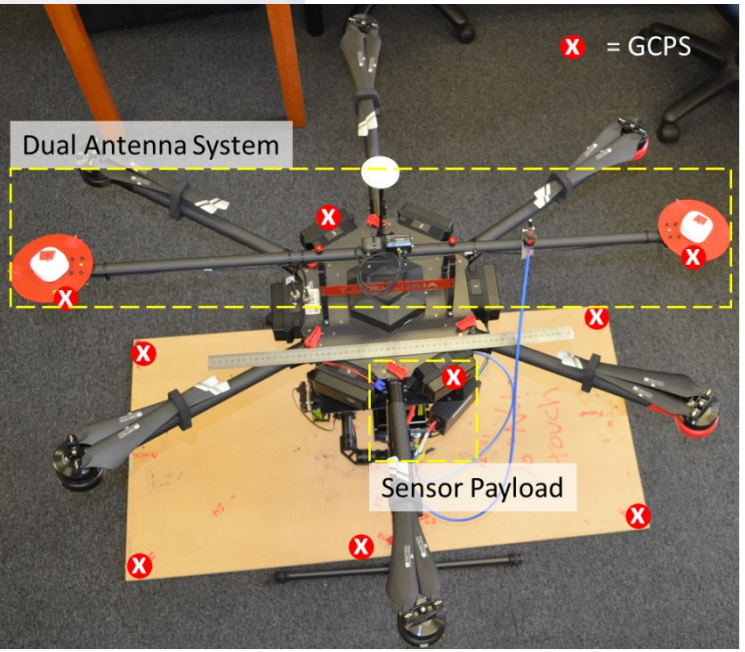
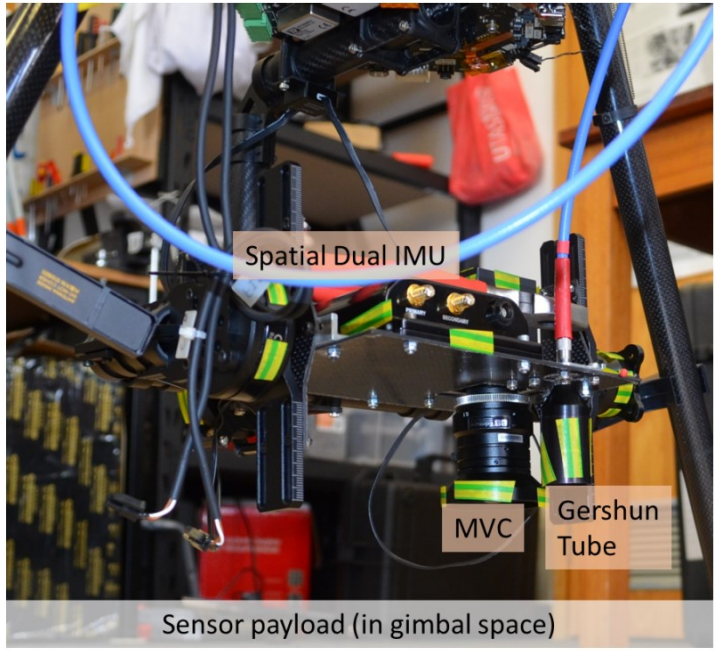
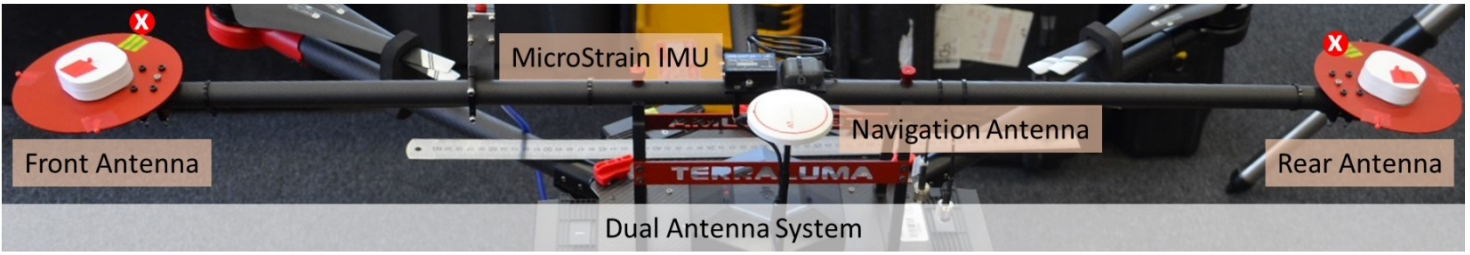
Dual antenna Lever-arm offset







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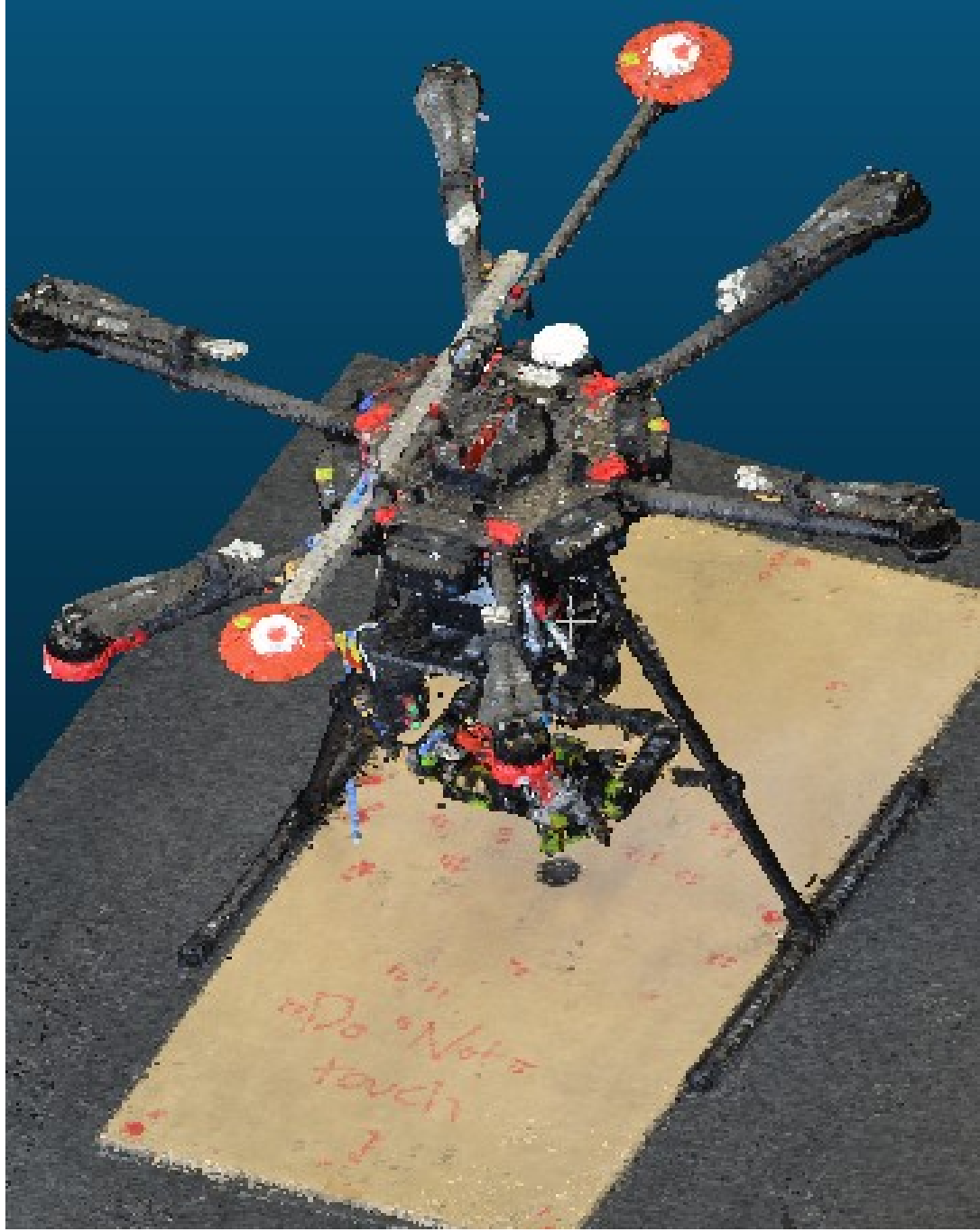
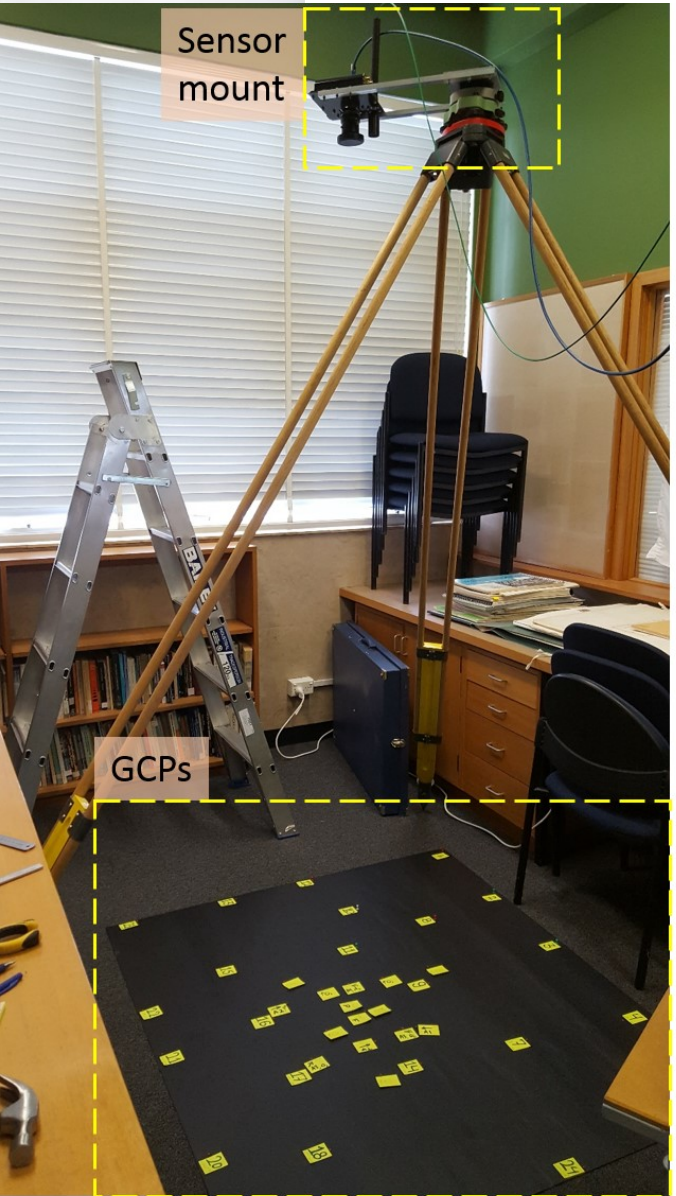
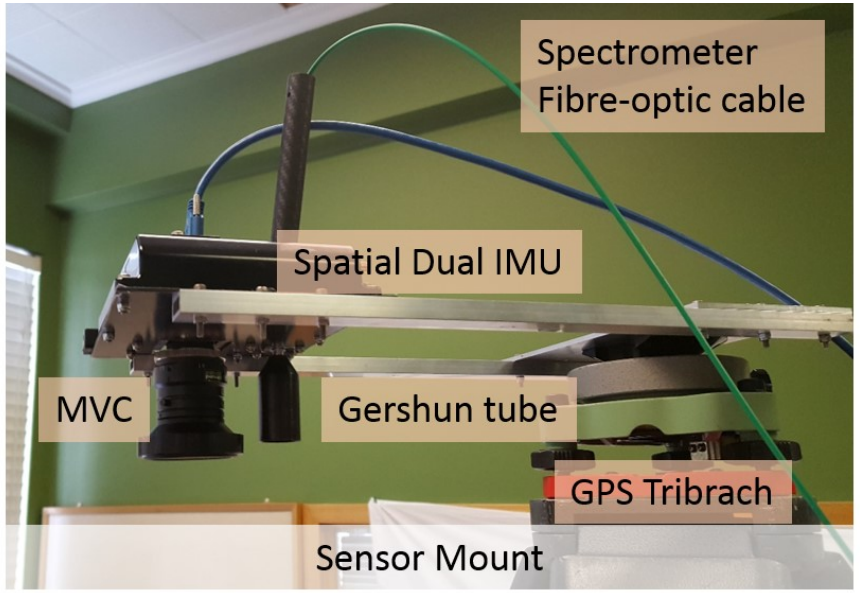
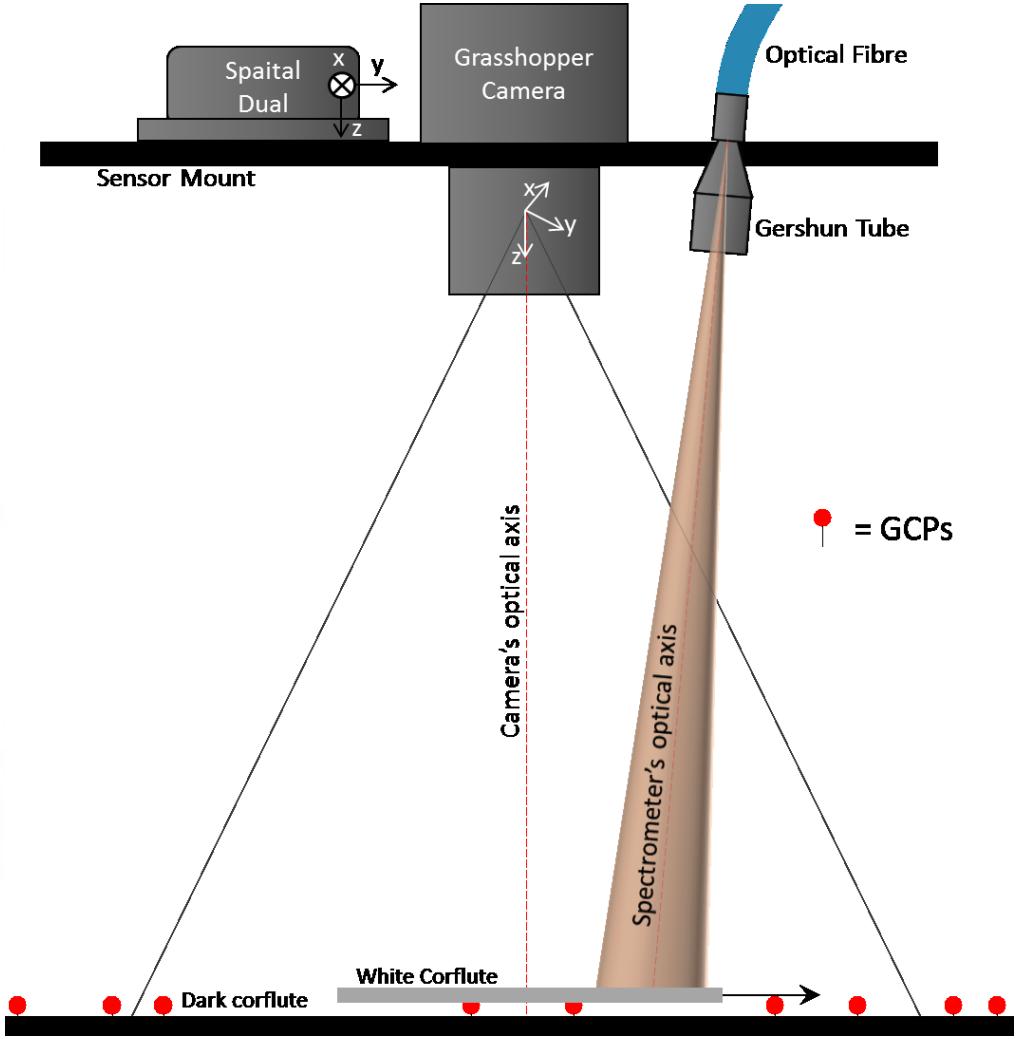


A scaled point cloud of the UAS spectrometer system

Bore-sight angle measurement







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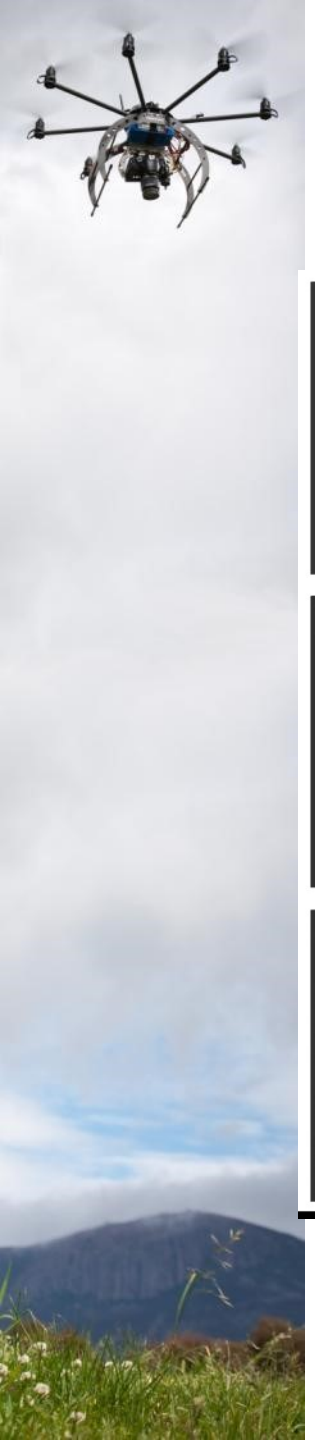
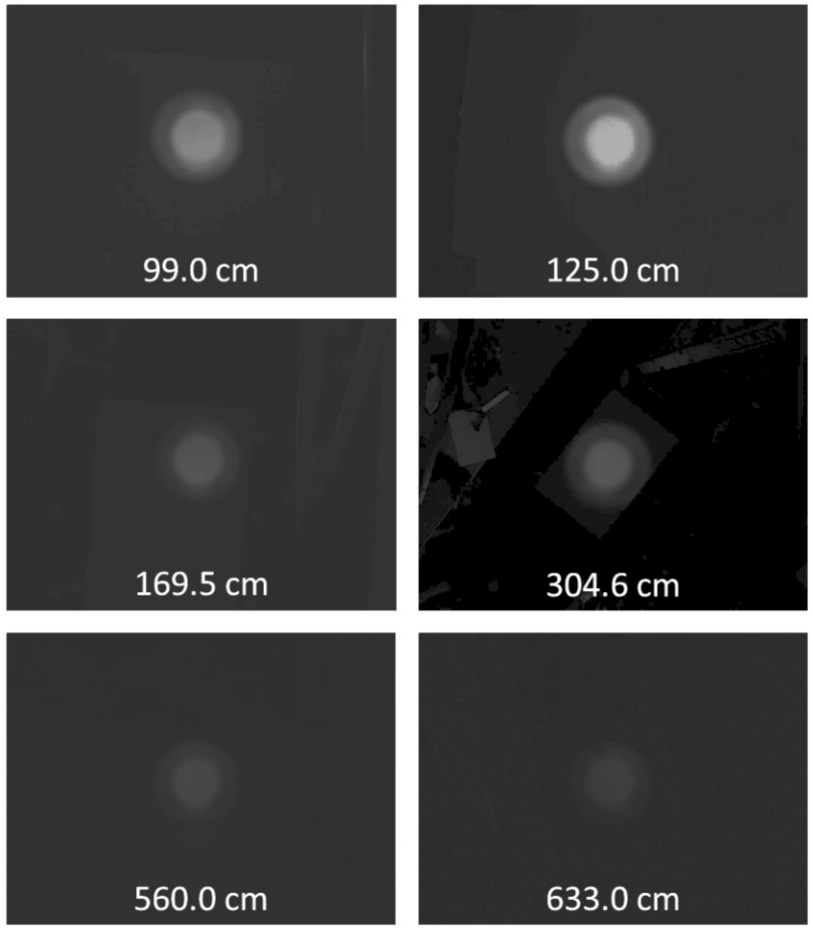
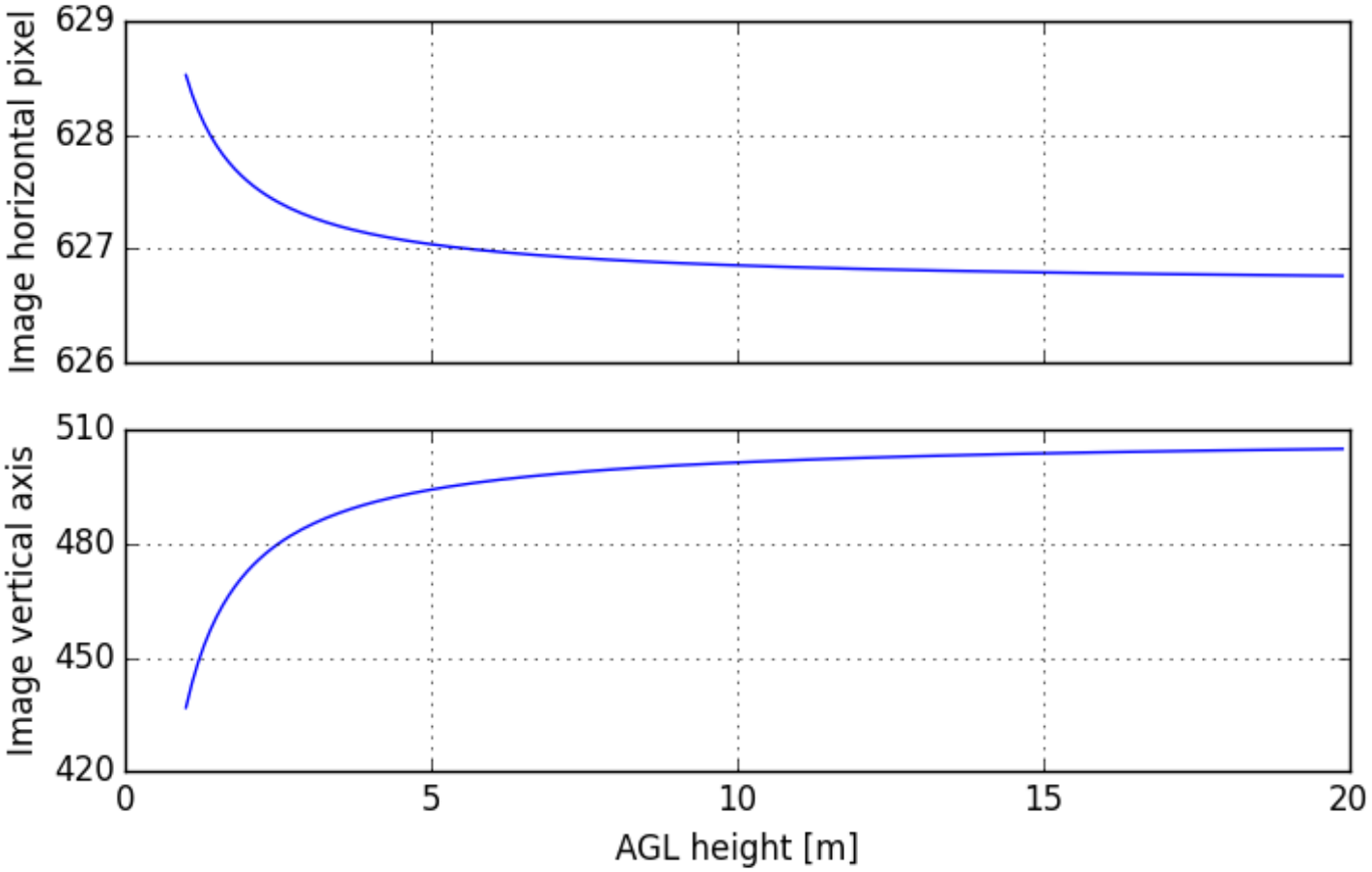


Co-registration of spectrometer and a monochrome camera (non-direct geo-referencing)



Monochrome camera images containing illuminated spectrometer footprint



Pixel location of the spectrometer footprint on the co-mounted camera image

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Spectrometer footprint geo-location error assessment

Sensor standalone uncertainties

White Gaussian Noise
Slow moving drift
Turn-on to Turn-on bias
Constant bias

+

Measurement/ calibration uncertainties

Lever-arm offset
Bore-sight angles
Uncertainty in AGL

Error Propagation Model

Spectrometer footprint uncertainty

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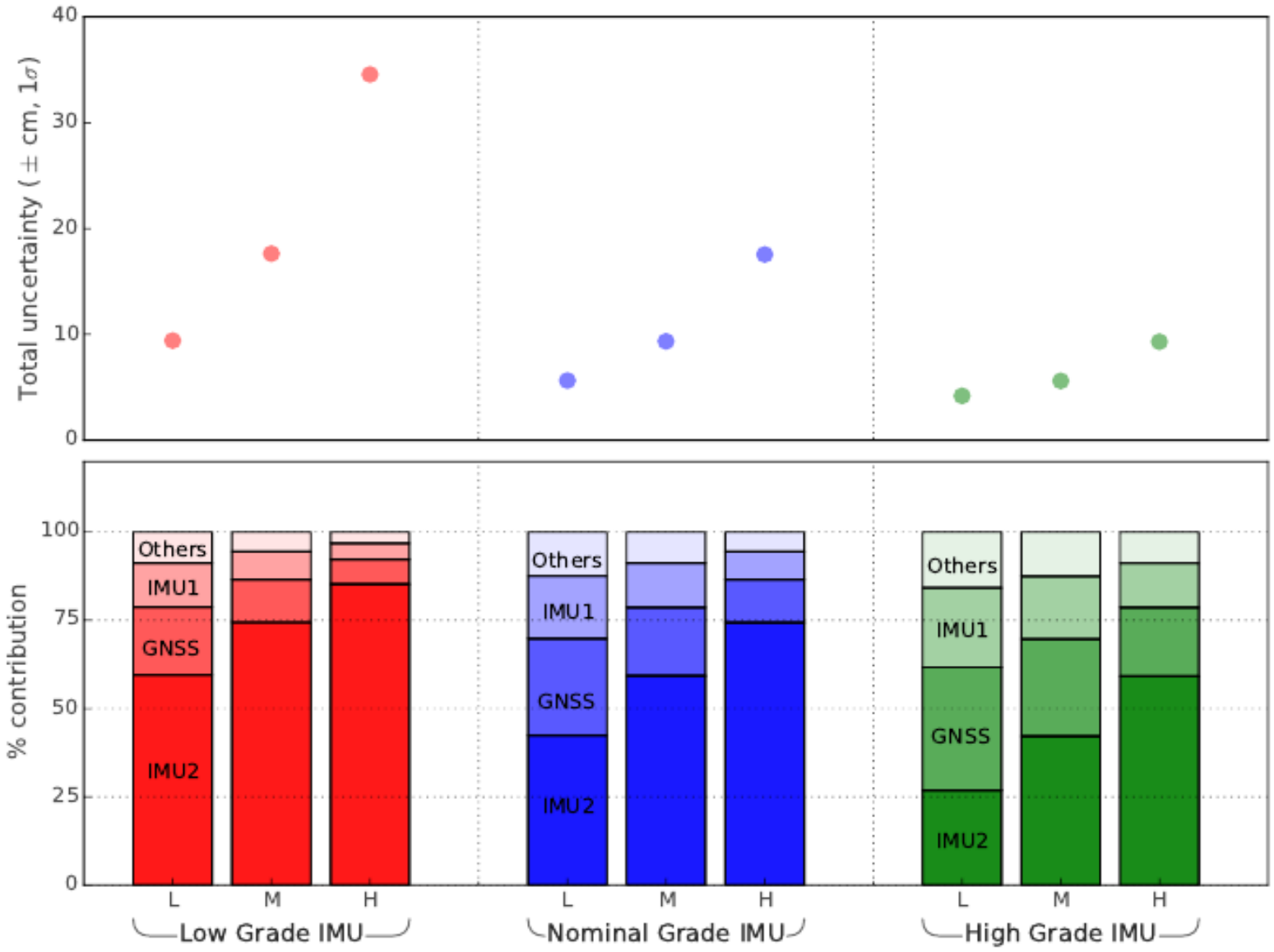
Geo-location error budget



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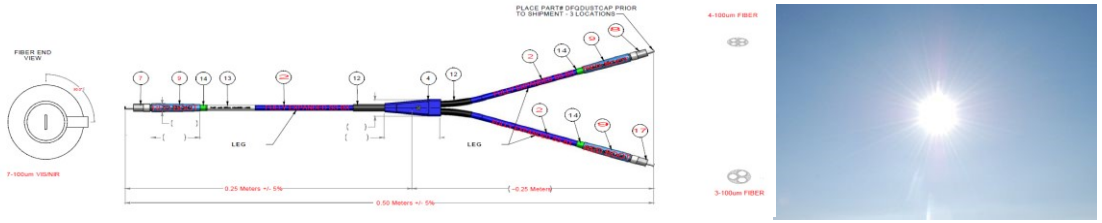
SIF UAS specifications

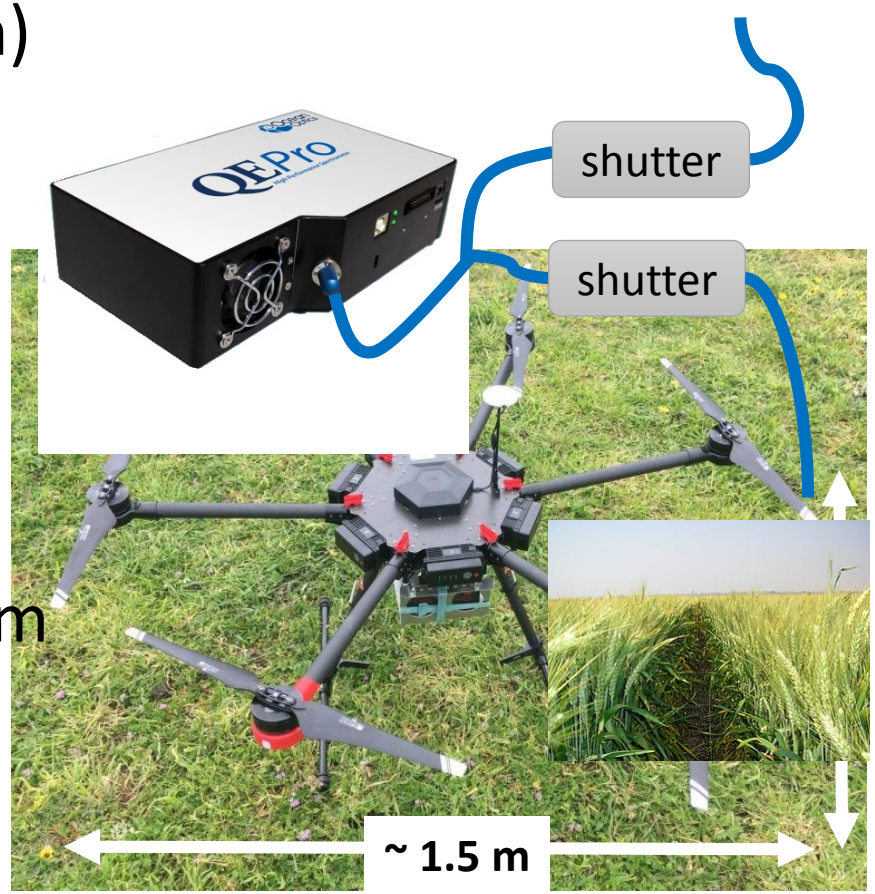
Airframe: **DJI Matrice 600**

- Payload: 6 kg
- Take off weight: 15 kg (our configuration)
- Flight time: c. 15 min
- Max. wind: 25 km/h (~ 14 knots)

Spectrometer: **Ocean Optics QE Pro**

- Range: 498-878 nm
- Grating: #H4 - 600 Lines Blazed at 750 nm
- Radiometric resolution: 0.36 nm (mean)
- Slit: 10 nm (aligned fibers in cable)





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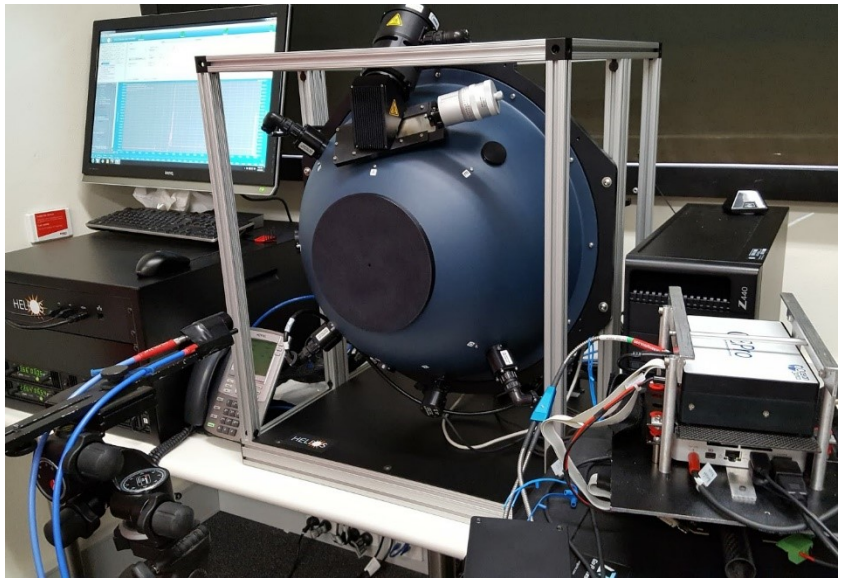
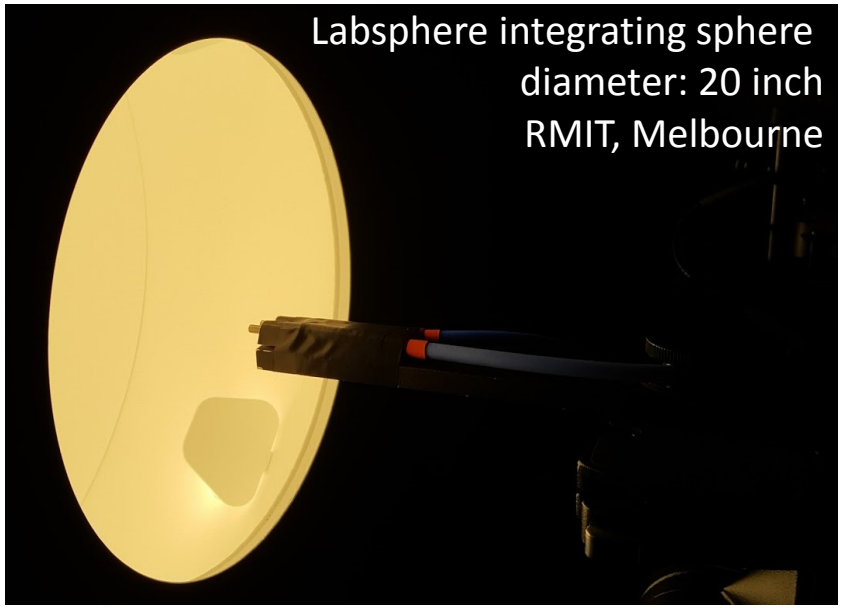
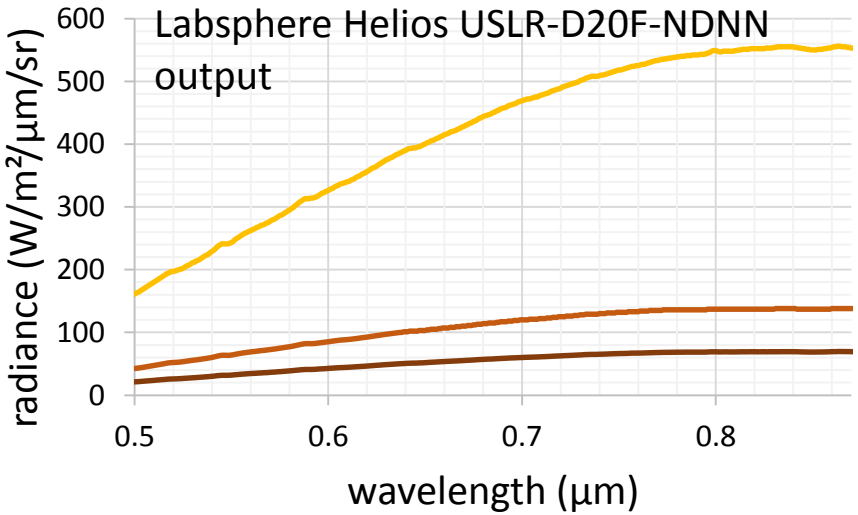
QE Pro radiometric calibration



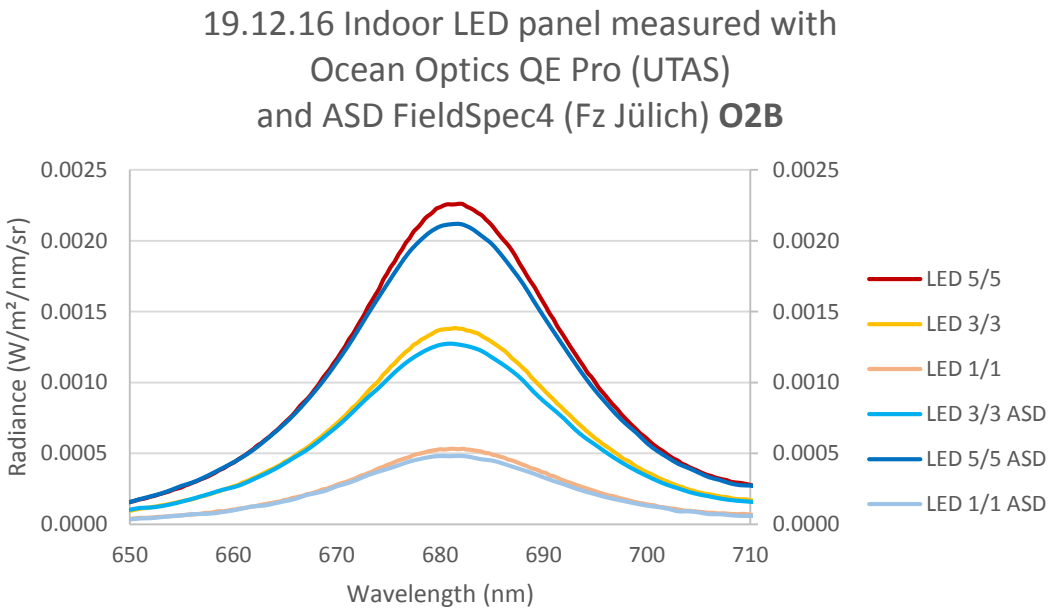


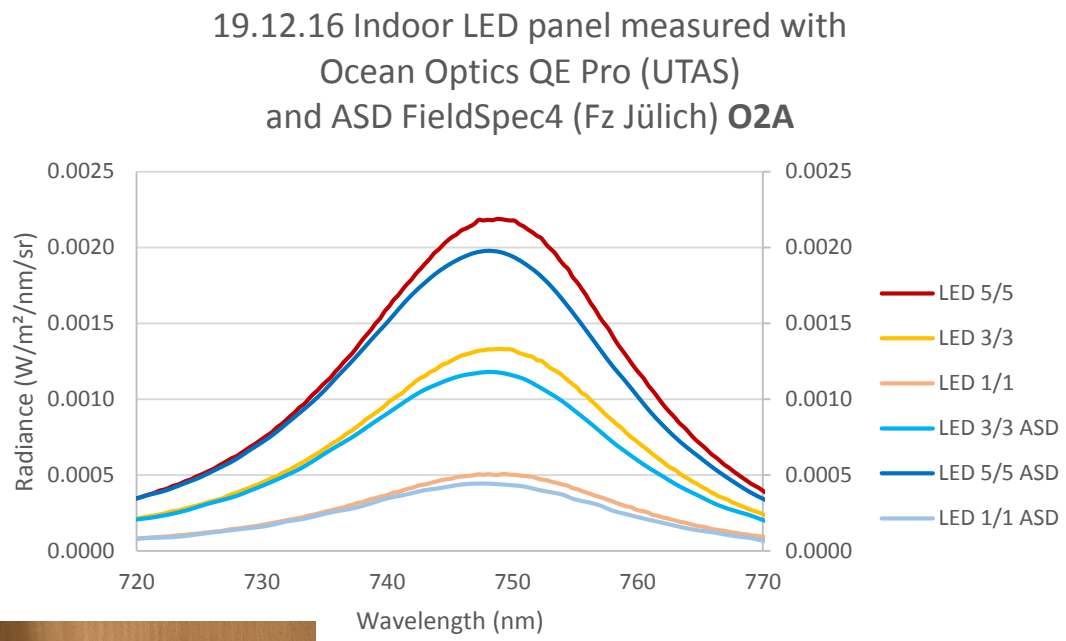
QE Pro settings tested

Fore optic	Channel	Setting
bare fiber	VEG	4/4 lamps on
	IRR	
gershun tube 2,3,6,8,10°	VEG	
cosine corrector	IRR	
gershun tube 8°	VEG	1/4 lamps on, variable attenuator open
cosine corrector	IRR	
gershun tube 8°	VEG	1/4 lamps on, variable attenuator at 0.6" closed
cosine corrector	IRR	



Indoor sensor comparison with LED panel





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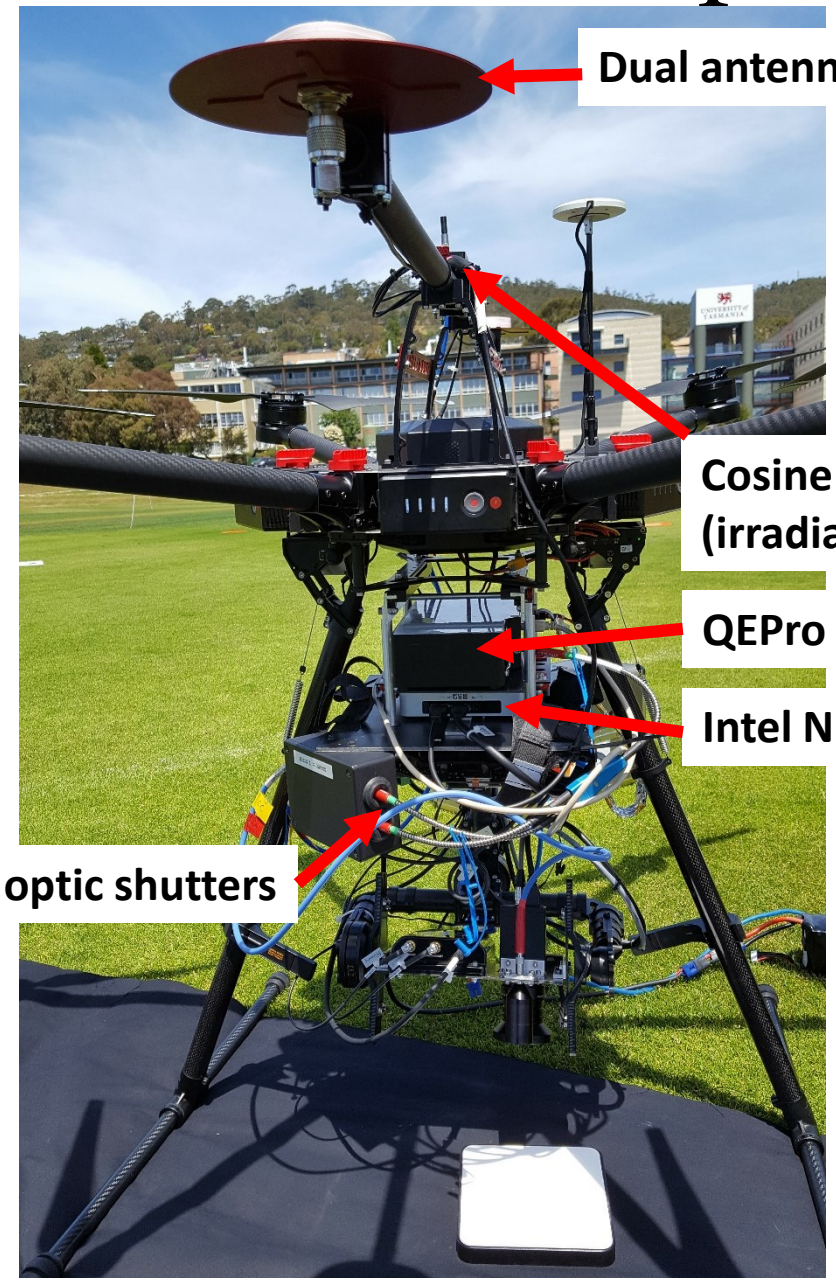
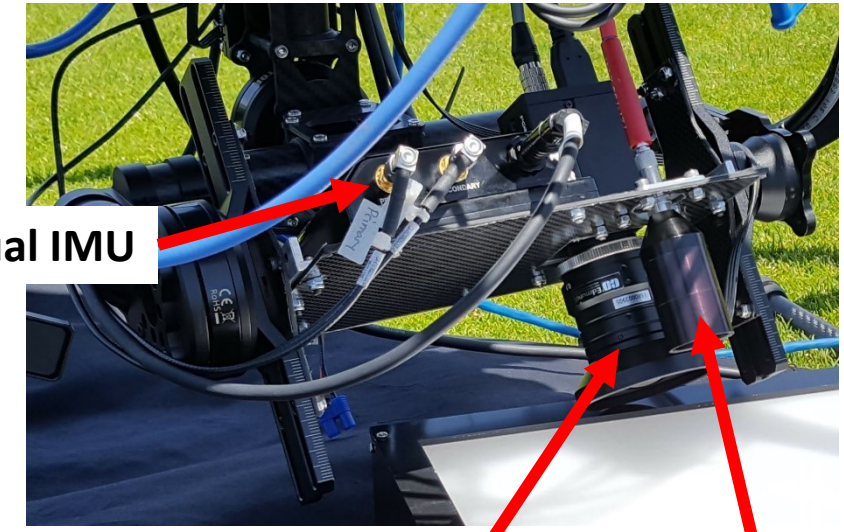
SIF airframe components





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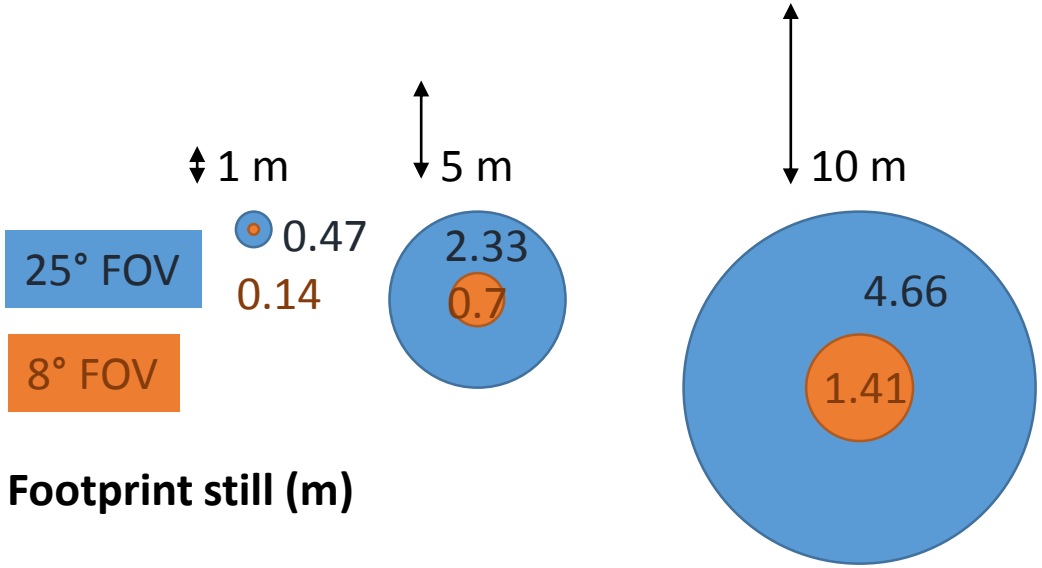
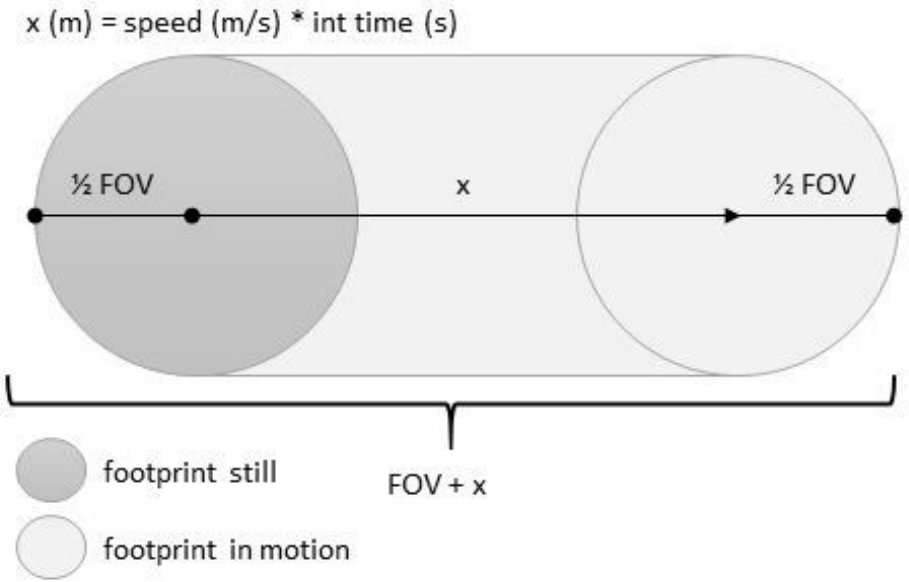
QE Pro Field of View (FOV) & integration times



Footprint still (m)



Flying speed: 3 m/s

Flying height:		1 m	5 m	10 m
FOV(m) 25°	0.6 sec*	2.3	4.1	6.5
	0.7 sec	2.6	4.4	6.8
FOV(m) 8°	0.6 sec	1.9	2.5	3.2
	0.7 sec	2.2	2.8	3.5

*typical integration times during flight

Courtesy of Juliane Bendig

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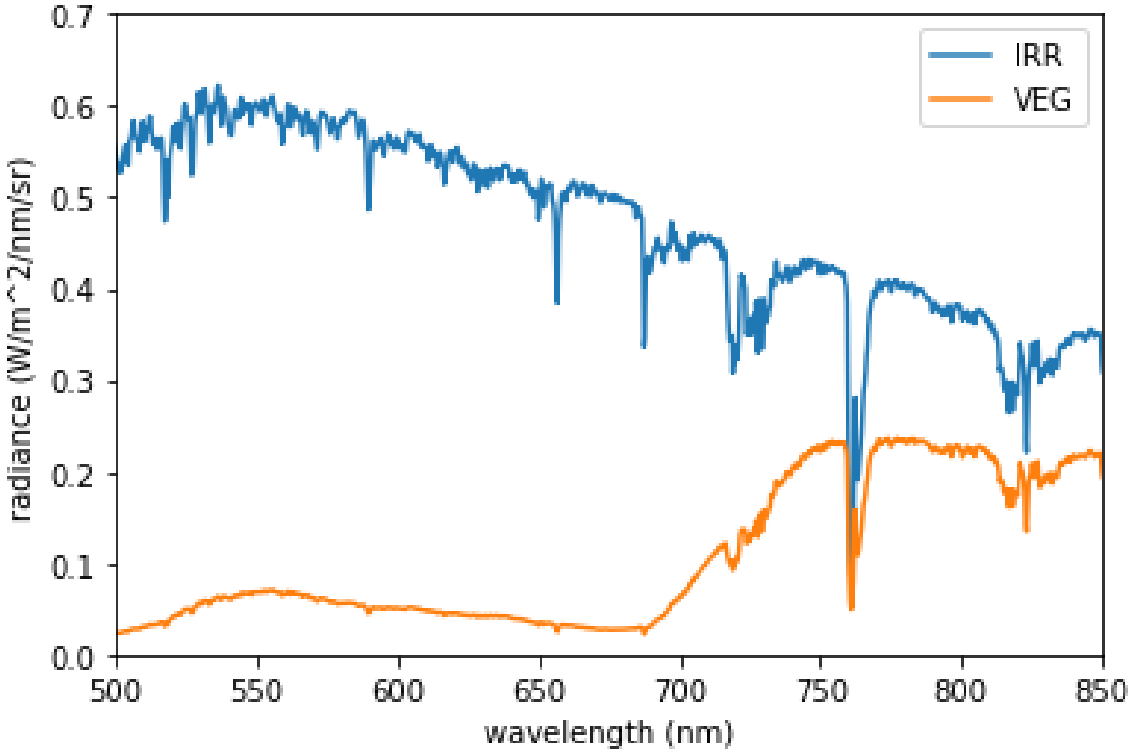
SIF UAS spectral products



- Radiance
- SIF (sFLD and 3FLD)
- Reflectance
- Vegetation indices:
  - NDVI
  - Red Edge Inflection
  - Chl. Indices
  - PRI
  - etc.

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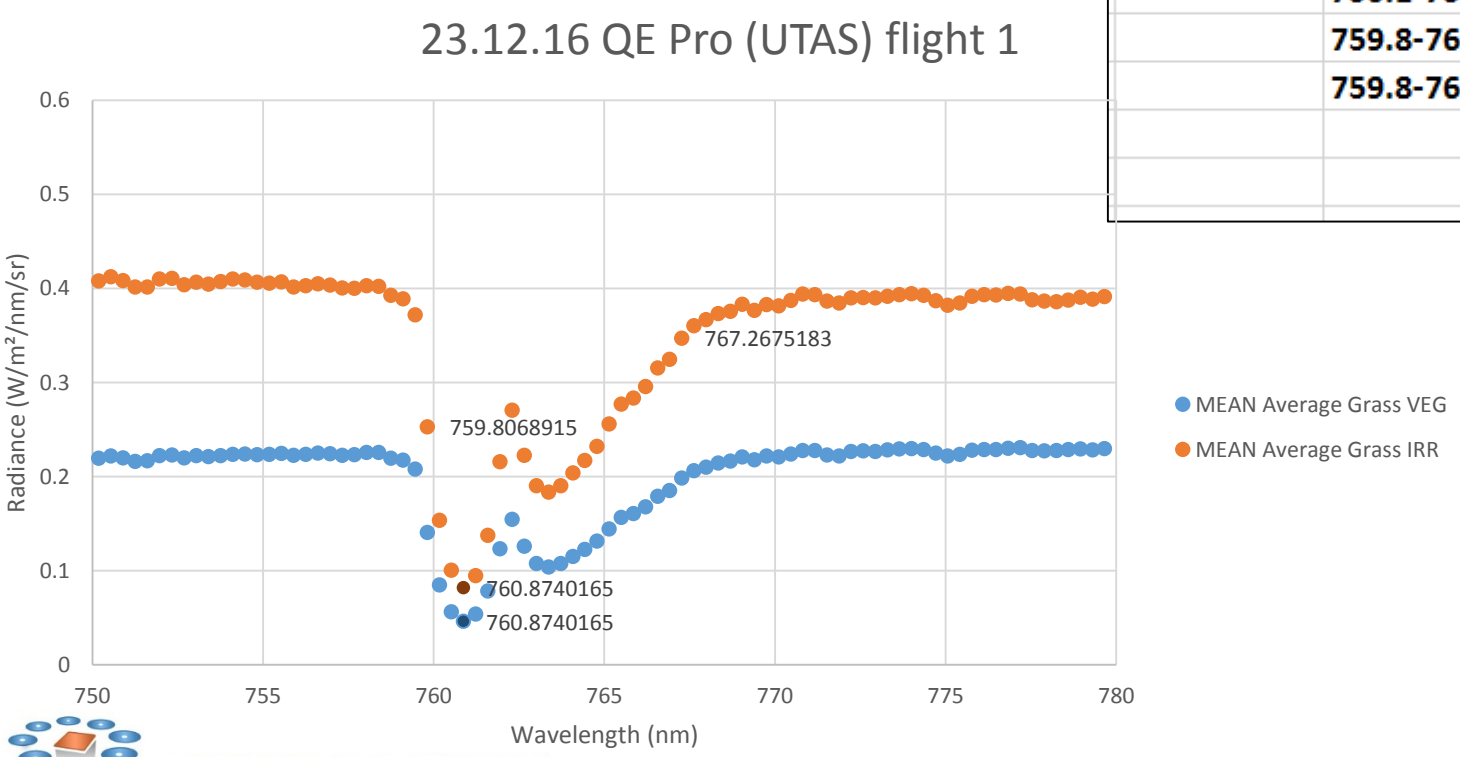
SIF calculations – O2A

```
o2a_IRRout= max([float(i) for i in irrDataPrev[674:690]])
o2a_VEGout= max([float(i) for i in iRowiData[677:693]])
o2a_IRRin = min([float(i) for i in irrDataPrev[702:706]])
o2a_VEGin = min([float(i) for i in iRowiData[705:709]])
o2a_sFLD = ((o2a_IRRout * o2a_VEGin) - (o2a_IRRin * o2a_VEGout)) / (o2a_IRRout-o2a_IRRin)
```

sFLD O2A code snippet

sFLD O2A calculated from wavelengths:

SIF O2A	750.1-759.4	IRRout max	0.4122595	
	750.1-759.4	VEGout max	0.22541024	
	759.8-767.2	IRRin min	0.08161624	
	759.8-767.2	VEGin min	0.04597746	
			0.00152207	1.5220707
		((IRRout*VEGin)-(IRRin*VEGout))/(IRRou		



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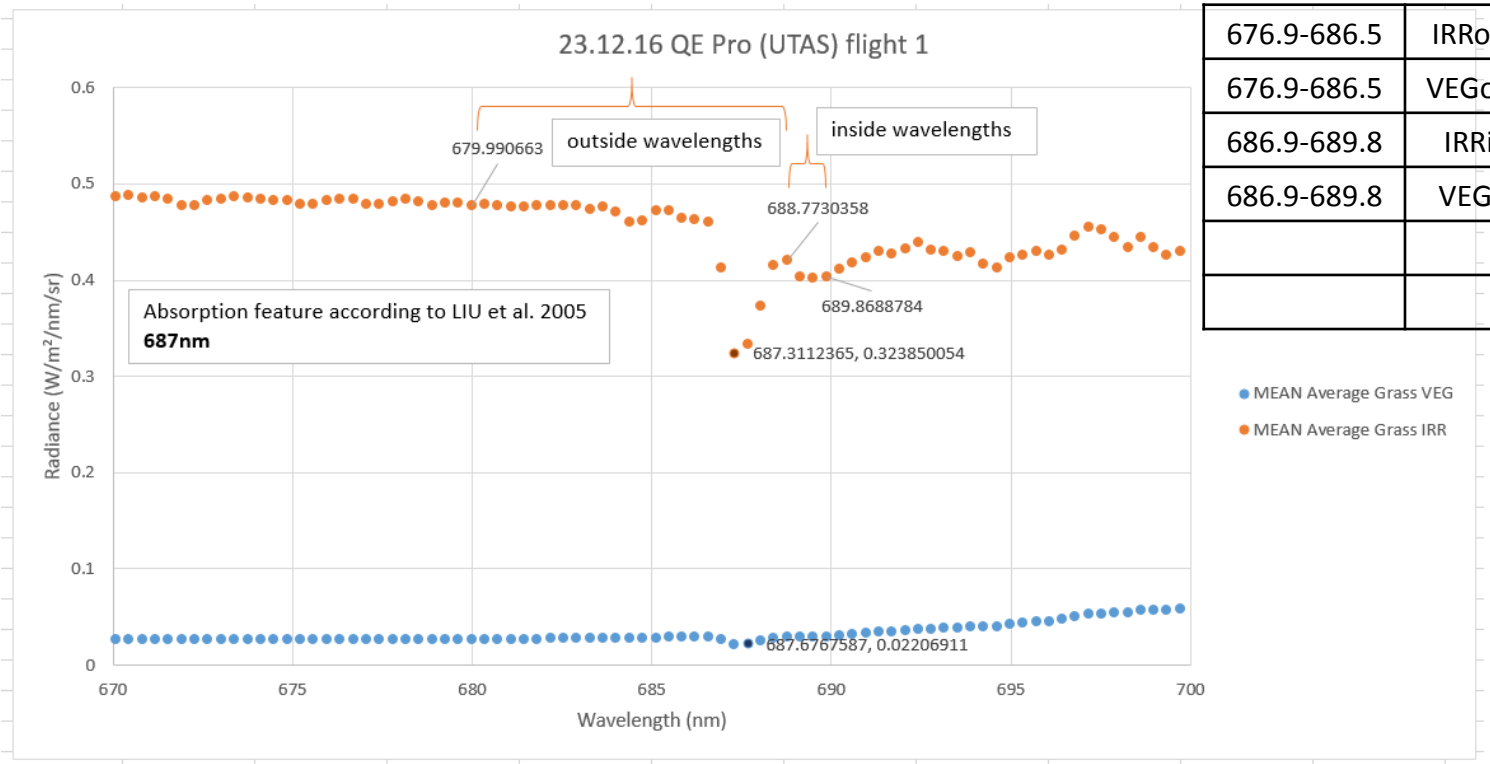
SIF calculation – O2B

```
o2b_IRRout= max([float(i) for i in irrDataPrev[481:504]])
o2b_VEGout= max([float(i) for i in iRowiData[484:507]])
o2b_IRRin = min([float(i) for i in irrDataPrev[505:508]])
o2b_VEGin = min([float(i) for i in iRowiData[508:511]])
o2b_sFLD = ((o2b_IRRout * o2b_VEGin) - (o2b_IRRin * o2b_VEGout)) / (o2b_IRRout-o2b_IRRin)
outFile.write(str(o2b_sFLD)+CSV_DELIM)
```

sFLD O2B code snippet



sFLD O2B calculated from wavelengths:

676.9-686.5	IRRout max	0.48433282	W/m²/nm/sr	
676.9-686.5	VEGout max	0.02905471	W/m²/nm/sr	
686.9-689.8	IRRin min	0.32385005	W/m²/nm/sr	
686.9-689.8	VEGin min	0.02119794	W/m²/nm/sr	
		0.00185149	1.85148909	mW/m²/nm/sr
	((IRRout*VEGin)-(IRRin*VEGout))/(IRRout-VEGin)			

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First SIF UAS test flight (UTAS cricket pitch)

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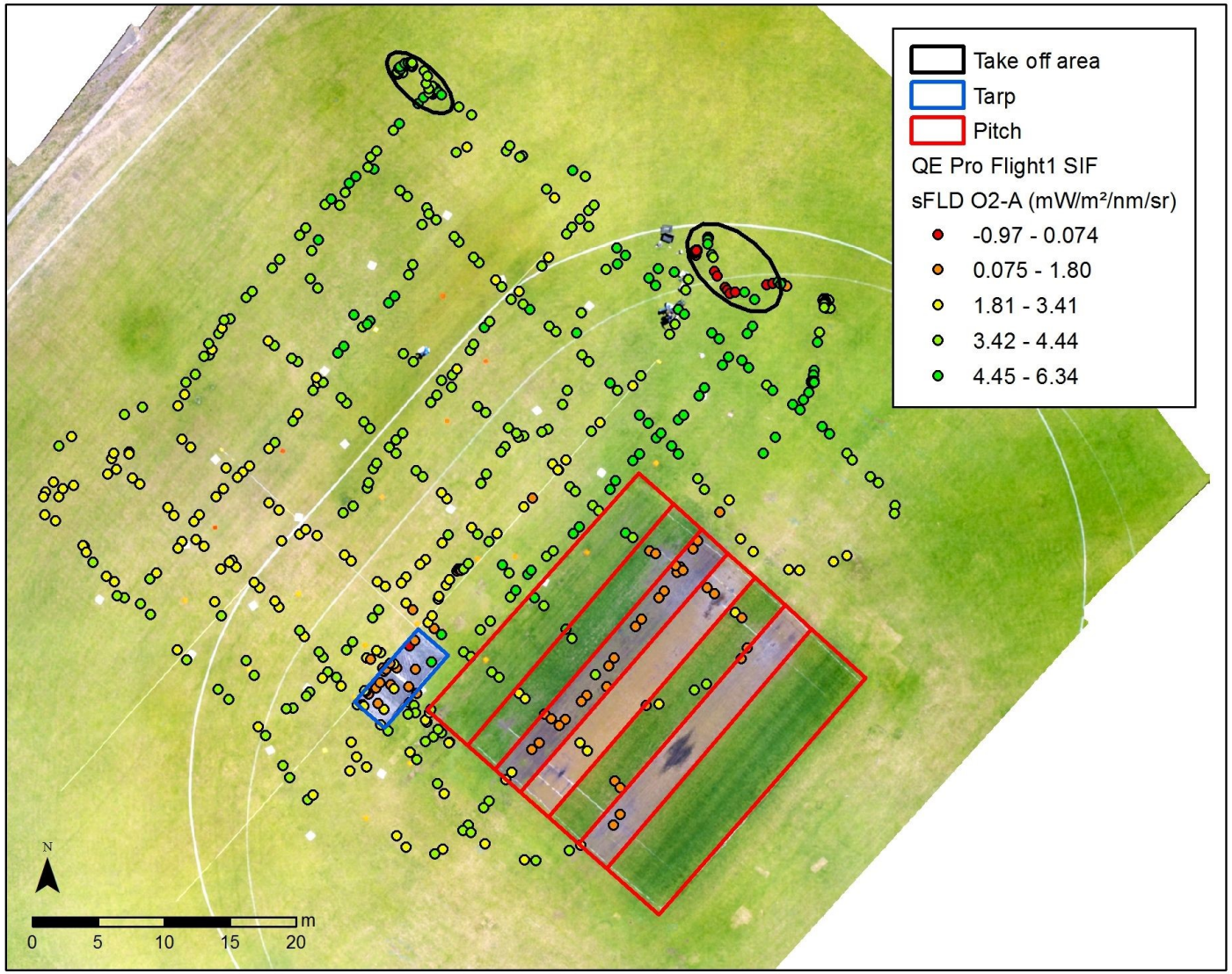
Results of the first SIF UAS test flight



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Concluding remarks

- SIF UAS with high accuracy footprint geo-location (error < 20 cm) using MEMs IMU (dual antenna) was developed and tested.
- Retrieved O2A SIF is gaining expected values (up to 6 $mW/m^2.nm.sr$).

Next steps:

- More flight experiments over more complex crop/orchard canopies.
- Solidification of data collection and calibration protocols.
- Error assessment of SIF observations (e.g. flying height and speed).
- Linking LIFT to SIF at canopy scale & scaling from ground to air.

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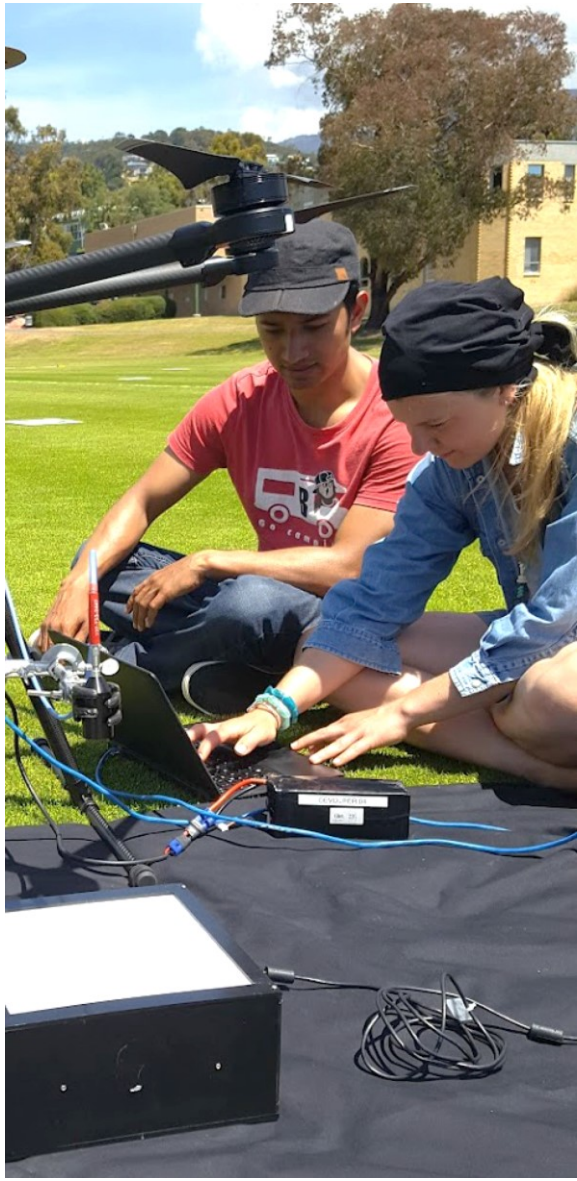
Credit goes to …



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