INNOVATIVE
IMAGING & RESEARCH

An Unmanned Aerial System (UAS)-Based Approach to Calibrate High to Moderate Spatial Resolution Satellite Imagery

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Co-contributors/Acknowledgements

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Introduction/Background

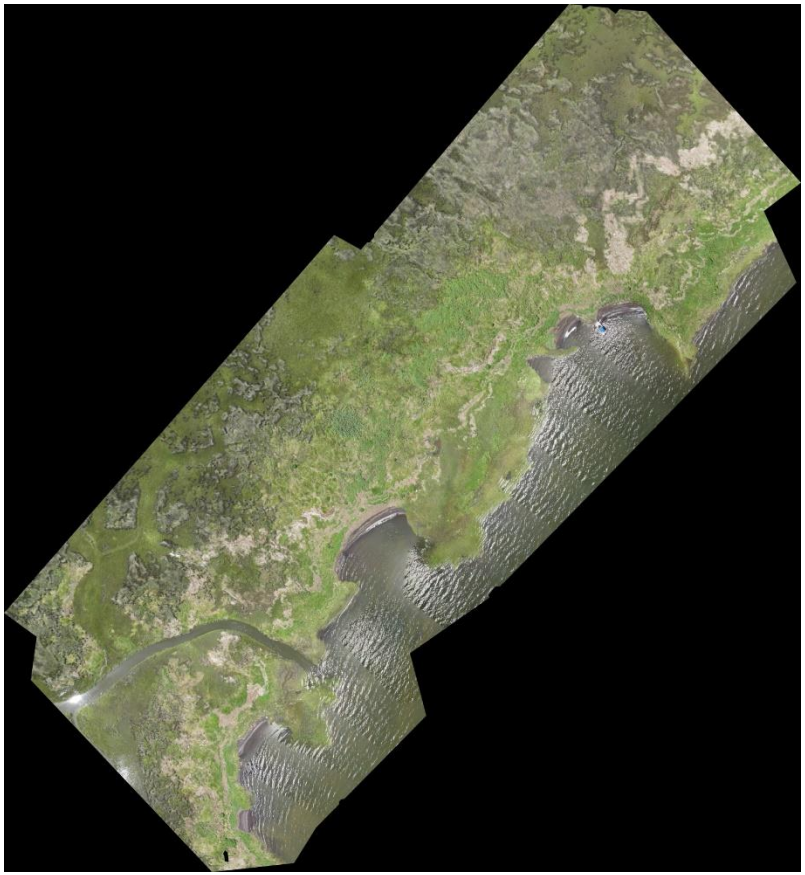
Small UAS for Remote Sensing

Vicarious CalVal

CalVal UAS Benefits

Growing Remote Sensing sUAS Applications

- Environmental monitoring
- Invasive species monitoring
- Landcover classification
- Change detection
- Precision Agriculture
  - High value crops
- Vegetation health assessments
- Satellite calibration ground truth support
  - Vicarious calibration under-flights



Common Remote Sensing Sensor Types and Calibration Requirements

Instrument Type	Spectral Range	Spatial Resolution (GSD)	Spectral Resolution (No. of Bands)	SNR	TOA Product	TOA Accuracy Req't	Ground Accuracy Goal
VNIR	400–1000 nm	~1–100 m	~2–50 nm 4–100s	> 100	Radiance	< 5% (Land) < 3% (Water)	< 3% < 1%
					Reflectance	< 3%	< 0.005 (reflectance)
VSWIR	400–2500 nm	~2–100 m	~5–50 nm 1–100s	> 50	Radiance	< 5%	< 3%
					Reflectance	< 3%	< 0.005 (reflectance)
TIR	7.5 – 14 µm	~10–200 m	0.1–4 µm 1 to several	NeDT 0.05–0.5 K	LST (Land) SST (Sea)	< 0.5 K < 0.1–0.2 K	< 0.2K < 0.1K

Common Field-Instrumented Vicarious Calibration Techniques

Method	Advantages	Disadvantages	Cost
Traditional Vicarious (VSWIR)	• Lowest uncertainty • Choose targets/sites	• Manual • Requires significant investment in equipment and personnel • Usually limited to bright sites	High
RadCalNet (VSWIR)	• Medium uncertainty • Automated • Expandable with more sites	• Limited number of sites • Inconsistent instruments/processes. Requires spatial homogeneity • Usually limited to bright sites	Mid
SPARC/ FLARE (VSWIR)	• Can provide both radiometric and PSF measurements • Simplified radiative transfer for TOA radiance or reflectance • Can test over the dynamic range of the sensor	• Requires target maintenance • Limited intercomparison and validation to date • Limited number of sites	TBD

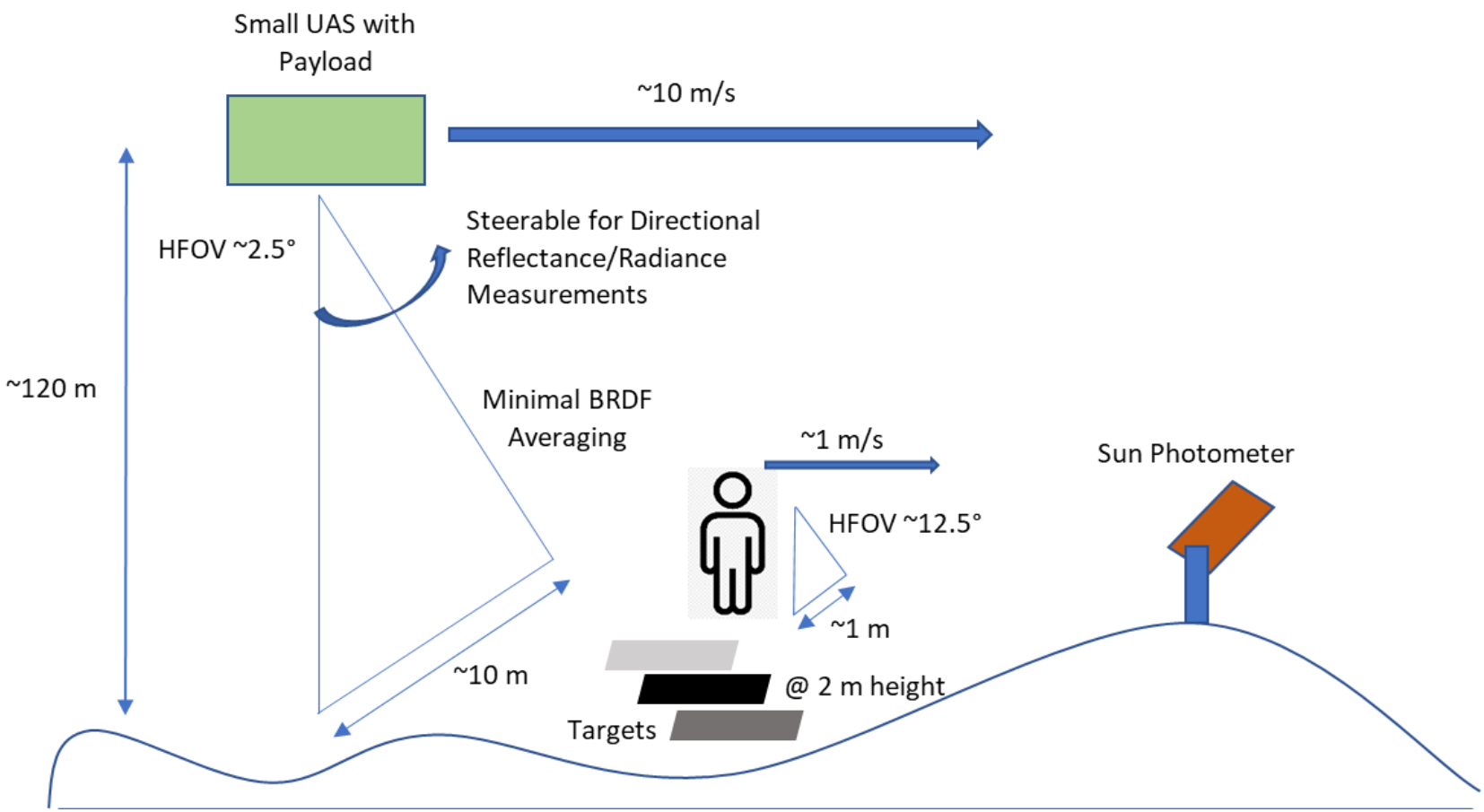
Common Field-Instrumented Vicarious Calibration Techniques

Method	Advantages	Disadvantages	Cost
MOBY/ BOUSSOLE (VNIR)	• Automated • For water radiance leaving measurements (dark scenes)	• Limited revisits due a few sites	High
Ship based / Buoy SST (TIR)	• Low uncertainty • Automated	• Limited measurements due to low number of opportunities	Mid-High

UAS-Based Calibration Advantages

- Measure land covers challenging to traverse on foot
- Reduce the risk of harm to personnel in harsh/rugged terrain
- Eliminate land cover damage from walking/driving
- Significantly increase measurement area coverage – improves measurement statistics and efficiency
- Acquire "whole" scenes with a wide range of reflectance
  - Acquire high-resolution imagery for "virtual" ground-truthing
  - Directly compare the sensor of interest performance against an application
  - Evaluate adjacency, stray light and spatial resolution effects
- Measure BRDF of a vicarious calibration field site

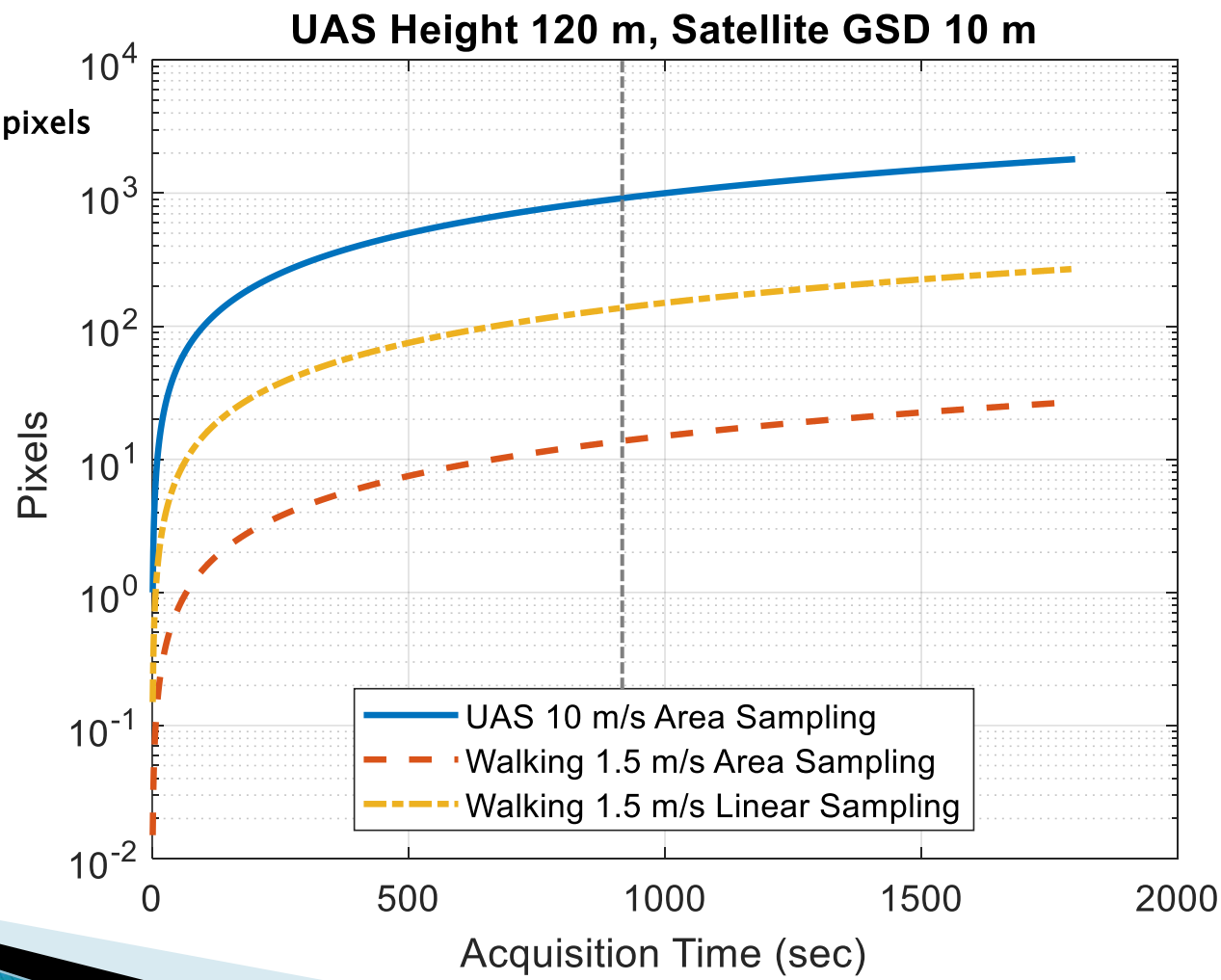
UAS CalVal Measurement Efficiency



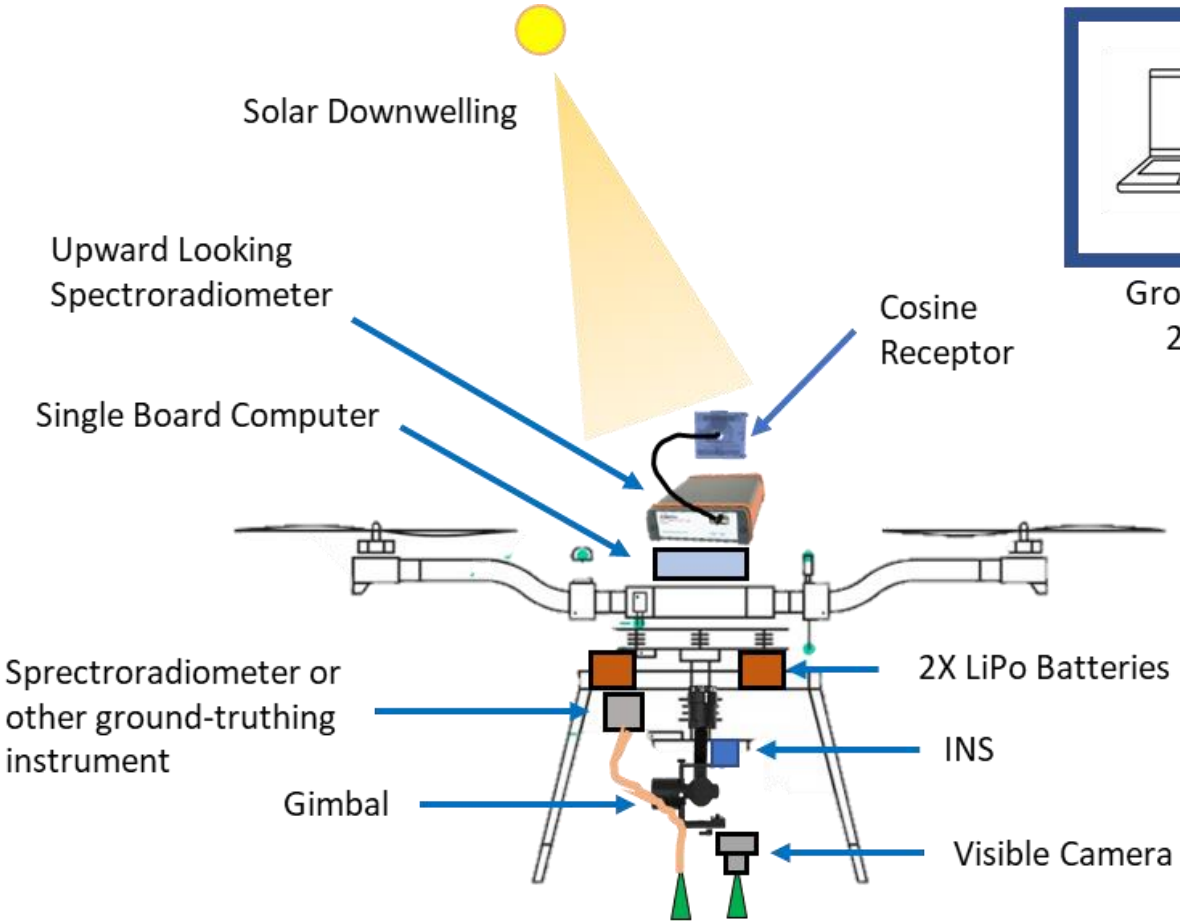
UAS CalVal Measurement Efficiency

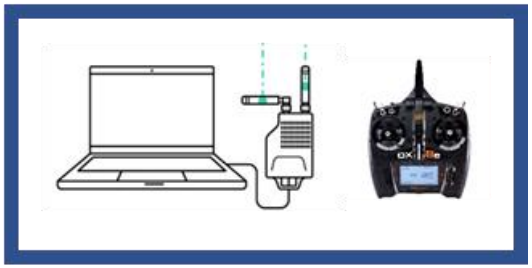
After 15 min (900 sec):

- UAS ~1000 pixels
- Walking straight line ~150 pixels
- Walking an area ~15 pixels



Notional Concept





Ground Control Laptop and 2.4 GHz Radio Control

Small UAS that falls under FAA Part 107 Guidelines

Payloads

Visible-Near Infrared (VNIR)

Visible-Shortwave Infrared (VSWIR)

Thermal Infrared (TIR)

VNIR Measurements

- Two Instrument Approaches
  - Single pixel, fiber-based measurements similar to current ground truthing methods
  - Hyperspectral pushbroom imager

Parameter	Headwall nano-Hyperspec VNIR Imaging Spectrometer	Avantes AvaSpec ULS2048CL-EVO
Dimensions (cm)	76.2 x 76.2 x 131	17.7 x 12.7 x 4.45
Weight (kg)	1.460	1.135
Range (nm)	400-1000	200-1100
Resolution at FWHM	6.0 nm	0.06 - 20 nm
Connections	Gigabit Ethernet	USB 3.0; Gigabit Ethernet
Instrument Power	13 W	12V DC, 300 mA (3.6 W)
Cross-track Pixels	640	1

VSWIR Instruments

- Two Instrument Approaches
  - Single pixel, fiber-based measurements similar to current ground truthing methods
  - Hyperspectral pushbroom imager

Parameter	Malvern Field Spec 4 Hi-Res NG	Spectral Evolution SR6500	Headwall Co-Aligned VNIR-SWIR Imaging Spectroradiometer
Dimensions (cm)	12.7 x 36.8 x 29.2	31.5 x 22.9 x 38.7	27.2 x 21.1 x 16.5
Weight (kg)	5.44	4.99	3.52
Range (nm)	350-2500	350-2500	400-2500
Resolution at FWHM	3.0 nm @ 700 nm 6.0 nm @ 1400 nm 6.0 nm @ 2100 nm	1.5 nm @ 700 nm 3.0 nm @ 1500 nm 3.8 nm @ 2100 nm	6.0 nm @ 400-1000 nm 8.0 nm @ 900-2500 nm
Connections	Ethernet	Bluetooth; USB	Gigabit Ethernet
Instrument Power	12V DC, 60 W	33 W	26 W
Cross-track Pixels	1	1	640

Upward Looking Solar Irradiance Measurements

- Spectroradiometer fiber is placed at the exit port of a small integrating sphere mounted at the top of the UAS
- Integrating spheres are excellent cosine receptors and provide a means by which solar radiance can be measured without having to point the fiber directly at the sun, which would be significantly challenging from a small UAS

TIR Measurements

- More challenging than VNIR/VSWIR
  - SST community has most stringent requirements
  - Non-imaging transfer radiometers commonly used
    - Uncooled, broadband, chopped, pyroelectric detectors
- Three Instrument Approaches
  - Slowly fly two or more spectrally filtered uncooled transfer radiometers
    - May require several seconds of integration time
  - Fly a cooled radiometer to provide rapid response and high sensitivity
    - Limited experience with this approach due to weight and cost
  - Fly an uncooled multispectral imaging radiometer.

Visible Imagery

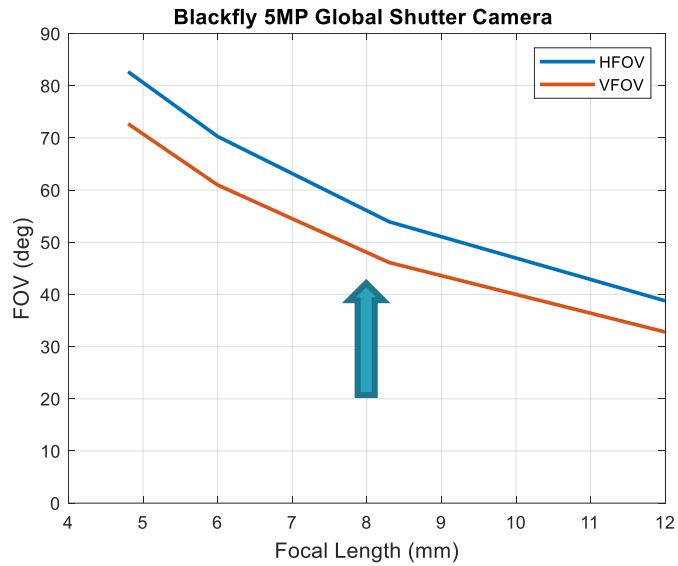
- Boresight with primary payload
  - Reference imagery
  - Create SfM-based digital elevation data and orthophotos
  - Virtual ground-truthing
  - Estimate BRDF

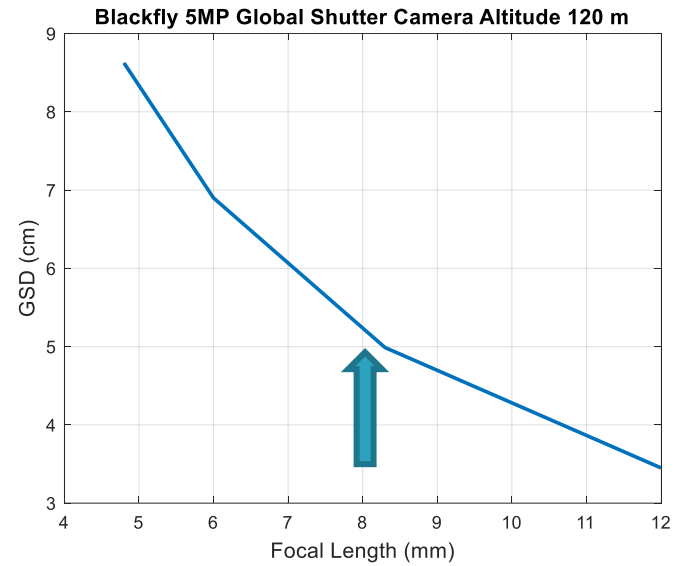
Visible Camera	FLIR Blackfly 50S5C
Sensor	Sony IMX264
Filter Pattern	RGGB (Bayer Pattern)
F-number	1.8-22
Shutter	Global
Focal Plane Array (FPA) Size	2448 (H) x 2048 (W)

Blackfly Camera

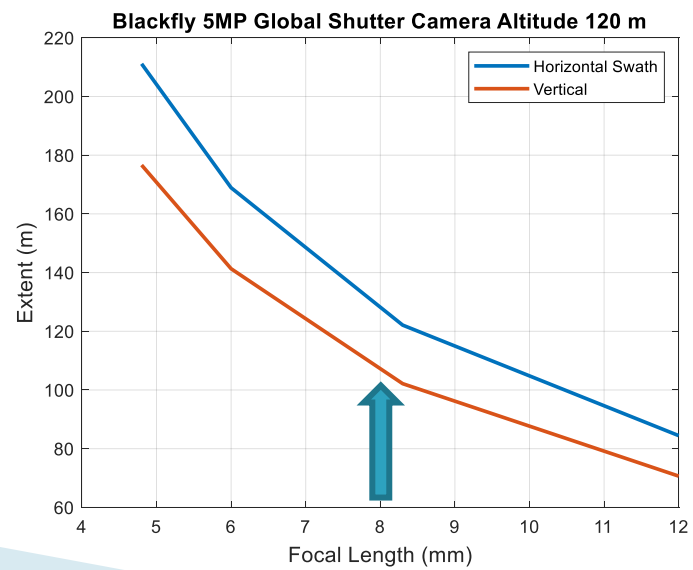
Fujinon Lens

High Resolution Visible Imagery





- Select lens based on mission needs
- For example, at 120 m alt, an 8mm lens would provide
  - 48 deg VFOV, 55 deg HFOV
  - 5.5 cm GSD
  - 108 m Vertical extent
  - 128 m Horizontal Swath



Additional Components

- On-board computing/data storage
  - NUC i7 single-board computer
- IMU
  - VectorNav VN100
- Gimbal
  - Sized according to payload weights

Parameter	Gremsy Pixy U	Gremsy T7 Heavy
Dimensions (cm)	11.2 x 14.5 x 20	26.0 x 25.3 x 34.5
Weight (kg)	0.465	1.860
Payload Capacity (kg)	0.465	3.180
Input Power (V)	14-52	15-52
Angular Vibration Range (deg)	0.02	0.02

Payload Summary

Payload Type	Mass (Kg)	ROM Price	UAS Lift Capacity
VNIR Spectroradiometer	3.75	$14,900	Moderate Lift
VNIR Hyperspectral Pushbroom Imager	3.97	$62,260	Moderate Lift
VSWIR Spectroradiometer	8.05 7.60	$100,260 $110,260	Heavy Lift
VSWIR Hyperspectral Pushbroom Imager	6.03	$210,260	Heavy Lift
TIR	5.12	$28,240	Moderate Lift

Moderate Lift Multi-Rotor UAS's

Parameter	Alta 8 Pro	UAS Systems International Aurelia X6 Pro	Harris H6 Hybrid HE+	Skyfront Perimeter 8
Payload Capacity (kg)	9.1	6.0	6.0	6.0
Flight Time with 5-6 kg payload (min)	15 (6.8 kg payload)	35	90	60
Maximum Diameter (mm)	1325	1270	1590	2000
Total Weight w/o payload (kg)	6.2	6.0	14.5	13
Battery or Hybrid	Li Battery 2 x 16Ah	Li Battery 2 x 21Ah	Hybrid 2 x 5Ah	Hybrid 1 x 4Ah
Battery Weight (kg)	4.0	3.6	1.6	0.88
1.2L Fuel Weight (kg)			0.9	0.9
ROM Price (base)	~$18K	~$6K	~$38K	~$60K

FAA Part 107 compatible

Heavy Lift Multi-Rotor UAS's

Parameter	Harris HX8 Efficiency	Alta X Quad	xFold X8 Cinema
Payload Capacity (kg)	15	15.9	8.2
Flight Time with 5-6 kg payload (min)	15-18	23	15
Maximum Diameter (mm)	1443	1415	1437
Total Weight w/o payload; (kg)	14	6.2	7.2
Battery Type	Li Battery 4x12Ah	Li Battery 2x16Ah	Li Battery 2x22Ah
Battery Weight (kg)	6.6	4.0	5.3
ROM Price (base)	~$28.5	~$22K	~$21K

FAA Part 107 compatible

Calibration UAS Hardware Summary

UAS / Payload	Battery Powered UAS		Hybrid Powered UAS	
	ROM Cost ($K)	Flight Time (min)	ROM Cost ($K)	Flight Time (min)
Moderate-Lift UAS with Non-imaging VNIR (fiber) Payload	$20.9-$32.9	15-35	$52.4-$74.9	60-90
Moderate-Lift UAS with Imaging VNIR Payload	$68.3-$80.3	15-35	$99.8-$122.3	60-90
Heavy-Lift UAS with Non-imaging VSWIR (fiber) Payload	$121.3-$138.8	15-23	N/A	N/A
Heavy-Lift UAS with Imaging VSWIR Payload	$231.3-$238.8	21-23	N/A	N/A
Moderate-Lift UAS with TIR Payload	$34.3-$46.3	15-35	$65.8-$88.3	60-90

Costs do not include engineering, assembly, software or required testing

Calibration UAS Summary

- Several approaches that utilize NIST-traceable instrumentation mounted on small, multi-rotor UAS's were explored
- Components that comprise a relatively low-risk VNIR-based calibration system using a fiber-based spectroradiometer mounted on a moderate-lift UAS can be purchased for as little as $21K (ROM).
- On the other extreme, components that comprise a higher risk imaging VSWIR-based calibration system mounted on a heavy-lift UAS would cost nearly $240K (ROM)
- There are less off-the-shelf options for the TIR. To fully address the TIR radiometric calibration needs, there may need to be custom instrumentation development.