Water-tightness Airborne Detection Implementation

D.3.3 – Onboard UAV integrated sensors system.

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Executive Summary

The development of an UAV (RPAS) water leak detection surveillance service requires the integration of all electrical, mechanical and computing systems that will intervene during the process of acquiring the ground imagery from the RPAS. Fortunately, the availability of miniaturized sensors in the market and the lack of serious difficulties to record the data on board of the RPAS has facilitated us the onboard integration of the different subsystems.

Nevertheless, the selected RPAS has solved the limitations in terms of payload and direct geo-referencing is achieved automatically using an autopilot with IMU and a GNSS (EGNOS) receiver that have allowed good geo-referencing results without any ground control points by the combination of bundle block adjustment and autopilot position data.

A particular attention has been placed on sensors ability to cope with the different constraints generated by an airborne use, i.e.: weight, dimension, power requirements, and ability to sustain altitude, temperature and vibrations. In order to accommodate the selected cameras, several mechanical and electronic adaptations have been designed, tested and finally installed for its use in real conditions during the further activities in the project.

The establishment of the overall requirements, recommendations for the optimal selection of a flying VNIR multi-spectral/IR cameras payload done during the first task of the WP.3 (D.3.1), has been very useful to study the Technical Specification documents for the cameras and other necessary complementary components (gyro stabilizing mounts, onboard computing system…), which will provide documentation to prospective cameras providers. Apart of these points that constrain the architecture of the system other relevant considerations (e.g. the easiness of use, best value for money, best time to deliver...) have been taken into account to select the cameras (sensors) to be finally mounted and tested in the RPAS.

Another important subsystem of the sensors integration is the ground segment. Apart from the work to be done in the RPAS, this subtask foresees the work for preparing the information to be displayed and monitored during the mission for the RPAS operator in the ground monitoring station. With the proposed monitoring station, the operator is able to manage the full operation parameters and change them during the flight if necessary and check if the flight is being developed according to the flight plan. In fact, the remote monitoring system has been tested using adaptation of the existing communication protocols between UAV and ground monitoring station.

This onboard RPAS integrated sensors system deliverable presents the architecture and integration details of a RPAS for water leak detection surveillance service, and describes the main components of the system, outlines the system architecture and all the process and work done for achieving the desired results. Thanks to the successful integration work done we have been able to assess afterwards the RPAS in different conditions (Subtask 3.3.2).

1 Table of Content

List of Acronyms

AGL Above Ground Level

APP Mobile application

CCW Counterclockwise

CW Clockwise

D.n Deliverable n

EMI Electromagnetic Interference

GNSS Global Navigation Satellite System

IR InfraRed

LOS Line of Sight

LWIR Long Wave InfraRed

MC Multispectral Camera

MTOM Maximum takeoff mass MTOM

NETD Noise Equivalent Temperature Difference

NDVI Normalized Difference Vegetation Index

OSAVI Optimized Soil Adjusted Vegetation Index

PWN Pulse-Width Modulation

RPAS Remotely Piloted Aircraft System

SWIR Short Wavelength InfraRed

S/N Signal to Noise ratio

TC Thermal Camera

UAV Unmanned Aerial Vehicle

VNIR Visible and Near InfraRed

WP.n Work Package n

RE Red Edge

2 Sensors to be integrated.

Two kind of sensors (cameras) have been integrated, on one hand a Multispectral Camera (MC) measuring visible spectral ranges but also the Red Edge (RE) band and the visible and near infrared (VNIR), since we are looking for anomalous vegetation growth which affect the typical physical effects in terms of darkening surface, and vegetation characterization. The associated physical parameters (i.e. reflectanceor radiance) can be extracted from the multispectral images acquired in particular spectral ranges. On the other hand, the other sensor to be integrated is a Thermal Camera (TC), as the temperature is measured in the Infrared (IR) spectral range and particularly a Long-wavelength infrared camera (LWIR) will be installed in the RPAS.

The airborne measurement tests using the MC and TC will be the basis for the real RPAS field campaigns of WP.5 and WP.6. Thanks to the success in the integration efforts, we have contributed definitely to the development of WADI's innovative concept integrating existing in the market (off-the-shelf) cameras operating at the required wavelengths, instead of using complex and expensive hyperspectral systems. This section consists of two main parts. In each one, we expose each selected MC and TC respectively, according to the set of requirements, recommendations made in D.3.1, that our selected sensors accomplish thoroughly when are mounted on RPAS. Such is a case for instance for requirements concerning to the image blurring (R_04) or several constraints like the environmental conditions (R_24), compactness (R_25) or resistance to dust, moisture, vibrations, electromagnetic fields and different environmental conditions (R_27, R_28, R_29, R_30, R_31 and R_32).

2.1 Multispectral Camera (MC)

For the MC selection it is clear that we have to be able to obtain the vegetation index necessary for the triangle/trapezoid method (NDVI, or preferably OSAVI), to study anomalous vegetation growth or the detection of a change in the type of vegetation require a multi-temporal surveillance service at different times or seasons. Furthermore, the change of vegetation nature can require a comparison with a reference scene. Therefore, one wavelength on each side of the red edge is necessary. Fortunately, the choice is not very strict: typically, between 0.65µm and 0.675µm for the first one and between 0.79µm and 0.87µm for the second one.

2.1.1 Candidates

All MC and imaging spectrometers in general collect data over three dimensions—two spatial (x, y) and one spectral (λ)—so that the complete (x, y, λ) dataset is typically referred to as a data-cube. The most common method used to categorize the various types of imaging spectrometers is by the portion of the data-cube collected in single detector readout.

For the selection of the camera we have taken into account the previously commented acquisition modes summarized below:

	Main features
Line-scanning (push-broom)	• High spatial resolution • Requires motion to occur
Multi-cameras	• Simultaneous capture of several discrete spectral bands (< 7) • Rugged design with no moving parts • Up to 6 optical paths
Sequential multispectral	• Interchangeable standard or custom spectral filters • Non simultaneous acquisition of multispectral information from a scene (rotating filter wheel)
Snapshot mosaic	• 4 × 4 or 5 × 5 mosaic patterns repeated continuously on the sensor surface. • Snapshot multispectral imager eliminates artefacts caused by motions in flight (global shutters expose the entire image at the same instant)

Table 2. 1 MC candidates main features

2.1.2 Final selection justification

For the final selection we have taken in consideration the potential VNIR cameras candidates proposed in the D.3.1 as shown below:

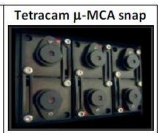
	S 137 Butterfly NIR	S219	DragonflEYE L6	RedEdge	Parrot Sequoia	Multispec NDVI-PRI	Tetracam µ-MCA snap
							
Acquisition mode	Snapshot	Snapshot	Snapshot	Snapshot	Snapshot	Snapshot	Snapshot
Detector	Si CMOS	Si CMOS	Si CCD				CMOS
Spectral range	600 - 875 nm	380 - 1100 nm	380 - 1100 nm	480-550-660-720-830 nm	550-660-735-790 nm	530-570-660-790 nm	380 - 1000 nm
Number of spectral bands	25	4	6	5	4	4	4
Number of pixels	400*218	4x 1296*966	4x 1296*966	1280*960	4x 1280*960 pixels	4 x 1.2 Mpix	4x 1280*1024 pixels
Spectral resolution/Channel width	20 nm	20 nm	20 nm	10 - 40 nm	10 - 40 nm		
FOV				47.2° (f = 5.5 mm)	70.6° x 52.6°	67° x 53°	38.3° x 31°
SNR	39 dB	39 dB					
Pitch on the ground @ 800 ft (AGL)				16 cm	26 cm	22 cm (IFOV: 0.9 mrad)	13 cm
Swath width @ 800 ft (AGL)				213 m	345 m	323 x 243	168 x 134 m
Exposure time	0.1 - 1000 ms	0.1 - 1000 ms	0.1 - 1000 ms				
Frame rate	20 FPS	4 FPS	typ. 2 FPS (max. 10)	1 capture/s (all bands)	up to 2 FPS		
Shutter	Global	Global	Global	Global	Global	Global	
Digitization	10 bit	8 bit	8 bit	12 bit	10 bit		10 bit
Power	15 W @ 9-24 V	15 W @ 9-24 V	DC 15 W @ 9-24 V	5.0 V DC, 4 W nominal	8 W nominal (12 W peak)		
Weight	350 g	800 g	500 g	180 g	135 g	160 g	500 g
Size				121 x 66 x 46 mm3	59 x 41 x 28 mm3	78 x 121 x 61 mm3	116 x 80 x 68 mm3
Computer interface	USB, GigE	USB, GigE	USB, GigE	Serial, Ethernet, GPS			USB 2.0
Operating temperature	0°C to +40°C	0°C to +40°C	0°C to +40°C				0°C to +40°C
Manufacturer	Cubert	Cubert	Cubert	MicaSense	Parrot	Airinov	Tetracam
Remarq		4 sensors	6 sensors	5 cameras	4 cameras	4 cameras	

Figure 2. 1 MC initial proposal

We examined them according to the stated requirements, recommendations and its aptitude for being integrated in our RPAS platform. Even though the candidates cameras satisfy most of the spectral and image requirements some solutions are more miniaturized and more RPAS-oriented designed than others. That's the case for the models DragonfEYE L6, Rededge, Sequoia, Multispec and micro-MCA.

However, still having considerable differences in weight among the models, and since the models with less of 200 g have very good spectral detection capabilities and fully accomplish the requirements and recommendations, we reduced the candidates to Rededge, Sequoia and Multispec. From these three final candidates we selected the Rededge model from Micasense, because of its great integration and configuration capabilities as well as a greater number of bands and image resolution. The selected model is in line with the WADI's innovative concept of integrating already existing multispectral and RPAS oriented cameras with a competitive price compared to other airborne systems or not market RPAS-oriented.

2.1.3 Rededge main camera features

This selected model provides multiple options for integration - from stand-alone to fully integrated. Advanced integrations take advantage of flexible interfaces including Ethernet, serial, GNSS, and trigger, for seamless integration with any drone.

A compilation of its basic specifications is shown in the following table:

BASIC SPECIFICATIONS	
Weight	150 g
Dimensions	12.1 cm x 6.6 cm x 4.6 cm (4.8" x 2.6" x 1.8")
Power	5.0 V DC, 4 W nominal
Spectral Bands	Narrowband: Blue, Green, Red, Red Edge, Near IR
Ground Sample Distance	8.2 cm/pixel (per band) at 120 m (400 ft.) AGL
Capture Speed	1 capture per second (all bands), 12-bit RAW
Interface	Serial, Ethernet, GPS
Field of view	47.2° HFOV

Table 2. 2 Rededge MC basic specifications

The camera measures five bands comprising VNIR spectrum with good bandwidth as shown below:

Band Number	Band Name	Center Wavelength (nm)	Bandwidth FWHM (nm)
1	Blue	475	20
2	Green	560	20
3	Red	668	10
4	Near IR	840	40
5	Red Edge	717	10

Table 2. 3 Rededge MC bands description

These spectral features allow us gathering data from the most interesting bands describing the plant reflectance in order to detect anomalous vegetation growth during the inspections of the pipes path (NDVI / OSAVI indexes process).

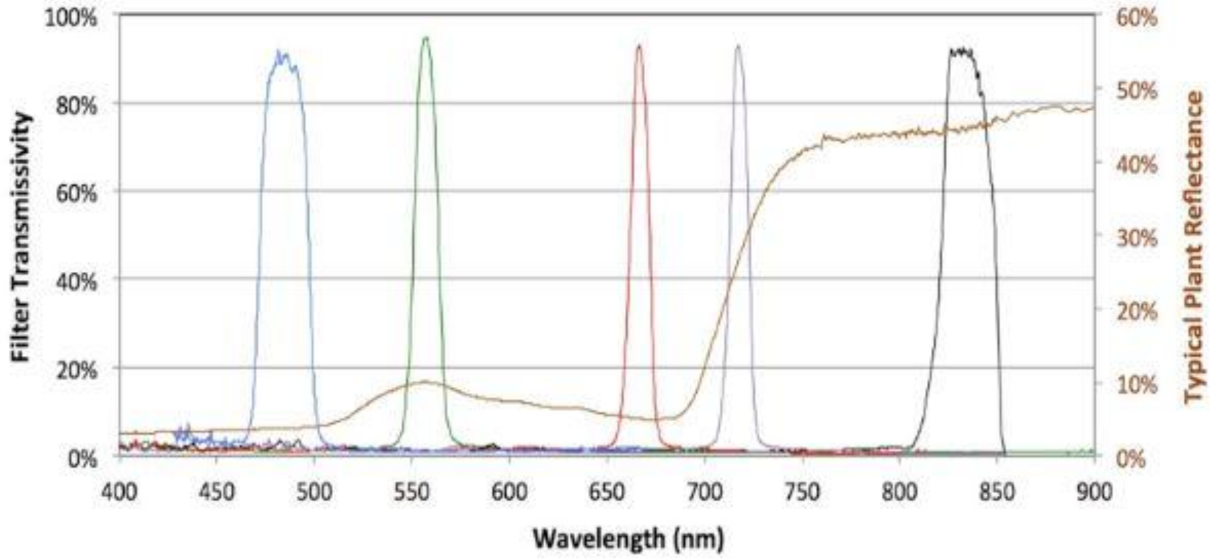


Figure 2.2 Bands distribution and typical plant reflectance

In the following figure we can see the position of the different sensors for each discrete spectral band. It has a rugged design with no moving parts

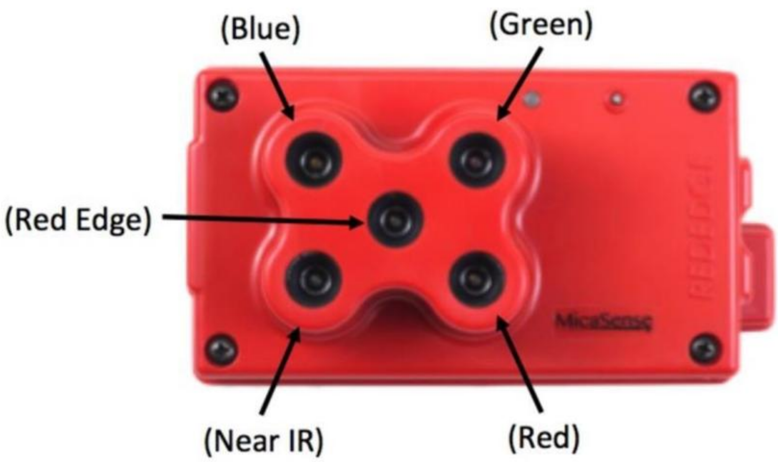


Figure 2. 3 Rededge MC with the different integrated band sensors

The mentioned spatial resolution is more than enough for the leakage inspections at very high spatial resolution (8 cm at 120m, AGL):

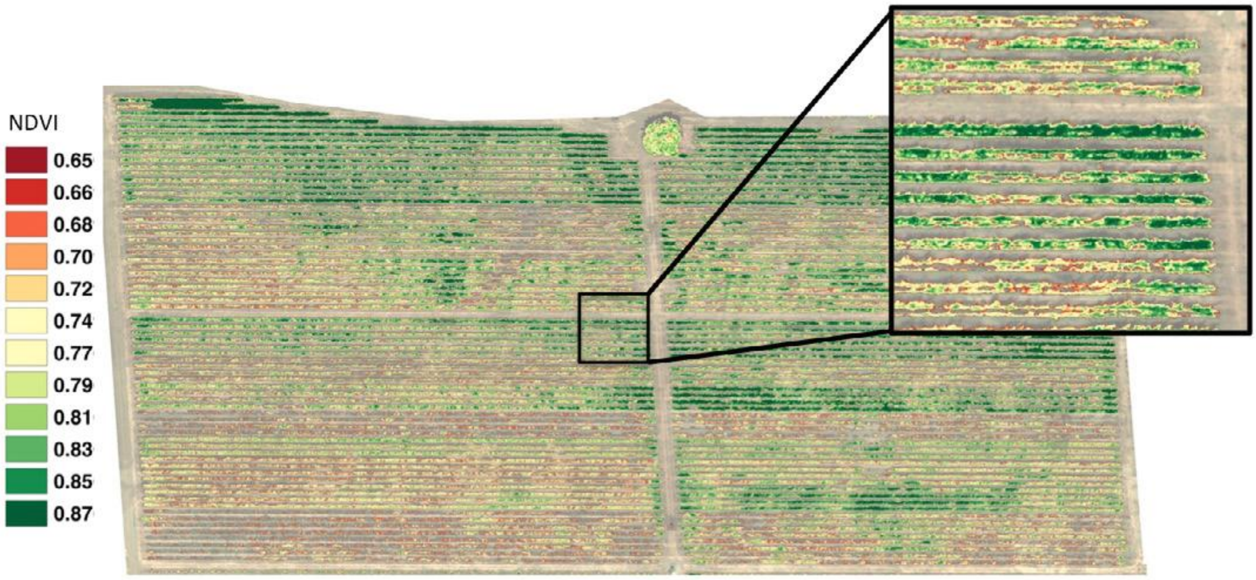


Figure 2.4 Rededge MC very high spatial resolution example

The RedEdge camera hosts a Wi-Fi access point that is used in conjunction with any Wi-Fi-capable device for configuration of the camera and live preview of images acquired with the camera, here we insist again in the fact that is very user friendly and oriented to the final customer in spite of being a complex product. In fact, the configuration tool allows the users to define the capture parameters of the images and questions like overlap, coverage, geo-referencing, reflectance settings or triggering.

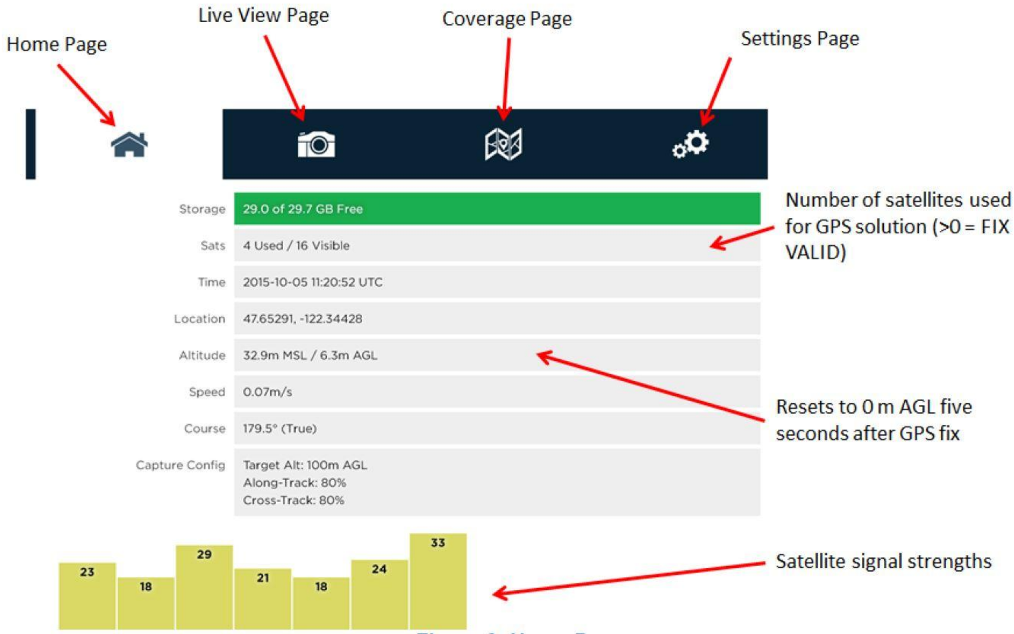


Figure 2.5 Rededge MC configuration access point

The following figures show different parameters for mission planning and file storage planning.

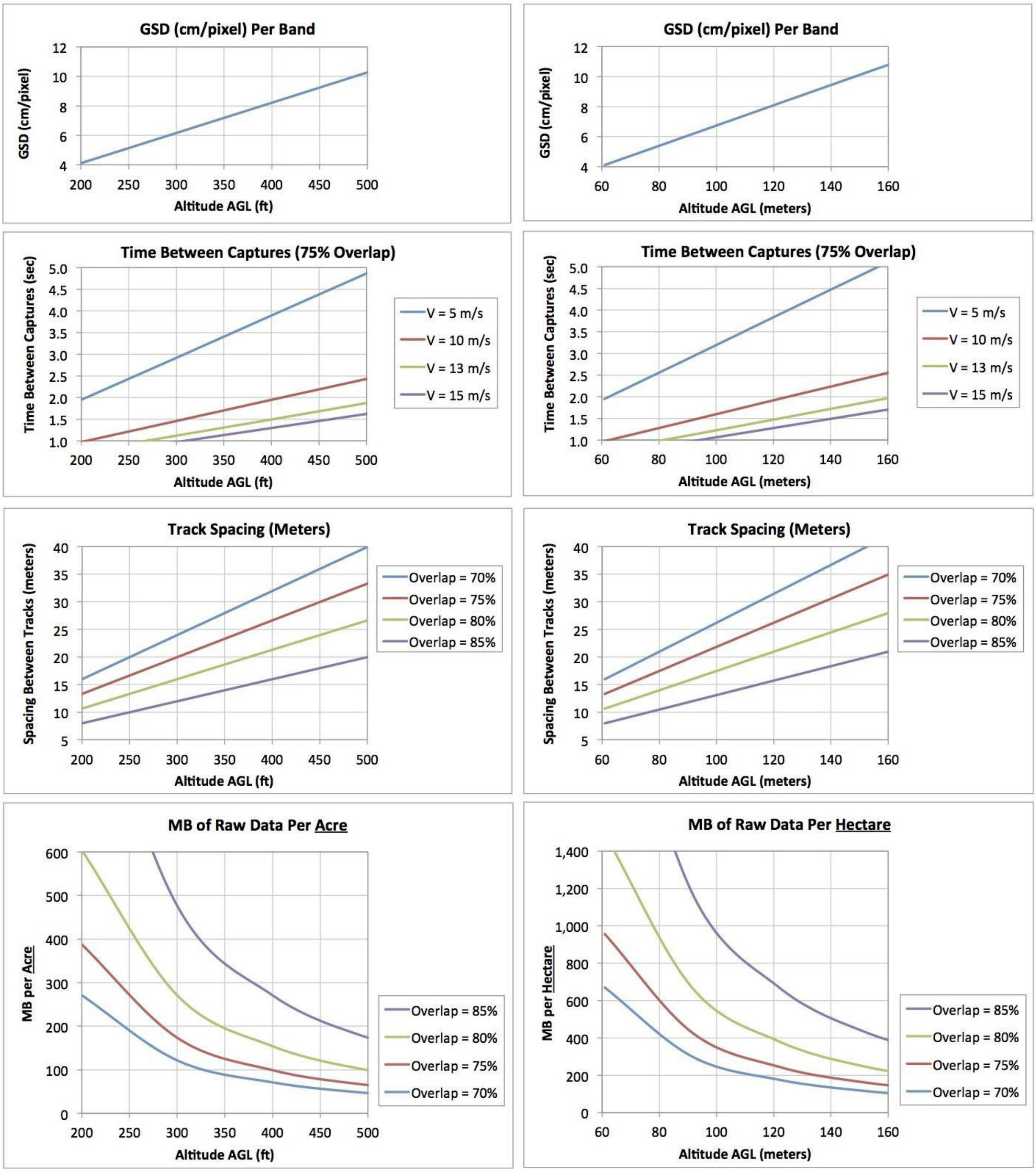


Figure 2. 6 Mission planner configuration parameters

2.1.4 Rededge details for integration

The selected model is very easy to integrate in the RPAS, with serial ports and connections to autopilot and GNSS data. The data storage is also very easy to access and consists in a SD card module. It has a rugged design with no moving parts, resists blow, and harsh environments.

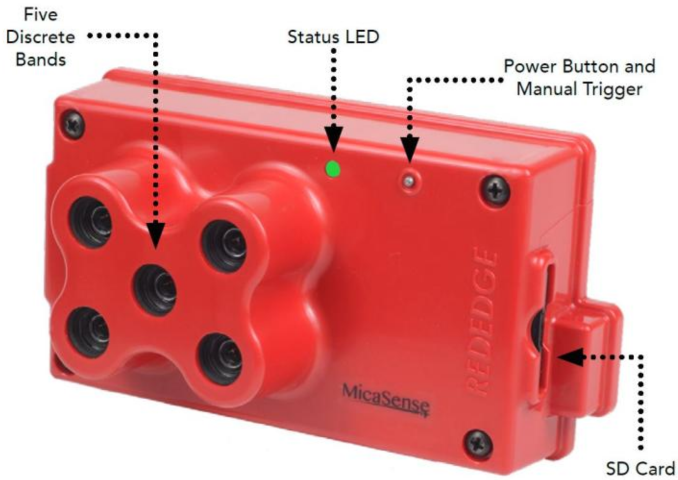


Figure 2. 7 Rededge MC elements detail

Regarding powering, it requires 5.0 Volts DC for operation, with a maximum operating voltage of 5.5 Volts. The supply must be able to provide 10W (2A@5V) peak. Power can be provided by a 5.0-Volt battery pack, a rechargeable Lithium-Ion battery pack with appropriate BEC, a power supply or with shared power from aircraft's main battery.

Nominal Voltage	Nominal Voltage
5.0 V DC	5.0 V DC
Voltage Range	4.5 V to 5.5 V DC
Absolute Maximum Voltage	5.5 V DC
Average Power	3.5 Watts average, 4.5 W peak (Camera Not Providing Power to External GPS Module)
	4.0 Watts average, 5.0 W peak (Camera Providing Power to External GPS Module)

Table 2. 4 Rededge MC power values

The camera can be triggered either with a rising-edge/falling edge pulse or a PWM signal (such as is typically used with standard servos). When using a PWM signal as the trigger, the camera detects a transition from a “long” PWM to a “short” PWM (or vice-versa depending on the configuration setup of the camera).

Item	Value
Nominal Voltage	3.0 V DC
Voltage Range	0.0 V DC to 5.0 V DC
Absolute Maximum Voltage	Voltage Range
Absolute Maximum Voltage	5.0 V DC
PWM Trigger Expected Range	1.0 ms to 2.0 ms

Table 2. 5 Rededge MC trigger voltage

Signal definitions and connectors:

Pin #	Signal
1	Trigger
2	Ground
3	Power
Connector on Camera	Hirose DF13A-3P-1.25H(21)
Mating Connector	Hirose DF13-3S-1.25C28AWG

Table 2. 6 Rededge MC trigger pins detail

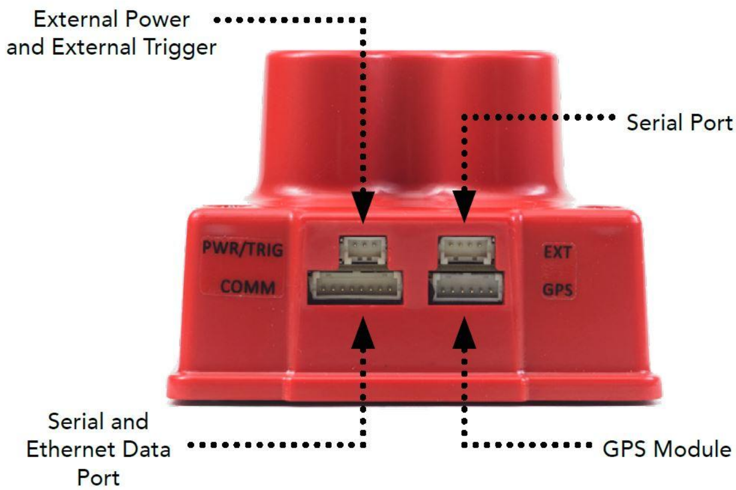


Figure 2. 8 Rededge MC external conectors

Below, an example of pin 1 indicator on DF13 family of connectors (DF13-3S-1.25C)

Figure 2.9 DF13 connector

The dimensions and weight (160 grams), are very suitable for a great variety of professional RPAS.

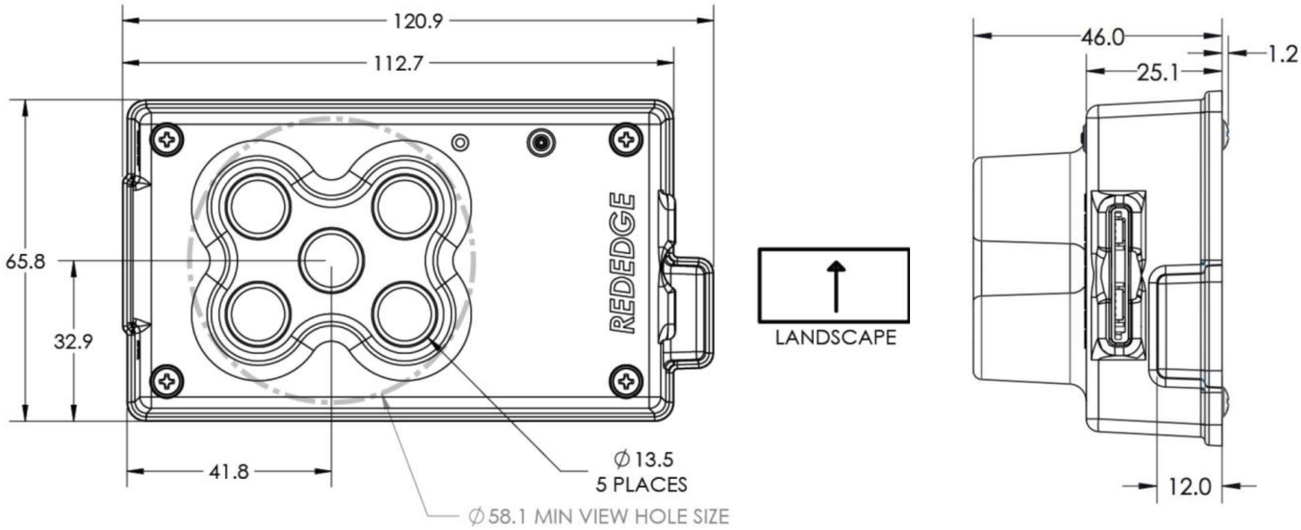


Figure 2. 10 Front and lateral dimensions

The camera was attached to the RPAS using the provided threaded mounting points. Four screws were used for this purpose. Thanks to global shutter imager technology, the camera is able to withstand some vibration without degrading image quality; nevertheless, vibration isolation between the camera mounting platform and the RPAS is recommended and a very light coating of non-permanent thread locker was used to prevent the screws from coming loose due to vibration. Wipe off excess thread locker from screw prior to insertion.

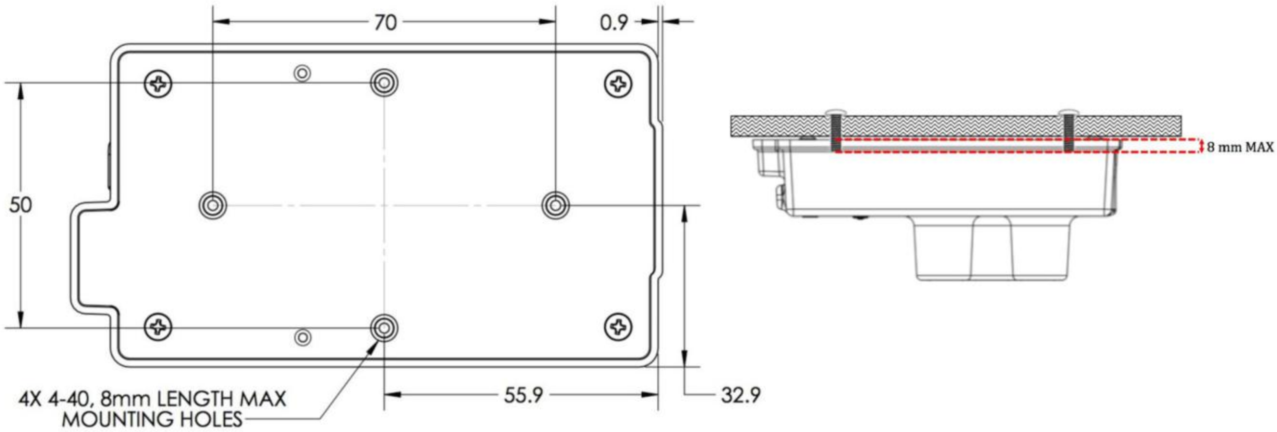


Figure 2.11 Back dimension with screws details and foam protection for vibrations.

The camera was integrated in the RPAS deck such that it has a clear view of the area directly below it. The “cone” of the lenses (47.9 degrees total Horizontal Field of View) was considered in the process of deciding where to mount the camera on the aircraft or payload bay.

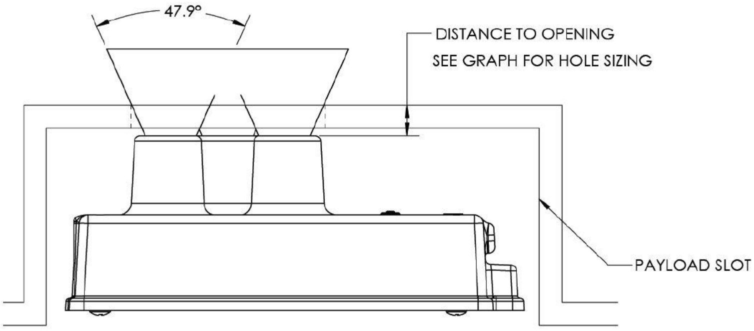


Figure 2. 12 Field of view detail

A GNSS module is used for providing geo-reference information to the camera, it was installed in a location of the aircraft where it will have a clear view of the sky and installed far away from any devices that could interfere with it (datalink or video transmitters for instance).It is critically important that the GPS module be mounted away from electric current sources which can produce electromagnetic interference (EMI), such as batteries, wires, and other electrical equipment on the drone.

Below we can see the signal definitions and connector. The camera uses the ublox UBX binary protocol for communication back and forth to the GPS using the NAV and RXM data classes

Pin #	Signal	Direction
1	5.0 V DC Output	Output From Camera
2	GPS RX	Output From Camera
3	GPS TX	Input To Camera
4	GPS PPS	Input To Camera
5	Not Connected	N/A
6	Ground	Ground
Connector on Camera	Hirose DF13A-6P-1.25H(21)	
Mating connector	Hirose DF13-6S-1.25C	

Table 2. 7 Camera different PIN connectors configuration

2.2 Thermal Camera (TC)

These cameras are employed to receive IR emissions of the soil, since a fast change of the temperature enables us to detect an anomalous emission related to presence of a moist underground volume. We use the TC for detecting anomalies in temperatures (moisture) content according to the triangle/trapezoid method. Therefore, an infrared camera in the thermal wavelength (8-12 μm) was selected for the leakage inspection missions, taking into account the RPAS features, then a slow micro-bolometer camera is sufficient.

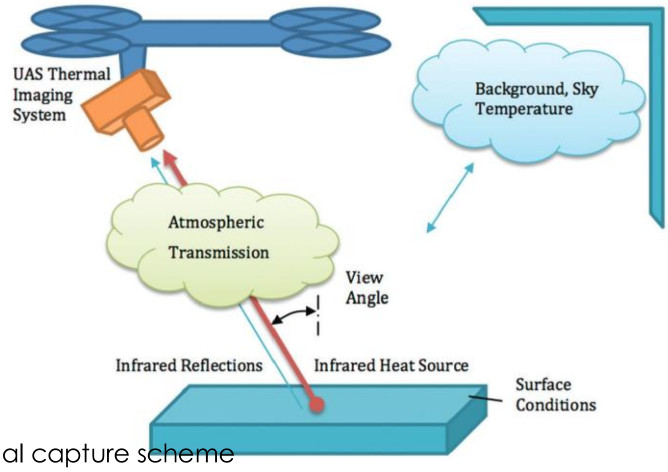


Figure 2. 13 RPAS thermal capture scheme

2.2.1 Candidates

As known, there were proposed two classes of thermal imaging camera systems available on the market today: cooled and uncooled systems:

-. Cooled infrared cameras, having an imaging sensor that is integrated with a cryo-cooler, allowing a better sensitivity (thermal contrast). With this camera feature NETD, it is easier to detect objects against a background that may not be much colder or hotter than the object. Cooled cameras have adjustable integration times and make use of a global shutter. This means that they will read out all pixels at the same time, as opposed to reading them out line by line, which is the case with uncooled cameras. This allows cooled cameras to capture images and take measurements on moving objects without image blurring.

-. Uncooled infrared cameras (microbolometers), in which the imaging sensor does not require cryogenic cooling, are generally much less expensive than cooled infrared cameras, have fewer moving parts and tend to have much longer service lives than cooled cameras under similar operating conditions. They have smaller sensitivity characteristics than cooled cameras and their response time is not adjustable.

2.2.2 Final selection justification

Below are shown some TC proposed candidates, however most of them are more appropriated to be mounted on tripods or manned aircrafts because of their weight, size and connections.

	InfraTec ImageIR 8820	FLIR A6751sc SLS	NOXCAM 640L	TELOPS TS-IR LW	VarioCAM HD head	FLIR A655sc	XENICS GOBI-640-17-50-GE
Detector	MCT	SLS	MCT	MCT	Microbolometer	Microbolometer	Microbolometer
Spectral range	8 - 10.2 mm	7.5 - 9.5 µm	7.7 - 9.3 µm	7.7 - 9.3 µm	7.5 - 14.0 µm	7.5 - 14.0 µm	7.5 - 14.0 µm
Number of pixels	640 x 512	640 x 512	640 x 512	640 x 512	640 x 480	640 x 480	640 x 480
Detector pitch	16 µm	15 µm	15 µm	15 µm	25 µm	17 µm	17 µm
Sensor cooling	YES (stirling)	YES (stirling)	YES (stirling)	YES (stirling)	NO	NO	NO
Maximum frame rate (full frame)	100 Hz	125 Hz		230 Hz	60 Hz	50 Hz	50 Hz
Accuracy	+/-1 °C or +/-1 %	± 2°C ou ± 2%	+/-1 °C	1 K ou 1 % (°C)	± 1.5 K ou ± 1.5 %	± 2°C ou ± 2%	
NETD	< 40 mK	< 30 mK	< 30 mK	22 mK	< 30 mK	< 30 mK	50 mK
Integration/Response time	50 µs à 200 µs	480 nsec. à 687 sec.				Typical 8 ms	
Computer interface	GigE, USB	GigE	GigE	Camlink, GigE	GigE	GigE	GigE
Digitization	14 bit	14 bit	14 bit	16 bit	16 bit	16 bit	16 bit
Power consumption		< 50 W	< 50 W	50 W	~ 8 W		< 4.5 W
Optics	13 mm (43 x 35)°	13mm (40,5 x 33°)	12 mm	13 mm (32.9 x 40.9°)	15 mm (56.1 x 43.6°)	13 mm (45 x 34°)	15 mm
Size (mm)	250 x 160 x 123	200 x 100 x 100	186 x 136 x 146	320 x 198 x 135	190 x 90 x 94	216 x 73 x 75	49 x 49 x 77
Weight w/o lens	4.0 kg	2.3 kg	< 2,3 kg	< 8 kg	1.15 kg	0.9 kg	0.22 kg
Distributor	Distrame SA	FLIR	Noxant	TELOPS	Distrame SA	FLIR	STEMMER Imaging

Figure 2. 14 TC initial proposal

Due to their better sensitivity and faster response time (factor limiting image blurring), a cooled LWIR camera would be preferred. However, after studying the proposed camera options, we noticed than one of the manufacturers (FLIR) has specific models more appropriated to be mounted on RPAS and specifically the LWIR camera FLIR VUE PRO R 640 13MM, 30 HZ. This model was finally selected for its radiometric capabilities, weight and its design for being integrated in RPAS platforms. The selected model is also in line with the WADI's innovative concept of integrating already existing multispectral and RPAS oriented cameras with a competitive price compared to other airborne systems or not market RPAS-oriented.

Figure 2. 15 Selected model FLIR VUE PRO R 640 13MM, 30 HZ

2.2.3 FLIR VUE PRO R main camera features

This TC is marketed as a radiometrically corrected thermal camera specifically designed for small UAV. The manufacturer claims that it records accurate, calibrated temperature data, rather than uncalibrated values found on other thermal sensors. It captures accurate, non-contact temperature measurements from an aerial perspective and saves images with calibrated temperature data embedded in every pixel.

Overview	FLIR Vue Pro R 640
Thermal Imager	Uncooled VOx Microbolometer
Resolution	640 × 512
Lens Options	13 mm; 45° × 37°
Spectral Band	7.5 - 13.5 µm
Full Frame Rates	30 Hz (NTSC)
Exportable Frame Rates	7.5 Hz (NTSC
Measurement Accuracy	+/-5°C or 5% of reading in -25°C to +135°C range +/-20°C or 20% of reading in -40°C to +550°C range
Size	2.48" × 1.75" x 1.75" (including lens)
Precision Mounting Holes	Two M2x0.4 on each of two sides & bottom One 1/4-20 threaded hole on top
Image Optimization for sUAV	Yes
Scene Presets & Image Processing?	Yes - Adjustable in App
Invertible Image?	Yes - Adjustable in App
Color Palettes	Yes - Adjustable in App and via PWM
Zoom	Yes - Adjustable in App and via PWM
Input Voltage	4.8 - 6.0 VDC
Power Dissipation (peak)	2.1 W (3.9 W)
Radiometric Temperature Range	0°C to +40°C
Operating Temperature Range	-20°C to +50°C
Non-Operating Temperature Range	-55°C to +95°C
Operational Altitude	+40,000 feet

Table 2. 8 TC main features

The selected model seems to provide real world surface temperature values, and it has been designed specifically to attend the demand of the emerging RPAS applications market

One big advantage of this selected model is that it is software/connector compatible with many MAVLink autopilots for automated image capture and image geo-tagging, the same Accessory Port connection gives us access to two camera controls over commands, so we can select color palettes, start and stop recording, or trigger the camera's e-zoom in-flight from the radio controller. The TC can be configured to use this bus to capture available telemetry data provided by GPS, altimeter, accelerometers, etc. This data is saved as standard EXIF metadata in Still Image files (JPEG & TIFF). This data is not saved to Video files as there is no current standard for doing this. Metadata is accessible through standard photo editing applications, file explorers, and mapping applications.

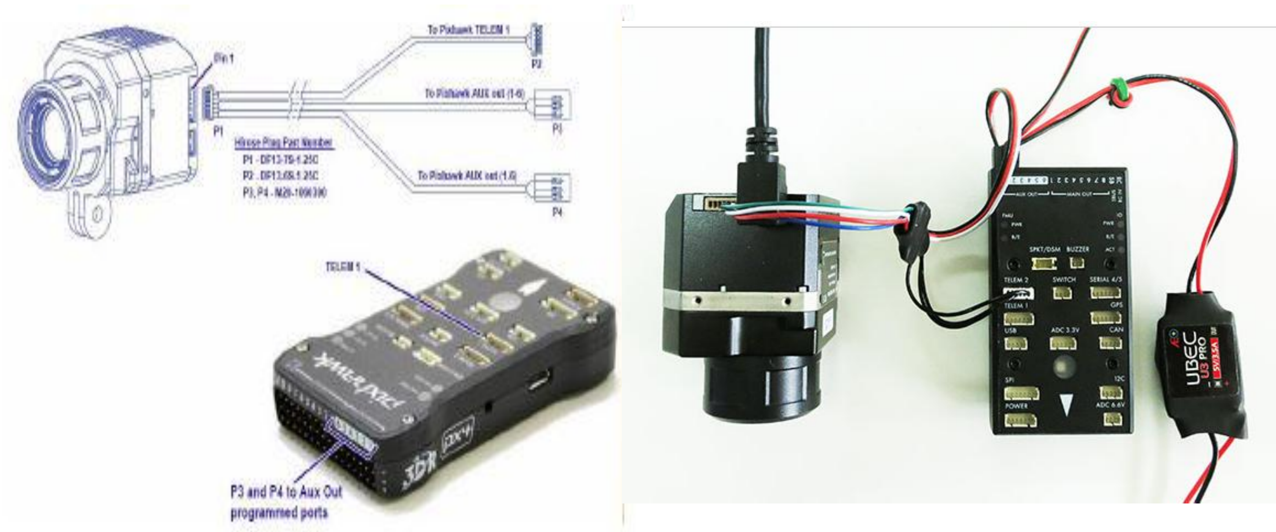


Figure 2. 16 TC integration with the autopilot

Another big advantage and very interesting feature is that it is managed through an APP as primary available control interface. It is compatible with many mobile devices equipped with Bluetooth LE running iOS 8.0 or later and Android V 4.3 or above. Manual controls are available to fine-tune the image for a particular scene. Manual adjustment is not required but it has the possibility of optimizing the image to bring out key details in a scene. This APP gives us lot of advantages for change color palettes, set the image optimization features, configure inputs, and start recording all without lugging a computer to the field.

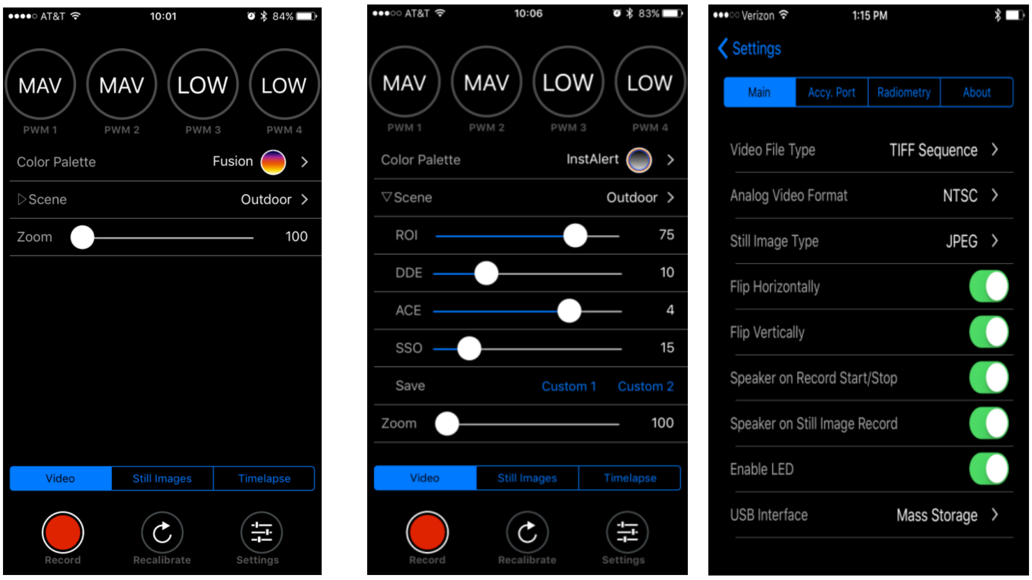


Figure 2. 17 APP from FLIR for camera configuration parameters

It records 8-bit digital video in MOV format or H.264 formats and 14-bit still imagery to a removable micro-SD card so we don't lose any of the data to transmission loss. Imagery is saved to the micro-SD card and can be retrieved either from the card or by plugging the camera into a USB cable, where the computer sees it as a storage device.

Figure 2. 18 TC image example taken from RPAS

2.2.4 FLIR VUE PRO R details for integration

The TC integration with the RPAS is quite quick as is designed and prepared for that, in first place its dimension is quite moderate to be mounted in the most of professional RPAS in the market. The camera has two threaded mounting holes on each side of the housing, as well as on the bottom. These threaded holes, 24mm (0.945 in) apart accept M2x0.4 screws.

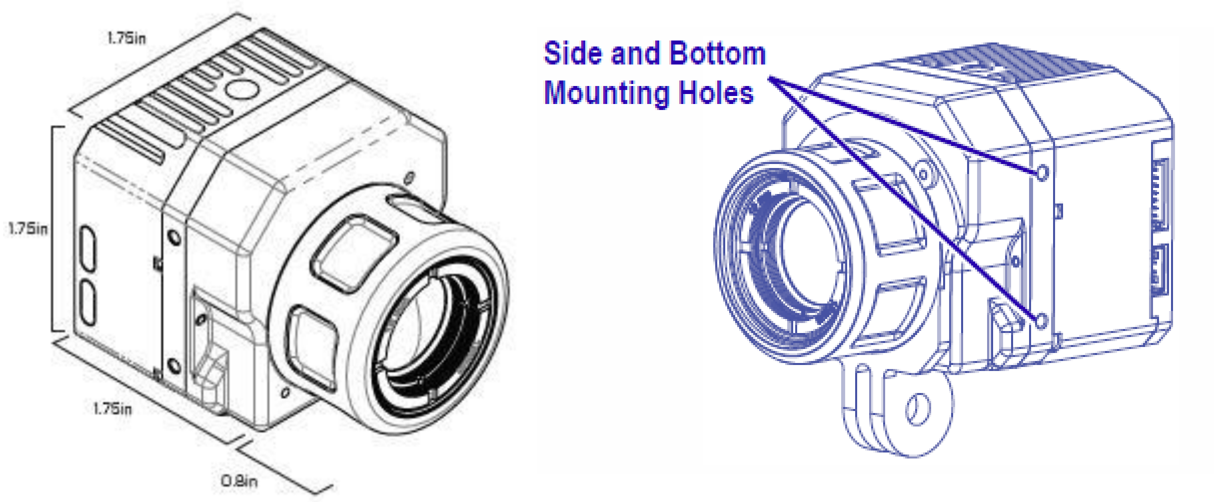


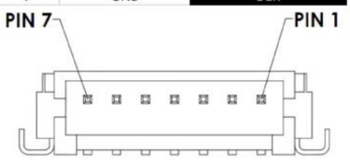
Figure 2. 19 TC dimensions and mounting holes for screws

The camera is compatible with many commercial off-the-shelf (COTS) 10-pin mini-USB cables that are used to provide power to, and receive video from, action cameras commonly mounted on small RPAS, simply plugging the chosen cable into the mini-USB port, power supply, and video to a downlink, if desired. Approximate operating current of the TC is 420 mA at 5Vdc. Inrush current can reach as high as 600 mA. The Accessory Cable is for connecting FLIR Vue Pro to a MAVLink compatible autopilot and/or standard R/C PWM outputs. The MAVLink interface operates at a default data rate of 57.6 kbps.

7PIN ACCESSORY PORT

MATING PLUG: DF13-7S-1.25C

Pin	Signal	WIRE COLOR
1	PWM_1	GRN
2	PWM_2	WHT
3	GND	BLK
4	PWM_3	ORG
5	GND	BLK
6	PWM_4	BLU
7	GND	BLK



10PIN mini-USB CONNECTOR

Pin	Signal	Notes
1	PWM_1	N/A
2	MAIN_PWR	4-6 VDC
3	PWM_2	N/A
4	DATA_L	USB PIN 2, GRY
5	VIDEO_L	D_GND
6	DATA_H	USB PIN 3, GRN
7	VIDEO_H	75Ω IMPEDANCE
8	-	NO CONNECT
9	-	NO CONNECT
10	MAIN_PWR_RTN	POWER GROUND
FRAME	DRAIN	TO CABLE SHIELD

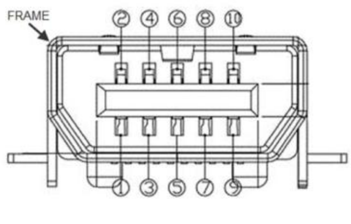


Figure 2. 20 Different connection configuration

3 RPAS system architecture

3.1 RPAS general features

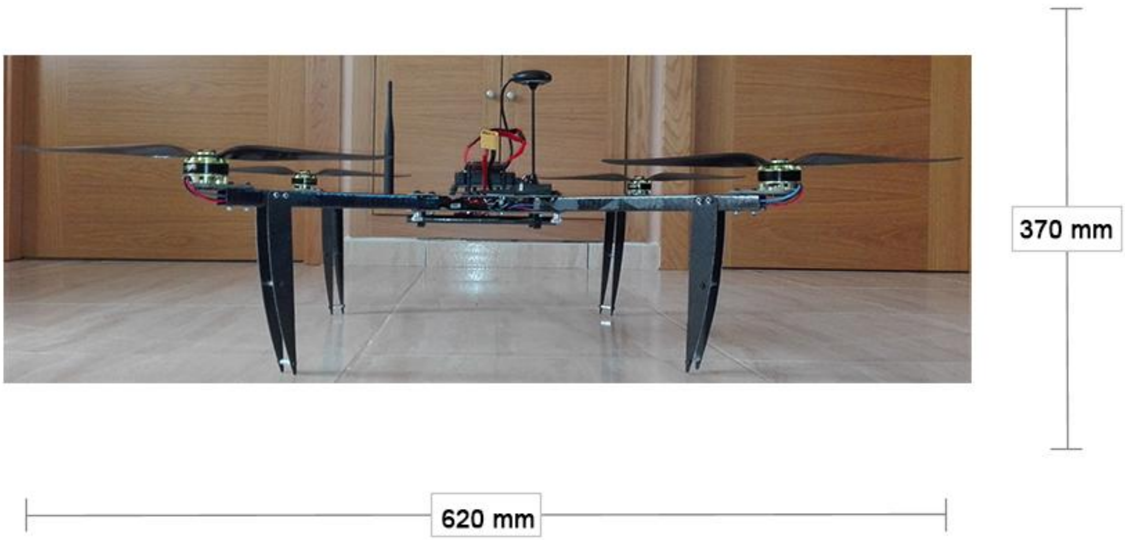
AIRCRAFT	
Class	Multirotor, with 4 rotors.
Manufacturer:	**Galileo Geosystems, S.L.**
Brand:	Galileo Geosystems
Model:	GG-65B01
Serial number:	AP20150002
Manufacture date:	01/02/2016
RADIO	
Manufacturer:	**TX and RX Module:** FrSky Electronic Co., Ltd. **Command:** Hextronik Ltd.
Model:	**TX Module:** FrSky XJT, **Receptor:** FrSky X8R, **Command:** Turnigy 9XR / Pro
AUTOPILOT	
Model:	GG Pixhawk
WEIGHT	
Empty mass (with 6S battery):	2.500 g (or less, without cardan)
Maximum takeoff mass (MTOM):	4.900 g

3.2 Aircraft platform

3.2.1 Original airframe

Front view

Side view



Top view

Figure 3. 2 Original airframe before redesign and sensors integration

3.2.2 Components and equipment

Cell
▪ Carbon fiber chassis, with four folding arms of 17 mm square profile, regularly distributed around a central plate. ▪ Measures (width and length measured from end to end of opposite motors, and height measured up to the highest point of the GPS antenna): 620 mm x 620 mm x 370 mm (930 mm x 930 mm x 370 mm with propellers). ▪ Landing gear based on 4 support legs, built in carbon fiber. ▪ 4 carbon fiber propellers 14 "x 5.5" (2 CW and 2 CCW).
Power systemt and energy
▪ 4 Engines. MULTISTAR 4225 390 kv ▪ 4 Hobbywing X-Rotor 40A Variators. ▪ LiPo 6S battery, 5,000 - 16,000 mAh
Avionics
▪ Autopilot and assisted navigation system GG Pixhawk. ▪ U-Blox M8N GNSS receiver with integrated compass.

Positioner
▪ Eagle Eye 2-Axis (two axes) or similar, built in carbon fiber and aluminum. ▪ Use together with landing gear of 300 mm.
Radio link control
▪ Remote control and command transceiver for the Turnigy 9XR pilot with FrSky XJT module. ▪ Receiver of the command and control radio link FrSky X8R.

3.2.3 Description of the autopilot, navigation systems and aircraft control

NAVIGATION SYSTEM
Flight Controller GG Pixhawk
Flight controller equipped with the following sensors: ▪ MEMS ST Micro L3GD20 3-axis gyro. ▪ ST Micro LSM303D accelerometer with 3 axes and 14 bits. ▪ MEAS MS5611 atmospheric pressure sensor. ▪ Redundant sensing by Invensense MPU 6000 accelerometer / gyroscope with 3 axes both and external magnetometer (in GPS unit with integrated HMC5883L compass). Provides automatic and manual navigation functions assisted by GPS and compass: ▪ Navigation through waypoints. ▪ Position maintenance. ▪ Return home automatic. ▪ Scope limitation. ▪ MEMS ST Micro L3GD20 3-axis gyro. ▪ ST Micro LSM303D accelerometer with 3 axes and 14 bits. ▪ MEAS MS5611 atmospheric pressure sensor. ▪ Redundant sensing by Invensense MPU 6000 accelerometer / gyroscope with 3 axes both and external magnetometer (in GPS unit with integrated HMC5883L compass).
GPS and integrated compass
▪ GPS receiver system. ▪ Equipped with NEO series U-Blox GPS receiver module and integrated compass HMC5883L.

COMMAND RADIO LINK, CONTROL AND TELEMETRY
Onboard transceiver FrSky X8R
▪ Receiver for control and remote control and transmitter for telemetry. ▪ Frequency band: 2,405 - 2,477 GHz. ▪ Modulation: ACCST. ▪ Dimensions: 46.25 mm x 26.6 mm x 14.2 mm. ▪ Mass: 19 gr. ▪ Antenna in PCB. ▪ Voltage range: 4 V ~ 10V. ▪ Bidirectional communication: command and control and telemetry.

3.2.4 Description of the power supply system and battery capacity

Aircraft battery
▪ Type: lithium polymer (LiPo). ▪ Configuration: 6S. ▪ Nominal voltage: 22.2 V ▪ Capacity: 5,000 - 10,000 mAh.
Power system of the pilot station: Turnigy 9XR / 9XR Pro
▪ Type: LiPo. ▪ Operating voltage: 11.1 V ▪ Approximate consumption: 180 mA

3.2.5 Description of the propulsion system

Power distribution system
▪ 4 Drivers of brushless motors Hobbywing X-Rotor 40A.
Engines (4 units)
▪ Brand and model: MULTISTAR, model 4225 390 kv. ▪ Type: brushless. ▪ Factor kv: 390. ▪ Dimensions of the stator (diameter x length): 42 mm x 24.5 mm. ▪ Mass: 86 gr. ▪ Continuous maximum power: 330 W.

3.2.6 Description of radio links

Radio command and control link and telemetry
▪ Frequency band: 2,405 - 2,477 GHz ▪ Modulation: ACCST. ▪ Maximum emission power: ≤100 mW / Work cycle <10%. ▪ Maximum range (LOS, according to EU / CE regulations): up to 2 km. ▪ Adjustable omnidirectional antenna. ▪ Bidirectional communication: command and control and telemetry (monitoring). ▪ Telemetry screen in the transmitter.
Radio link for video transmission
▪ Brand and model of the shipped transmitter: FatShark 5G8 TX V3. ▪ Brand and model of the receiver in the ground control station: Uno5800. ▪ Frequency band: 5.8 GHz. ▪ Emission power: 25 mW (with capacity up to 600 mW). ▪ Use: video transmission.

3.2.7 Description of the payload supports

Positioner
▪ Eagle Eye 2-Axis positioner (two axes), built in carbon fiber and aluminum or similar model. ▪ Includes an independent IMU module. ▪ Mass: 540 g. ▪ Dimensions: 190 mm x 130 mm x 230 mm. ▪ Load capacity: 500 grams. ▪ Range of rotation, pitch angle: + 90 ° ~ -90 ° ▪ Rotation range, roll angle: ± 40 °

3.2.8 Description of the flight termination system

Manual landing
▪ Vertical landing, on the support legs that make up the landing gear, under the control of the pilot in command.
Automatic landing
▪ Vertical landing, on the support legs that make up the landing gear, under the control of the autopilot. ▪ Height control using a barometric sensor.

3.3 Ground control station.

Turnigy 9XR / 9XR Pro Remote Control and Transceiver
▪ Emitter and receiver for remote control and receiver and telemetry receiver (only monitoring). ▪ Operating frequency band: 2.4 GHz. ▪ 24 Channels. ▪ Dimensions: 185 x 225 x 105 mm. ▪ Mass with battery (approximate): 870 gr. ▪ Folding antenna Screen for configuration, warnings and telemetry visualization. ▪ Warning system through text messages, acoustic signals. ▪ Adjustable omnidirectional antenna.
Computer system for telemetry and flight planning.
▪ MS-Windows platform, based on portable personal computer. ▪ Alternative Android platform based on mobile device or Tablet. ▪ Configuration software, telemetry and flight planning: Mission Planner (Windows) / Tower (Android). ▪ 433 MHz telemetry base module (configuration, monitoring and flight plan).
Turnigy 9XR / 9XR Pro control transceiver with FrSky XJT module
▪ Frequency band: 2,405 - 2,477 GHz ▪ Modulation: ACCST. ▪ Maximum emission power: ≤100 mW / Work cycle <10%. ▪ Maximum range (LOS, according to EU / CE regulations): up to 2 km. ▪ Adjustable omnidirectional antenna. ▪ Emitter for remote control and control and telemetry receiver. ▪ Bidirectional communication: command and control and telemetry.
Telemetry transceiver (configuration, monitoring and flight plan)
▪ Frequency band: 433,050 - 434.79 MHz. ▪ Maximum emission power: ≤20 mW. ▪ Maximum range (LOS): up to 2 km.

4 Integration

The imaging subsystem of a RPAS relies on a variety of enabling technologies including sensors, computing devices and radio communications. Our proposed platform comprises digital cameras that interface to a geospatial processor. The autopilot is used to trigger the camera, store and prepare images for storage while recording data such as camera settings, altitude and position that are attached to images as metadata. The RPAS flight position is then sent to the ground station via radio capable of achieving real-time data retrieval.

Flight path and other mission requirements are programmed by ground station engineers into the mission planning software that feeds the autopilot with the data necessary to direct and control the aircraft during the mission. Cameras can be combined into a unique assembly to increase the sensing capabilities of the RPAS. A modular mounting scheme allows for multiple camera modules to be configured on a single camera frame assembly to suit the need of a specific mission. The multiple camera approach can be used to acquire a mix of VNIR and LWIR images covering the same target area. The cameras optical axis must be parallel to one another and their shutter synchronized to operate simultaneously.

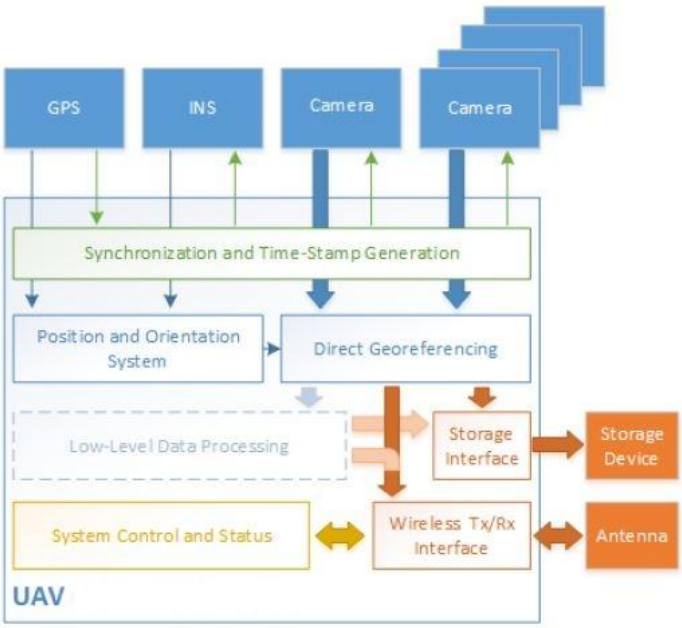


Figure 4. 3 Basic integration scheme of the WADI RPAS

4.1 Aircraft platform

Taking into account the previous description of cameras and equipment we have proceed to integrate the cameras in the previously described RPAS. We saw it in the last section where the original platform was. However, for mounting the new cameras and according to the requirements and recommendations of the project we proceeded to redesign some parts. Because of the size and dimensions of the payload a bigger size and grip adaptations were needed to hold the cameras with safety allowing also a good access to the different elements. Even the landing gears were redesigned with larger measures for keeping the cameras at a safe distance from the surface.

The new top and bottom part of the frame were designed also with a wider size and the parts where manufactured in carbon for its unique properties like lightness and high shapeability, that makes it ideally suited for frames and components and has an easy integration of metal inserts, links and functionality, resulting in high-speed, precise assembly. Some of the main new designed parts are shown below.

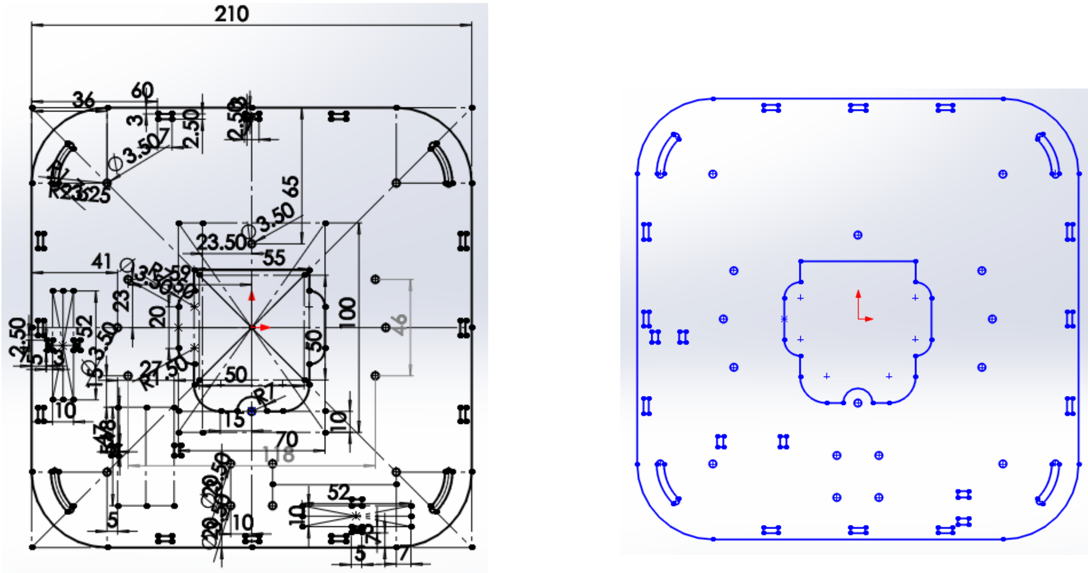


Figure 4. 2 New designed top part of the RPAS.

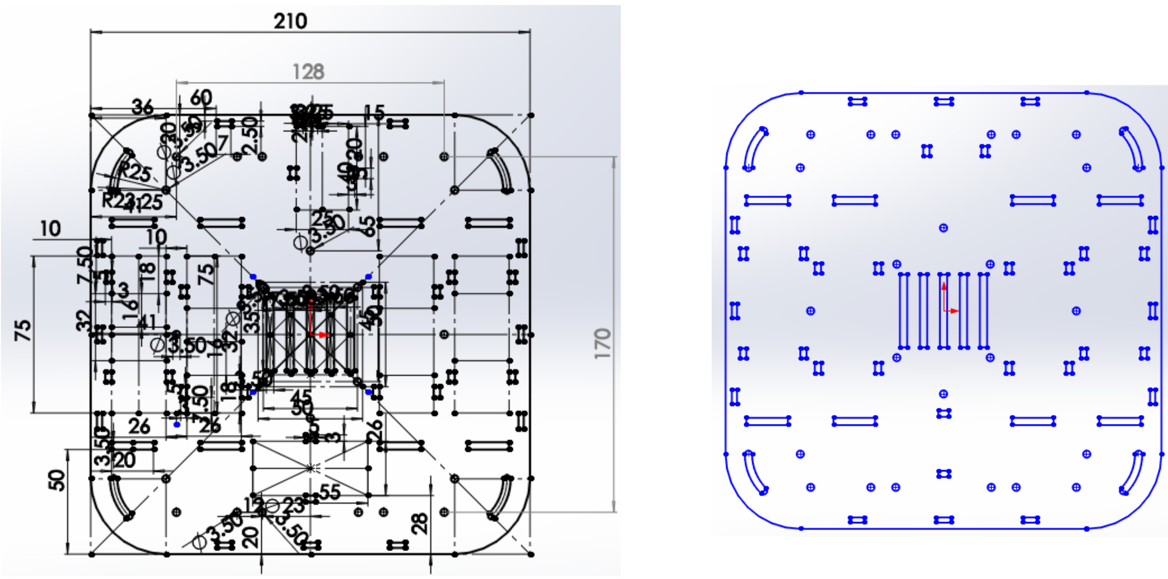


Figure 4. 3 New bottom part of the RPAS.

Other parts of the aircraft needed to be designed and manufactured but also plastic materials were introduced in the new parts because of the availability of new, affordable and rapid 3D printers that gave us flexibility for adjusting different parts designs easily and with enough quality and resistance to be used in our RPAS. Below we can see some of these new parts and integration works.

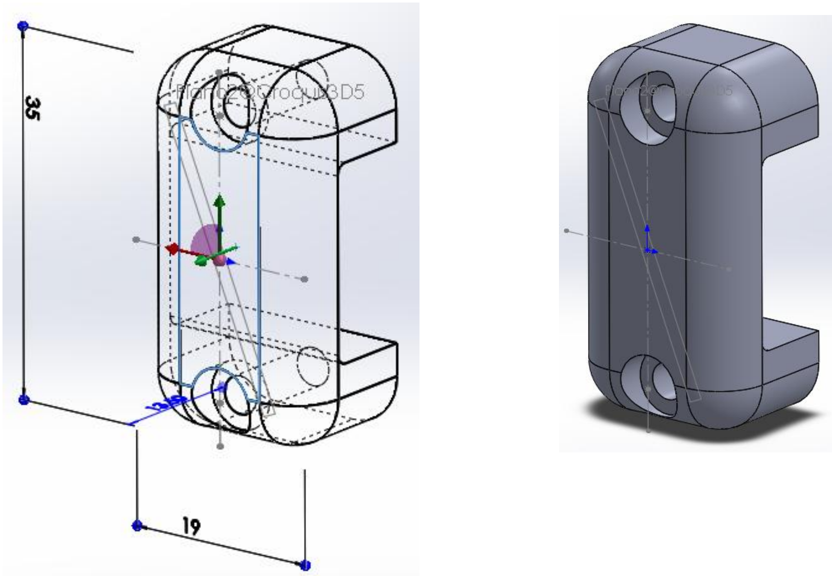


Figure 4. 4 New RPAS adaptation parts for holding the sensors

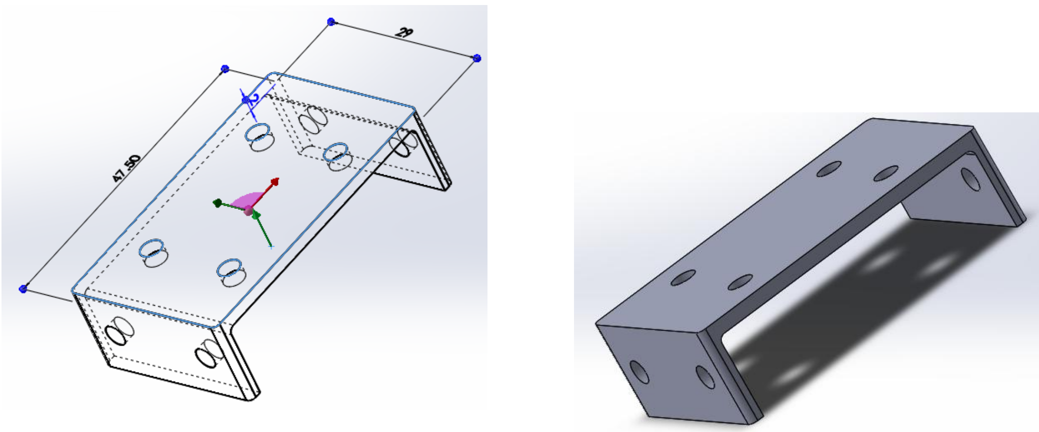


Figure 4. 5 New RPAS adaptation parts for holding the sensors

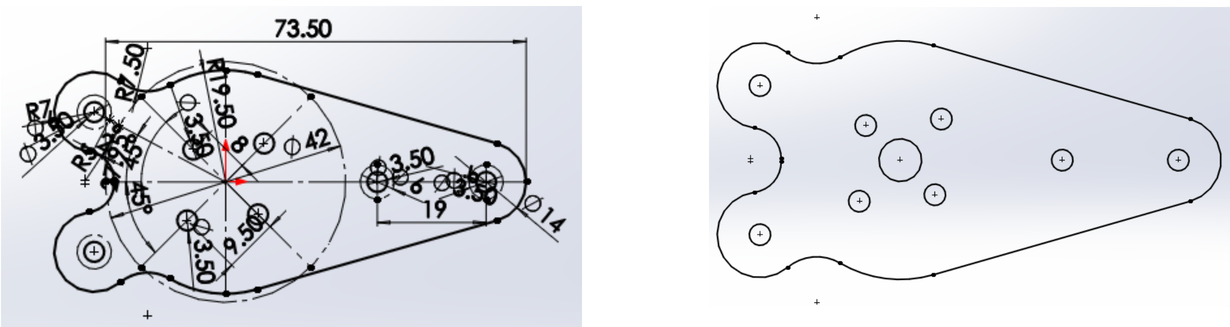


Figure 4. 6 New RPAS adaptation parts for holding the sensors

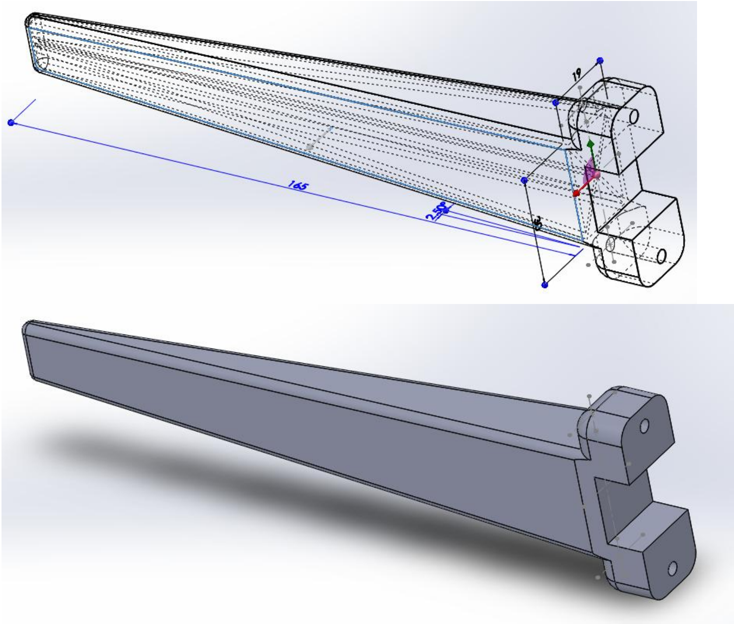


Figure 4.7 New redesigned gears

The cameras are now integrated with a new module and grips that protect and minimize vibrations that in normal conditions would blur the images. In fact, as shown below, the TC is protected with a new designed case that will be attached to the bottom of the RPAS and will protect it from vibrations.

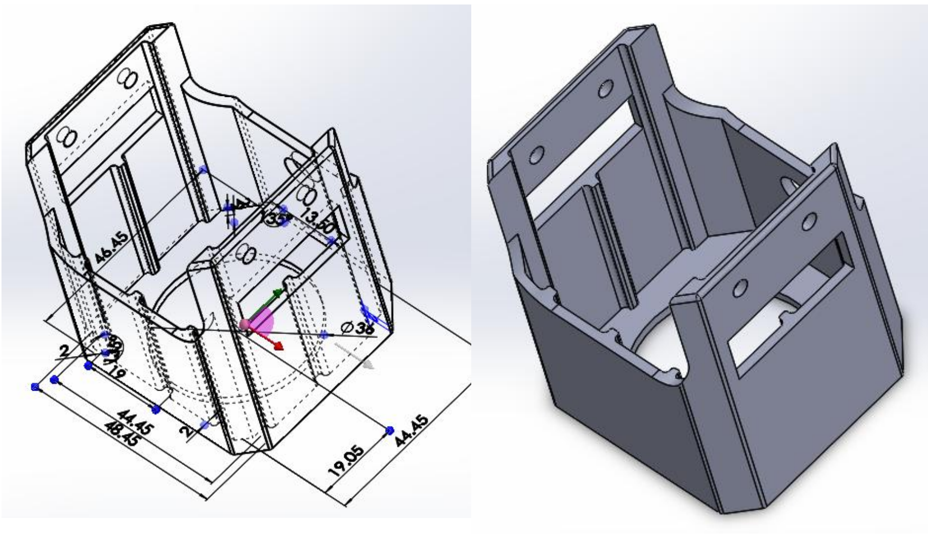
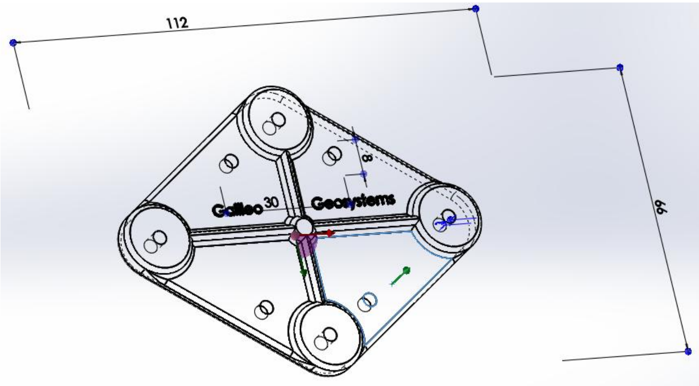


Figure 4. 8 TC case integration

The next part was also expressly designed for mounting the MC, but in this case we took advantage of the screw possibilities that offers the chosen model and since it has a rugged design by itself, no protection case was designed but it is mounted also with a thin layer that absorbs the RPAS vibrations.



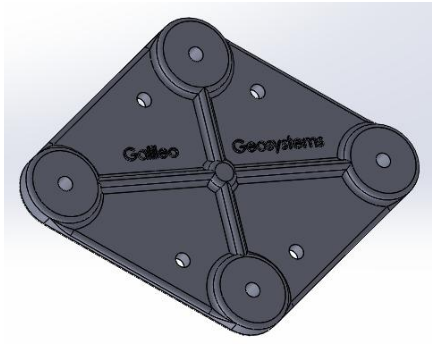


Figure 4. 9 MC integration support

The integration of the cameras in the autopilot (Pixhawk V2) was quite easy to obtain as has very good connection alternatives for external sensors. In fact has eight pulse-width modulation (PWM) outputs connected to IO ports that can be controlled by IO directly via R/C input and on-board mixing even if FMU is not active (failsafe / manual mode). Multiple update rates can be supported on these outputs in three groups; one group of four and two groups of two. PWM signal rates up to 400Hz can be supported.

That is the case of our MC camera that can be triggered through a PWM signal coming from the Pixhawk auxiliary out pins. The camera expects to see a PWM trigger in the range of 1.0ms to 2.0ms and can be rising edge or falling edge triggered. We configured one of the sets of pin to be a camera trigger, the trigger style can be configured in the mission planner.

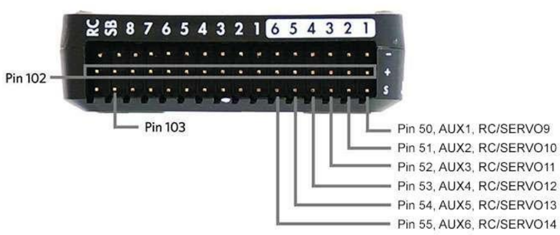


Figure 4. 10 GNSS, MC and autopilot integration and pin connections details

The selected cameras accept several MAVLink protocol messages, mostly regarding GPS information, aircraft attitude, and camera control. When sending these messages, they should come through telemetry ports 1 or 2 (TELEM 1 and TELEM 2 on the Pixhawk), which will likely need to be configured prior to use if not used before. This can be done through mission planner, for TELEM 2 for example, by setting the SERIAL2_BAUD field to 57. RedEdge expects a baud rate of 57600 for MAVLink messages. For each of the TELEM ports, pin #2 is the TX line, pin #3 is the RX line, and pin #6 is GND.

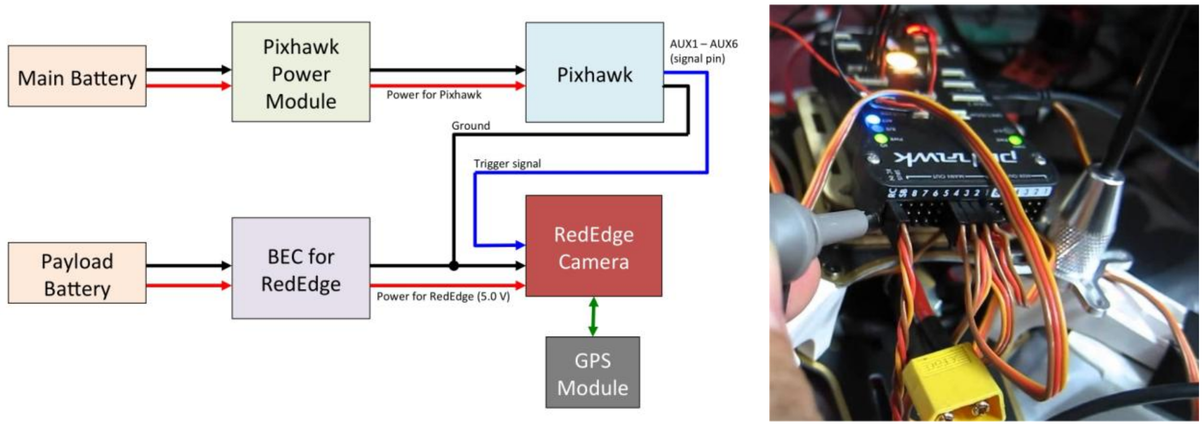


Figure 4. 11 Installation diagram of the RPAS sensors.

Finally, below we can see the sensors, new parts and configurations integrated in the project RPAS.

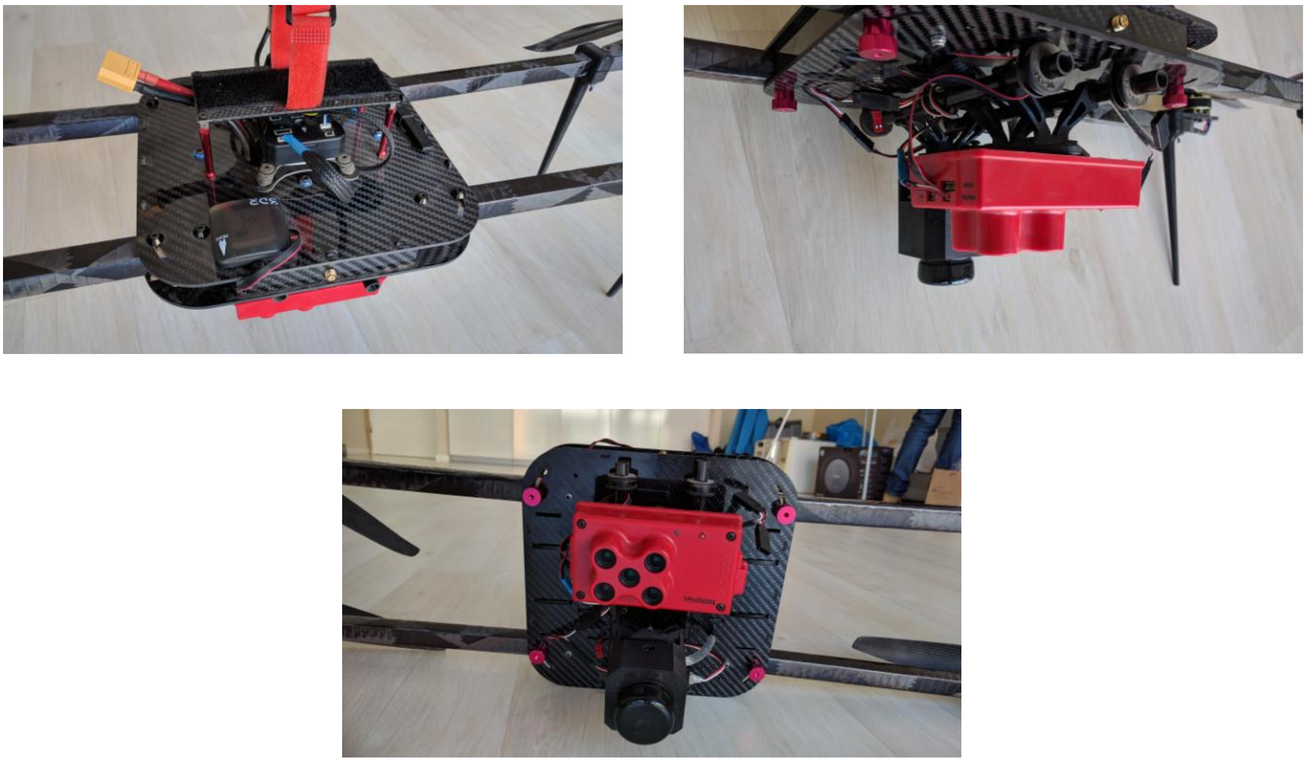


Figure 4. 12 Final redesign, configuration and integration of both sensors in the RPAS

4.2 Ground control station

We also have integrated the cameras in the ground control station using the software Mission Planner to define and control the flight missions. Mission Planner is a full-featured open source ground station application for the ArduPilot project. It is compatible with Windows only. Mission Planner allow us very useful things like integrate, configure, and tune the RPAS for optimum performance, to plan, save and load autonomous, download and analyze mission logs, interface with a PC flight simulator and with the radio link installed in our control station we can monitor the RPAS and cameras while in operation.

Figure 4. 13 Ground control station

The communication with our RPAS is quite rapid by Telemetry Radio. Once the communication is established, Windows automatically assigns to the autopilot a COM port number, and that shows in the drop-down menu. The appropriate data rate for the connection is also set (typically the USB connection data rate is 115200 and the radio connection rate is 57600). The project cameras have been integrated in the software and are ready to be used at any moment for a mission without starting new configurations. Planning a camera mission is almost exactly the same as planning any other mission with waypoints and events. The camera missions are configured now to specify commands to trigger the camera shutter at waypoints or at regular intervals as the vehicle moves.

Figure 4. 14 3DR SiK telemetry-radio modules

As is shown above, for the telemetry control from the ground control station, we have integrated a 3DR SiK telemetry-radio because it's a reliable and easy way to setup a telemetry connection. Our autopilot (Pixhawk) telemetry ports use a DF13 6 pin connector cable (15cm) instead of the 5 pins used on previous models. The configuration is quite quick. The ground control station module has a USB connector making it easy to connect directly. We need to have a windows 7 or higher machine, the required drivers should be automatically installed the first time we plug in the ground module. The 'aircraft' module has a FTDI six pin header, allowing it to be directly connected to our Mission Planner. The connections required are shown below.

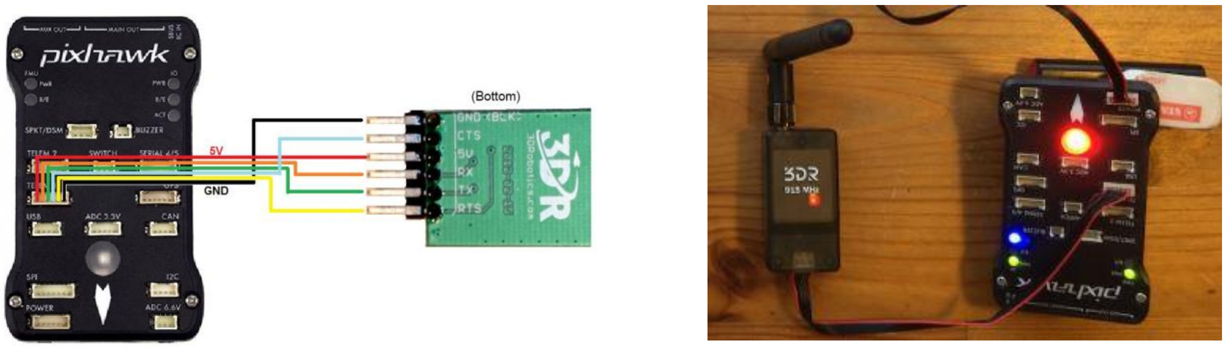


Figure 4. 15 Pin connections details for the telemetry

The ground control station displays a configuration screen where our models are introduced and where other parameters like overlap are automatically calculated based on this information. After clicking on Accept, Mission Planner will generate a list of waypoints covering the specified area, and including take-off and landing waypoints. Therefore, in control station we plan each flight mission with our configured sensors checking important configuration results like flight duration and area to be covered for the planned mission. During the mission although we have configured an automatic mission, new orders can be sent to the RPAS and the real and planned flight plan is compared in real time.

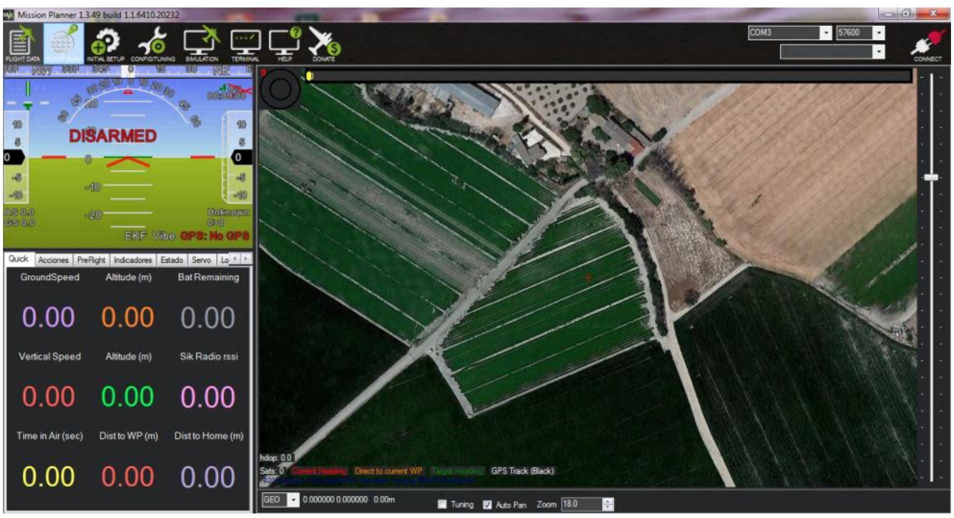


Figure 4. 16 Flight control screen during the mission

The ground control station provides also a filtered list of the commands appropriate for our RPAS and adds column headings for the parameters that need user-supplied values. These include navigation commands to travel to waypoints and loiter in the vicinity, and commands to execute specific actions like taking example taking pictures from a pipeline, and condition commands that can control when these commands are able to run.

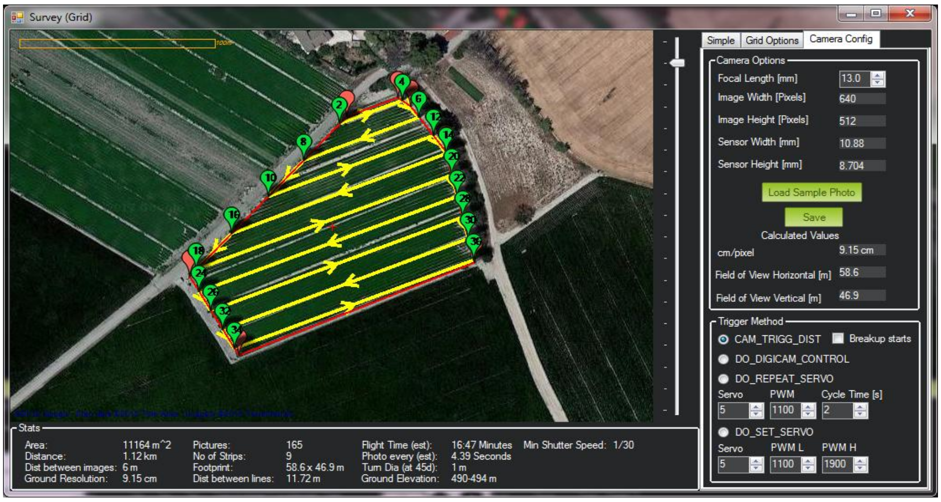


Figure 4. 47 Mission and parameters control during the flight

5 Conclusions

The objective of this deliverable was to inform of the different components and their integration in the WADI RPAS that is tested in the same WP.3 (D.3.4) and that will be immediately applied in operational environment demonstrations over the two pilot sites (WP5 and WP6). The most significant findings can be outlined as follows:

- RPAS sensors (TC and MC) selection accomplishes with the stated requirements and recommendations of D.3.1.
- The selected sensors are designed for being easily integrated in professional RPAS models and are very user friendly.
- The cameras have been integrated after a process of redesign of several parts of the RPAS and reconfiguring some elements like the autopilot, GNSS, telemetry, power systems and the ground control station.
- Both cameras are easily configured with a wireless connection with our smartphone or computer.
- The integrated system is ready for tests and real missions in the following WPs.
- The proposed integration accomplishes with the WADI's innovative concept of integrating existing RPAS oriented and affordable sensors in the market.