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EXECUTIVE SUMMARY

Multispectral and hyperspectral cameras were tested in the lab as part of WP3 within the task dedicated to downward looking sensors. As part of WP5, these cameras were integrated on several different types of unmanned aerial vehicles (UAV) for operations over the ocean and coastline and for gathering data related to reflectance of items of interest and seawater constituents. The cameras were physically integrated using brackets and gimbals specially designed for UAVs. The combined sensor and UAV platforms were field tested to ensure that data could be collected according to the intended use (flight time and pattern) and data requirements (good resolution and item identification). The sensor/UAV systems were successfully tested in relation to physical, electrical, and data communication integration and ready for calibration and validation activities in WP6 and to be described in D6.1 and D6.5.

LIST OF FIGURES

LIST OF ACRONYMS AND ABBREVIATIONS

Abbreviation	Definition
AGL	Above Ground Level
CDOM	Coloured dissolved organic matter
Chl-a	Chlorophyll-a
EOV	Essential Ocean Variables
FTP	File Transfer Protocol
GNSS	Global Navigation Satellite System
GSD	Ground Sample Distance
GPIO	General Purpose Input / Output
HSI	Hyperspectral Imager
IMU	Inertial Measurement Unit
MP	Mega Pixel
MSFD	Marine Strategy Framework Directive
MSI	Multispectral imager
NDVI	Normalised Difference Vegetation Index
NIR	Near Infra-Red
OC	Ocean Colour
OLI	Operational Land Imager
RGB	Red Green Blue
ROI	Region of Interest
RRS	Remote sensing reflectance
SST	Sea Surface temperature
TIFF	Tag Image File Format
UAV	Unmanned Aerial Vehicle
UV	Ultraviolet
VAC	Volts Alternating Current
VDC	Volts Direct Current
VIS	Visible
VNIR	Visible and Near InfraRed

I. INTRODUCTION

Downward looking sensors were developed in WP3, of which a subset of the sensors was intended for integration and use on UAVs. The use of downward looking sensors like hyperspectral and multispectral cameras enable novel and diverse observations of the sea surface without the need for deploying instrumentation *in situ*, which can pose issues related to safety, logistics and cost. The integration and use of these cameras on UAVs supports observations of the sea surface that are high in spatial resolution and fewer issues related to cloud coverage and atmospheric scattering that would otherwise affect satellite-based observations.

II. SENSORS INTEGRATED WITH UAVS

Two types of downward looking sensors were integrated on UAVs; multispectral and hyperspectral cameras. Both types of sensors are introduced in detail in Deliverable 3.3. In brief, both sensors measure the light that is backscattered from the ocean and not absorbed by seawater constituents of interest like phytoplankton, inorganic particles, litter, etc. This reflected light can be detected in the visible and near-infrared light spectrum. Multispectral sensors measure light at discrete bands of wavelength (usually ~10-60 nm bandwidth) while hyperspectral sensors measure light across a full spectrum ranging from visible to near infrared. Both sensors provide insight regarding quantity and quality of seawater constituents or temperature based on light detection.

1. MULTISPECTRAL CAMERAS

Two different multispectral systems are being used in WP7 demonstrations and therefore integrated on UAVs; a Micasense Altum PT and a Micasense RedEdge-P dual, both manufactured by AgEagle. The Micasense sensors share common technical characteristics - only their spectral bands are different. In addition to their spectral bands, both systems also have a panchromatic band. This band covers all visible and near infrared spectrum. Therefore, it does not contain spectral information, but because it integrates all the signal over the whole visible and near IR range, it has higher intensities in each pixel increasing the signal to noise ratio, and consequently the spatial resolution. Whereas the lack of signal is compensated in increased ground pixel size to increase the emitting surface, limiting the spatial resolution of spectral bands. The high spatial resolution panchromatic images can be used to obtain higher spatial resolution for the multispectral images using panchromatic sharpening methods which consists of merging spectral and panchromatic images.

Both systems have an auxiliary sensor that records both downwelling irradiance to correct for global illumination changes in the middle of a flight, due to clouds covering the sun for example. This Downwelling Light Sensor, DLS 2, (Figure 1Figure 1) connects directly to the camera and can also provide GPS data to cameras unless GPS data is provided from an external source such as an UAV. During a mission, the DLS 2 measures the ambient light and

sun angle and records this information in the metadata of the TIFF images captured by the camera as well as the geotagging.

Figure 1: Downwelling light sensor (DLS2) reference for Micasense cameras.

1.1.   Micasense Altum PT

The Micasense Altum PT multispectral camera (Figure 2) simultaneously captures six bands: Blue (centred at 475 nm, 32 nm bandwidth), Green (560 nm, 27 nm bandwidth), Red (668 nm, 14 nm bandwidth), Red edge (717 nm, 12 nm bandwidth), Near-IR (842 nm, 57 nm bandwidth) and IR 11000 nm (7.5 -13.5μm) (Figure 3Figure 3) and a panchromatic band. The IR thermal band can be used to measure temperature.

Figure 2: AgEagle MicaSense Altum PT multispectral camera.
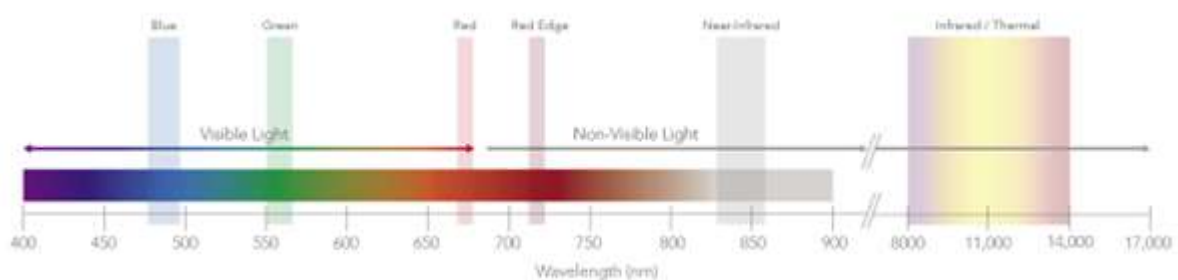
Figure 3: The MicaSense Altum's five bands over the electromagnetic spectrum.

The MicaSense Altum multispectral camera has a 2064x1544 pixel resolution (3.2MP) for the visible bands, 4112 x 3008 (12MP) for the panchromatic band and 320 x 256 for the thermal band, with fields of view of 50° x 38°, 46° x 35° and 48° x 40° respectively, which results in a Ground Sample Distance (GSD) of 5.2 cm, 2.5cm and 33.5 cm per pixel respectively at 120 m.

The camera's dimensions are 11.0 x 8.0 x 6.9 cm and the camera + the DLS and cables weighs 577 g.

1.2.　　　　Micasense RedEdge-P dual

The Micasense RedEdge-P dual multispectral camera is a combination of two identical sensors, only with different spectral filters to increase the number of different bands that can be used for detection (Figure 4).

Figure 4: Micasense RedEdge-P dual camera setup.

Each instrument has five spectral bands, so in total the combined system has 10 different bands: deep blue, (centred at 444nm, 28nm bandwidth), blue (475 nm, 32nm), green (531nm, 14nm), Green (560 nm 27), red (650nm, 16nm), red (668 nm, 14nm), red edge (705nm, 10nm), red edge (717nm, 12nm), near infrared (740nm, 18nm) and near infrared (842nm, 57nm), plus a panchromatic band for each sensor (Figure 5).
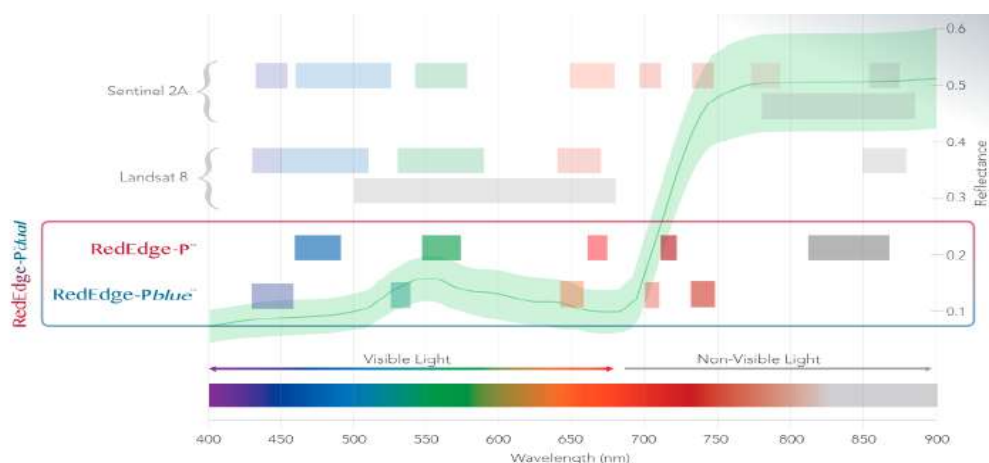
Figure 5: RedEdge-P + RedEdge-P blue dual setup spectral bands, compared to ESA's Sentinel 2 Multispectral imager (MSI) and NASA's Landsat 8 operational land imager (OLI) spectral bands. Note that Landsat 8's OLI also has a panchromatic band.

With a field of view of 50° x 38° for the multispectral bands, and 44° x 38° for the panchromatic band, and a sensor resolution of 1456 x 1088 (1.6 MP) per multispectral band and 2464 x 2056 (5.1 MP) for the panchromatic band, the instrument has a GSD of 7.7 cm per pixel at 120 m AGL (Altitude above ground level) for the spectral bands and of 3.98 cm per pixel at 120 m AGL for the panchromatic band. The capture of all bands is synchronised, with a rate up to 3 images per second.

The whole set up, including the two cameras, the mounting hardware, and the downwelling sensor and cable weighs 745 g.

2. HYPERSPECTRAL CAMERA

The hyperspectral camera is a Specim AFX10m (Figure 6); a visible and near infrared (VNIR) hyperspectral imager (400 to 1000 nm with a 5.5 nm spectral resolution) specially designed to be deployed on UAVs; it has a navigation system (GNSS) and an inertial measurement unit (IMU), included in its compact enclosure that weighs 2.1 kg.

Figure 6: Specim AFX10 camera.

The Specim AFX10 hyperspectral camera has a 1024 pixels resolution with a field of view of 38° which gives a swath of 72 m and a Ground Sample Distance (GSD) of 7 cm at 100 m high or 3.5 cm at 50 m. It has 512 spectral pixels, which gives a 5.5 nm spectral resolution.

III. PLATFORMS

The multispectral and hyperspectral cameras will be deployed on three different UAVs from NIVA's drone fleet during demonstrations in WP7: two multirotor UAVs, a MJI Matrice 300 RTK and a DJI Matrice 600 Pro, and one VTOL (Vertical Take Off and Landing) fixed wing UAV, a DeltaQuad Evo. These three UAVs being part of NAUTILOS' autonomous vehicle platforms, they are also introduced in deliverable 5.2.

1. MULTIROTOR UAVs

1.1. DJI Matrice 300 RTK

The DJI M300 RTK is a high performance reliable and versatile commercial multirotor UAV with up to 55min of flight (Figure 7). It is approximately 1m*1m, has a maximum payload of 2.7 kg and is compatible with numerous models of gimbals. It also allows the use of up to 3 gimbals at the same time, one upward looking and 2 downward looking. The M300 is powered by 2 batteries of 46.2V and 5935mAh in parallel. The DJI Matrice 300 RTK is used to deploy the multispectral sensors. The multispectral sensors can also be combined with RGB, as the M300 had a double gimbal.

Figure 7: The DJI Matrice 300 RTK with a micasense camera onboard.

1.2. DJI Matrice 600 Pro

The Matrice 600 pro is a 1.5m multirotor UAV, capable of carrying up to 6kg, and flying up to 18 m.s-1 (Figure 8). Its high payload capacity allows us to deploy the hyperspectral camera, which weighs over 4kg with its gimbal. The M600 pro is powered by 6 batteries of 22.8V 5700mAh coupled by pairs to provide 46V to the motors. Its autonomy is 15min with its maximum payload and its maximum autonomy is ~30min. The MJI M600 Pro is mainly used to deploy the Specim AFX10.

Figure 8: DJI Matrice 600 Pro carrying the AFX10 camera in Mausund, Norway.

2. FIXED WING VTOL UAV

The DeltaQuad Evo is a light and robust VTOL UAV made from carbon, Kevlar, and fiberglass material (Figure 9). It has a versatile dual slots payload, allowing different flight configurations: it can carry a single large instrument using both slots or carry two instruments simultaneously up with a total weight up to 3kg and 3 hours autonomy. One slot can also be used to carry an extra battery to extend its autonomy up to 4.5 hours. The VTOL technology combines the advantages of fixed wing and multirotor UAVs: it can cover large distances as standard fixed wing UAVs, but no runway is needed as it can hover, take-off, and land vertically like a classic multirotor UAV. This also reduces the risk of crashing compared to standard fixed wings as take-off and landing are critical operations. The DeltaQuad UAV will be used to deploy the multispectral instruments when large spatial coverage or further offshore deployments are needed.

Figure 9: the DeltaQuad evo, with the downward irradiance sensor (DLS2) from Micasense integrated on its top.

IV. INTEGRATION

1. MECHANICAL INTEGRATION

1.1. Multispectral cameras

The Micasense multispectral cameras are deployed either from multirotor UAV, either from fixed wing UAV for larger spatial coverage, depending on each application requirements. For example, a multirotor UAV would be used for detailed imaging campaigns over a relatively small area. On the other hand, fixed wing UAVs can be used for measurements on a relatively long and straight transect with fewer options for programming a tight overlap and flight pattern commonly used for imaging missions (i.e., baustrophedonic "lawnmower" pattern).

Multirotor UAV mechanical integration

Deployed from DJI drones, they are mounted to a skyport damping bracket (Figure 10), which absorbs the vibrations with silicon damping. The skyport allows quick release: no tools are needed to screw or unscrew the cameras from the skyport.
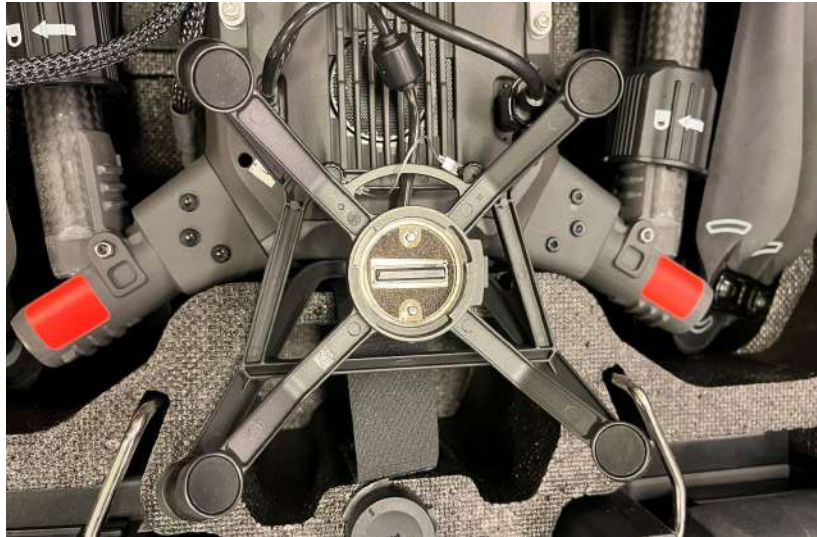
Figure 10: the M300 skyport damping bracket.

The DLS2 irradiance reference sensor is also installed a damping bracket, on the highest position on the drone, to avoid shadowing of the collector by the drone parts when collecting the downwelling signal (Figure 11).

Figure 11: The DLS2 reference irradiance sensor integrated on the DJI Matrice 300 RTK.

Fixed wing UAV mechanical integration

On the DeltaQuad Evo, the payloads are swappable without the use of any tools. They are integrated into the Evo's bottom panels in specialised brackets and openings that allow for

insertion and removal from the Evo's fuselage (Figure 11). The multispectral cameras then are attached internally within the body of the UAV, and not externally mounted as with the multirotor UAVs.

Figure 12: Micasense redEdge (left) and Altum PT (right) integrated into deltaquad panels.

The DLS2 Irradiance is also fully integrated into the top panel of the evo (Figure 9)

1.2.   Hyperspectral camera

The AFX10 is deployed only on the MJI Matrice 600 pro due to sensor's weight and UAV payload restrictions. It is attached to the M600 pro through a Gremsy T7 3-Axis Digital Gyro-Stabilised Gimbal made of aluminium that weights 1860g (Figure 13). A heated and temperature controlled IMU sensor with advanced 6-point calibration measures the pan, roll, and tilt and immediately corrects the angles through adjustments to the motors for each rotation angle, with a range of +/- 345° for the pan, +80 / -264° for roll and +/- 150° for the tilt, to keep the camera steady pointing at the nadir. The Gremsy G7 high performance gimbal controller provides fast response and accurate calculation. The sensor data and motors correction are updated as fast as 2000 times per second to enable very smooth footage. The gimbal's input voltage is 15V to 52V. The AFX10 camera has 5 ¼-20 UNC tapped holes on its top and 4 on its bottom used to attach it to the gimbal (on parts 09 and 12 on Figure 13 below). The T7 gimbal provides an easy one step plug and play installation that takes only 5 seconds to complete.

Figure 13: Gremsy T7 Gimbal: 01 HDMI Hyper Quick Release, 02 Pan motor, 03 Pan adjustment, 04 Roll motor, 05 Gimbal controller, 06 Roll adjustment, 07 Tilt motor, 08 Tilt top bar, 09 Camera plate, 10 Tilt front- back adjustment, 11 Tilt vertical adjustment, 12 Camera top cross bar.

2. ELECTRICAL INTEGRATION

2.1. Multispectral cameras

The multispectral cameras are powered by the drone's batteries through the DJI skyport connector when installed on a DJI drone. The M300 has an embedded power converter from 46VDC to 24VDC. The DJI Skyport is then connected to the JXT connector on the Micasense cameras (Figure 14). The DLS sensor installed on the top of the drone (Figure 14) is connected to the camera also through the DJI skyport and JXT connectors. The camera's input power must be between 7.0 V and 25.2 V, with an average power consumption of 7W per camera.

Figure 14: The DJI skyport connected to the Altum PT through JXT connectors.

2.2.   Hyperspectral camera

The AFX10 hyperspectral camera can be powered with 10 to 30 VDC. Integrated on the DJI M600 pro (Figure 15), the AFX10 and its gimbal are powered with 22.8V directly from UAV's batteries. The camera's power connector is a Lemo EGJ.1B.306.CWA.

Figure 15: The AFX10 integrated on the MJI M600 pro.

The hardware interface includes a variety of ports to quickly interface with multiple devices such as 3rd party flight controller, remote control, auxiliary I/O and power (Figure 16).

Figure 16: The hyper quick release connectivity: (1 to 9 top left to bottom right, will add numbers on the image on local doc) 1: JST S3B-ZR:JR: interface with JR/SPEKTRUM satellite receiver. 2: Micro USB type B: USB: interface with a computer or to upgrade firmware. 3: JST SM04B-GHS-TB: CAN: interface with CAN bus on DJI Flight controller or another module that uses CAN bus. 4: JST S2B-XH-A(LF):PWT OUT: 14.5V 2A output for camera and accessories. 5: SBUS/PPM: interface with SBUS/PPM receiver. 6: JST SM10B-GHS-TB: AUX: 9 optional signal (0.25A max) f to connect to other devices such as AV signal or camera trigger. 7: JST SM06B-GHS-TB: COM2/COM4: interface with Pixhawk via Mavlink protocol or other modules that use serial protocol (UART). 8: Micro HDMI: HDMI: HDMI video output from the camera. 9: =1

3. COMMUNICATION PROTOCOLS

3.1. Data transfer

All cameras (both multispectral and hyperspectral) store the collected data internally. The Micasense instruments save the data on their dedicated high-speed CF express type B compact flash memory card which can be read through a USB reader on a computer. On the AFX10, data is stored on internal memory. The data is to be downloaded via file transfer protocol (FTP) with a network cable (RJ45 connector).

3.2. Triggering of measurements

The Micasense cameras can be triggered in two different ways; using the camera's internal system, it can be set to automatically take shots at distance intervals specific to the altitude, based on overlapping of the images. A typical setup is 70-80% of overlapping forward and 60-70% sidewise for a good compromise between travel speed and data quality. Or it is also possible to trigger the cameras from the drone through the skyport, taking in account the camera's optics properties to calculate the overlapping. For external triggering, the Micasense cameras can be interfaced through three configurable general-purpose input/output (GPIO) pins.

The AFX10 acquisition is triggered internally by the Specim software configurable through ethernet connection via cable prior to deployment. During the deployments, the hyperspectral camera is turned on before the flight, recording at a set frequency and associating the frames with the IMU records for geolocation.

V.   FIELD TESTS

The AFX10 has been flown on a MJI M600 Pro and the Altum PT on a MJI M300 RTK between 11-15 May 2023 over Oslo fjord and NIVA's marine station to test mechanical, electrical, and communication protocol integration between the sensors and UAVs. The sensor integration and data collection were successful and the sensor/UAVs were used for T6.1.2 (reported in D6.1) and T6.2.3 (reported in D6.5). The data over the fjord and over a beach where plastic litters were placed (Figure 17, as an example of collected data) are being used for T9.4.
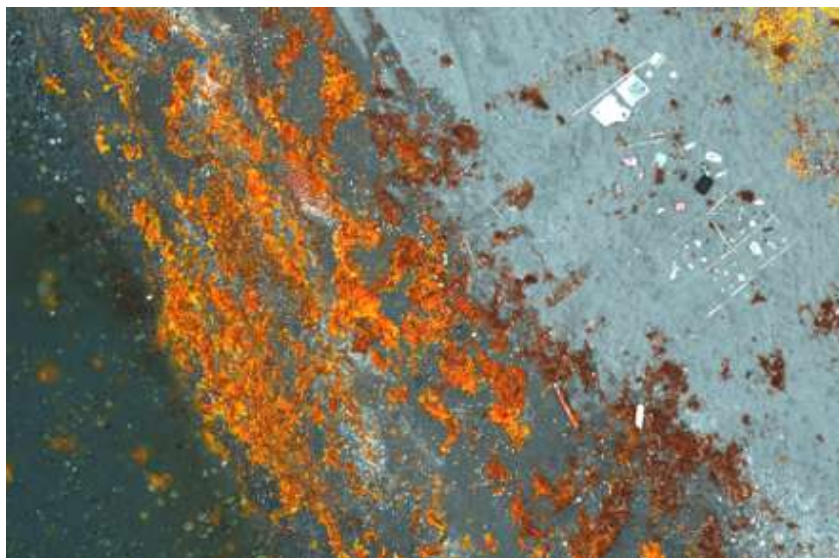
Figure 17: False colour map over the beach with plastic litters from Altum PT multispectral camera.

VI.   SUMMARY

This deliverable describes integration of multispectral and hyperspectral cameras as part of T5.2.3: Integration of payloads and sensors on Unmanned Aerial Vehicle (UAV) platform. This included three different camera models – two AgEagle Micasense multispectral cameras and one Specim AFX10 hyperspectral camera. The two different types of cameras were integrated onto different UAV models due to the heavier weight of the AFX10 requiring UAV models with a higher payload capacity. The integration included physical attachment: brackets and gimbals for attaching the cameras to the bottom of the UAVs; electrical connection: wires providing power and auxiliary functions are JXT and LEMO-type connectors that are OEM-specified; communication/data transfer protocols: data are stored on the sensors and transferred to a computer via flash memory card and FTP/RJ45 connector. The integration between the sensors and UAVs were tested in May 2023 prior to the T6.1.2 calibration and validation activities that were also carried out at NIVA's field station. The various aspects of the integration were tested, and data collected were checked for proper functioning of the sensors and collection of data. The completed integration (this deliverable) and calibration/validation (D6.1) of the sensor and platforms as a complete system will be followed up by field demonstrations in Task 7.2: Demonstration on platforms of opportunity which is planned for coastal Norway in late 2023 and early 2024.

VII. APPENDIX 1: REFERENCES AND RELATED DOCUMENTS

ID	Reference or Related Document	Source or Link/Location
1	*D3.3 Downward looking sensors laboratory tests*	NAUTILOS Web-site
2	*D5.2 Report on integration of sensors on Unmanned Vehicles/Platform*	NAUTILOS Google Team Drive
3	*D6.1 Report on results and methodology of calibration/validation experiments performed in T6.1*	NAUTILOS Google Team Drive
4	D6.5 *Report on the testing results of the joint operations of sensors and UAV in ST6.3.3*	NAUTILOS Google Team Drive