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A PROTOTYPE OF UNMANNED AERIAL VEHICLE (UAV) PLATFORM AND DEDICATED PAYLOADS FOR COASTAL ENVIRONMENT EXPLORATION

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Indice

Introduction

Remotely Piloted Aircraft Systems - RPAS [ICAO, 2011], usually called drones, are an emerging technology presenting a huge potential for innovative research in territory management. These systems will revolutionize most of the environmental studies (e.g. population ecology, vegetation dynamics, ecosystem processes, etc.) that are improved by remote sensing data, overcoming satellite-based data that provide not easy repeatable information and only at regional/global scale (from about 50-100 km up to 10.000 km).

RPAS or Unmanned Aerial Systems (UAS[1]) history begun in 1916 (i.e. the Wright brothers Hewitt-Sperry Automatic airplane) and it has been mainly unfolded until today thanks to military applications [Colomina and Molina, 2014; Pappot and de Boer, 2015]. Nowadays, UAS based technology is rapidly developing in the industrial market and in civil applications for several kind of monitoring services (i.e. traffic monitoring, border surveillance, environmental monitoring, imaging and mapping, archaeology, search and rescue operations, etc.) [Valavanis and Vachtsevanos, 2015]. Moreover, the use of drones, in the global consumable market is continually growing due to the integration on Unmanned Aerial Vehicle (UAV) platforms of high performance processors, sensors and electronic devices with lower and lower power consumption. Mainly, light Remote Piloted Aircraft Systems (RPASs) are used in several application fields due to their low weight and low size.

In 2013, it has been estimated that the UAVs market size was 5400.0 M€ and it was expected to grow up to 6350.0 M€ by 2018 [Markets and Markets, 2013]. In fact, due to the Remote Sensing technologies on-board, UAVs are now able to collect qualitative and quantitative data about a given territory. *"Let them fly and they will create a new remote sensing market in your country"* this is the message by a recent review article on UAS for photogrammetry and remote sensing [Colomina and Molina, 2014].

The benefits from semi-autonomous monitoring based technology are several; it can help to improve the traditional approach for decision makers in order to manage the environmental issues, disasters, emergencies and accidents. For these reasons, the drones are equipped with special sensors, and then they are sent over the fields to gather information on the status of crops, in town for the detection of heat loss in buildings, for the analysis of pollutants in the atmosphere and more. UAVs have a huge potential in order to efficiently and safely bridge critical information gaps and advance understanding of key-processes in Earth systems [NOAA, 2012]. The coastal monitoring by the use of UAVs is still scarcely reported in the scientific literature; in particular, most of the numerous advantages of UAVs in general photogrammetric mapping to depict coastal features are: low hardware costs, high level of automation of photographic survey and very low operating cost. An example of application for coastal monitoring, limited to aerial image acquisition and using an unmanned rotor wing vehicle, are presented in Delacourt et al., 2009.

This technical report describes several recent innovation that have enabled the design and development of an innovative UAV-based platform, with the goal to create an integrated system consisting of a semi-autonomous Unmanned Aerial System prototype equipped with a scientific payload managed by a Ground Control Station (GCS) and dedicated to advanced geo-environmental monitoring in marine-coastal areas (e.g. photogrammetry, thermography, pollutant detection, visual census, etc.). The prototype system herein presented, consisting of an UAV carrier, scientific payload and GCS customized for coastal monitoring purposes, is an outcome of the two synergic projects PITAM (Advanced Technology Platform for geophysical and environmental parameters monitoring at the sea - PON01_02812 - http://www.pitam-stigeac.eu/it/) and STIGEAC (Systems and Integrated Technologies for detection and advanced monitoring of geophysical and environmental parameters in marine coastal areas – PON01_02812 - http://www.pitam-stigeac.eu/it/) both funded by the Italian National Operative Programme PON R&C 2007-2013.

Combining the use of UAV technology with fully developed techniques for automated data acquisition and delivery, it is possible to offer a new kind of methodology in order to meet stakeholders and decision-maker's requirements for environmental and coastal marine monitoring surveys. Particularly, the system prototype capabilities, together with the dedicated payload features, are extremely useful for monitoring and observing inaccessible areas, or operating during natural disasters (e.g. in the verification of architectural structures affected by earthquakes or other disasters) but also for several kind of applications (i.e. patrolling, power lines inspections, coastline monitoring etc.) including accurate geo-information about the terrain state.

[1] As defined by US-Department of Defence (DOD) and UK-Civil Aviation Authority (CAA).

1. System framework and components

The innovative architecture of the prototype system herein presented fully integrates an Unmanned Aerial Vehicle (UAV) equipped with scientific payload, with a double-dedicated Ground Control Stations (GCSs) that are able to provide both flight management (belonging to the AUV), payload control and mission planning, including a survey in cooperation also with other semi-autonomous systems.

Furthermore, this prototype is an operating part of a wider multi-purpose platform infrastructure designed in the framework of PITAM and STIGEAC projects for the intelligent monitoring and geo-environmental surveys along the coast, which also includes two unmanned marine surface vessels (UMV), a jack-up barge (self-lifting platform) and a fast cargo vessel (Fig. 1).

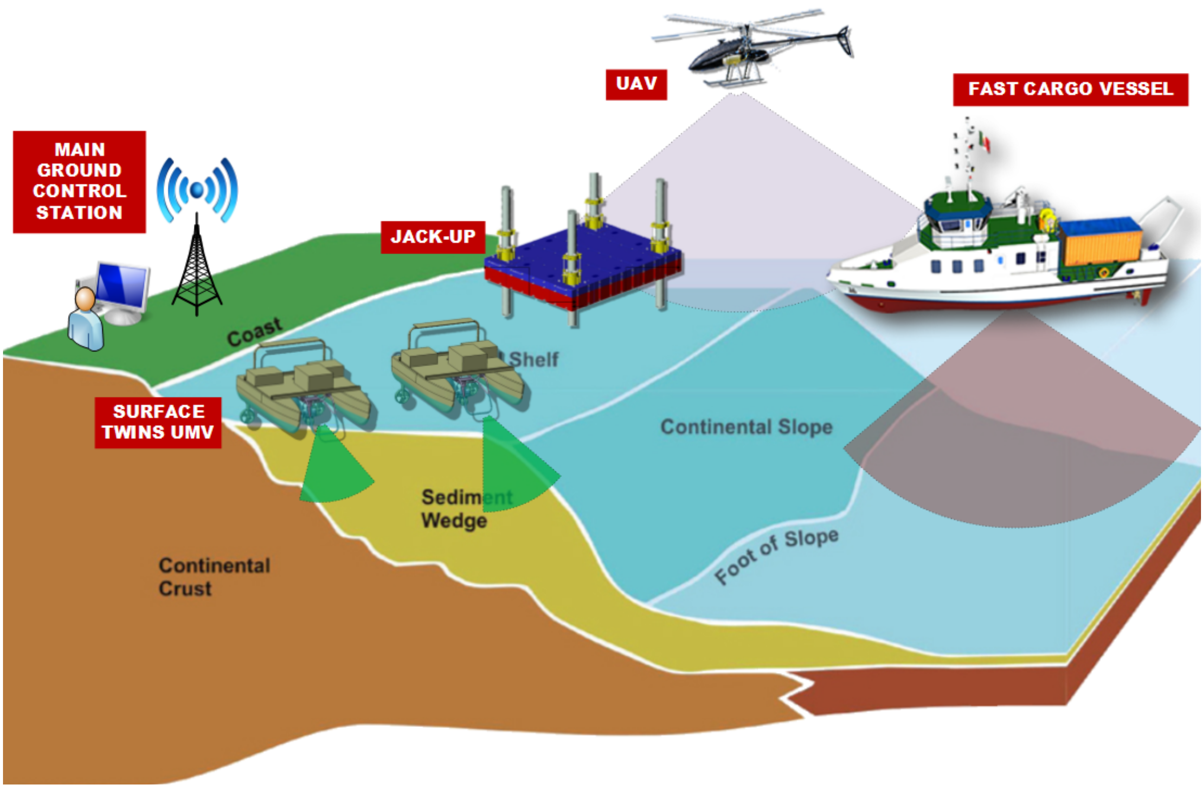

Figure 1. Multi-purpose technological platform infrastructure for multidisciplinary coastal monitoring designed in the framework of PITAM and STIGEAC projects.

The aim of this UAV prototype system is to raise the capacity of exploration and measuring of phenomena and processes that affect the coastal system, even during high-risk events (e.g. oil spills, inundations, flooding, fires, ship collisions, etc.), to protect the marine environment and the human health. The system framework includes hardware and software components that allow managing a mission planning and guarantee data acquisition from payload-sensors through a flight control system and a payload control system working together into a dedicated control room (Fig. 2). The system framework is also designed in order to transmit data to a "main control room" to improve processing of other datasets acquired by the jack-up, the fast cargo vessel and the UMVs.

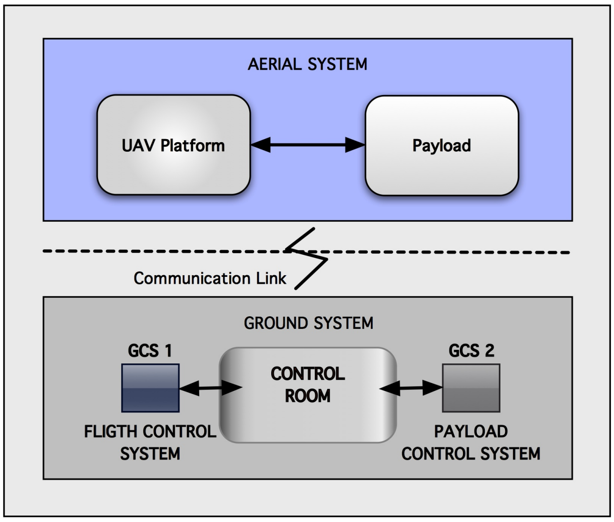

Figure 2. UAV Platform and Payload control framework.

The prototype system herein presented is constituted by:

(i) UAV platform "synchropter" Dragon 35 with a payload up to 26kg;
(ii) Ground Control Stations (GCS) for drone mission and payload management;
(iii) Communication link between UAV and GCS;
(iv) Payload devices (i.e. Thermal camera, High Resolution (HR) camera, Lidar System).

1.1 Unmanned Aerial Vehicle (UAV) platform

The UAV platform (Maximum Take-Off Weight – MTOW 73 kg) is constituted by a 19.5 Hp engine fuel powered and by a "synchropter" rotor-based technology. In figure 3 a picture of the UAV platform is showed, while the technical specifications are summarized in Table 1. This is classified as a large size according to the US Department of Defense (DoD), with a maximum operating range of about 10 km and endurance under two hours. This UAV platform was chosen after a technological scouting analysis that allowed the identification of the best technologies available on the market that could be appropriately re-engineered in order to create a prototype platform, to be equipped with scientific payload, for intelligent monitoring of coastal and marine areas.

The main objective of technological scouting activity was to integrate the operational needs of the coastal marine system exploration with the flexibility of the system (i.e. manoeuvrability, payload capacity, type of supported sensors). This last aspect was important in order to guarantee the possibility of making technical changes and re-engineering on both hardware and software to ensure that the whole system could be integrated into a customized and dedicated GCS for the management of multiple missions/sensors undertaken by cooperating unmanned systems.

The "synchropter" configuration (Fig. 4) characterized by high stability and excellent lifting capacity allowing the two rotors to rotate in opposite directions with the axes of the two shafts divergent relative one to another avoiding the interference of the trajectories. One of the advantage of this technology, suitable for environmental profiling and coastal studies, is the capability of maintaining an hovering point on a fixed target as well as performing spatial surveys. Recently, many authors reported that small and micro UAVs exhibit less vibration than fixed-wing systems, making them better suited to photogrammetric data capture [Wallace et al., 2012; Anderson and Gaston, 2013].

The UAV is equipped with a dedicated control system, which permits a stand-alone use. Furthermore, the system control allows management of complete telemetry or the control of the coordinates, altitude, fuel level, battery power, altitude, ground speed, etc. The remote system control is guaranteed by a communication link with operating frequencies of 400-450 MHz in a control range up to 50 km.

The choice of this kind of UAV platform is based on the following technical and logistical considerations:

(i) the aircraft flight capability totally autonomous from take-off to landing, with the possibility of intervention by the operator at any stage of the mission;
(ii) the configuration "synchropter" allows a high stability of the aircraft during hovering;
(iii) in the event of loss of engine, the UAV is able to land safely by autorotation maneuverer in complete autonomy.

Figure 3. The UAV platform without scientific payload, during a preliminary testing phase.

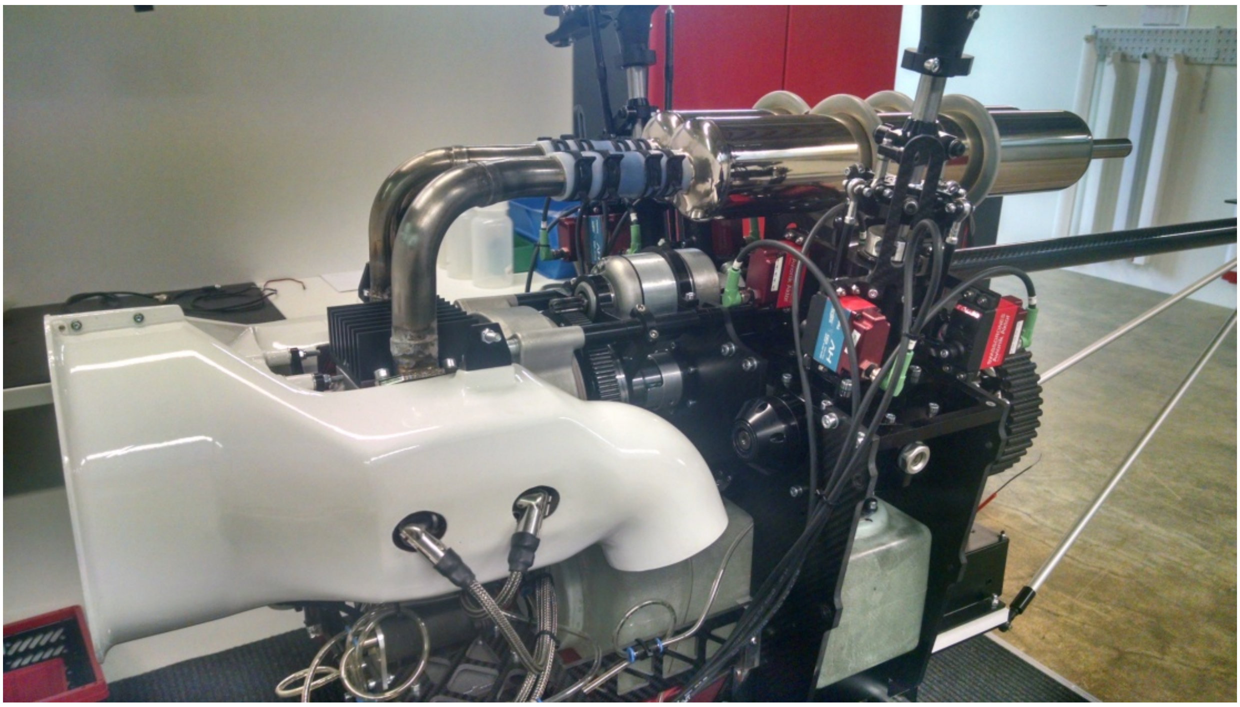

Figure 4. A particular of the UAV 19.5 Hp engine fuel powered and the rotor tail.

UAV "synchropter" Drone specification

Length	2170 mm
Width	700 mm
Heigth	980 mm
MR Diameter	2 x 2800 mm
Dry Weight	38 Kg
Fuel capacity standard	6 L
Max Fuel capacity	20 L
Endurance 6 L Fuel	50 min
Endurance 20 L Fuel	200 min
Payload 6 L Fuel	26 Kg
Payload 20 L Fuel	18 Kg
Max Airspeed	80 Km/h
Max Crosswind	24 Km/h
OAT	"-10°C / +35°C"
Maximum system operating altitude	120 m

Table 1. Technical specification of UAV.

Moreover, the UAV is able to land autonomously in a relative small area of 5x5 metres. The UAV platform is able to flight in three different modes (Fig. 5): a) Radio controlled, b) Manual, c) Degraded /Automatic. The flight mode choice allows operational optimization and security in case of failure. Particularly, the degraded mode helps to control the drone in case of GPS loss with low-level commands (i.e. attitude control, vertical speed, heading rate), while in automatic mode is possible to set the "home mode" that allows to reach the home waypoint in case of data-link lost providing the engine shutdown when ground is reached. This kind of feature helps to improve security of flight and manoeuvrability of the entire system.

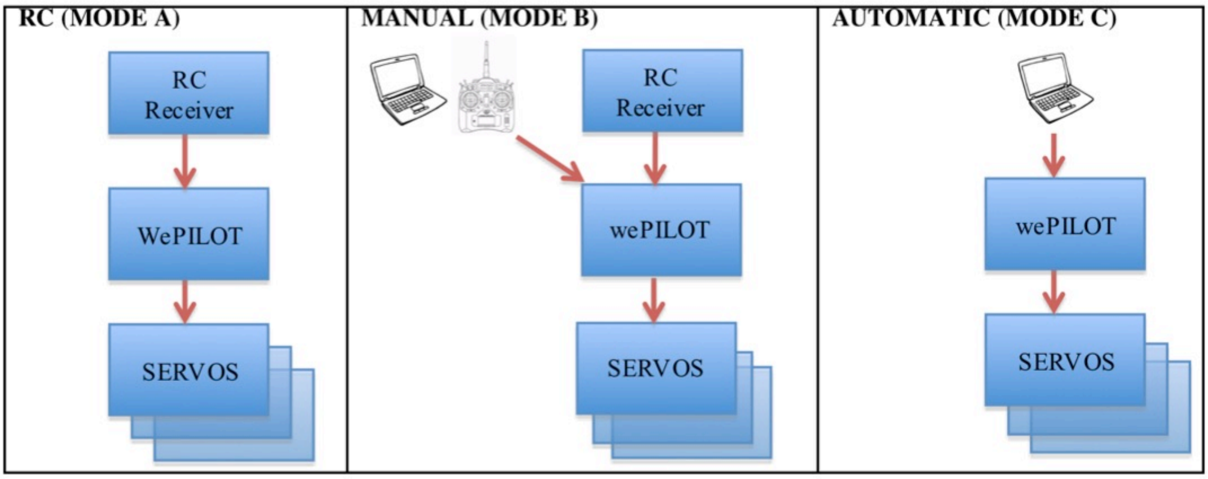

Figure 5. Possible flight modes of UAV: Radio controlled (Mode A); Manual (Mode B) ad Degraded /Automatic (Mode C).

1.2 Ground Control Station

The Ground Control Station (GCS) is constituted by two integrated control stations, the first one dedicated to UAV flight and mission control (Fig. 6), and the second one that allows managing on-board payload and the scientific mission (Fig. 7). In order to improve data integration and processing, the basic idea is that the whole dataflow is integrated with other monitoring platforms outputs (e.g. static and dynamic monitoring: buoys, radars, geophysical sensors, etc.). Since surveys management is carried out into a dedicated control room, located on land or at sea (on board the jack-up or fast cargo vessel) according to mission requirements, we designed two different GCS to manage more efficiently the dataflow.

Figure 6. Ground Control Station (GCS) for UAV flight and mission control.

The payload Ground Control Station is constituted by a sealed Pelicase box, a pc and a data link. The control box is fully contained into a Pelicase including a video receiver, a data link for data transmission, an Ethernet grabber/ Ethernet switch and a power supply (Fig. 7).

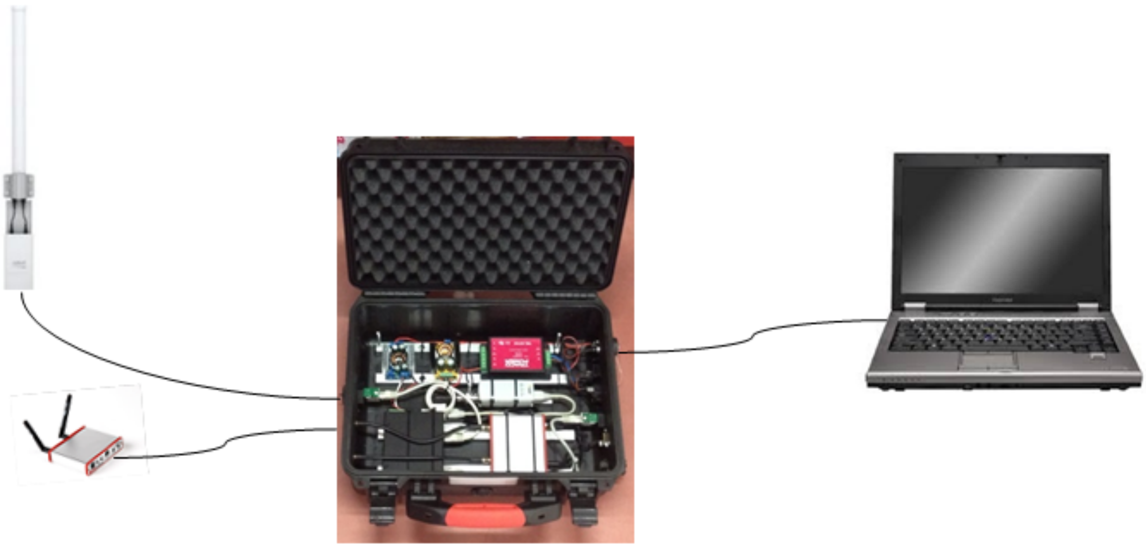

Figure 7. Payload Ground Control station: data-link, box pelicase and pc.

The software interface used by both the GCSs is based on the open source software “Mission planner” (http://ardupilot.org/planner/docs/mission-planner-overview.html) customized for system and payload control requirements (Fig. 8). This choice allowed us to maintain a good degree of flexibility of the system for future implementations.

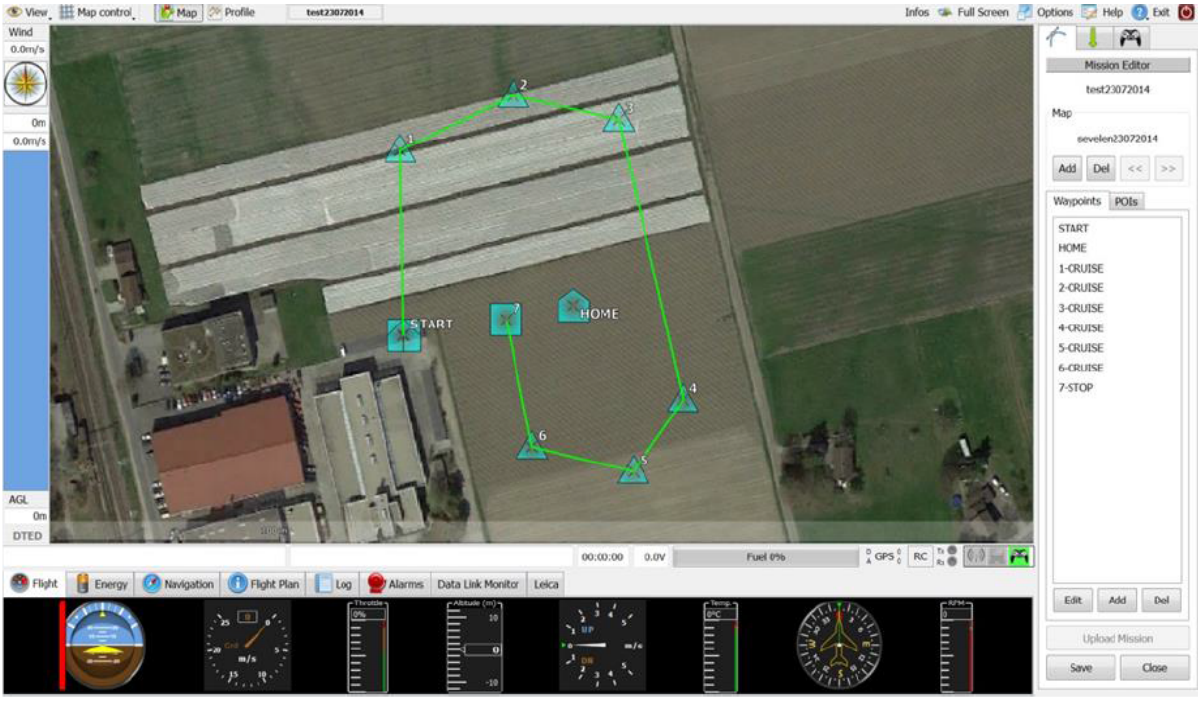

Figure 8. GCS mission planner interface.

The UAV platform flight control system includes: GCS, Data link system, Inertial Measurement Unit (IMU), GPS, Magnetometer and Barometer providing many functions for the system, such as: attitude stabilization, longitudinal/lateral speed control, hover control, rotor speed, autonomous landing and take-off, coming home function in case of link failure, pseudo autorotation in case of engine failure (Fig. 9).

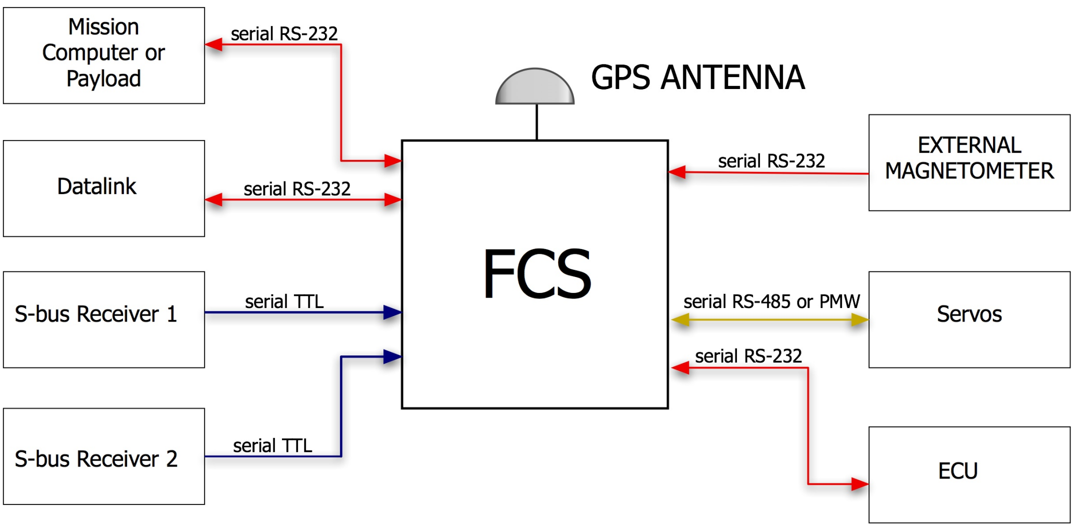

Figure 9. Scheme of flight control system (FCS) of UAV prototype.

Moreover, the flight control system allows verifying and monitoring mission preparation and execution in real-time, also simulating the training phase and controlling commands from RC-Transmitter, joystick controller or computer control.

This part of the system permits to control and to manage the whole data acquisition performed by the payload, and providing a total control of the servo-mechanisms (gimbals) that manage a real-time video acquisition by the three “Gopro” cameras installed on-board. The GCS on-board computer hosts a dedicated software to control the UAV’s payload (e.g. on/off and sensors check) and the video capture system through high-resolution cameras.

This last function allows managing directly cameras position and taking HR pictures. The connection to the on-board computer is established via a VNC that allows to administer the system remotely, receive an image of the screen and send keyboard and mouse input. A VNC server is installed on the machine to be controlled and a client (or viewer) is placed on the Ground Control Station PC.

1.3 Payload devices

The UAV system has been designed in order to provide data acquisition for coastal areas and land monitoring under different application scenarios mainly dedicated to photogrammetric and remote sensing surveys. For this purpose, we designed two dedicated payload configurations mounted on a suitable support and fixing casing made of lightweight composite material. The payload devices were chosen meeting the challenges of emerging survey requirements for the UAV system both in measurement performance as in system integration (e.g. with regard to the specific restrictions and flight characteristics).

The first configuration includes the photogrammetric system Riegl Vux System (Lidar Vux-1, control unit, Nikon D800 camera), two “Gopro - Hero 4” cameras and a high-resolution camera Canon EOS 5D mark III (Fig. 10). The second designed payload configuration is dedicated to simultaneously photogrammetric and thermometric monitoring including the Riegl Vux System, three “Gopro - Hero 4” cameras and a high-resolution thermal imaging camera (Fig. 11). The two payload configurations are designed in order to maximize the system requirements both of data acquisition and mission performance. Tables 2 and 3 show technical specification of payload configuration #1 and #2 and their on-field application for coastal environment monitoring.

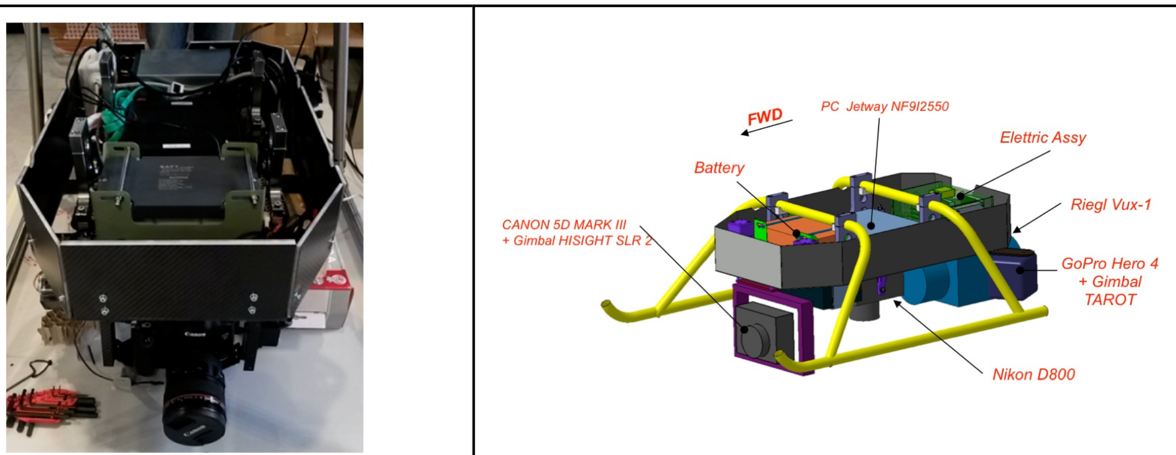

Figure 10. Payload configuration #1: Hardware housing (left) and configuration sketch (right).

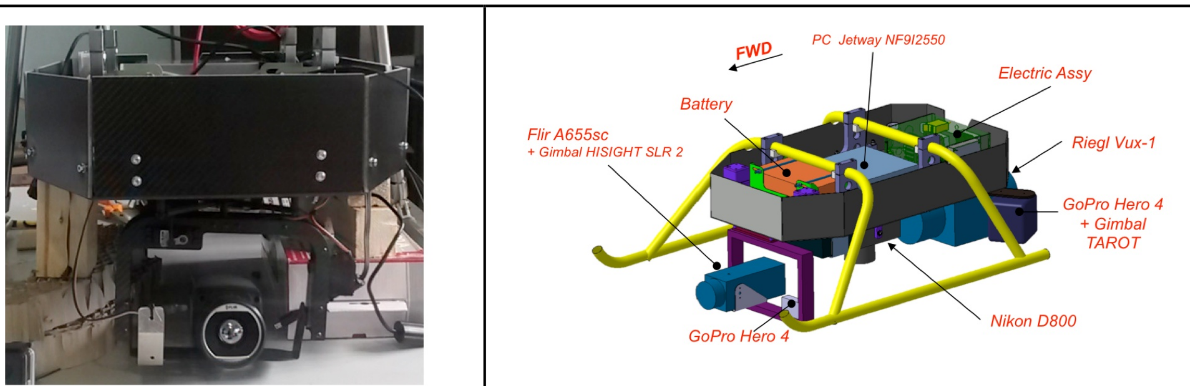

Figure 11. Payload configuration #2: Hardware housing (left) and configuration sketch (right).

PAYLOAD CONFIGURATION #1			
Instrument	Items	Accuracy	Main Applications
Riegl Vux-1 System	1	– 10 mm survey-grade accuracy – scan speed up to 200 scans / second – operating flight altitude up to more than 1,000 ft – field of view up to 330° for practically unrestricted data acquisition	– archaeology and cultural heritage documentation – corridor mapping (i.e. power line, railway track, and pipeline inspection) – topography – construction-site monitoring – surveying of urban and costal environments – natural resource management
Canon EOS 5D mark III	1	– 22.3MP Full-Frame CMOS Sensor – DIGIC 5+ Image Processor – Full HD 1080p Video Recording at 30 frames per second	
Gopro - Hero 4	2	– High Resolution video (1080p60; 720p120), 12MP photos from up to a maximum of 30 frames per second	

Table 2. Payload Configuration #1 technical specifications.

PAYLOAD CONFIGURATION #2			
Instrument	Items	Accuracy	Main Applications
Riegl Vux-1 System	1	– 10 mm survey-grade accuracy – scan speed up to 200 scans / second – operating flight altitude up to more than 1,000 ft – field of view up to 330° for practically unrestricted data acquisition	– agriculture & forestry – topography & corridor mapping – environmental risk surveying and monitoring – water pollution detection – natural resource management
FLIR Sc655	1	– Thermal sensitivity/NETD < 0.05°C at +30°C (+86°F) / 50 mK – Image frequency 50 Hz (100/200 Hz with windowing) – IR resolution 640p480	
Gopro - Hero 4	3	– High Resolution video (1080p60; 720p120), 12MP photos from up to a maximum of 30 frames per second	

Table 3. Payload Configuration #2 technical specifications.

1.4 Communication link

The communications for the system prototype are twofold: a data link enables a link between the drone (UAV) and its specific ground station (GCS) and another allows connecting the payload to the ground control station directly using a TCP/IP protocol. The data-links antenna operates between 400 MHz – 450 MHz.

In the first case, there are two radio links possible in the system to communicate between UAV and GCS and between the GCS and UAV. The data link uses safe frequency hopping spread spectrum (FHSS). The video link from UAV to its specific ground control station provides live videos. The system hardware of payload ground control station is constituted by a hybrid module operating in the ISM band 450- 400 MHz. The system, without specific permission and remaining under the 100 mW, is able to cover the distance of 2 km in free air with a power of about 25 mW and 14 dBm of power radiated from the antenna.

The UHF transceiver, designed to transmit digital signals, is characterized by low electricity consumption and complies with the European R & TTE directive EN300220 2012. The receiver stage has a sensitivity of 117 dBm and, like the transmission stage, covers 2 km with a 25 mW with data rates between 4.8 and 115.2 kbps. The module has a UART interface and can operate in transparent mode, in addressed mode, packet mode and repeater mode. The power supply is a voltage between 2 and 3.6 V with consumption of 22 mA and 37 mA in transmission in transmission 14 dBm.

All commands are encapsulated using the protocol “MAV link” but any science-based commands are managed directly from the payload ground control station. In any case, on board control units are demanded all the tasks of scientific data management therefore both for the interrogation of the sensors that for the recovery of the same data. Moreover, the payload data link was developed to handle communications between multiple autonomous systems such aerial, marine and terrestrial drones working together as collaborating systems.

2. Application scenarios

There is a broad range of potential applications for this UAVs system, including surveying, mining, agriculture, spatial ecology, archaeology, environmental monitoring, territorial management, search and rescue, risk management and conservation. However, the references to the use of UAVs for coastal monitoring are still scarce in the scientific literature [Delacourt, et al., 2009; Gonçalves and Henriques, 2015].

One of the most important applications of the herein presented system is certainly the photogrammetry, together with other monitoring activities that include visual patrolling and thermographic mapping that can be easily performed in coastal zones. The photogrammetric potential of UAVs has been evaluated recently in several studies [Capolupo et al., 2015; Gülch, 2011; Haala et al., 2011; Küng et al., 2011; Vallet et al., 2011; Rosnell and Honkavaara, 2012; Barry and Coakley, 2013]. Most of the obvious advantages of this UAV are especially for photogrammetric mapping and coastal surveying. These advantages include: relatively low hardware costs and high repeatability of the survey with low costs contrarily to other remote sensing techniques; high level of automation of photographic survey and very low operating cost. Moreover, small class UAVs are particularly adapted for the supervision of small lifting areas (e.g. self-lifting platform) working nearby the coast.

From an operational point of view of data acquisition, the UAV system allows obtaining aerial photography with high resolution due to the proximity of the photography subject. The GCS onsite operability gives the possibility of advance preparation of the terrain with ground control points (GCPs), at the time of the survey, together with the possibility of immediate viewing photography in the field and allowing repetition in case of fault detection.

Comparing the operation of light UAVs in coastal areas to other environments, it should be noted that two issues are usually present. The main one is the difficulty posed by the weather, especially the wind. In an operational context, a careful planning is required, looking for periods of lower wind, normally in early morning. In this case, the UAV platform herein presented ensures a tolerance of a maximum airspeed of 80 Km/h and a max crosswind velocity of 24 Km/h offering a good operational level always considering all the constraints related to safety. And then, the majority of small UAVs are not suitable for lifting too large areas in a short period of time, conversely the UAV prototype herein described has a good flight duration (≈ 2 hours) that could candidate it also to more different scientific applications studies such as atmospheric monitoring (e.g. Lidar profiling). Another important aspect is related to the exposition of instrumentation to seawater spry that can cause corrosion; this can be avoided using a carbon-sealed housing specifically designed.

Obviously, there are also some technical disadvantages, which include, some operational limitations due to the rotary wings configurations (i.e. extra power consumption for lifting) with respect to the fixed wings platforms that are energetically more efficient but less manoeuvrable (i.e. no chance of hovering). For instance, fixed wing systems are able to cover longer distances, survey much larger areas, and loiter for long times monitoring their point of interest. Moreover, as for other systems in use, the management of a scientific mission needs at least one technician dedicated to the acquisition and processing of multidisciplinary datasets (e.g. photogrammetric data, thermographic data, air quality data etc.) and in a fully operating framework, the UAV carrier, needs a certified pilot.

Another interesting aspect is safety. The system is characterized by very low risks in case of accident, due to the light weight of the devices and short time needed for a mission planning, which allows it to be used quickly, for example right after a storm. Safety is ensured both by GCS mission planning control, and by AUV autopilot safety function "automatic mode-c" (see fig.5) ensuring that the system comes back home in case of signal or control loss. Furthermore, the high manoeuvrability and attitude of the AUV's synchropter configuration gives many advantages during logistically complex operations, for example when hovering handles are necessary. All these aspect are relevant for a risk analysis documentation needed to obtain the permit to fly (ENAC SAPR Regulation, issue n.2 16/07/15 and rev. 22/12/16).

All these aspects lead to consider that the overall performance of the system is very advanced with respect to other systems of the same category for both the characteristics of the payload and the all-operational capabilities offered by the UAV carrier.

3. Conclusions

The UAV prototype including the payload configurations herein presented are an operating part of a wider multi-purpose platform infrastructure designed for the intelligent monitoring and geo-environmental surveys along the coast, which also includes two twins surface unmanned marine vessels (UMV), a jack-up barge (i.e. a self-lifting platform) and a fast cargo vessel.

In this framework, the application scenarios for this system are aimed to a broad range of research projects in the field of environmental sciences, such as photogrammetric surveys, monitoring of pollutants, real-time fires monitoring, acquisition of data for ecosystem processes evaluation (e.g. atmospheric profiling, species control, population dynamic). The flexibility of the system for different suitable payload configuration makes it very appropriate for photogrammetric application, visual exploration and fire monitoring.

One main elements of innovation of the whole system is the introduction of a cooperation capacity between UAV and UMVs, with the final goal of obtaining high-resolution "seamless" topographic mapping in the land-sea transition zones that are the most complex to explore and also the most interesting given their dynamic nature due to the simultaneous interaction of natural and anthropogenic factors.

Since the prototype herein presented has been realized within the framework of the PITAM and STIGEAC projects which aim was the integration of intelligent autonomous system prototypes (i.e. AUV and UMVs) for geophysical and environmental monitoring of the coastal zone, the following first test case has been created with this main purpose rather then on the evidence of dataset acquisition. Furthermore, the interface between UAV platform GCS and payload GCS is designed considering the possibility of managing a group of collaborating unmanned vessels operating like a fleet for a simultaneous monitoring in both air and underwater space along a coastal areas. Therefore, the preliminary goal was in order to test the system potentials for land-sea explorations using cooperative unmanned systems.

The whole autonomous system operability in a fully cooperation mode (that is together with the two Unmanned Marine Vessels - UMVs) was tested on field at the Cilento National Park "Alento River Oasis" (Fig. 12) nearby the homonymous dam (40° 9′ 49.46″ N, 15° 8′ 35.7″ E, Campania Region - Southern Italy) on June 2015.

The first demonstrating test consisting of a cooperative (i.e. AUV and UMVs prototypes) mission fully managed by the developed mission control GCS. This test included only a patrolling activity (i.e. HD video acquisitions) and a manoeuvrability test (i.e. Take-off, hovering and landing) in coordination with two UMVs. This has suggested very interesting scenarios in terms of AUV systems operating performance in such complex exploration conditions (i.e. coastal zone pollution monitoring together with UMVs) testifying a huge potential for innovative research in coastal marine environment monitoring.

Figure 12. Drones cooperation test at the Cilento National Park "Alento River Oasis" Southern Italy and the two Unmanned Marine Vessels (left side, bottom) and the AUV payload equipped (right side, bottom).

Acknowledgments

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