

# Rapporti tecnici

## INGV

**A new prototype of Unmanned  
Surface Vehicles to survey the coastal  
marine environment: design, modelling  
and control**

# 374



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# Rapporti tecnici INGV

## A NEW PROTOTYPE OF UNMANNED SURFACE VEHICLES TO SURVEY THE COASTAL MARINE ENVIRONMENT: DESIGN, MODELLING AND CONTROL

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## Introduction

In the recent years, Unmanned Surface Vehicles (USVs) have proved their usefulness in particular to collect data for marine research and environmental survey. The use of these controlled remotely platforms, without direct human control, have improved the capacity to image, and monitor the seabed and the coastal-marine environment. Outfitted with different instruments (payload), the USVs are used for marine, river and lake activities, such as environmental monitoring, water quality sampling, hydrologic survey, target tracking and scientific survey [Bertram, 2008; Manley, 2008; Giordano et al., 2015]. Other fields of application include harbor surveillance, maritime search, rescue and natural disaster damage assessment [Steimle et al., 2009].

One of the first USV was ARTEMIS, designed in 1993 at MIT (Massachusetts Institute of Technology, Sea Grant Collage) [Manley, 1997] to collect bathymetric data and it was characterized by a propulsion system with two electric motors and a rudder servant-implemented. The USV was equipped by an automatic control of the heading and an autonomous navigation capacity through reference points (waypoints). Its small dimension (about 1.37m long) was the main shortcoming, limiting the endurance and the sea keeping. Following the development of ARTEMIS, to improve the transverse stability and to design more payload capacity and redundancy as regards the buoyancy, MIT adapted the catamaran shape for the hull and removed the rudder; the steering is based on a differential propeller revolution rate. After the MIT, several USVs were designed within many research projects. Among these, other USV were realized. The DELFIM, capable of working in close cooperation with an Autonomous Underwater Vehicles (AUV) [Pascoal et al., 2000] and the ROAZ, ROAZ II, that, set up for bathymetry survey, were designed to allow testing and validation of new developments in monitoring, coordinating multi-vehicle navigation, sampling and other research topics related to marine surface vehicles [Ferreira et al., 2006a, 2009]. Further developed concerned the SWORDFISH, MESSIN and SPRINGER vehicles. The SWORDFISH [Ferreira et al., 2006b, 2007] is a survey vehicle, with modular sensor payloads and a mobile gateway for air to underwater communication. The MESSIN [Majhor and Buch, 2006] is a catamaran dedicated to delivering sensors for oceanographic operations or hydrological mapping. The vehicle is suitable to operate in very shallow water, without destructive effects on the marine environment. The autonomous navigation system allows following the pre-programmed routes efficiently. The SPRINGER was developed in 2004 [Naeem et al., 2006; 2008] for tracking of pollutants, hydrographical surveys in rivers, water resources and coastal waters. As marine platform, SPRINGER was designed to be used also as a test-bed for intelligent navigation systems and for testing of new technologies for the sensors. Several developments in the modelling of twin hull USVs were presented also by the CNR-ISSIA (Italy) [Caccia et al., 2006] that within the SESAMO project designed the catamaran Charlie for sampling activity in the Antarctic Region [Caccia et al., 2006].

This technical report describes an innovative and integrated prototype system of Unmanned Surface Vehicles (USVs) for advanced environmental monitoring; the water platform's is developed at the Coastal Marine Environmental Institute – National Research Council (Italy), within the Project: Integrated Systems and Technologies for Geophysical and Environmental Monitoring in coastal-marine areas (STIGEAC), in the framework of the National Operational Programs 2007-2013. The project concerns in the research of new technologies and the design of vehicles, for the surveys of the coastal marine environment, understood as a “multipurpose” laboratory for sea research with characteristics of modularity and portability. The goal involves not only the execution of scientific and technological research but also for the valorization of marine cultural heritage, for industrial activity and for emergency interventions related to environmental crises. Major innovations concern the design of a new architecture of the control system and/or to allow the cooperation between heterogeneous unmanned vehicles, the integration of distributed sensing techniques and real-time image processing capabilities [Marsella et al., 2015].

## 1. Vehicle Design

One of the main goal of the STIGEAC Project is to build up an innovative prototype system, composed by two twin USVs, equipped with radio communications and high-performance sensors on board for multi-applications missions that include bathymetric mapping, velocity profiles. This represent an important aspect for the scientific data capturing, monitoring and survey for preservation activities in coastal marine environment.

To this aim, the objective of developing unmanned vehicles for multipurpose marine operations led to the need of a robust, hydrodynamic and very stable vessel. The vehicle design involved the hull and propulsion design, electronic devices, sensor selection and data link, with the aim to combine small dimension, speed and manoeuvrability performance.

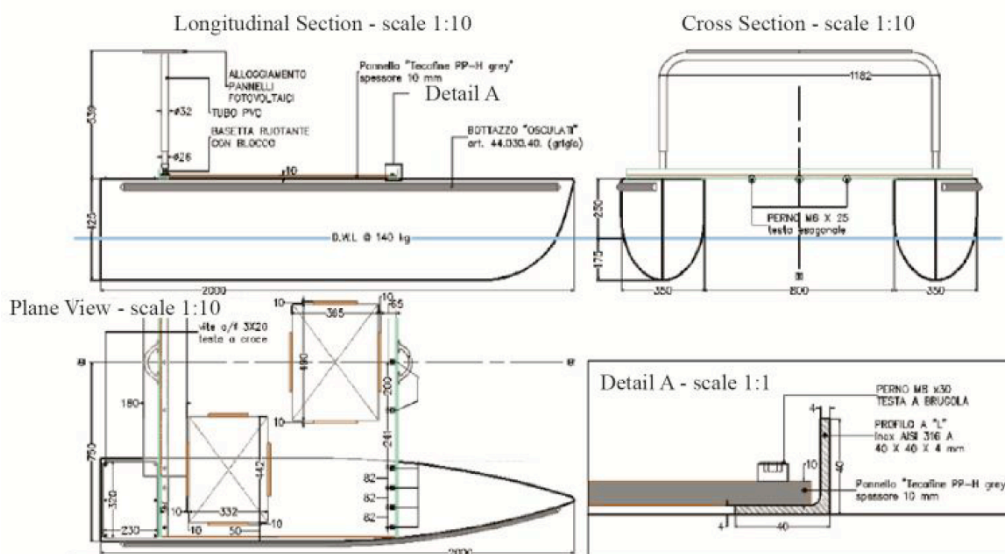
The choice was to design a catamaran-type watercraft platform (twin-hulls), that provides low hydrodynamic drag strength and high stability of the rolling movement and wavy motion [Caccia et al., 2005; Manley, 2008]; it was the most suitable solution to satisfy the requirements as to best place of several sensors, electronic system and batteries.

The twin-hulls are in vinyl ester resin (H034-ADB-30 Hydropol™); a panel and a crossbeam (fig. 1a) connecting them. These components are in PVC material in order to minimize electromagnetic effect on the navigation sensors (magnetometer) and radio systems (data link, GPS, video system). The vehicle weights 85 kg (with 30 kg from batteries), is 2.0 meters long, 1.5 meters width and 1.2 meters height (with A-frame).

The figure 1b shows the technical draws of the USV.



(a)



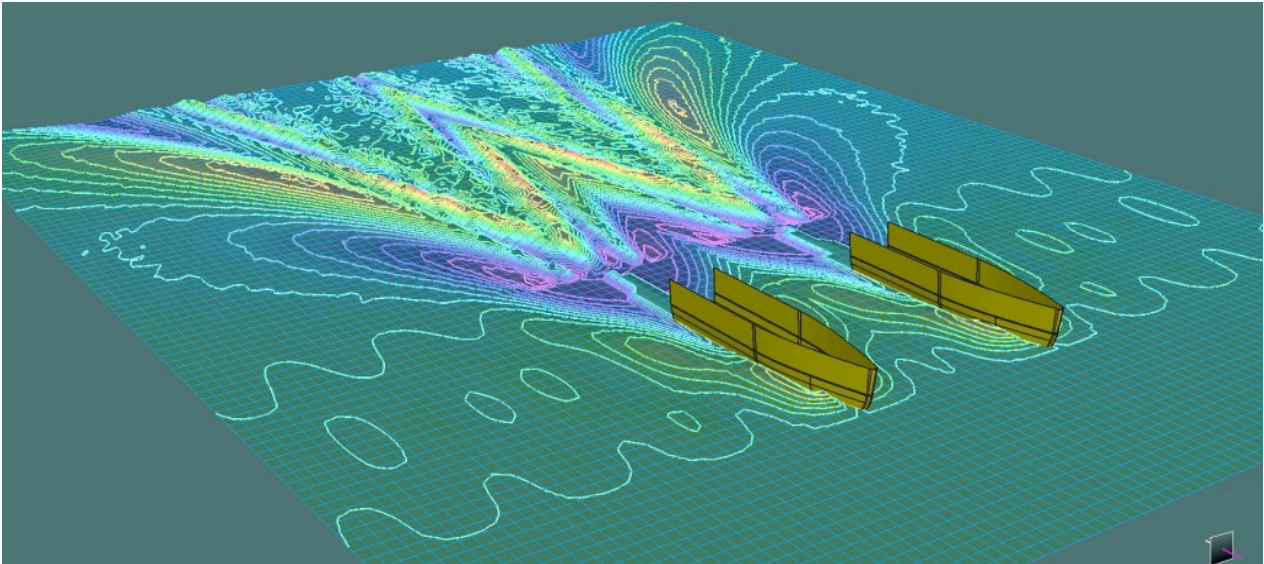
(b)

**Figure 1.** USV: (a) picture and (b) technical draw of the USV.



The design optimization of the hull was performed with the support of the commercial software MAXSURF (Naval Architecture Software for all Types of Vessels). The calculation of stability and hydrostatic characteristics shown a zero trim of vessel, obtaining the position of the barycenter at 0,80 m from the stern and symmetrical position between two hulls. This condition occurs for a displacement of 120 kg, corresponding to draft of 0,40 m. Analyses of the vehicle resistance show that, setting a maximum velocity of 7 knots (3.6 m/s), the resistance is equal to 88.14 N and the power required ranging 600 W. This computation is used to estimate the total payload for the platform, as will be discussed in the follow.

The figure 2 reports the simulation of the wave field at the assumed velocity.



**Figure 2.** Simulation of the wave field assuming a velocity of 7 knots.

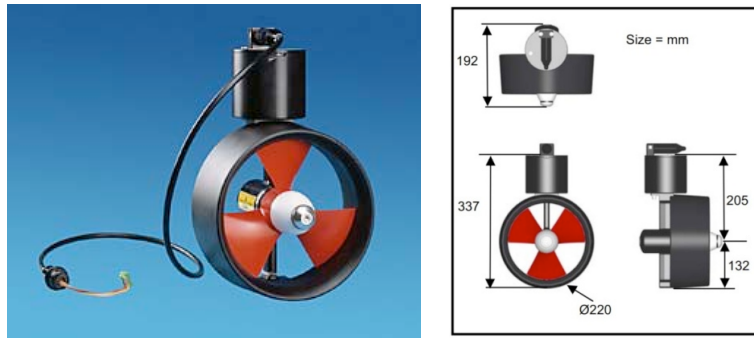
The operative low speeds, to fit the low sampling rate of scientific equipment, the low resistance of the vehicle provide a better maneuvering performance and increase the efficiency of the thrusters.

The numerical analysis suggests equipping the USV of two motors, under the backside of each hull, in order to provide a wheel effect, simply operating on the propellers rates in differential mode. This type of control, in fact, allows the vehicle to realize yaw operation with a very small radius of curvature, and avoiding the usage of other mobile parts needed for the implementation of one or more rudders, with advantages in terms of final weight and time reliability.

### 1.1 Propulsion System

Two Seaeye SI-MCT01 electrical thrusters (fig. 3) compose the propulsion of the system. This choice was carried out for the following reasons:

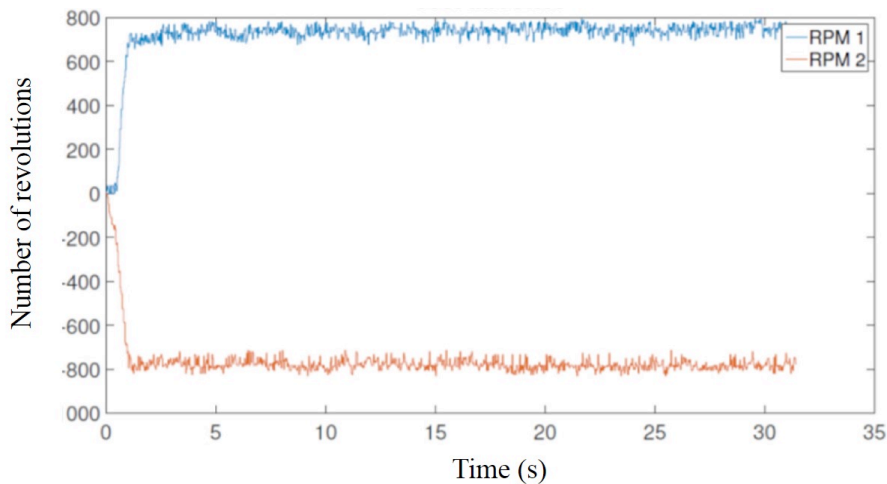
- the system is almost symmetric, providing 13kgf and 12.8 kgf in forward and reverse respectively; this feature is important to control the direction and is more than enough to handle standard catamarans and well higher weights than that estimated;
- the power supply system (48VDC) does not require high voltages, simplifying the design of the supply and DC / DC converters;
- the power electronics is contained within the thruster itself, and is equipped of the an overcurrent protection circuit.



**Figure 3.** Thruster Seaeye SI-MCT01.

The electronic is placed within the box HPRC that is mounted on the deck of the catamaran. These choices were made to simplify the design, the use and maintenance of USV. These aspects will be explained following.

Two isolated supplies DC/DC @ 24V (TracoPower TEQ-200) power the two electrical engines. The figure 4 shows the response of the motors speeds (in RPM), during the first test of the propulsion subsystem, for one changing of the speed required (step) from 0% (minimum RPM) to 100%, (maximum RPM) that corresponding a velocity about of 1.8 km/s. The Table 1 summarize the technical specification.



**Figure 4.** RPM of the thrusters during the test.

**Table 1.** Technical Specification.

Length: 2 m	Max payload (including box payload): 35 kg
Beam: 1.5 m	Power engines: 300 W (x2)
Draught: 0.4 m @ 120 kg	Engines push forward: 13 kgf (x2)
Height (with roll bar): 1.2 m	Thrust engines in reverse: 12.8 kgf (x2)
Hull: 35 kg	Supply voltage (min-max): 35-55 V
Thrusters: 10 kg	Supply voltage nominal: 46.8 V
Box Control: 10 kg	Capacity: 69.6 Ah
Battery Box: 30 kg	Charging time: 12 hrs

## 2. Sensors

It is well known that the evaluation of the spread of pollutants, measurement of the depth of the seabed and their morphology are an important branch in coastal-marine monitoring and survey. Detect the changes near coastal areas is important for the marine geological study and for environmental studies and also in the design of the works of marine engineering.

On the USVs were installed specific sensors for bathymetric survey, habitat mapping, geo-archaeology studies and hydrodynamic modelling.

These sensors are:

- acoustic Doppler Current System Profiler (ADCP);
- sub-bottom profiler;
- 3D Microbattery.

Low power consumption, low weight and data transmission requirements have characterized the choice of the specific instruments and the performance of the USV.

The Acoustic Doppler Profiler is the SonTek AD500 (fig. 5a); it is easy to use and allows a three-dimensional shape of the sea current for oceanographic and hydrographic application. The operative frequency ranges is from 250Hz to 1500 kHz; the velocity is  $\pm 10$  m/s (up to 100 range cells) with a resolution of 0.1cm/s, and an accuracy equal to  $\pm 1\%$  of measured velocity,  $\pm 0.5$  cm/s. The power input requires is 12-24 VDC; the power consumption is from 2 to 5 watt in typical operating mode and is  $< 1$  mW in sleep mode.

Acoustic data are collected by a 1.35 MHz Blueview MB1350 Multibeam sonar system (fig. 5b), with a  $42^\circ$  field of view.

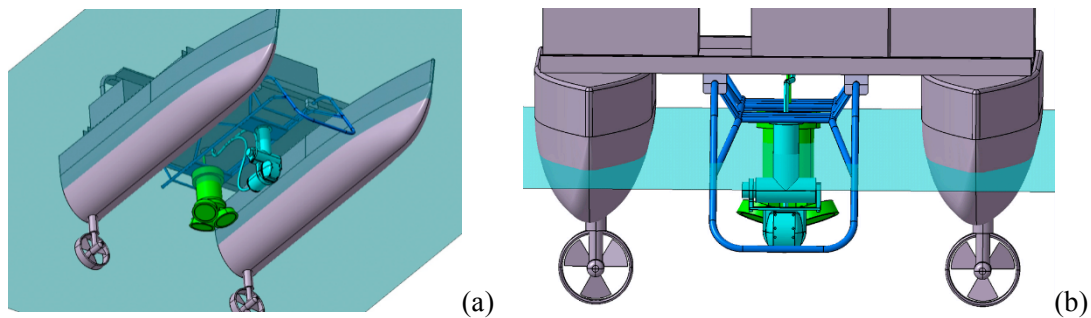
The EdgeTech SubBottom-424 is a full-spectrum sub-bottom chirp-sonar technology profiler (fig. 5c) and generates pulses which a sweep frequency of 4 kHz to 24 kHz for 10 ms with a vertical resolution of 40 cm.



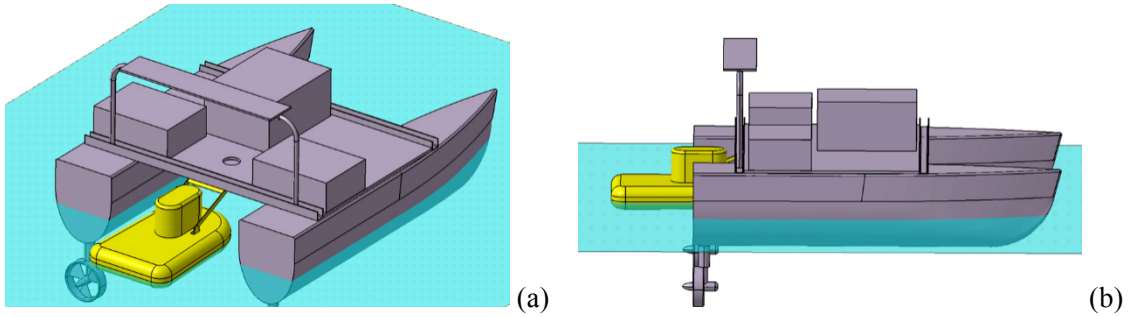
**Figure 5.** Scientific payloads: (a) ADCP; (b) 3D Multibeam sonar and (c) Sub-bottom profiler.

These instruments were arranged in the bottom of the panel as shown in figure 6 in order to optimize the balance of the hull at maximum allowable load.

To install the explained instrument under the USV, a stainless steel tubular framework was developed. This mechanical interface allows the modulation of the sensors positioning in accordance with design requirement (fig. 6b).



**Figure 6.** Configuration of the USV with ADCP and 3D Multibeam sonar: (a) isometric view of the layout and (b) frontal view.



**Figure 7.** USV configuration with Sub-bottom: (a) 3D view and (b) lateral view.

For each configuration, many tests were conducted to verify the mechanical compatibility of the towing payload and electromagnetic compatibility of the sensors, on board instruments and radio when they operate simultaneously.

### 3. Hardware/Software Architecture

A Ground Control Station (GCS) is the core system, through which it is possible to control independently the USVs and the payload. The advantages of the modular solution appear clear; the decoupling of the two controls allows the management and the development of a scientific mission independently from that of autonomous control. The station provides more interconnected modules, so it is possible to drive the USVs and manage the payload separately.

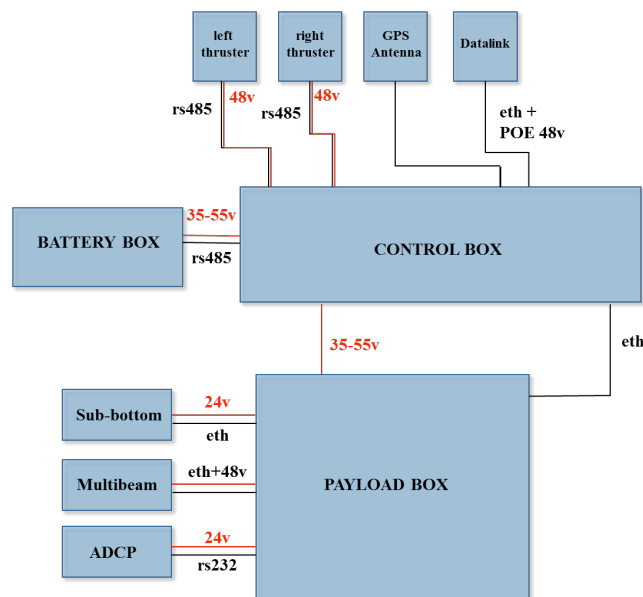
The GCS is a transportable hardware device and can operate from the ground or sea.

As the USV, the ground control station is important because enables an interface with the operator for some changing during the route of the platform, and to correct some eventual errors on the platform. Furthermore, it receives the outcome of the sensors remotely and shows the data on the monitors.

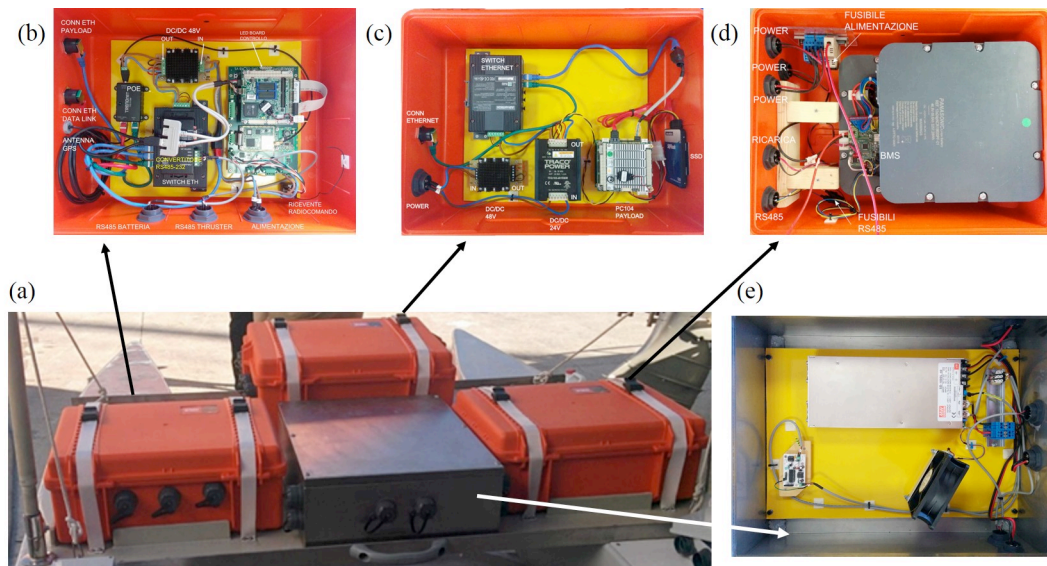
The operator sends commands to the USV via the GCS during the uplink operation to program, control and guide the vehicle during the mission. Meanwhile, the GCS receives data from the USV during the downlink and forwards it to the operator. The data include position information, mission status and other important information.

The figure 8 reports the architecture of the electronic on board devices. The batteries, the USV main control and payload control systems are located at the central of the platform, in 4 Peli-cases (fig. 9a).

This choice was aimed for simplifying the design and the maintenance of marine drone.



**Figure 8.** Architecture of the electronic devices on board.



**Figure 9.** The electronic systems on board the platform (a). The internal mounting of the USV control box (b), the payload controller (c), the battery (d) and the thrusters control (e).

The technological setup of the USV control box is reported in figure 9b. On the right side, it is located a custom PCBs, containing the dsPIC microcontroller, that mechanically houses the GPS OEMStar signal and the PC104 control board. At the center and on the top, there is the DC/DC that, by the battery voltage, generates the 48V for PoE injector (black box on the left) that powers, through the Ethernet cable, the External data link. At the center of the box, instead, is located the Ethernet switch, above which there is an isolated converter RS485-RS232 in order to connect the control PC104 with the battery telemetry.

On the left side, there are two ethernet connectors: one is used for the connection with the data link (red cable), while the second one is used for the connection with the payload box (blue cable). On the same side, there is a cable gland for the GPS antenna one, which is routed in the box until it get to OEMStar receiver.

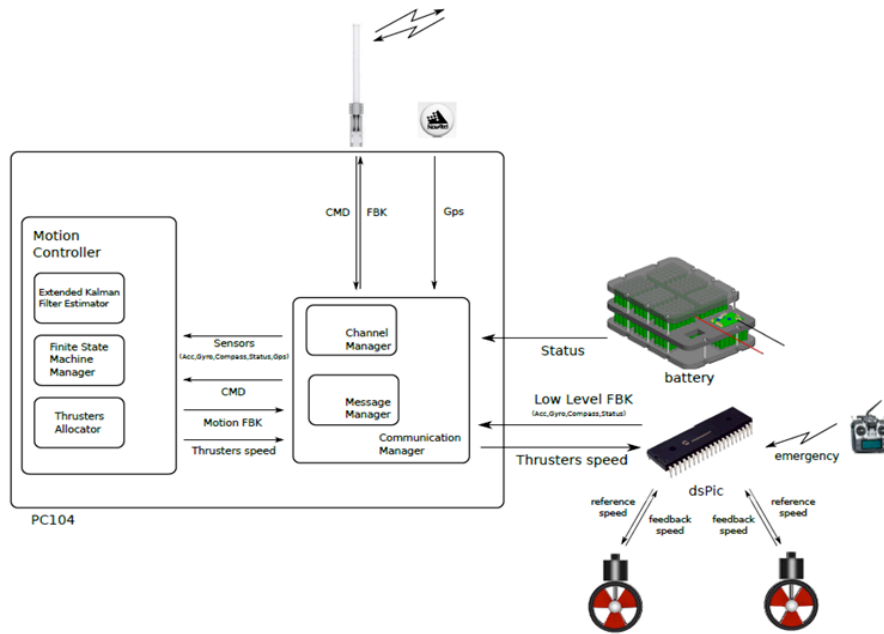
Figure 9c shows the payload controller box. It is possible to see two connectors, one for power and one for the Ethernet connection. The Ethernet cable is connected to the control box. In the rest of the box, there are present Ethernet switches, which can be linked to the sensors, a 48 Volt DC/DC for powering the payloads, a 24 Volt DC/DC for powering the switch, the PC104 and the payloads.

The electrical devices of the thruster are located in a stainless steel box (fig. 9e); it contains a DC/DC (1kW) to stabilize the battery voltage to 48V as required by the engines. Two pairs of connectors on the metal box are for the powering and for the serial buses 485 A fan, improving the dissipation on the box surfaces and a card records temperature.

The choose of the batteries was made considering the consumption of the devices that are installed on the USV, the weight and dimensions that characterize these vehicles. In order to guarantee a satisfactory autonomy and communication, the main consumption is estimated equal to 616W and in large part, thrusters characterize it. The payloads have a less consumption of about 50W. The total consumption evaluated for a mission is about 670W. To reach an autonomy of about 5 hours, with a nominal battery voltage equal to 48V, it is required an energy capacity of about 70Ah.

The battery are lithium ion cells in order to maintain the weight less than 20 kg. The battery box (fig. 9d) contains an integrated BMS board (battery Management System), that checks the battery charge status and manages the charging process.

In figure 9d, it is possible to see the terminal box, which distributes the powering on three connectors on the panel (one for the payload box, one for the control box and one for the box of the DC/DC of thrusters) and a 25A fuse on the positive battery terminal. At the bottom, it is possible to see three cables of the RS485 communications, each ones provided by a 250mA fuse. The second connector, instead, is used to recharge the battery. The figure 10 shows a sketch of the block diagram of the control box. The watercraft platform was also equipped with waterproof camera for monitoring and localization purposes.



**Figure 10.** The block diagram of the control system on board the watercraft platform.

#### 4. Communication link

The USV and payload are remotely controlled by a long-range data radio link, composed by two omnidirectional antennas with 13 dB gain: the first one installed on the Ground Station and the second one on the USV. The video transmission uses a datalink with frequency of 5.8 GHz and a antenna gain of 1.9dB. The Wi-Fi datalink and GPS antennas are anchored to the A-frame in order to mitigate phenomena of reflection and absorption of the radio waves generated from the Wi-Fi link and to have better resulting from the point of view of robustness of the communications. As regards the control system and remote supervision, it is necessary to remind that the standard European regulations are very restrictive in terms of transmissible power. In Europe, there is a free band of 1.7 MHz around the frequency of 433.92 MHz, with EIRP 10mW.

The national frequency allocation plan (GU n. 273 of 21/11/2008), since Ministerial Decree 20 February 2003, assigns for use of the wireless-lan, and in compliance with ERC Recommendation 70-03 of wireless equipment at short-range (SRD), the following frequencies:

- 2400-2483 MHz Radiolan
- 5150-5350 MHz HiperLAN (only inside the buildings)
- 5470-5725 MHz HiperLAN
- 5725-5875 no specific apparatus SRD

The transmission in these frequency ranges is regulated by ETSI. These rules also are been reaffirmed by Ministerial Decree of 10 January 2005.

The private use of Wi-Fi networks that cross public land is no longer subject to the payment of contributions and even to the general ministerial authorization of communications; in essence, it is allowed the free use, provided that they comply with the power (EIRP) and are used in devices with CE marking.

Another exception is made for non-specific wireless devices that operate in the frequencies around of 5.8 GHz, for which it was never necessary to pay any fee, i.e. it is generally granted unlimited use. It should however be pointed out that, because of the heavy restrictions on the transmission power (25mW max), it is not possible to travel more than a few hundred meters.

For these reasons, it was necessary to set the study of the “budget of the link”, conducting a detailed analysis of trafficking, including through tests performed in the laboratory and in the field, that led to the determination, of the characteristics of the equipment and the operation field of the remote control.

Specifically, the analysis of the route of a link is based on the Friis equation's.

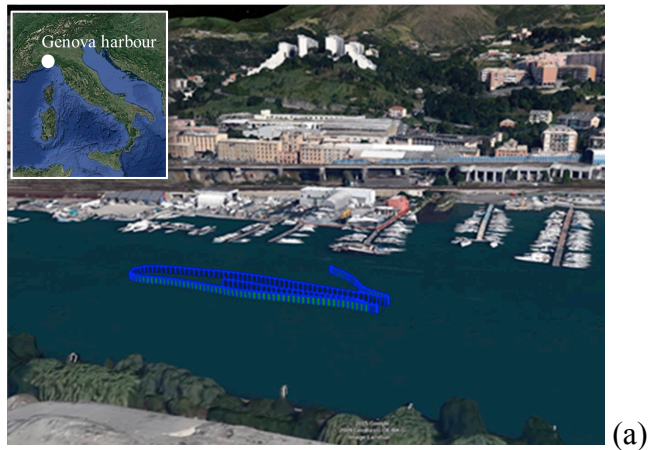
**Table 2.** Analysis of trafficking: control/payload.

Sensitivity [dBm]	PT [dBm]	G1 [dBi]	G2 [dBi]	F [MHz]	D [KM]	Code
-94	27	13	13	5470-5825	50+	Power not compliant Frequency compliant
-80	25	13	13	5470-5825	8.5	Power not compliant Frequency compliant
-77	23	13	13	5470-5825	4.8	Power not compliant Frequency compliant

From tests carried out, the use of solutions compliant with the regulations, has enabled the achievement of a distance <1KM.

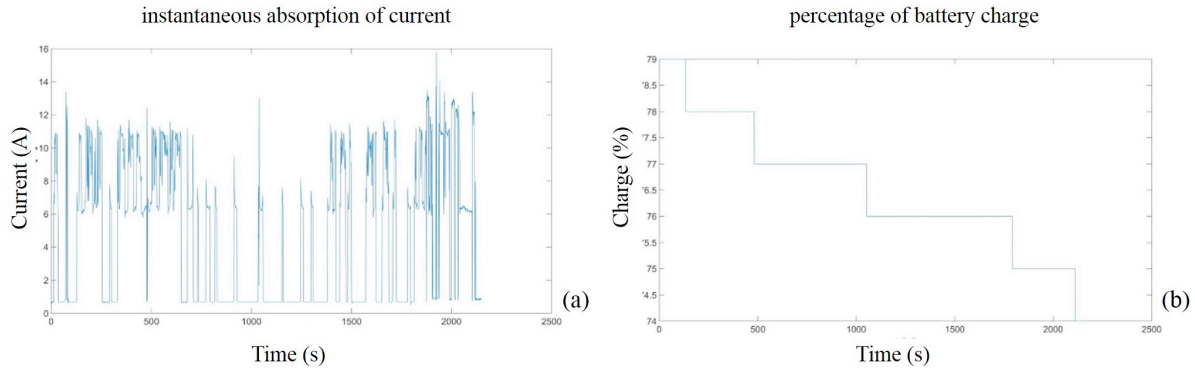
## 5. First Tests

The first test was carried out in the Harbor of Genova. The USV operates in both manual and automatic modes, with waypoints (fig. 11). The automatic test covered a sea surface of 40mx90m, within which the UVS did two rotations in the middle of the test path and two rotations at the limit of the test area. The data obtained from the sensors were stored in the database with the marker time.



**Figure 11.** Place where the test was made. (a) Rendering of the test path; (b and c) the USV during autonomous mission in the Harbor of Genova.

The data recorded are a set of about 35 minutes per tests. Figure 12a shows the instantaneous current absorption. During this test, the battery charge, that was not fully charged (the initial charge was about 80%), has decreased of 5% as showed in figure 12b and, after the test, the two thrusters have consumed about the 40% of the initial power.



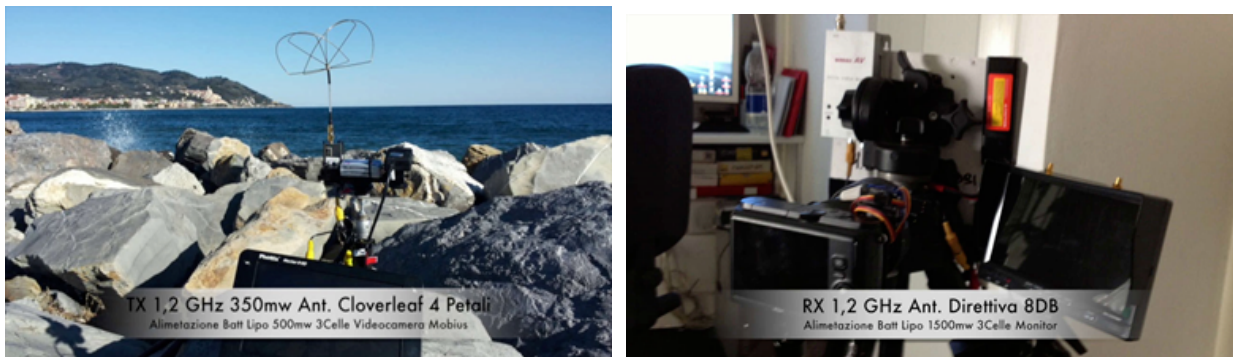
**Figure 12.** Current consumption (a) and percentage of battery energy (b) used during the test.

Experimental tests on the maximum performance of the USV showed that:

- the maximum forward velocity is equal to 3,5 Knots;
- the maximum velocity of rotation is about 45°/s;
- the maximum cumulative heading during the rotation is more than 600°;
- the radius of curvature depends on both the feed rate and on the speed of rotation. The UVM is capable of rotating on the spot if the speed is zero, while a radius of curvature equal to 7m is realized when the maximum feed rate and speed of rotation are reached.

Some preliminary tests of the video transmission system, operating at a frequency of 1.2 GHz, were carried out on the ground in a place relatively close to the operative area. Transmitter and receiver were placed on the ground, near the coast, a few meters of elevation from the sea (fig. 13).

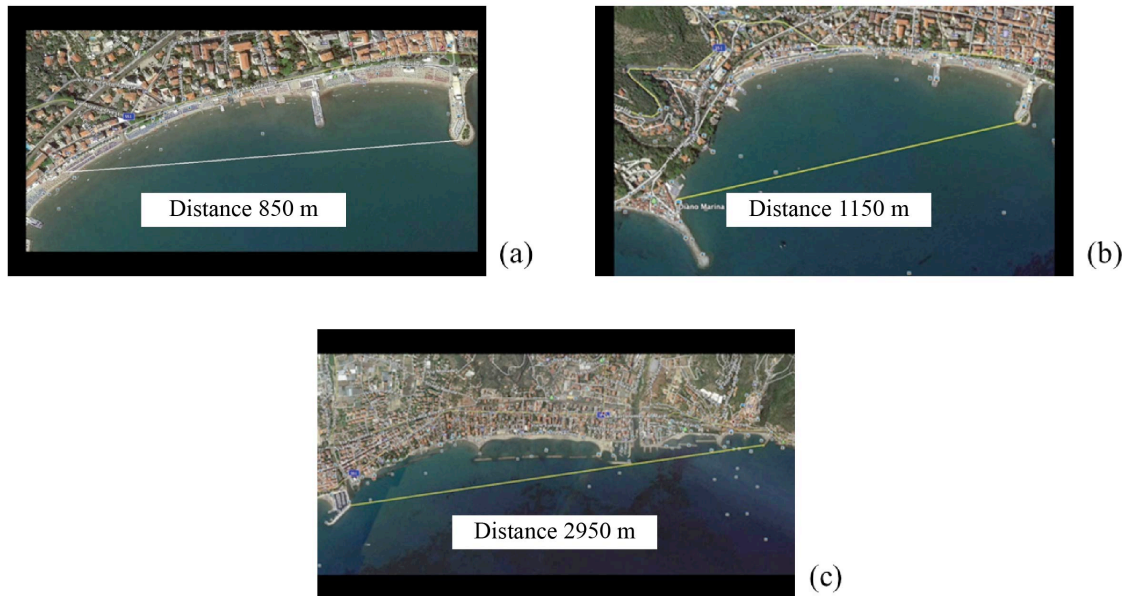
The TX system transmits the signal of a Mobius video camera with a power of 350 mW and uses a cloverleaf 4-petals antenna. The RX system is a directional antenna with a gain of 8db. Tests verified the quality of the video signal transmitted at three different distances of communication: 850m, 1150m and 2950m.



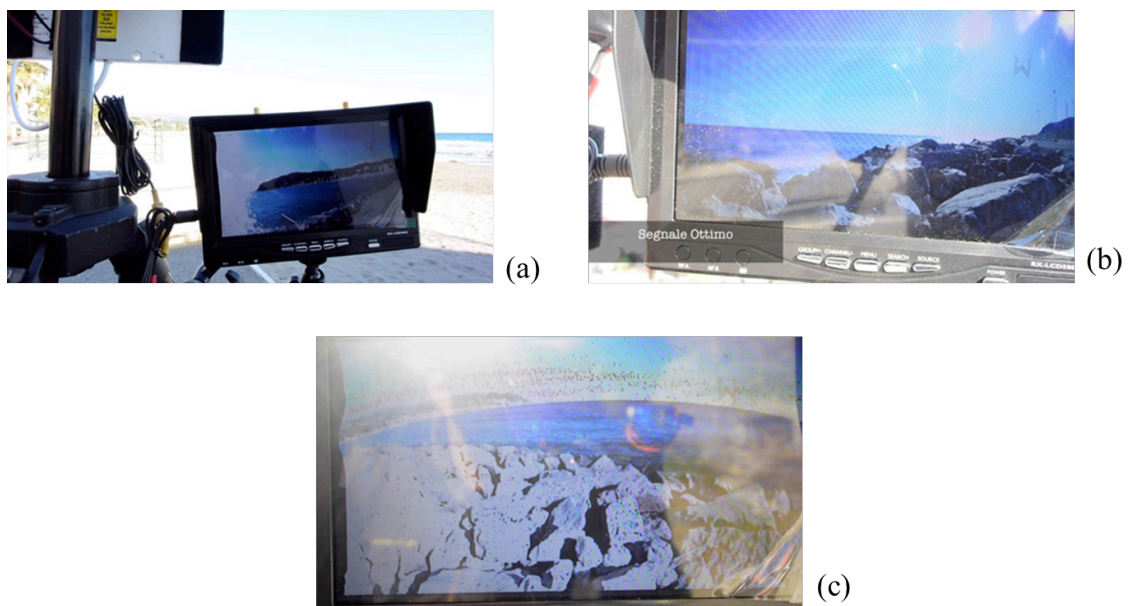
**Figure 13.** Test of the transmission system at 1.2Ghz.

The results were satisfactory. The following images are frames that show the quality of video obtained (fig. 15).





**Figure 14.** Maps with the paths set, followed by the USV during the three test.



**Figure 15.** Examples of video frames received during the three test.

## 6. Conclusions

As member of the project STIGEAC, the Coastal Marine Environment Institute (IAMC) of the National Research Council (CNR) has designed and realized two prototypes of Unmanned Surface Vehicles, characterized of constructive and innovative features and suitable for research, monitoring and acquisition of multidisciplinary scientific datasets. All parts of these vehicles were designed to be well integrated in order to having platforms with innovative characteristics, such as modularity, functionality and portability. These vehicles are been developed in according to the payload requirements and to for the executive missions in heterogeneous environments of the coastal marine and in logistically complex areas. The result of this work is the realization of two catamarans and 35 kg payload equipped of an one ADCP profiler and a multi-beam 3D micro-bathymetry system. The applications field consist of surveys along the coast and in shallow water.

The sensors used are for geomatics activities, for monitoring and protection of the territory from natural hazards, such as hydro-geological and environmental risks. The overall objective achieved is to have an integrated system for sampling, monitoring and analysis of environmental parameters in different layers (air-water-sediment) with the possibility of intervention in coastal areas, river and lagoon, including the land area with difficult access. Such system offers a support for conducting scientific and technological research activities, for the promotion of cultural heritage in the sea, for the development of industrial activity and for emergency interventions related to environmental crises. The test missions have demonstrated the ability of the prototype to operate in collaboration with others devices, for testing the capacity of some tools necessary to support situations in the event of an emergency.

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