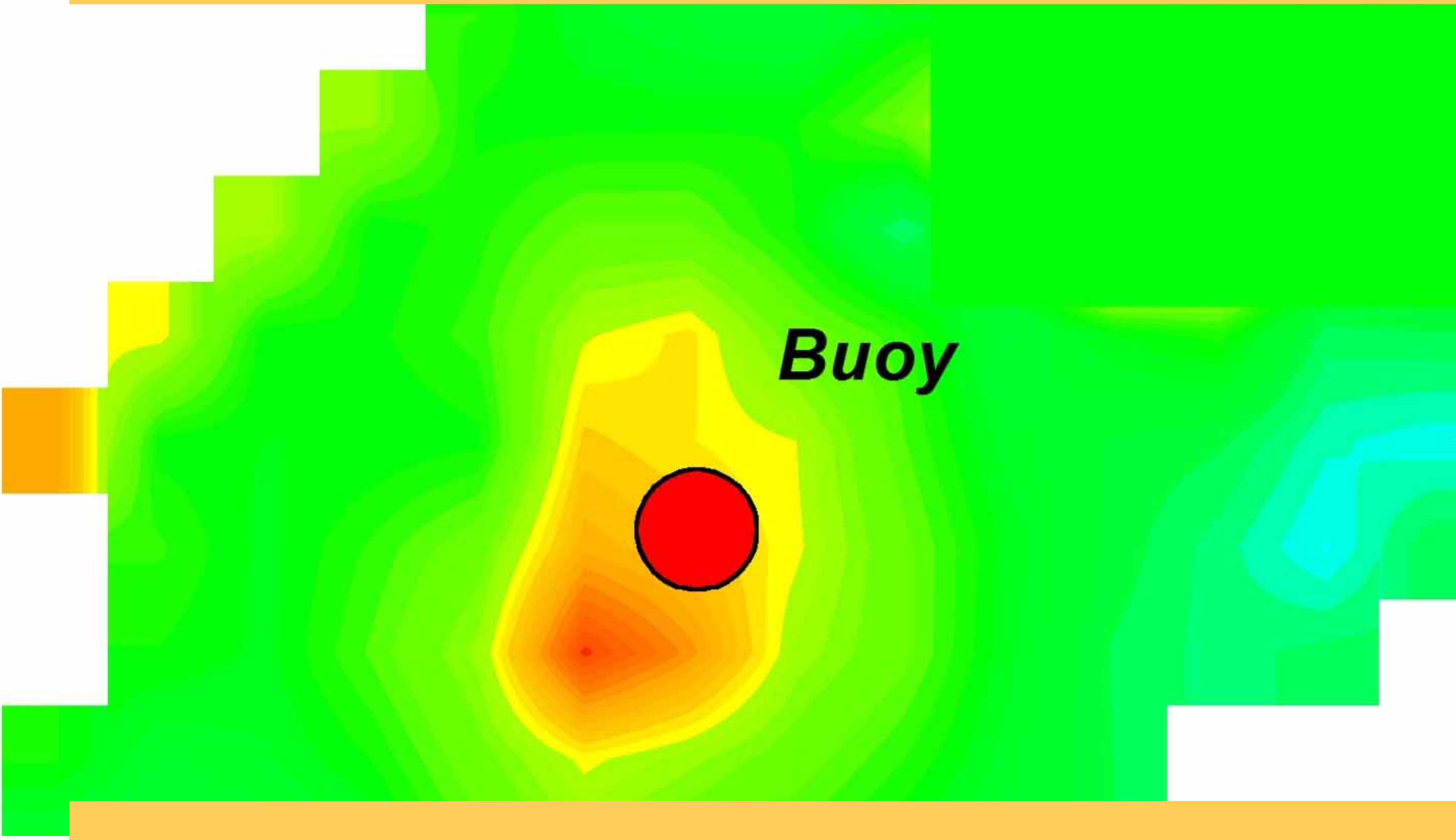
ISSN 2039-7941
anno 2022 numero 453



RAPPORTI TECNICI INGV

Development of a remote underwater platform for multidisciplinary investigation of marine environment: conceptualization, design development and first results

ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

453

REGISTRAZIONE AL TRIBUNALE DI ROMA N.174 | 2014, 23 LUGLIO

Rappresentante legale: Carlo DOGLIONI
Sede: Via di Vigna Murata, 605 | Roma

ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

ISSN 2039-7941
anno **2022** numero **453**

RAPPORTI TECNICI INGV

Development of a remote underwater platform for multidisciplinary investigation of marine environment: conceptualization, design development and first results

Luca Cocchi, Filippo Muccini, Marina Locritani

INGV | Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Geomagnetismo, Aeronomia e Geofisica Ambientale

Accepted 23 March 2022 | *Accettato 23 marzo 2022*

How to cite | *Come citare* Cocchi L., Muccini F., Locritani M., (2022). Development of a remote underwater platform for multidisciplinary investigation of marine environment: conceptualization, design development and first results. Rapp. Tec. INGV, 453: 1-26, https://doi.org/10.13127/rpt/453

Cover Map of analytic signal of survey area | *In copertina Mappa del segnale analitico dell'area di indagine*

453

INDICE

Abstract

The study and evaluation of the health state of oceans and major seas requires an integrated approach able to discern all the information about quality of the marine environment where seabed, water column and marine circulation should be considered as a unique ecosystem. Marine litters have a very important impact on the global pollution of the coast and offshore area because they are present both on the water column, as micro/nano litters, and on the seabed as macro items. Within the large family of marine litters, we also recognize all those objects related to the military activity of the last World Wars, which are largely widespread along the coast of our seas. Most of these anthropic objects are nowadays partially or completely buried below the seafloor. Investigation of the seabed for detection of any possible anthropic objects represents thus a very important task. Here we present the conceptualization of a remote-controlled underwater platform integrating magnetic sensor, multiparametric probe, direct camera visualization and an acoustic beacon for underwater positioning. This newly developed system aspires to become a versatile investigative tool for a multidisciplinary study of the marine environment especially for the coastal areas and very shallow regions having anthropic influence. We report the results of the first test where we describe capability of the platform and possible future development.

Keywords ROV; Magnetic anomaly; Unexploded Ordnance; Seawater temperature; Underwater acoustic communication.

Introduction

With a total amount of about 10 million tons of land based waste [Jambeck et al., 2015] that ends in the ocean, marine pollution represents one of the major contributions of the decreasing quality of the health of our planet. Marine litters, which comprise plastic based waste and other anthropic objects, have a very important negative finger-printing not only for the seawater areas but also for the entire society and the global economy. Considering only plastic-type litters, the global effect of this pollution produces a negative impact on the global economy estimated at about $8 bn per year [Löhr et al., 2017].
The coast shoreline and marine antrophized areas like harbours, docks, embarcaderos and military areas record the presence of large quantities of anthropogenic material (micro and macro litters) carpeting the seabed and often also placed under the first meters of the marine sediment. This material can give an important negative impact on the health of the marine environment in general, both from a biological and chemical-physical point of view. The general term of marine litters can include all the objects regarding the human activity spanning from common household wastes to more dangerous explosive devices (bombs, mines and others) related to past military activities. The identification of explosive devices addresses a leading role in seafloor reclamation, especially in the case of those areas interested by the presence of unexploded objects, known with the acronym of UXO (UneXploded Ordnance), [Billings et al., 2002; Zalvsky et al., 2012]. In addition, in some specific cases, marine areas can be interested by the presence of an ensemble of chemically loaded ordnances, which represent a high danger for all the people living and working close to those sites (fishers and/or recreational activity). UXO detection and more generally the assessment of the presence of any type of anthropic macro-litter in the seabed is a priority for all cases of civil/industrial reclamation and/or exploitation of the seabed (Oil and Gas industrial plant, wind farm, seafloor mining).

In the last 15 years, INGV has conducted different marine geophysical surveys in harbour and coastal areas having as specific aim the detection of ferromagnetic objects laid over and below the seabed. In 2009 INGV collaborated with Italian Navy, ISPRA and NATO-CMRE in the framework of the PRO.BA project (*Prospezioni Ordigni Bellici Basso Adriatico*) focused to investigate harbours and littorals interested by the presence of UXO and other devices related to the II° World War. In 2004 and 2015, INGV collaborated with the Hydrographic Institute of the Italian Navy in several surface magnetic investigations of Taranto harbour for its partial reclamation. Considering these consolidated experiences and also knowing the difficulties related to the detection of submerged objects, especially in low visibility areas, we develop an innovative underwater platform able to join the classic direct observation of the seafloor with geophysical and oceanographic data collection. This integrated system would provide a specific tool for a more accurate identification of objects located over and/or below the seafloor.
In this work, we describe the development of an observer-class Remotely Operated Vehicle (ROV) equipped with different payloads such as: fluxgate magnetometer, CTD probe (Conductivity, Temperature and Depth), acoustic positioning with attitude sensor, HD camera and forward looking sonar. In the subsequent sections, we introduce the conceptual idea of the project with specific details about each single instrumentation integrated in the system. Finally, we present the result of a first test survey recently conducted in La Spezia Gulf aimed to evaluate the real operative capabilities of this new scientific platform.

1. The multidisciplinary underwater platform

Remotely Operated Vehicles (ROVs) are mobile robotized devices tethered from the surface (or from a supply vessel) that nowadays are engaged in a very plenty of submarine duties. The ROVs are able to investigate a wide range of sea depths, from the shallow harbour areas to the deepest abysses. The first pioneering prototypes of ROVs were developed in the first 50' by the Royal Navy as skilled tools mainly engaged to recover mines and/or torpedoes.
Working class ROVs are common in offshore industry where they are employed in all specific activities related to the maintenance of the underwater portion of the Oil and Gas platforms and also as support to the mining operation (partially replacing most of the common human activities). In the last 40 year, ROVs have assumed a leading role in development of marine science because of their capability to provide direct imaging of abyssal depths. Most of the new discoveries about geology and biology of the deep oceans has been achieved also thanks to the support of remote operated vehicles [i.e. Marsh et al., 2013; Katija et al., 2017; McLean et al., 2020 and reference therein]. INGV is owner of SIRIO (Figure 1; https://www.lighthouse-geo.com/equipment/rov/rov-sirio), an observer-class ROV for underwater visual inspection which can operate at a maximum depth of 300 m. In Table 1, we report the technical specification and the standard equipment of the ROV Sirio.

Operation depth	300 m	**Propulsion**	2 vertical oblique vectored DC brushless thrusters; 2 horizontal DC brushless thrusters
Dimension	590x560x450 mm	**Standard function**	Auto-depth; auto heading
Weight	40 kg	**Camera**	Colour camera 700 tvl
Payload	8 kg	**Illumination**	2 lights
Power input	220 VAC single phase	**Manipulator**	2 functions electric manipulator

Table 1 Technical features of the ROV Sirio.

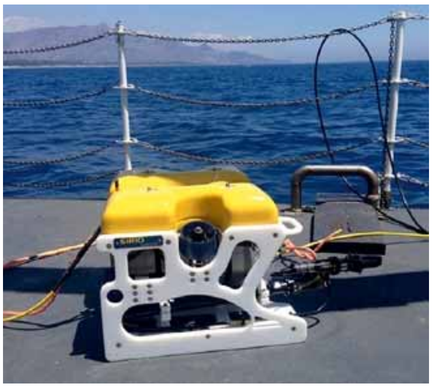


Figure 1 The ROV Sirio placed on the stern of Nave Aretusa (Italia Navy); from Cavallaro et al. [2016].

Considering its small dimensions and technical features, the ROV Sirio is mainly used for direct observation of the seafloor or water column with the possibility of a real-time video recording. The subsea unit is controlled from the surface by using a HCU (Hand Control Unit) which manages all the commands required for diving, navigation and real-time observation. Special features such as the auto-heading and the auto-depth commands permit to operate the vehicle at a fixed depth and following a pre-defined direction (heading navigation). In addition, the Rov Sirio is also equipped with an electrical manipulator managed by a specific joystick.
In 2020, in the framework of the project *Pianeta Dinamico* (Task A3), we started to plan an updating of the ROV Sirio integrating new additional payloads in order to develop a more versatile submarine platform. Our idea was to overcome the operative limitations of the ROV Sirio (considering its use limited to the underwater observation) coupling new scientific sensors providing thus the possibility to acquire geophysical and geo-spatial data in concomitance with the direct observation. In particular, we integrated a miniaturized magnetometer, an acoustic beacon for exact localization of the ROV during the underwater navigation, an additional HD camera and, finally, an environmental multi-parametric probe for the evaluation of physical and chemical parameters of the water column (Table 2).

Main underwater platform	ROV Sirio 300m rated
Additional Sensor	
Magnetometer	Digital Fluxgate model AP1540 by Applied Physics
Acoustic underwater communication system	X150 USBL modem and X10 acoustic beacon by Blue Print SubSea
DATA logger (for the magnetic sensor)	AIR Drive pro
Additional HD camera	GoPro Hero 8 black with customized waterproof case 250m depth rated - 128gb SD
Multiparametric Probe	SA8060.10 by B&C electronics

Table 2 Technical details about the new additional sensors integrated on the ROV Sirio.

The focus of the project was the development of a small and smart junction box which can interface the main ROV electronics with new specific sensors. As the first step, the ROV was integrated with a fluxgate magnetometer and an acoustic beacon, but in the future, we are planning to integrate other different probes such as Sound Velocity Profiler, Turbidimeter,

CO_2 probe and others. In Figure 2, we report a schematic overview of the junction box and main connection with the ROV system.

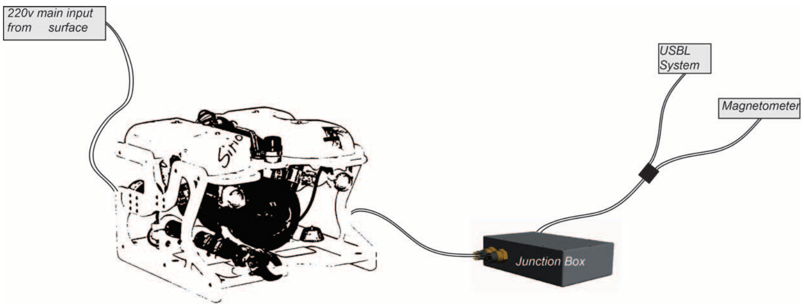


Figure 2 Schematic representation of the main connection ROV-USBL and magnetometer. Not in scale.

1.1 The new junction box

The junction box represents the core of the submarine platform that provides mutual connection from ROV to the other sensors. This item has been designed to be as versatile as possible in order to permit integration with different sensors. As already stated, at this stage the junction box is used to record magnetic data from a fluxgate magnetometer and, at the same time, to supply the power to an acoustic beacon.

The junction box is a waterproof rectangular box made in POM material (Polyoxymethylene) with dimensions of 177x46x113 mm (Figure 3). The box has an internal thickness ranging from 10 to 15 mm, which ensures the resistance for a depth rate of 250/300 m. We chose the POM material because it is a very versatile thermoplastic with peculiar features as:

- High strength, rigidity and toughness
- Good impact strength, even at low temperatures
- Low moisture absorption
- Excellent machinability
- Good creep resistance
- High dimensional stability

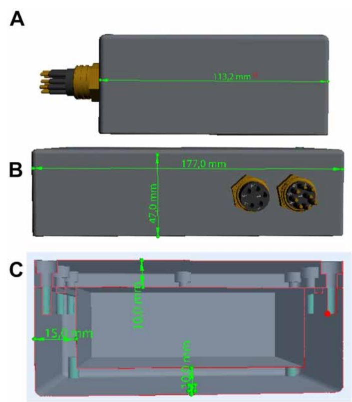


Figure 3 CAD drawing and dimensions of the Junction Box. A) Side view; B) front view; C) cross section (side view) showing the internal thickness of the box.

The top cover of the box is transparent in order to allow a direct observation of the status of the electronic board placed inside the box (Figure 4).

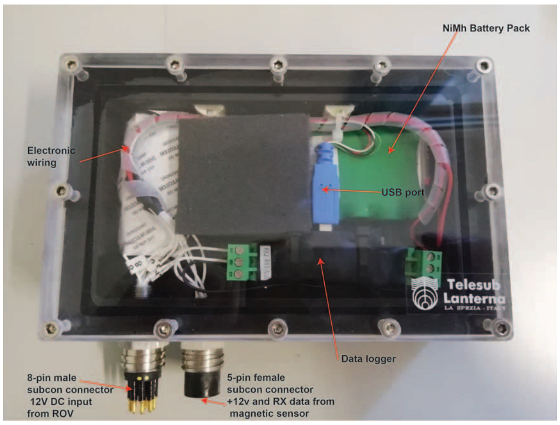


Figure 4 Image of the junction box with internal view of the main electronic components.

A schematic description of the several connections between junction box and the ancillary sensors is shown in Figure 5.

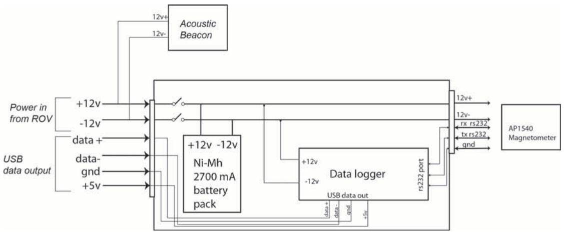


Figure 5 Sketch of the main electronic connections of the junction box.

The submarine unit of the ROV Sirio is provided by an auxiliary +12 VDC port, which can be plugged to other additional sensors. Through this auxiliary interface, the ROV shares concomitantly the main 12V DC to the magnetometer and acoustic beacon by using a Y-shaped marine cable. When this cable is plugged on the junction box, the magnetic sensor and the data logger (placed inside the junction box) are directly powered through the main power line coming from the ROV. In case of lacking connection with the ROV Sirio, the junction box can operate using the internal battery pack. This operation mode is acted by the User plugging a dummy connector that closes off an electronic switch ensuring thus the power supplying from the battery pack.
Two marine connectors, type SubConn MCBH8M 8 pin and MCBH5F 5 pin are installed on the front side of the box (Figure 6). 8-Pin connector shares the +12 VDC power coming from the ROV electronics to the magnetometer and to the acoustic beacon. On the other hand, the 5-pin connector ensures the data communication via RS232 between the magnetometer and the data logger (AIR Drive serial drive pro model).

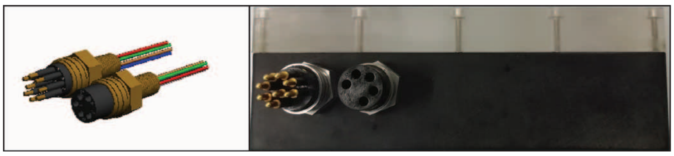


Figure 6 Details of the two marine connectors: left panel, CAD representation; right panel, real view.

The junction box hosts a 12V Ni-Mh rechargeable battery pack formed by 10 cells providing a maximum current intensity of 2700 mAh (Figure 7). This battery pack permits the use of the junction box without the main power supplied by the ROV. This solution permits thus to use the magnetometer-beacon coupled sensors as a standalone system which could be thus integrated also on different platforms (i.e drone).

Figure 7 Image of 12V NI-MH battery pack placed inside the Junction Box.

The number of cells of the battery pack has been previously defined taking into consideration the dimension of the hosting box and the possibility to use the entire system (magnetometer and data logger) for at least 1 working day. In Table 3, we report the energy consumption estimation for the junction box.

Component	Power supply	Typical Current Draw	Percent of usage	Hour of usage
AP1540 fluxgate magnetometer	DC 12V	55 mA	2.07 %	49 h
AirDRIVE data logger	DC 12V (5V in USB mode)	65 mA	2.4 %	41 h
	total	120 mA	4.47 %	22.5 h

Table 3 Energy balance and time estimation.

The power consumption estimating indicates that the battery pack can supply the entire system for 22.5 hours, in a continuous way. The battery pack can be recharged connecting the junction box to a plug-in Ni-Mh type battery charger by using a dedicated 8-pin male-ended cable. Data coming from magnetic sensor are stored inside a data logger that also provides the time-stamp for the data synchronization (using NTP- server). The logger has an internal memory flash of 16 Gigabyte and the possibility to merge a second stream of data coming from an additional RS232 interface. The data logger has an integrated Wi-Fi module operating as an Access-Point. The user can access the data logger by connecting to its static IP address and interfacing thus to the own web-page. The user can also check the real time streaming of the data coming from the RS232 port and subsequently downloads them to other support (i.e. Personal computer) for a secure backup. The user can also access the flash memory through the USB interface (using a dedicated cable plugged into the 8-pin connector of the junction box).

1.2 The Fluxgate Magnetometer AP1540

The magnetometer integrated on the new platform is the AP1540, a fluxgate sensor model produced by the Applied Physics System Inc (https://www.appliedphysics.com/). The AP1540 is a high speed 3-axis digital sensor which employs a 24 bit A/D converter. The instrument is basically constituted by a 3 orthogonal rings core integrated with an analogic processing electronics. As typical for the class of fluxgate magnetometers, the AP1540 system measures analogic output voltage proportional to the external magnetic field along 3 orthogonal axes. The data are converted to digital using a 24 bit A/D converter. The sensor is featured by a magnetic dynamic range of ± 0.65 Gauss, with a resolution of 0.01 nT and a noise level <0.5 nT. The internal microprocessor permits to: i) control and acquire data from the 24 bit A/D converter, ii) correct data for sensor scale, offset and alignment factors, iii) implement a bi-directional RS232 communication between the magnetometer and external device. Data output transmission mode can be selected among different protocols: ASCII and binary IEEE754 32 bit data format.
The magnetic sensor has a cylindrical shape with 2.54 cm diameter (1.0'') and 12 cm (4.725'') length (Figure 8). These limited dimensions make it suitable to be integrated on small vehicle like ROVs and UAV (Unmanned Aerial Vehicle).
Generally speaking, fluxgate magnetometers record the variation of the single components of the Earth's magnetic field and for this reason, they are commonly installed in magnetic observatories. The application of fluxgate sensors for geophysical prospection is less common due to the not high accuracy of the estimation of the (F) total component if it is compared to other magnetic sensor as the Caesium optical pumped magnetometers. Anyway the AP1540 fluxgate has been already successfully implemented in several marine investigations on board of AUV (Autonomous Undersea Vehicle), [Cocchi et al., 2013, Szitkar, et al., 2015], and also hosted on UAV [Pisciotta et al., 2021]. The integration of the AP1540 magnetometer on the Sirio platform has required the construction of a dedicated watertight case. We designed a specific cylindrical case made of the same POM material used for the junction box. In Figure 8, we report the CAD drawing (with dimensions) and photos of the magnetometer sensor placed inside the POM waterproof case.
The fluxgate sensor requires a voltage input ranging from 4.95VDC to 12VDC. The main power input and the bi-directional RS232 communication are provided connecting a dedicated cable to the 8-pin female SubConn-type connector placed on the external side of the cylindrical case (Figure 8D). The 8-pin connector is interfaced with the internal wiring of the magnetic sensor (flying leads). In Table 4, we report the pin-out of 8-pin female connector and associated functions.

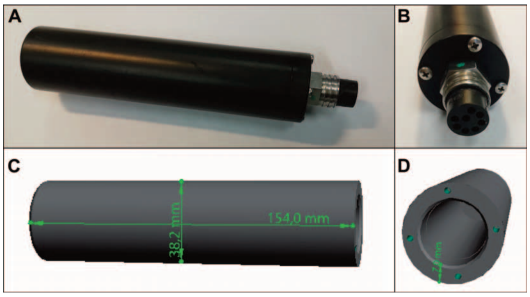


Figure 8. The POM case hosting the magnetic fluxgate sensor. Panels A and B show the real view; CAD representations are reported in panels C and D.

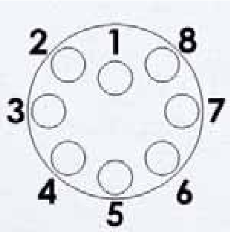
Female face view	Pin-out	Function	Corresponding colours of AP1540 flying leads
	1	RS232 serial in (RX)	Orange
	2	RS232 serial out (TX)	Yellow
	3	+12VDC	Red
	4	TTL serial IN	Orange/white
	5	Ground	Black
	6	TTL serial OUT	Yellow/white
	7	Free	N/D
	8	Free	N/D

Table 4 Pin-out of the 8-pin female connector of the magnetic sensor.

The AP1540 can be configured providing specific commands via RS232 communication. The User can change the baud-rate, data output mode (binary, ASCII) and sampling frequency (from 2 Hz to 10 Hz). In addition, the User can configure the real time data output choosing between the polling mode (collect 1 set of data at the specific request) or the auto-sending mode (the sensor will send data once it is powered up with a predefined sampling frequency). For our specific needs, the magnetometer was configured selecting the auto-sending mode with a sampling frequency equal to 2Hz that represents a well-justified time interval for low-rate dynamic acquisition as expected for a typical ROV survey.

1.3 Underwater acoustic positioning system

The identification of the geographical position of a submerged object, such as a ROV or AUV (or other type of dynamic vehicle), is not as simple as in the case of positioning of surface devices based on the GPS tracking. Submarine positioning technique requires the implementation of an extended array of acoustic beacons (baseline), which is able to provide bi-direction acoustic interrogation. Considering the length of baseline, we distinguish different acoustic systems such as: LBL (Long Base Line), SBL (Short Base Line) and USBL (Ultra-Short Base Line). This latter is widely used in underwater positioning because of the limited size and the ease of usage. The USBL system is based on the estimation of the slant range and azimuth of acoustic signal (acoustic wave) between transmitter and receiver beacons. The traditional USBL systems are mostly based on narrow-band acoustic signal geometry used for estimation of phase signal difference (or ratio).
A standard USBL positioning system is composed by two main units:1) an USBL transceiver mounted on a vessel (or on a dock) which transmits an acoustic signal to determine the slant and azimuth of a tracking target; 2) a transponder installed on the tracking target which replies the acoustic signal from the USBL transceiver with specific acoustic pulse allowing it to calculate its position. This simple configuration can be complicated by adding several transponder beacons that interplay each other improving thus the quality of positioning.
The principle of the USBL position system is based on the estimation of angle and distance between two array elements. The positioning of the target is referenced to the own frame coordinate of the USBL transceiver. Real world coordinates of the submerged target can be achieved by coupling the USBL system with a third part external GNSS receiver.
In Figure 9 we report a schematic representation of the USBL transceiver formed by a structure of 4 array elements.

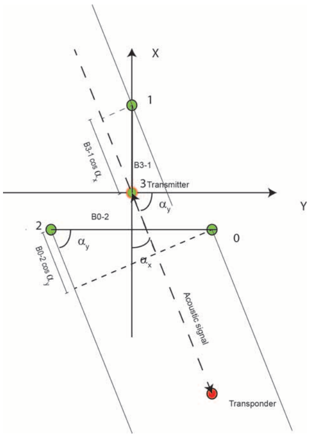


Figure 9 Schematic representation of an acoustic beacon formed by 4 elements. Node nr. 0, 1 and 2 are receivers; node 3 receives and transmits; α_x and α_y are the angle formed by the trace of acoustic signal and the axis X and Y, respectively.

The equation for USBL position is based on the estimation of slant range and azimuth as following:

$$D=Vs*T,$$

where D is the "slant range" equal to the distance from the transmitter and the receiver; Vs is the sound velocity and T is the one-travel propagation time of the acoustic wave. The speed at which acoustic waves propagate through the medium of water is dependent on temperature, salinity and depth. The value of the sound velocity in water can be recorded using a specific probe (i.e. SVP, Sound Velocity Profiler).
The azimuth of the acoustic signal can be obtained starting from the value of its wavelength λ and the phase difference φ between the array elements having distance B:

$$\alpha_x = \frac{\lambda\phi_{3-1}}{2\pi B_{3-1}},$$

$$\alpha_y = \frac{\lambda\phi_{2-0}}{2\pi B_{2-0}},$$

In this project, we implemented a Blueprint Seatrac USBL system (Figure 10; https://www.blueprintsubsea.com/seatrac/) formed by two main units: USBL X150 modem transceiver (vessel unit) and the X10 beacon, installed on the ROV platform.

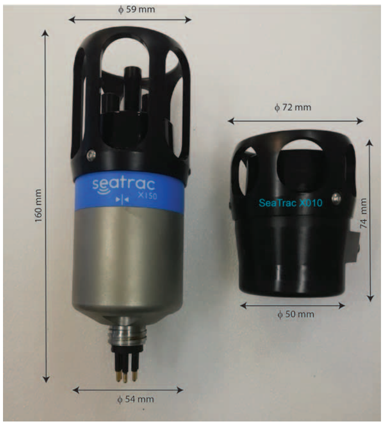
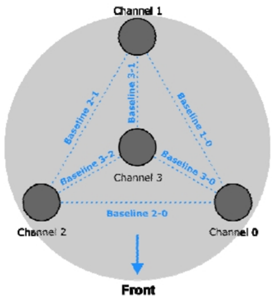


Figure 10 USBL modem X150 and the acoustic beacon X010 by Blueprint Subsea.

The beacon X10 is the smallest version of the acoustic beacon proposed by Blue Print Inc. This transponder replies the acoustic signal to the USBL in order to provide the distance and the bearing computation. The X150 modem includes an Ultra-Short Baseline (USBL, Figure 11) receiver array and it can work also as standard acoustic modem able to interpret message (packets of data) coming from other modems. The X10 beacon is integrated on the top-cover of the ROV Sirio and connected to its +12 VDC power line as already shown in Figure 5.

Figure 11 Geometry of acoustic array elements of the X150 USBL modem transceiver.



The geographical positioning of the ROV has been achieved interfacing the USBL transceiver with the specific software Seatrac PinPoint running on a dedicated PC. The Pinpoint software manages the X150 transceiver by frequency modulating of the acoustic signal and at the same time, detecting the returning pulse from submerged beacon; in this way the software provides the 3D positioning of the submerged target. In addition, the PinPoint software can merge NMEA strings coming from a third-part GNSS receiver providing thus the real world coordinates of the ROV (Figures 12-14).

Figure 12 Example of visualization of the USBL tracking by using Seatrac PinPoint software; purple line identifies the track of submarine target. The upper right panel gives information about the position of the Vessel and USBL target.

Figure 13 Visualization and logging of the attitude values (pitch, roll and heading) of the USBL transceiver.

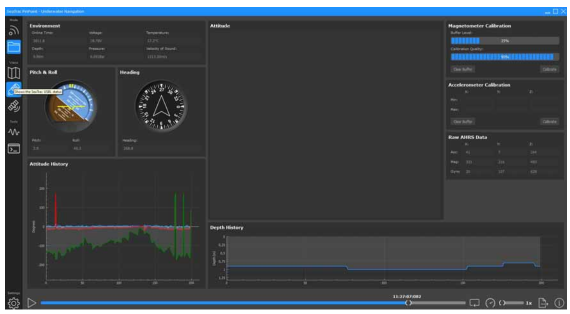
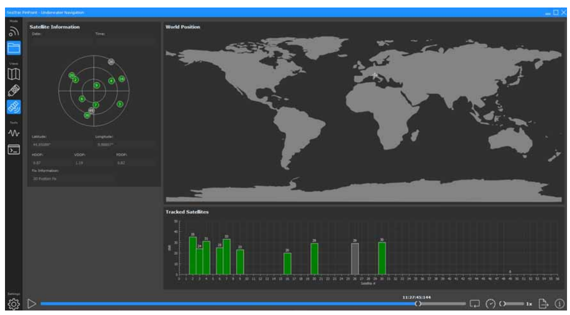


Figure 14 Geographic positioning data coming from a third part external GPS receiver (real-world coordinates, number of satellites and quality of position) interfaced with the PinPoint software.



2. Marine survey: test of the system and first results

In November 2021, we conducted a set of marine surveys in order to evaluate the real capabilities of the new integrated platform. The aim of the tests was twofold: i) to check the stability and the navigation performance of the ROV Sirio after the integration of the junction box and additional sensors; ii) to evaluate the investigative capability of the integrated system (magnetometer and USBL positioning) conducting a near-bottom magnetic prospection of a submerged ferromagnetic target. Additionally, a further test was conducted installing on the platform a CTD probe. The ROV Sirio was integrated with the following items (Figure 15):

- Magnetometer AP1540
- Junction box
- Acoustic beacon BluePrint Seatrack X010
- CTD Probe S&B 8500
- HD camera GoPro Hero 7 Black (with a 128Gb SD)

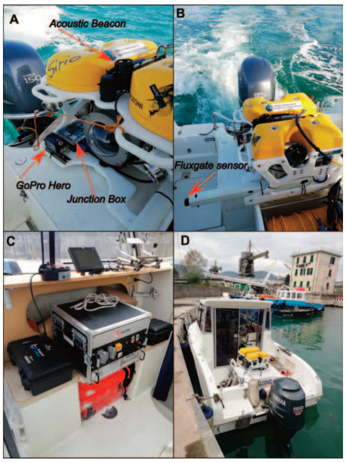


Figure 15 Images of ROV Sirio taken during the test on board of INGV vessel "Big One"; panels A and B show the integration of the new sensors on the ROV Sirio; panel C shows an image of the main power and communication units of the ROV Sirio placed inside the cabin of Big One; the panel D represents a rear view of the Big One vessel with the subsea unit of ROV Sirio.

The marine tests were performed about 2 NM offshore La Spezia Gulf, into an area far from the commercial shipway. The test site is characterized by a muddy seabed almost flat morphology with a depth ranging from 13 to 15.5 m b.s.l. Marine activities were conducted using the INGV survey vessel named "Big One", a 7.10 m long, Saver Cabin Fisher 22'' (Figure 16). The Big One is equipped with a GNSS receiver and Qinsy software (https://www.qps.nl/qinsy) for inshore navigation. The boat provides either 12VDC and 220VAC power supply. In addition, the boat is equipped with a small crane useful for launching and recovering heavy instrumentation like the ROV Sirio.

Figure 16 The INGV boat "Big One".

2.1 Rov-based magnetic survey

In order to evaluate the capability of the magnetic sensor to detect ferromagnetic objects, we deployed at the center of the test site an iron ballast having dimension of 50x10x10 cm and a weight of about 30 kg (Figure 17A).

The magnetic anomaly generated by the iron ballast was previously evaluated in laboratory, performing some measurements using the AP 1540 magnetometer. In Figure 17B, we report the magnetic anomaly profile obtained placing the magnetic sensor about 1.5 meter above the target. The recorded magnetic anomaly shows a maximum peak of 3000 nT. This information indicates that the magnetic sensor has the capability to detect the small ferromagnetic object in static condition. Results of marine investigation could be very different especially because of the difficulty of the ROV to intercept exactly the small object with a high level of accuracy.

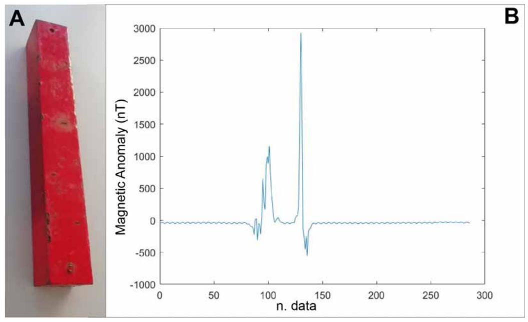


Figure 17 A) image of the iron ballast; B) magnetic anomaly field (residual) related to the ballast (laboratory test).

In Figure 18, we report the track of the ROV during the magnetic investigation of the ferromagnetic submerged target. The magnetic survey was conducted performing several ROV dives running different routes very close to the target. The ferromagnetic object has been laid on the seabed after being connected to a small floating buoy for its identification from the surface. The position of the target was 9°52’33.49” E – 44°03’06.16” N (at the sea-surface level).

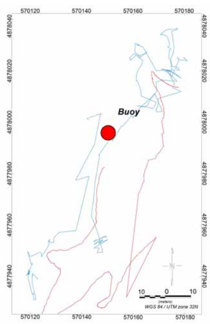


Figure 18 Maps of the ROV survey. The blue line represents the track of the ROV Sirio; the red line indicates the track of the vessel. Red filled circle identifies the position (at sea level) of the ferromagnetic target.

The 3 single components (X, Y and Z) of the Earth’s magnetic field were sampled at 2Hz (2 samples per second) and subsequently geo-referenced by means of time synchronization with the geographical position of the ROV (provided by the USBL system). In Figure 19, we report a portion of the recorded magnetic data extracted from a survey line. The 3 single Earth’s magnetic components are affected by an intrinsic noise related to the magnetic field generated by the 4 thrusters of the ROV and by the electronic parts placed close to the magnetic sensor (upper panels of Figure 19). The magnetic noise related to the ROV is characterized by specific spectral features dominated by high frequency contribution clearly distributed on all the recorded profiles with any distinction from one component to the other one.

In the lower panel of Figure 19, we report the total component F of the Earth's Magnetic field (obtained by the quadratic summation of the single components) and the related residual magnetic anomaly. This latter was computed subtracting from F its mean value. The high frequency noise has thus been moved out using a Gaussian low pass filter. The resulting profile shows a smooth pattern where we can clearly distinguish a high amplitude peak of about 1800 nT. This anomaly is recorded very close to the surficial buoy and it is mostly related to the presence of the ferromagnetic object. In Figure 20, we report an interpolated grid representation (we used the Minimum Curvature gridding algorithm with a 5 m of grid-cell size) of the filtered magnetic anomaly data recorded by the ROV Sirio.

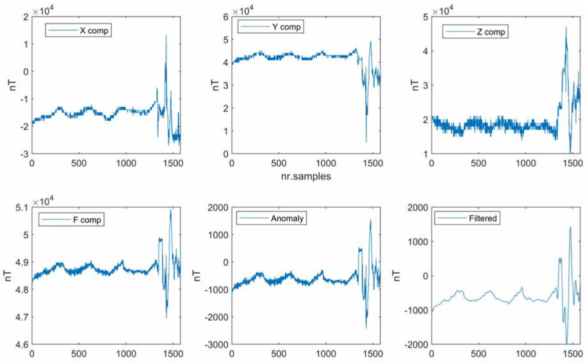


Figure 19 Plot of magnetic data acquired during the ROV investigation. X, Y and Z components are plotted in the upper panels. F total component, residual magnetic anomaly and the result of Gaussian filtering are reported in the lower set of plots. Labels of the x-axis reported in all the sub-plots refer to the number of the recorded samples.

The magnetic anomaly map highlights high positive peaks placed very close to the geographical position of the investigated target. The anomaly is not completely detected by the survey line path and its positive peak is placed at west of the track line. This is probably due the uncertain position of the target and/or due to the floating of the buoy some meters eastward the real position of the target (confirmed by the typical direction of the current in that site). The discrepancy error is in the range of 5 meters that can be considered as a well acceptable result. Some other magnetic anomalies having short wavelength and minor amplitude are present in the survey area. These anomalies are probably related to the remaining magnetic effect generated by the ROV which is not completely minimized by the filtering procedure. Finally, we computed the Analytic Signal (AS) of the magnetic anomaly field. This interpretative technique tends to minimize the dipolar shape of magnetic anomaly providing more adequate information about the position of the magnetic generating source. This procedure represents a combination of the horizontal and vertical gradient of the magnetic anomaly and is useful for enhancing the edges of the magnetic sources [Nabighian, 1984; Roest et al., 1992]. The three-dimensional analytic signal results in a bell-shaped distribution having maximum amplitude along the lateral edges of the causative body. The Analytic signal (AS) is obtained by applying the following formula:

$$AS = \sqrt{\left(\frac{\partial F}{\partial x}\right)^2 + \left(\frac{\partial F}{\partial y}\right)^2 + \left(\frac{\partial F}{\partial z}\right)^2}.$$

The resulting map (Figure 21) shows a very narrow AS anomaly located very close to the portion of the buoy. The limited dimension of the anomaly is mostly related to the small size of the generating source. Although the ROV based magnetic investigation was performed with a very limited number of track lines, the results of magnetic analysis suggest the capability of the new developed platform to detect small size ferromagnetic objects placed over the seabed. A clear estimation of the minimum size of a ferromagnetic object detectable by our platform is not easy to achieve because the related magnetic anomaly has amplitude and spectral behaviour strongly dependent by different factors, first of all the distance between object and magnetometer.

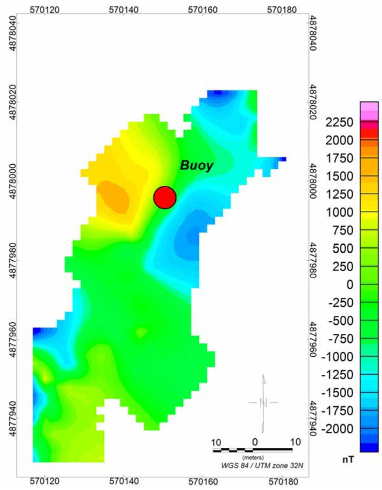


Figure 20 Map of Filtered magnetic anomaly field (grid cell size 5m).

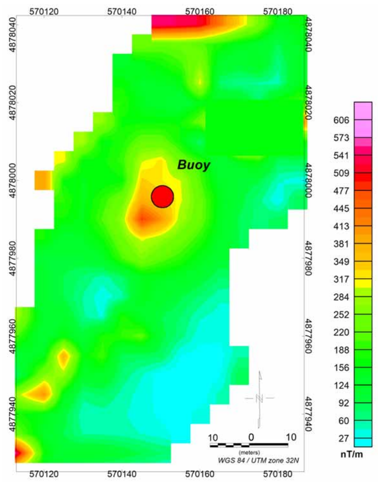


Figure 21 Map of Analytic signal computed starting from the filtered magnetic anomaly data of Figure 20.

2.2 CTD cast

A multi-parametric probe is an instrument able to record a set of physical and chemical parameters of the water column. The multi-parametric probe is usually mounted on a rosette system (cluster of water sampling tanks) for a punctual analysis of temperature – conductivity value of the seawater column. Anyway, the multi-parametric probe can be hosted on AUV or ROV for a dynamic oceanographic investigation. We installed a SA 8060.10x probe by B&C electronics on the ROV Sirio for a dynamic acquisition of oceanographic data (Figure 22). The SA 8060.10x probe is featured by inbuilt data-logger and an internal battery pack, which make it a stand-alone sensor. In this configuration the ensemble of chemical physical parameters are sampled and stored with a step of 1 set of data per minute. The test of the instrumentation was performed in the same area of the magnetic survey. The ROV Sirio performed a 500 m long track, in a depth range between 8 and 14 m b.s.l (track lines in Figure 23). In Figure 24, we report the pattern of distribution of Temperature and Conductibility of the seawater measured during the test. Although the resolution of the survey was not high due the low sampling rate, the results of the investigation provided a consistent dataset able to characterize the physical parameters of the water column of the study area. In the next future, the ROV Sirio Platform will be implemented with a new and more performing CTD.

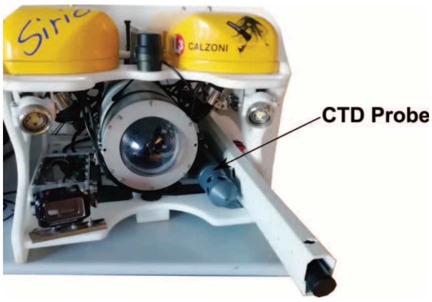


Figure 22 Image of ROV integrated with the SA 8060.10x CTD Probe.

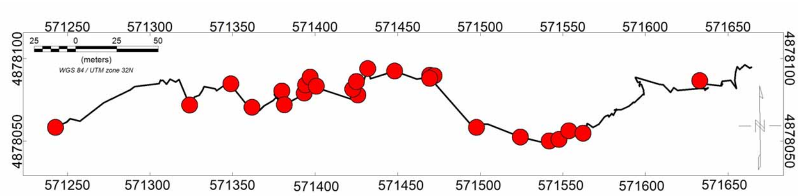


Figure 23 Track of the ROV during the CTD survey; the red filled circles indicate the points where CTD data were collected.

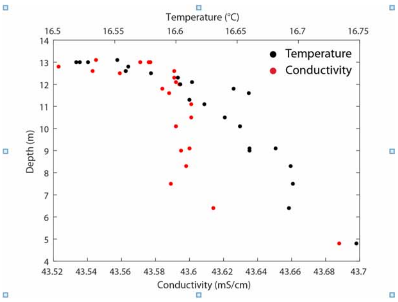


Figure 24 Distribution of the Temperature and Conductivity vs depth; data acquired during the CTD survey (see the path in Figure 23).

3. Conclusion

The present study outlines the technological development of a new submarine remotely-operated platform integrated with geophysical and oceanographic sensors. The aim of our activity was to provide a smart and flexible technological solution which can help to study the marine environment in all its components: water column, the sea floor and also the interconnected biological processes. Starting from a commercial observer-class ROV, we designed and realized a smart junction box able to integrate new instrumentation on the submarine vehicle. The technological development consisted in accurate choice of material, design of the electronic wiring and outlining of the best protocol for data communication.

As a first attempt, we integrated a miniaturized digital Fluxgate magnetometer, a multi-parameters probe and acoustic positioning system for an underwater positioning of the recorded data. Laboratory test and real marine survey provided very interesting results highlighting the capability of the platform to detect magnetic anomaly related to small ferromagnetic object placed over the seabed. These results suggest us the possibility to engage this system in UXO prospections and/or in classic geophysical/geological near bottom investigations. The integration of the CTD probe with the ROV platform permitted also to perform a dynamic acquisition of physical parameters of the water column. This investigative approach may be very helpful for studies related to the submarine volcanism, featured, for example, by active hydrothermal vents. The next step, will be the integration a second magnetometer for gradient estimation and a new addition of chemical sensors such as a CO_2 probe and/or turbidity meter for a complete study of the water column.

References

Billings S.D., Passion L.R., Oldenburg D.W., (2002). *UXO Discrimination and Identification Using Magnetometry*. SAGEEP, https://doi.org/10.4133/1.2927059

Cavallaro D., Cocchi L., Coltelli M., Muccini F., Carmisciano C., Firetto Carlino M., Ibanez J.M., Patanè D., Filppone M., Buttaro E., (2016). *Acquisition procedures, processing methodologies and preliminary results of magnetic and ROV data collected during the TOMO-ETNA experiment*. Ann. Geophys. 59(4), S0431, https://doi.org/10.4401/ag-7084

Cocchi L., Plunkett S., Augustin N., Petersen S., (2013). *High-resolution AUV-based near bottom magnetic surveys at Palinuro volcanic complex (Southern Tyrrhenian Sea)*. Agu Fall Meeting 2013, San Francisco, 8-13 Dicembre.

Jambeck J.R., Geyer R., Wilcox C., Siegler T.R., Perryman M., Andrady A., Narayan R., Lavender Law K., (2015). *Plastic waste inputs from land into the ocean*. Science, 347(6223), 768, https://doi.org/10.1126/science.1260352

Katija K., Sherlock R.E., Sherman A.D., and Robison B.H., (2017). *New technology reveals the role of giant larvaceans in oceanic carbon cycling*. Sci. Adv. 3:e1602374. https://doi.org/10.1126/sciadv.1602374

Löhr A., Savelli H., Beunen R., Kalz M., Ragas A., Van Belleghem F., (2017). *Solutions for global marine litter pollution*. Curr. Opin. Environ. Sustain. 28 90–99.

Marsh L., Copley J.T., Huvenne V.A.I., and Tyler P.A., the Isis Rov Facility, (2013). *Getting the bigger picture: using precision remotely operated vehicle (ROV) videography to acquire high-definition mosaic images of newly discovered hydrothermal vents in the Southern Ocean*. Deep Sea Res. Part II Top. Stud. Oceanogr. 92, 124–135. https://doi.org/10.1016/J.DSR2.2013.02.007

McLean D.L., Parsons M.J.G., Gates A.R., Benfield M.C., Bond T., Booth D.J., Bunce M., Fowler A.M., Harvey E.S., Macreadie P.I., Pattiaratchi C.B., Rouse S., Partridge J.C., Thomson P.G., Todd V.L.G., Jones D.O.B., (2020). *Enhancing the Scientific Value of Industry Remotely Operated Vehicles (ROVs) in Our Oceans*. Frontiers in Marine Science, 7, https://doi.org/10.3389/fmars.2020.00220

Nabighian M., (1984). *Toward a three-dimensional automatic interpretation of potential field data via generalized Hilbert transforms: fundamental relations*. Geophysics, 49, 780–786.

Pisciotta A., Vitale G., Scudero S., Martorana R., Capizzi P., D'Alessandro A., (2021). *A Lightweight Prototype of a Magnetometric System for Unmanned Aerial Vehicles*. Sensors, 21, 4691. https://doi.org/10.3390/s21144691

Roest W.R., Verhoef J., Pilkington M., (1992). *Magnetic interpretation using the 3-D analytic signal*. Geophysics, 57, 116–25.

Szitkar F., Petersen S., Caratori Tontini F., Cocchi L., (2015). *High resolution magnetics reveal the deep structure of a volcanic-arc-related basalt-hosted hydrothermal site (Palinuro, Tyrrhenian Sea)*. Geochem. Geophys. Geosyst., 16, 1950–1961, https://doi.org/10.1002/2015GC005769

Zalevsky Z., Bregman Y., Salomonski N., Zafrir H., (2012). *Resolution Enhanced Magnetic Sensing System for Wide Coverage Real Time UXO Detection*. Journal of Applied Geophysics, 84, 70-76.

QUADERNI di GEOFISICA

ISSN 1590-2595 http://istituto.ingv.it/it/le-collane-editoriali-ingv/quaderni-di-geofisica.html/

I QUADERNI DI GEOFISICA (QUAD. GEOFIS.) accolgono lavori, sia in italiano che in inglese, che diano particolare risalto alla pubblicazione di dati, misure, osservazioni e loro elaborazioni anche preliminari che necessitano di rapida diffusione nella comunità scientifica nazionale ed internazionale. Per questo scopo la pubblicazione on-line è particolarmente utile e fornisce accesso immediato a tutti i possibili utenti. Un Editorial Board multidisciplinare ed un accurato processo di peer-review garantiscono i requisiti di qualità per la pubblicazione dei contributi. I QUADERNI DI GEOFISICA sono presenti in "Emerging Sources Citation Index" di Clarivate Analytics, e in "Open Access Journals" di Scopus.

QUADERNI DI GEOFISICA (QUAD. GEOFIS.) welcome contributions, in Italian and/or in English, with special emphasis on preliminary elaborations of data, measures, and observations that need rapid and widespread diffusion in the scientific community. The on-line publication is particularly useful for this purpose, and a multidisciplinary Editorial Board with an accurate peer-review process provides the quality standard for the publication of the manuscripts. QUADERNI DI GEOFISICA are present in "Emerging Sources Citation Index" of Clarivate Analytics, and in "Open Access Journals" of Scopus.

RAPPORTI TECNICI INGV

ISSN 2039-7941 http://istituto.ingv.it/it/le-collane-editoriali-ingv/rapporti-tecnici-ingv.html/

I RAPPORTI TECNICI INGV (RAPP. TEC. INGV) pubblicano contributi, sia in italiano che in inglese, di tipo tecnologico come manuali, software, applicazioni ed innovazioni di strumentazioni, tecniche di raccolta dati di rilevante interesse tecnico-scientifico. I RAPPORTI TECNICI INGV sono pubblicati esclusivamente on-line per garantire agli autori rapidità di diffusione e agli utenti accesso immediato ai dati pubblicati. Un Editorial Board multidisciplinare ed un accurato processo di peer-review garantiscono i requisiti di qualità per la pubblicazione dei contributi.

RAPPORTI TECNICI INGV (RAPP. TEC. INGV) publish technological contributions (in Italian and/or in English) such as manuals, software, applications and implementations of instruments, and techniques of data collection. RAPPORTI TECNICI INGV are published online to guarantee celerity of diffusion and a prompt access to published data. A multidisciplinary Editorial Board and an accurate peer-review process provide the quality standard for the publication of the contributions.

MISCELLANEA INGV

ISSN 2039-6651 http://istituto.ingv.it/it/le-collane-editoriali-ingv/miscellanea-ingv.html

MISCELLANEA INGV (MISC. INGV) favorisce la pubblicazione di contributi scientifici riguardanti le attività svolte dall'INGV. In particolare, MISCELLANEA INGV raccoglie reports di progetti scientifici, proceedings di convegni, manuali, monografie di rilevante interesse, raccolte di articoli, ecc. La pubblicazione è esclusivamente on-line, completamente gratuita e garantisce tempi rapidi e grande diffusione sul web. L'Editorial Board INGV, grazie al suo carattere multidisciplinare, assicura i requisiti di qualità per la pubblicazione dei contributi sottomessi.

MISCELLANEA INGV (MISC. INGV) favours the publication of scientific contributions regarding the main activities carried out at INGV. In particular, MISCELLANEA INGV gathers reports of scientific projects, proceedings of meetings, manuals, relevant monographs, collections of articles etc. The journal is published online to guarantee celerity of diffusion on the internet. A multidisciplinary Editorial Board and an accurate peer-review process provide the quality standard for the publication of the contributions.

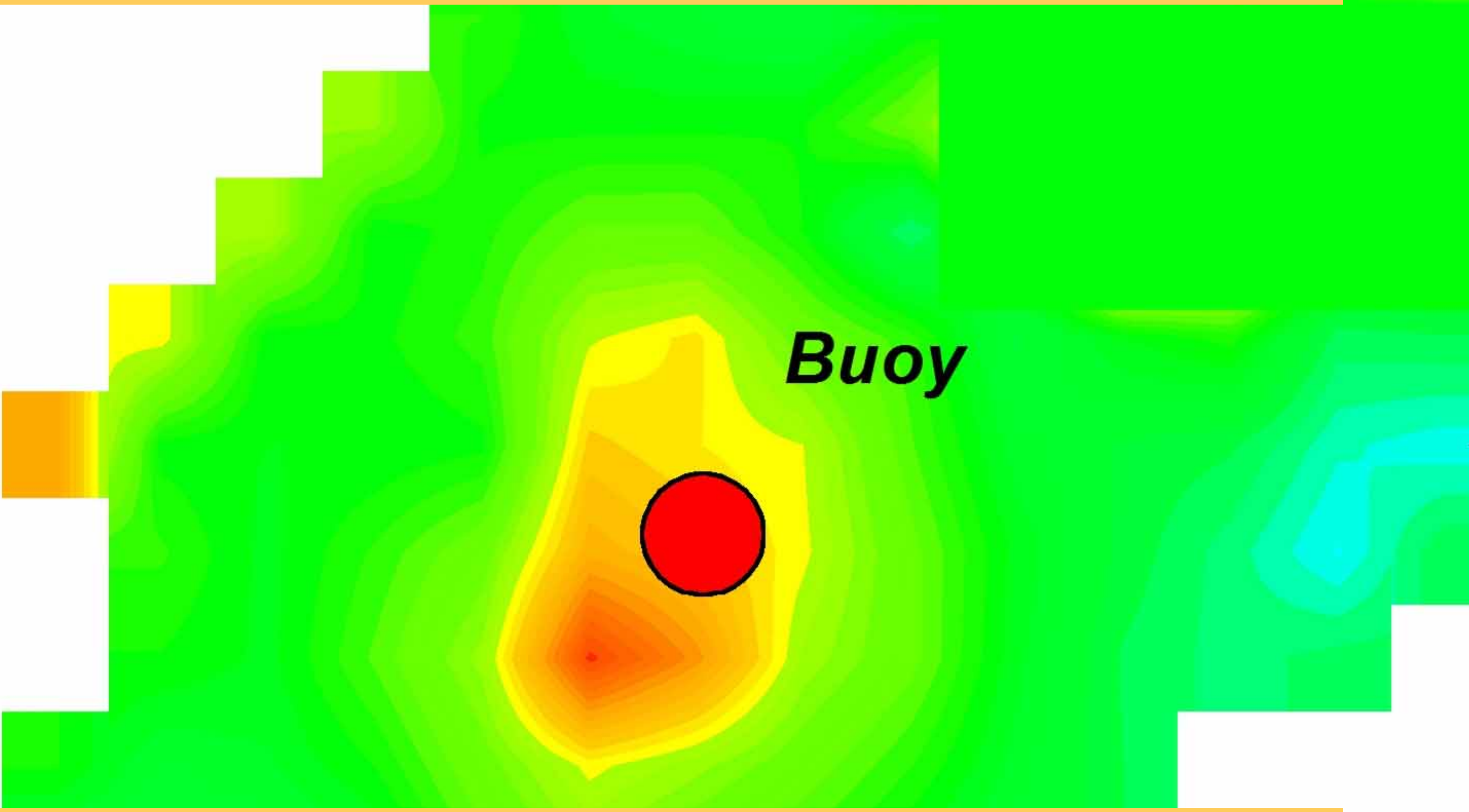
Coordinamento editoriale
Francesca DI STEFANO
Istituto Nazionale di Geofisica e Vulcanologia

Progetto grafico
Barbara ANGIONI
Istituto Nazionale di Geofisica e Vulcanologia

Impaginazione
Barbara ANGIONI
Patrizia PANTANI
Massimiliano CASCONE
Istituto Nazionale di Geofisica e Vulcanologia

Istituto Nazionale di Geofisica e Vulcanologia
Via di Vigna Murata, 605
00143 Roma
tel. +39 06518601

www.ingv.it



ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA