Remotely controlled aerial and underwater vehicles in support to magnetic surveys

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Abstract— **This article deals with the creation of a professional magnetometer, a flexible, light and compact instrument that can be installed on aerial and marine drones. The instrument can accurately measure the local magnetic field. Subsequently, it was installed on AUV and a micro ROV to test its effectiveness for archaeological purposes and magnetic surveys. Experimental data show that both systems can be used by filtering disturbances from vehicles.**

Keywords— magnetic survey, archeo-geophysics, remotely operated vehicles.

INTRODUCTION

Magnetometry is among the most used and effective geophysical techniques employed in the archaeological exploration survey [1 – 6]. The magnetic technique measures the magnetic field to detect the anomalies, which could be of geological or anthropogenic origin; among the latter, also the archaeological features. Buried features such as stonemasonry structures have usually different magnetic properties from the surrounding environment and the cover terrain, resulting in anomalies in the order of a few nT. Signals coming from buried metal objects or related to the effects of some human activities, induce anomalies in the order of some tens of nT and up to some hundreds of nT in presence of shallow ferrous objects [6].

The classical magnetic surveys for archaeological purpose is performed by a walking operator which covers the investigated area with rectilinear, parallel paths traveled in opposite directions. This mode is very consuming in terms of time and human resources. Low-altitude surveys carried out using unmanned aerial vehicles (UAVs) make faster, more reliable, and even safer, to perform the observations, helping to overcome the limitation of the traditional ground surveys difficult in the accessibility, uneven terrains, or presence of obstacles [7 - 10]. Moreover, UAV-surveys are still able to get the required resolution for the near-surface layer. Similarly, underwater magnetic surveys are difficult and expensive, when not impossible, because of the objective logistic difficulties.

This work focuses on the realization of a lightweight and compact data logger for magnetic surveys that can be easily integrated with remotely controlled aerial and underwater vehicles. This device is based on an 8-bit microcontroller which handles a high-resolution fluxgate magnetometer and provides georeferenced data that are either stored and real-time transmitted via a radio module.

REMOTELY CONTROLLED AERIAL VEHICLES

In the last years, thanks to recent technological developments, remotely controlled aerial vehicles are increasingly used in support of geophysical surveys, especially in areas hardly accessible.

Drones, also referred as Unmanned Aircraft Systems (UAS), Unmanned Aerial Vehicles (UAV) or Remotely Piloted Aircraft (RPA), are aircraft without pilot on board, they are remotely controlled by a pilot located on the ground or board of another aircraft, or by an autonomous piloting system [11, 12].

Drones have evolved in different configurations to develop different flight characteristics that could be exploited for various uses. The European Association of Unmanned Vehicles Systems (EUROUVS), according to their size, flight altitude, endurance and capabilities, has classified UAVs in several categories.

UAVs	Micro and mini	Strategic	Airschip	Flying wing	Fixed wing	Rotaty wing
Size	Small	Big	Massive	Small	Medium	Small
Altitude	Low	High	Very High	Low	High	Low
Endurance	Limited	Long	Very Long	Limited	Long	Limited
Rage	Short	Long	Very Long	Short	Very Long	Limited
Payload	Low	Medium	High	Low	Low	Low
Speed	Medium	Medium	Low	High	Very High	Medium

Tab. 1: Categories UAVs and specific.

The type chosen for our application is rotary-wing UASs. They are drones able of vertical take-off and landing, with the capability of stationing in flight (hovering). The control of the main rotor allows these drones to easily fly in all directions without limitation; this great flight control,

however, is obtained at the expense of the autonomy of flight. A configuration that remedies to the complexity of the chain of command of a helicopter is that of multicopter. This uses pairs of counter-rotating rotors to achieve the same stability without the need of the tail rotor for the contrast to the rotational movement caused by the main rotor. The drones allow the 'remote' location of a sensor, and to transmit the information, without the need to expose risks human life. Their ability to reach areas difficult to inspect from the ground, quickly and in a repetitive manner, allows them to minimize inspection costs and avoid exposure of personnel to possible environmental risks. A specific drone must ultimately be chosen according to its peculiarities in response to specific operating requirements.

REMOTELY CONTROLLED UNDERWATER VEHICLES

ROVs (Remotely Operated Vehicle), are underwater vehicles operated from the surface, able to integrate geophysical and surveys carried out from research vessels. ROV dives combine with those of specialized live operators, both because researchers can observe in real-time what the ROV sees through its cameras and because ROV can reach depths excluded to scuba divers. Due to their size and weight, the use of standard ROVs is limited by heavy operational requirements, as they necessarily involve, for their launch and recovery, the use of large vessels equipped with appropriate cranes. Obviously, the use of large size equipped vessel has a significant economic cost that cannot be often sustained, especially if repeated research campaigns are necessary.

Low-cost micro-ROV (Class <3 kg) was implemented and equipped with geophysical instrumentation to be employed in shallow marine surveys.

The micro-ROV uses the open-source philosophy of the OpenROV system (www.openrov.org). Vessel, payload and electronic features are completely open to improvements and third-party add-ons.

Fig. 1: *Micro-ROV assembled at the MEMSLab of Palermo.*

Figure 1 shows the micro-ROV assembled at the MEMSLab of Palermo connected with 100 m tether cable to the notebook used for remote control. The micro-ROV has been balanced to be slightly floating and easily recoverable in case of technical problems.   The micro-ROV was employed in its first diving in shallow seawater (Fig. 2) equipped with the Magnetometer.
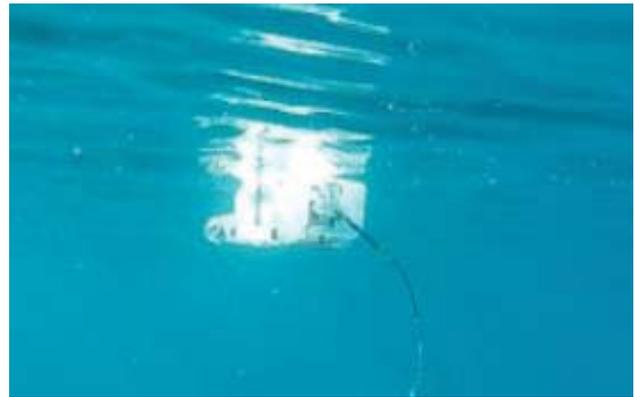

Fig. 2: *Micro-ROV on first diving in shallow seawater.*

The magnetometer employed is the model 1540 produced by Applied Physics System. The sensor is a high-speed 3-axis fluxgate magnetometer employing 24-bit analog-to-digital converters. The 1540 system communicates over a bi-directional serial interface using TTL logic levels on RS232 serial port. Magnetic field data are transmitted in Gauss (G) units. The use of 24-bit converters enables the 1540 system to measure magnetic field magnitudes from ± 0.65 G down to the system noise level (5 μG peak-to-peak) using a single range. The magnetic surveys, carried out together with photogrammetry, will allow us to detect low magnetization in areas with hydrothermal activity and to distinguish and characterize volcanic and not-volcanic rocks.

With the use of Proximity, IMU/Compass/Depth sensors an extension of the OpenROV's controller has been developed, enabling further motion control modes, including depth-constant navigation. More precisely, once the human operator has specified a desired depth value, the vertical propeller of the ROV is automatically controlled to achieve and maintain such a depth requirement. This navigation mode allows the operator to steer the robot along a plane at constant depth, and it uses information from the on-board depth sensor to correct the motion if it deviates from this plane.

Moreover, by using information from the accelerometer and gyroscopes, an on-board algorithm based on the Extended Kalman Filter has been devised. This proposed filter allows short-term position localization of the OpenROV, even in the absence of an external positioning system (such as GPS), which is unavailable underwater. Preliminary tests have been made showing the effectiveness of the proposed algorithm.
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SKILL AND PROTOTYPE

The device to be manufactured must be compact and lightweight. To be suitable for marine drones it is important to reduce the size of the pond case, in addition to the drones, it is necessary to minimize the loss of the device as the payload stated in the commercial drones is a maximum of 300 g. The data must be stored on SD memory so the user can easily extract the data. It provides the possibility to

manage the device from the serial terminal by creating a small menu with three options: Sampling mode, Data read mode, SD Formatting mode. Below a short description of the device.

The Atmega 2560 microcontroller (8bit) is the heart of the system, it manages all the peripherals, calculates and does logical operations that allow synchronizing all external elements by operating clock at 16 MHz. Maxim's built-in ds1307 is a Real-Time Clock (RTC), a low-energy clock that also implements 56 bytes of non-volatile SRAM memory, with a backup battery. The circuit provides information on seconds, minutes, hours, days, months, and years. GY-NEO6MV2 GPS is a GPS module equipped with the new high-quality Ceramic Brand antenna, with its EEPROM memory for saving the settings, the date and time backup with buffer battery and a LED light signal for the high- satellite engagement. 1540 is a 3-axis fluxgate magnetometer, whose sample rate is set to 1 Hz and the output unit is Gauss (G). The 24-bit converter allows measuring quantities in the order of ±0.65G, lowering the noise level (to-peak) without signal filtering. The GY-80 module is a complete inertial platform, containing a gyroscope (L3G4200D), an accelerometer (ADXL345), a magnetometer (HMC5883L), and a pressure sensor (BMP085). A serial interface is used to connect the device to a personal computer or by telemetry, to send data or to receive commands. The 3D Radio Robot 3DR telemetry is an ideal module for setting up the remote sensing module between the instrument and the ground station. All modules of the system are connected to an electronic card which design was performed with the EAGLE PCD software. Proper tests followed the component assembling. The firmware has been developed following the "divide et impera" method: this is a very effective approach to solve various computational problems. These algorithms recursively divide a problem into two or more sub-problems until the latter become of the simple resolution, and then combine the solutions to get the solution to the given problem.

There are three operating modes of the device, to change the mode of operation via serial connection UART adapter - USB Virtual COM or a RADIO - UART - USB Virtual COM adapter.

The experimental test was conducted by feeding the 12V system, to adapt the supply voltages two step-down modules were used. The step-down modules were respectively adjusted in the following way: the step-down module that supplies the magnetometer provides 9V output; The stepdown module that powers the acquisition device provides 5V output. The test was carried out by rotating on the spot the sensitive part of the instrument on itself for small angular variations simulating the trajectory that could be performed by the navigation of an ROV or the flight of an Air Drone. The prototype worked properly by generating datalog.txt files.

PERFORMANCE EVALUATION

The acquisition module was tested in static mode; about 10,000 records have been acquired during the session. The stability of the sampling rate was evaluated measuring the difference between each timestamp. For about 52% of the samples, the offset is zero and it is never greater than ±1 ms.

At the end of the session, a negligible, cumulative offset of about 500 ms was measured.

Similarly, we evaluated the stability in the magnetic measures. The sensors provide as output three different values corresponding to the three measured components of the magnetic field. The resulting total magnetic field is calculated in real-time by the device. To evaluate the performance, we calculated the offset between the output from the datalogger and the re-calculated total magnetic field. The histogram in Figure 4 shows the offset distribution. Generally, the device tends towards a slight underestimation (average value is -0.0018 nT) of the total magnetic field. The resolution of the sensors as specified by the manufactures is 0.01 nT; the measured offset is always lower, therefore the provided measures have good reliability.
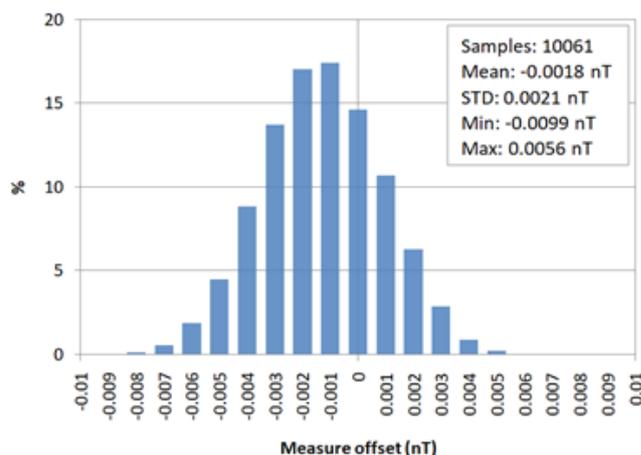

Fig. 4: *Histograms of the offset in the total magnetic field.*

UAV SURVEY

To confirm the usefulness and performance of this light magnetometric prototype system, a test on the field were performed using an Unmanned aerial vehicle. Unmanned aerial vehicles (UAVs) or drones have become widely available for use in a broad range of disciplines. UAVs offer advantages over traditional field work or high-altitude remote sensing techniques and open various new applications in the close-range domain. A DJI Phantom III Professional drone was equipped with the magnetometric prototype system, for the field test. Drone flight plan and parameters were fixed: trace line, flying speed to 2m/s and altitude to 13m. The survey has been carried out in an area with a relatively quiet natural magnetic field located an overgrown field. Here a rectangular metallic panel (2m x 1m) was buried at a depth of 0,2m. Figure 5 shows the sketch of the flying path and the test site setting. The noisy recordings of the three magnetic components (Figure 6) are clearly due to the oscillation of the sensor hanged below the UAV. However, in the total magnetic field (red line in Figure 6) the noise is filtered and the signal is stable. The magnetic anomaly corresponding to the buried metallic panel is recognizable between 600 and 750 s (Figure 6).
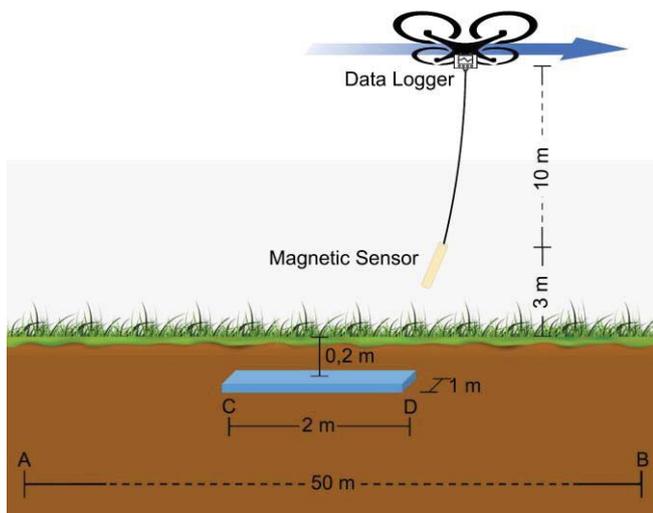
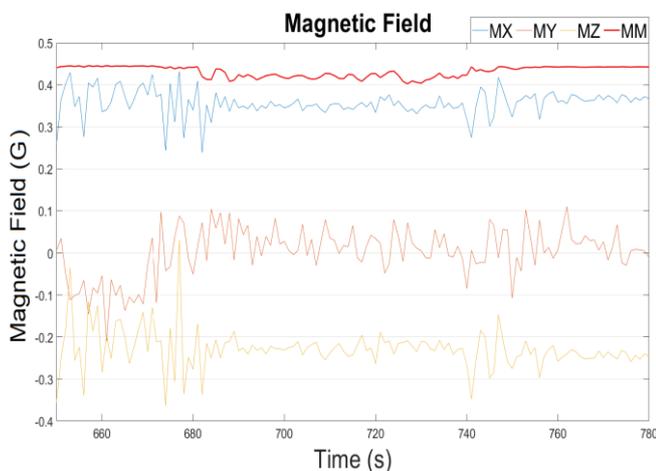Fig. 5: *Flying path and the test site setting.*

Fig. 6: *Plot of magnetic component (MX, MY, MZ) and total magnetic field (MM).*

I. CONCLUSION

The design of a professional magnetometer has been realized, with the specifications of being light and compact.

Once assembled, the prototype was tested for its functionality in the laboratory. Later experimental tests in the field were carried out both with AUV and with ROV, these tests show that by filtering the disturbances coming from vehicles it is possible to extract useful information. A future application of this system is to create a remote program that receives data in real-time and instantly realizes the magnetic map of the area.

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