Geomatics for underwater electromagnetic harbour protection systems and Newtonian systems for coastal navigation safety – Applications

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Two examples of systems for harbour protection and port navigation safety are shown with the results obtained during several operative tests performed to develop a new anti-intrusion undersea system based on a magnetometer self-informed network (our goal is to detect the presence of underwater threats, such as terrorist divers in harbours) [Faggioni et al., 2018; Nasta et al., 2015].
The main purpose of the magnetic system is to fill the gaps of classical sonar systems, whose performances deteriorate, due to reflections and attenuations, in the boundary of the volume of water to be controlled (sea bed, docks...) [Gabellone et al., 2007].
Our experiments took place in port protection scenarios, characterized by medium-high environmental noise with a relevant human origin magnetic noise component. Divers performed approach runs above the array. The system has two different input signals: the magnetic background field (natural plus artificial) and a signal composed by the same magnetic background field superimposed on the target magnetic signature. The system uses the first signal (background field) as filter for the second one (background field plus the target signature) to detect the target presence [Faggioni et al., 2010]. The effectiveness of the procedure is related to the position of magnetic field observation points (reference devices and sentinel devices): sensors must obtain correlation in the noise observations (all the sensors record the same background field) and de-correlations in the target signal observations (only one sensor records target signature) [Faggioni et al., 2009].

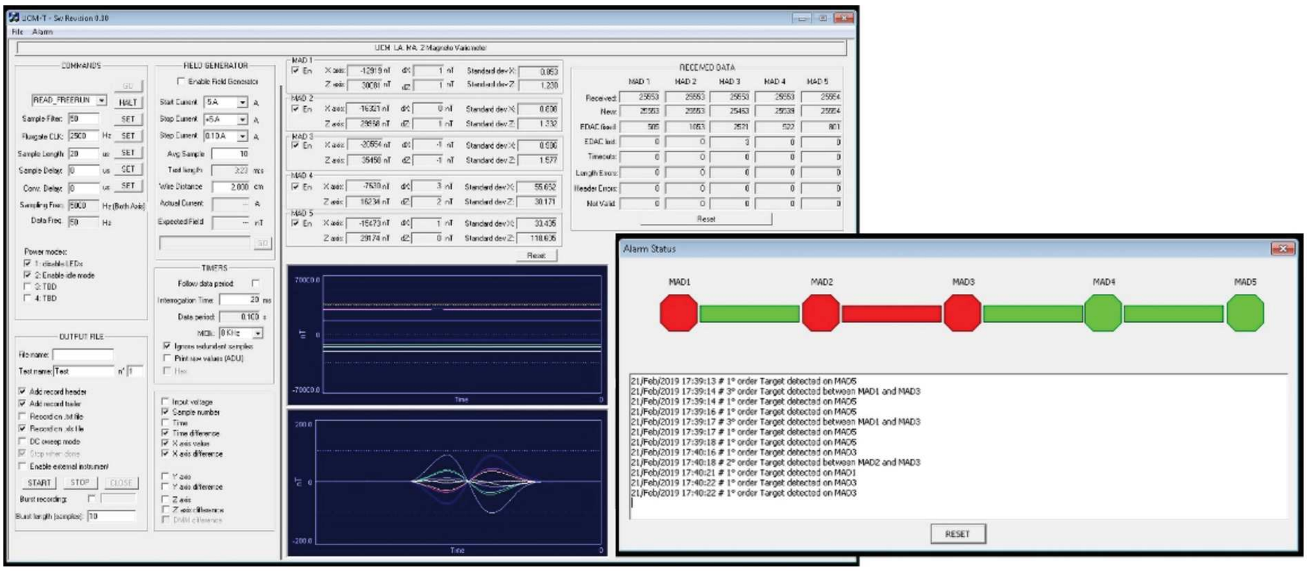

Figure 1 Alarms generated by a diver.

To generate alarms when a target is detected, we have developed a software program that processes data acquired by magnetometers and turns on a red light and a beep sound when a magnetic anomaly is identified. Figure 1 shows alarms generated while a diver was crossing the barrier swimming first above the sensors n. 1 and then halfway between n. 2 and n. 3.
A multi-year study carried out in several Italian ports allowed us to obtain an estimate of the hydro-barometric transfer factor J_{ph} from atmospheric pressure variations to consequent sea level fluctuations (Newtonian correlation between atmospheric weight variations and sea level adjustments) [Faggioni et al., 2013].
We analyzed many occurrences of this phenomenon (meteorological tides, i.e. due to variations in atmospheric pressure) in Italian ports (data acquired by means of Italian National Tide-gauge Network, managed by ISPRA - Italian Institute for Environmental Protection and Research) and for each of them we calculated the value of the hydro-barometric transfer factor as:

$$J_{ph} = \Delta h / (\Delta p \; [cm \cdot hPa^{-1}] \qquad (1)$$

where is the variation of sea level, while represents the gradient of atmospheric pressure [Faggioni et al., 2006]. Then, a multi-year statistical analysis on all the events that have occurred allowed us to obtain, port by port, an estimate of the J_{ph} factor. It often assumes, in many ports, values even double compared to the typical 1 cm · hPa-1 of the offshore. The knowledge of the J_{ph} factor is very useful in Harbour Waterside Management (optimization of ship navigation, dock performances, boat moorings, refloating of stranded ships, ...) to forecast the water depth starting from the expected atmospheric pressure [Faggioni et al., 2008]. Obviously, a low tide within a port hinders navigation; vice versa, a high tide facilitates navigation.
The effects of pressure variations on water depth have been applied to bathymetric maps in several Italian ports: sea level goes down consequently to an atmospheric pressure increase, and goes up consequently to a pressure decrease; then, pressure variations change the bathymetry of a basin. A pressure change can be converted, through J_{ph}, into an expected sea level variation and then into a new bathymetric map.
To automate this, a software program is being developed for dynamic updating bathymetry maps in harbours (Figure 2), depending on the sea level measured in real time (by means of mareographic stations) or the expected atmospheric pressure.
Two-threshold levels variable ship by ship, depending on its draft, divide the harbour basin into three zones characterized by different colours (green, yellow and red); these colours indicate three water depth ranges (respectively deep or allowed for that vessel, shallow or warning, forbidden). By varying the sea level, an area that initially was allowed (green), can become a warning (yellow) or prohibited area (red): this implements what is called a “virtual traffic light” customized for each ship.
In the dynamic bathymetric map of the port of Livorno shown in Figure 2 (thresholds 9 and 12m, respectively), the same point (UTM coordinates: easting 604625 m, northing 4822760 m, at the center of the white circle) changes from green to yellow light. In fact, its depth decreases from 12.44m to 11.71m, due to sea level variation from 13/01/2017 10:10.00 UTC to 14/01/2017 01:30.00 UTC; more generally, the “green channel” inside the white circle becomes narrower.
Experimental tests carried out on the magnetic detection system, in undersea environments with high magnetic noise, has provided extremely positive operational results in detecting intruders transiting in its proximity, both in the case of divers equipped with commercial air tanks and in the case of rebreathers. In the context of antiterrorism systems for harbour protection, the magnetic detection system is required to support the acoustic component in peripheral acoustic shadow zones close to the seabed, docks and so on.

This abstract also highlights the importance of analysis of hydro-barometric inversion in harbour safety. Its applications for Harbour Waterside Management allow us to improve the effectiveness in maritime works and to optimize ship navigation, dock performance, boats mooring and refloating of stranded ships.

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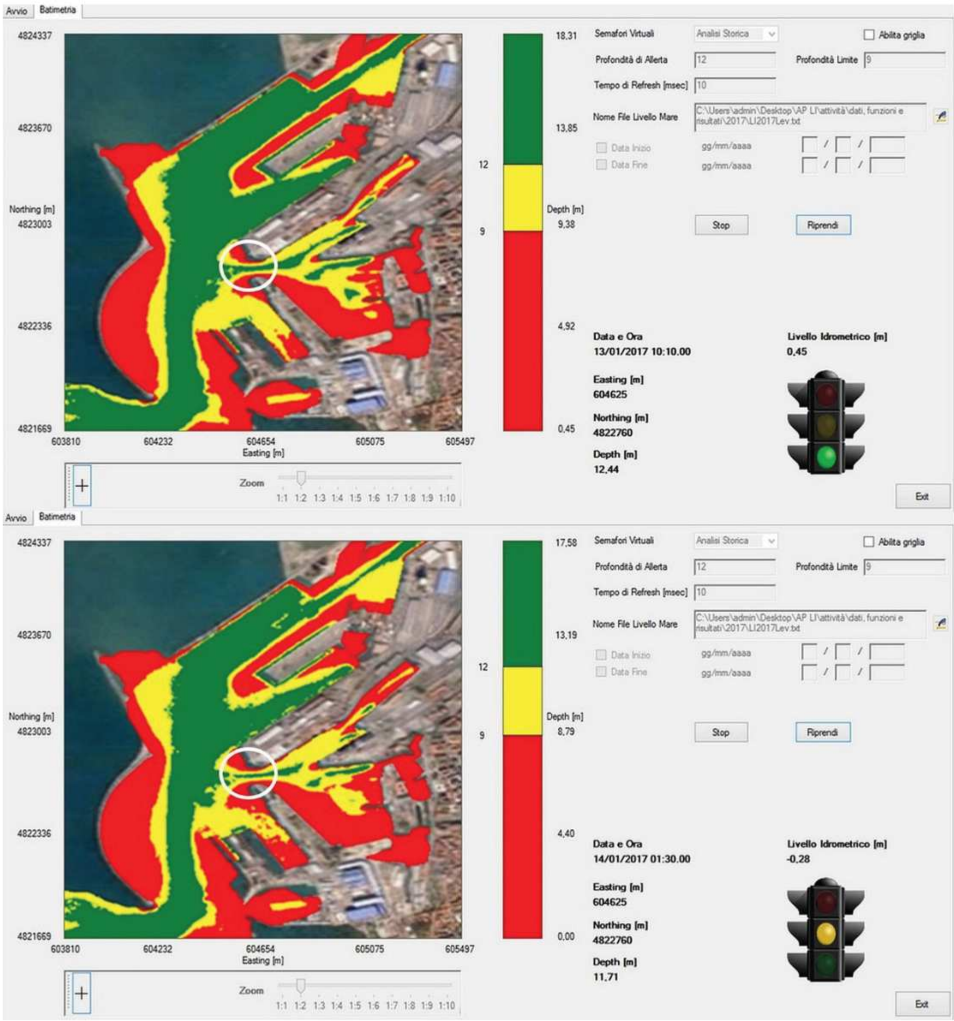

Figure 2 Dynamic bathymetric map in the port of Livorno (thresholds 9 and 12 m, respectively) from 13/01/2017 10:10.00 UTC to 14/01/2017 01:30.00 UTC.

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