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

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The effectiveness of magnetic signal measurements in harbours is very uncertain. The phenomenon of interference of the background field with the useful signal is accentuated if the latter is coming from a labile, quasi-point-like and kinetic source, such as divers. The problem is not of a technological nature, as commercial magnetometers guarantee redundant reading sensitivity with respect to the signal sought. It is constituted by the environmental noise that can heavily over-modulate the target signal in amplitude. Moreover, the wavelengths of these signals are inside the noise band and therefore the “FFT techniques of signal strengthening” are structurally inadequate.

INGV has provided a solution based on a new specific metrological approach to detect labile elementary signals in a high noise environment. This new measurement technique is known as “singular magnetic metrology”. The classification of low amplitude signals in high noise is obtained by observing the magnetic field simultaneously at different points distant *L* from each other. This distance is such that the noise signal is correlated and the target signal is decorrelated. This measure (of singularity) is based on the space stability of each magnetic signal. The topic researches developed by INGV have been supported by national and European projects (European Defence Agency and Piano Nazionale della Ricerca Militare, Italian Ministry of Defence, SEGREDIFESA/DNA).

The magnetic field is observed by means of several sensors aligned and distant *L* from each other, with *L* is such that one sensor records the total magnetic field with the target signal while other sensors record only the total magnetic field (for this application it’s only the noise), see Figure 1-A. This procedure is objective since the filter function obtained to avoid the noise from the target signal is a measured function [Faggioni, 2018]. INGV has provided MINIDIFE, the L-calculation method and its use technique both in the “self-reported intelligence” (old standard) and in the “self-informed” version (new standard), see Figure 1-B. The final technique (“OC” - OVER_CROSSED intelligence) is currently undergoing theoretical development. With the expansion of the elementary cell from 2 to 3 instruments, also the central transit ambiguity of the target was exceeded (Figure 1-C): the third sensor has the role of comparison and verification in the case of “zero difference” is recorded between the two sensors considered.

This new measurement technique has significant experimental implications and provides the effective ability to detect the signals of labile, quasi point-like and kinetic sources in a high noise environment [Faggioni et al., 2018, Faggioni et al., 2010]. From the metrological point of view, the singularity approaches required to formalize the metrological concepts of “Informative Energy” and “Passive Energy” and the numerical ones of “Information Content” of the record and “Information Capacity” of elementary signal [Faggioni, 2018]. In the new measurement technique, the concepts of useful signal and noise is overcome with the introduction of the concepts of informative energetic group value and information capacity value of each elementary signal.

Marine magnetometric surveys for the research of small sinking metal sources (and often covered by silt) require high sampling density and precision in the localization of the sampled points. In addition, from the point of view of the information analysis, a high precision is required to define the signal band of the micro-sources (targets).

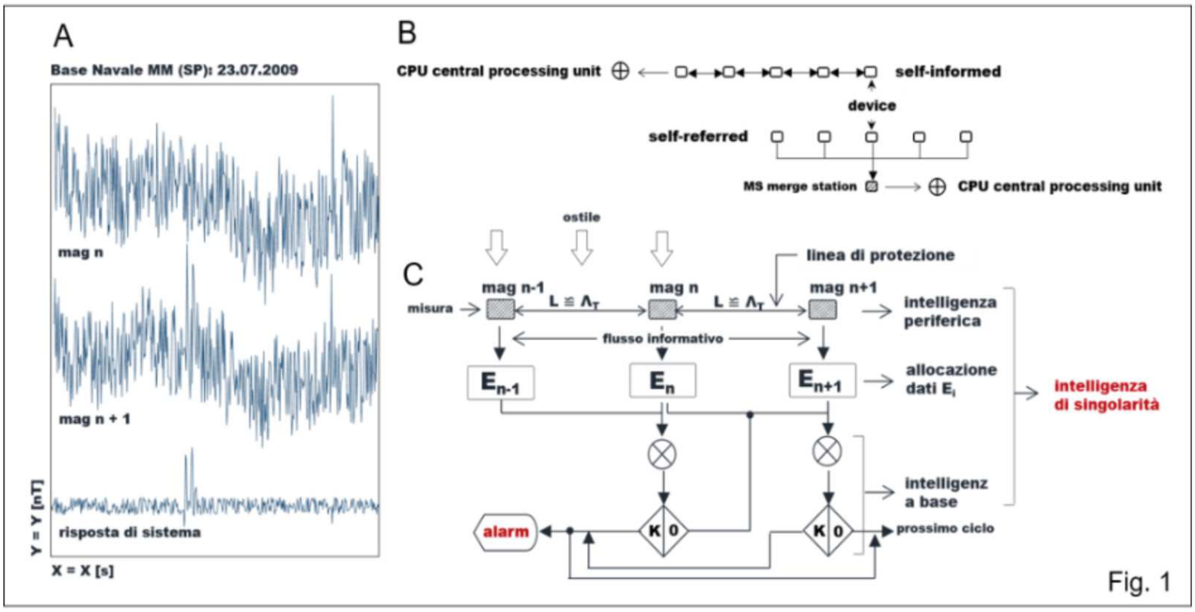

Figure 1 Measure of singularity: system architecture and performances.

The metrological problems for magnetic underwater HD surveys are the temporal reduction of the detection and the isolation of the band containing the target signals [Di Gennaro et al., 2008]. In a standard signal extraction actions from the detected field (so-called temporal reduction) or in the classification of the component bands of (so-called extraction of the anomaly field by reference field) produce the effective reading of the signals generated by the micro-sources. In particular, the reference adopted for the construction of terrestrial magnetic fields (IGRF) does not have adequate detail for this purpose. INGV has produced and formalized a new method of classification of the magnetic field bands of the micro-sources, which has allowed us to overcome the problem of detail by producing effective actions to detect extremely paying targets (recovery of mines, projectiles and unexploded rockets or bins and tracking low voltage power lines). As is known in high detail surveys in shallow waters (coastal areas, ports, etc.), the gradiometric systems (and in general for the control of temporal variations) are operationally not very effective because they have low evolutionary nautical response to towing and need of high sustenance speeds and heavy towing cables. For these reasons the surveys performed with this class of instruments, theoretically the most suitable for high detail, do not give adequate operational answers. INGV has proposed a marine survey method called HD (High Definition) for reading signals from micro-targets that bases its effectiveness on two specific steps: 1) a temporal reduction for controlled comparison; 2) a detailed reference field suitable for the production of the anomaly field associated only with micro-sources.
This temporal reduction is performed by comparison with a proximity reference station (terrestrial or underwater). The critical point of this technique is the verification of the spatial coherence of the reference station with the entire detection area. It is necessary to verify with a good approximation that the temporal variations measured by the reference station are constant, and therefore applicable, to the entire surface surveyed. The proposed technique is the “TT technique” (Time Track course, time route). The magnetic field from the observatory to

the farthest point of the array is measured by means of a straight run back and forth, before starting to perform the survey [Faggioni et al., 2002]. The data are organized in two distinct series (S_O series "out" from the observatory to the remote point and S_I series "in") the values of S_I are reversed and compared by overlapping (S_O ∩ S_I). The result of the subtraction cannot be null since the data series considered are of type and the rest of the difference will be equal . The two series are time reduced by comparison with the magnetogram of the reference station, if the reference station is coherent with the whole path, after TT reduction the result of the comparison (S_O - S_I) will result equal to zero (except for numerical approximations). In case of need more TT can be performed.

The computation of the Spectral Reference Field (SRF) (Figure 2-B) starts from the square mesh normalization of the 2D HD data. This field includes possible signals from very superficial artificial micro-sources (HD targets), signals of crustal and epicrostal origin, possible residues of the F(s) component that survived the TT technique, and, in remote cases, signals from large artificial sources (wrecks), irrelevant to the purpose of the HD survey. The contribution due to the "IGRF component" has to be considered a constant (field carrier) since its latitudinal gradient is too low to produce a differential effect measurable in the low extension typical of HD surveys.

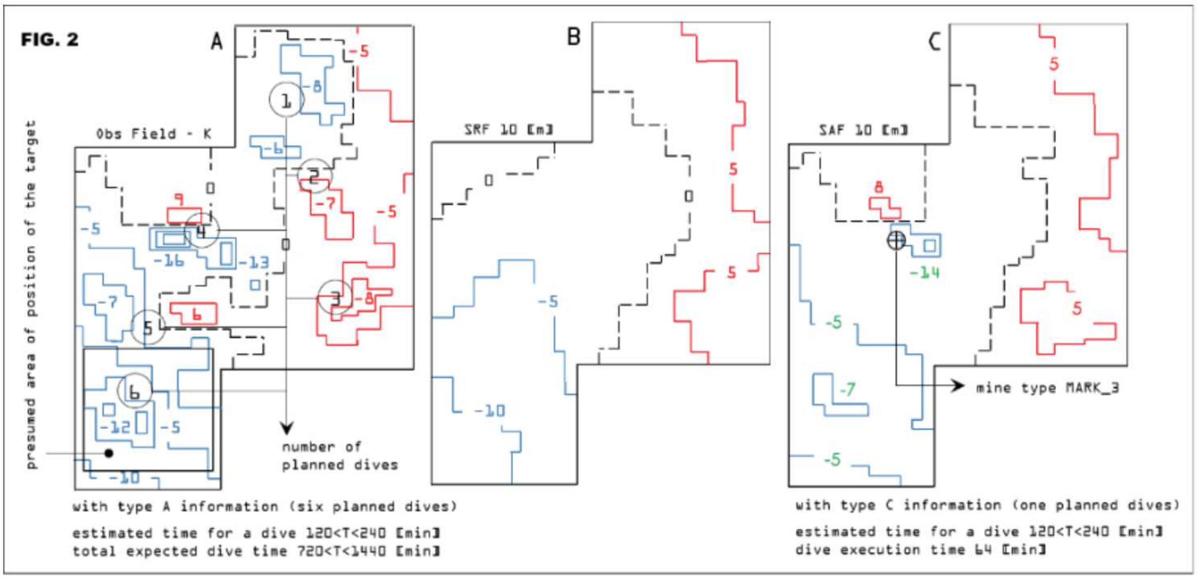

Figure 2 Example of High Definition survey: HD (A), Spectral Reference Field SRF (B) and Spectral Anomaly Field SAF (C).

The HD field (Figure 2-A) is substantially composed of two variation components: the low frequency of epicrostal natural origin (or, possibly, coming from large wrecks that can be easily identified a priori) (Figure 2-B) which is the Spectral Reference Field and the high frequency corresponding to the range of targets (artificial bottom micro-sources). The SRF (Figure 2-B) corresponds to the filter "D_LP of the total magnetic field in HD (Figure 2-A) and in theory its FFT^{-1} produces the Spectral Anomaly Field (SAF). In general, however, to obtain the SAF spectrum it is preferred to proceed in TD: HD – (FFT^{-1} SRF) = SAF. This method allows to avoid the HF instability due to the transit of SAF data through the Fourier protocol (1, -1).

During the last decade the national port community observe some anomalous tidal fluctuations. These events, known as "supersecche" and "super high" tides are due to the hydrostatic compensation of the weight change of the atmosphere. In harbours, this phenomenon is higher than the off-shore one (where the hydrostatic compensation factor *J* is 1cm for 1hPa) [Faggioni et al., 2006]. INGV provided the geodetic interpretation of the phenomenon and the metrological solution for its measurement and forecast. The horizontal component of the compensation motions is inhibited towards the coast and the consequent compensation defect is discharged on the vertical component amplifying thrust and delocalization of compensating mass in this direction. A campaign of tidal measurements of the atmospheric pressure and of the corresponding variation of sea level (supported by UE-EFRD and several Port Authorities) allowed to calculate *J* factors for several ports and the respective *K* (delay times) of the arrival of tide wave compensation (forced) with respect to the transit of the atmospheric pressure change (forcing): hydro-barometric forecasting of the first-order [Faggioni et Al. 2013]. Subsequently, with the aim to improve the precision of the measurement and the forecasting of the phenomenon, a comparison was made between the amplitude and the time of arrival of tide wave with the variation of acceleration of gravity due to the change in weight of the atmosphere: hydrobarometric forecasting of the second-order. The experiments related to the studies of the second-order were carried out in the Gulf of La Spezia. The quantitative values of the harbor *J* factor were approximately twice (or major) compared to the off-shore ones, while those of *K* were variable from some hours to more than a day.

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