Harbour Sea-floor Clearance: "HD" High Definition Magnetic Survey Performance

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Abstract — **Seafloor clearance methods based on acoustic, direct-inspection, and single-sensor magnetic approaches suffer from limitations in controlling the target-sensor distance, and may prove ineffective when the small size or the dangerous nature of targets requires high accuracy in localization. Moreover, random magnetic variations over time bring about spatial decorrelation phenomena, and hinder the application of double-sensor methods in noisy harbour environments.**

The new High Definition (HD) magnetic survey protocol tackles the measurement-distance problem in two ways: first, by varying the sensor depth dynamically, and secondly by back-projecting the measured field according to seafloor data and vertical incremental factors associated with the bandwidth characteristics of targets. The method to make up for time-induced loss in spatial localization ability exploits the local behaviour of a coherence function, which correlates local observations to a set of spatially-stabilized reference stations. The consequent normalization of measured magnetic signals allows one to assign the monitored areas with a specific level of confidence in the detection results, ranging from 100% (certainty) to 0% (random events).

The principles of HD detection have been fully applied in the seafloor clearance of the firing test site located south of Cape Teulada (Sardinia, Italy), where very weak signal sources such as cartridge cases, mines, and small objects down to 1 Kg mass values (lobster pots) have been successfully localized, even when covered by extensive colonies of Posidonia.

Index Terms— **Seafloor clearance, magnetic survey, magnetic detection, proton Overhauser magnetometer.**

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I. Introduction

In May 2007, following a request by Italian Ministry of Defence and Autonomous Region of Sardinia, Italian Navy (ITN) – prime contractor – and NURC agreed to provide the marine survey part of the Capo Teulada NATO firing range. In this job the research team used acoustic and optic standard methods and a new magnetic survey methodology developed by ITN COMFORDRAG and INGV: the "HD mag survey". A proton Overhauser sensor was towed from CRV Leonardo and a magnetometer reference station was set ashore in site of time variations space coherency, to permit the use of observatory magnetograms [F(t)] as filter of magnetic survey [F(t,s)]. The contribute of HD mag was relevant in the detecting in case of Posidonia areas, in targets sand-covered and in hard condition of sea bottom topography. The operative area is shown in Fig. 1.

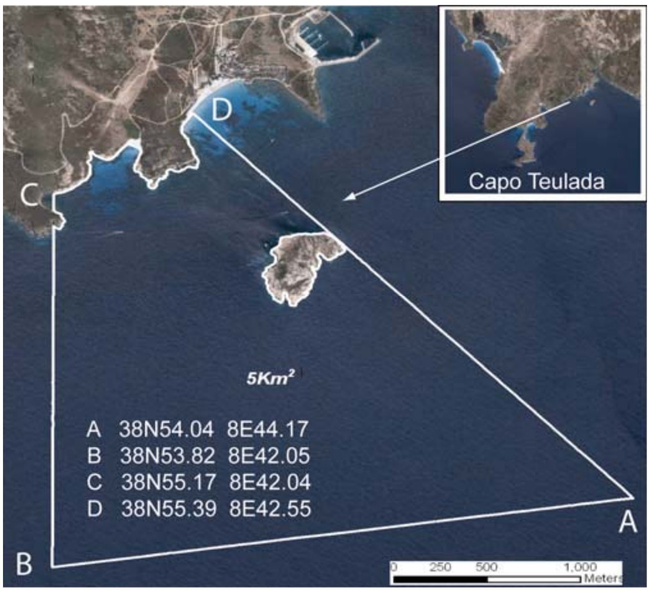


Fig. 1 Geographic scenario of high definition magnetic survey.

The operation was planned to be conducted within 15 days and more than 200 contacts were classified. The performance of HD mag in the Teulada operation has convinced ITN to ask NURC for a common development programme with the aim to validate at sea a fully integrated multi-sensor approach (sonar, magnetic and optical) in MCM short term ops. using USV/AUV platforms.

II. The HD magnetic method

Teulada area is characterized by the presence of Posidonia in proximity to the coast, and by sandy sea bottom in off-shore area. These environmental conditions make very high the probability of presence of hidden targets. These targets are very small (also quasi dot-like objects) and have a high magnetic mark. These environmental conditions qualify the magnetic exploration method as the best option to integrate optical and acoustical exploration techniques. The effectiveness of our magnetic survey to detect micro-sources is related to three metrological conditions: high density in the magnetic field measurements, sensor nearness to the sea bottom, and high precision in the time reduction of the survey data. On the other hand, we project a typical HD (high definition) geomagnetic survey to environmental purpose. As well known, the gradiometric system effectiveness in micro-sources targets in a little area is very low, because weighting devices (e.g. gradiometric apparatus) have not nautical characteristics to produce the necessary precision in their underwater navigation. We use a single device and the "base station" time reduction procedure [1]. Of course, to have the HD time reduction, it is strictly necessary having a good verify of the space coherency of observatory time variations over the whole survey area.

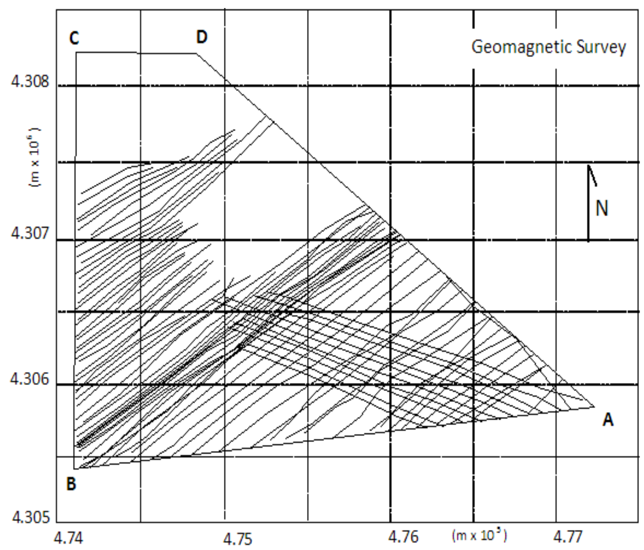


Fig. 2 Geomagnetic survey of Capo Teulada (South Sardinia - Italy) - standard tracks.

III. The Survey

The survey area is included in four corners (UTM coordinates): A 4305849 477214.9 (SE), B B4305411 474097.6 (SW), C 4308291 474107.1 (NW), D 4308289 474848.2 (NE) (Fig 2). The area was covered by a proton magnetometer measurements over 75 standard tracks and 19 special tracks performed to have more definition over specific targets. The standard tracks survey has a sampling rate of 1 [s]; the transversal distance between tracks is related to the local density of targets: its range is 10 [m] - 70 [m]. The use of a single magnetometer allows a very low survey navigation speed (standard 2-3 knots) and a good control of distance between the magnetometer and sea bottom, controlled by a length variation of the magnetometer traction cable. In the standard condition this distance "h" is 1 [m] $< h <$ 2 [m]; over the Posidonia area, the survey height h becomes more or less 3 [m] from the sea bottom to prevent biological damages. The spatial position of the magnetometer is obtained by the HI-PaP system, that is based on a transponder towed near the magnetometer by the magnetometric system traction cable and on a master station locked to the GPS of the ship: the transponder measurements Δx, Δy, Δz are corrected by the satellite position and the bathymetry (by the ship echo-sounder system) to have the absolute position of the magnetometer.

About the measurements sensibility, we consider that a device sensibility of 1 [nT] is sufficient for our purpose, because we decide a magnetic signal with amplitude lower than 5 [nT] has not informative capability about our targets (much more if it has not a well defined dipolar form). In fact, the signals with amplitude lower than 3-5 [nT] can be produced by a lot of kind of sources, as little device shaken, magnetic induced signals (not ferromagnetic), etc...

IV. The TTs Reduction

The reference geomagnetic observatory is located in Isola Rossa, near to the northern border of the surveyed area. To control its spatial coherence, we use the Timer Tracks (TT) techniques, based on the time correction of the geomagnetic profiles and on the correlation between the corrected profiles. The spatial coherence defines the spatial stability of the geomagnetic time variations measured in an observatory [2,3]. If the same profiles are performed in two different times, the two geomagnetic surveys have not the same results, because they have the same geomagnetic spatial contribution but also have different geomagnetic time contributions. If the profiles have the same values after the time correction, and then the time variations measured in the observatory are stable over all distance surveyed, then the observatory geomagnetic is named "in spatial coherency".

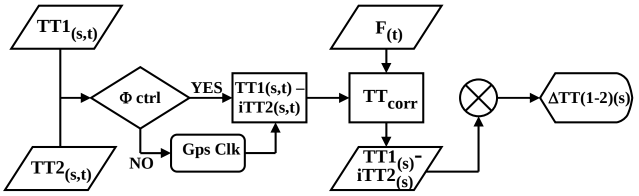


Fig. 3 Procedure of the reference geomagnetic time variations space stability.

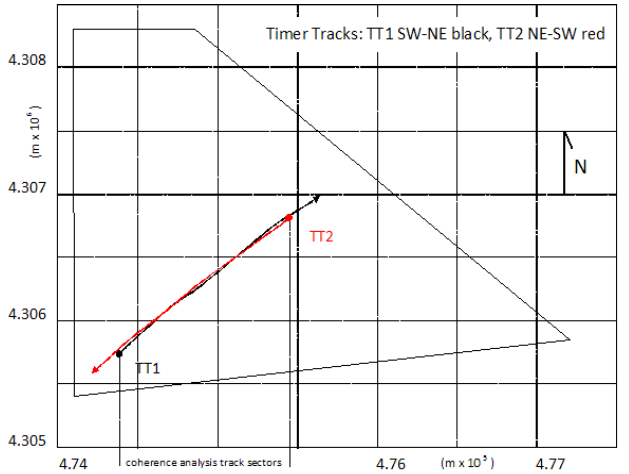


Fig. 4 Timer Tracks for the geomagnetic time variations spatial coherence computation (Isola Rossa geomagnetic reference station).

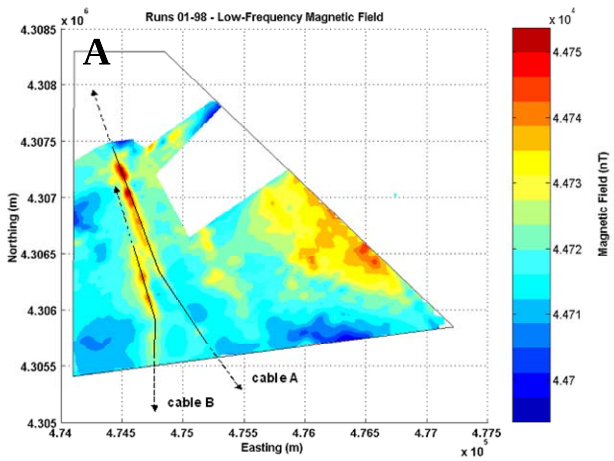
To test the Isola Rossa observatory spatial coherency, we use a profile sampled in two different times (go and back), then we verify the sampling phase and reverse the second survey (back run), and lastly we subtract the second survey to the first one (Fig. 3) [4]. The level of Isola Rossa observatory spatial coherence is defined by the difference between the corrected TT1 track (black marked, from SW to NE) and the corrected and reversed TT2 Track (red marked, before elaboration oriented from NE to SW) (Fig 4); this difference will be nearly zero. In the present experiment, the effective analysis of coherence is executed in the sector of tracks superimposition. Figure 4 shows the coherence survey (without the ship evolution runs) and the sectors of tracks superimposition. The TTs analysis shows that the 70 % of the samples have, after the correction, a geomagnetic amplitude residual of $0 < \Delta F <= 2$ [nT], the 25 % 2 [nT] $< \Delta F <=$ 3 [nT] and lastly 5% 3 [nT] $< \Delta F <=$ 5 [nT]. We consider that the geomagnetic observatory of Isola Rossa is in spatial coherence with the area of Capo Teulada survey.

The length of coherence computation sectors is more or less 1500 [m] and its circular surface centred in the Isola Rossa geomagnetic observatory covers more or less the 80% of survey surface; furthermore, in the external area (corner of SE) there are not sources of local noise able to change the high frequency band of the geomagnetic field. This class of noise sources are typical of the coast and urbanized area.

V. The Results

A. Figures and Tables

The HD geomagnetic survey of Capo Teulada and the cleaning of its data set permits to detect and localize 258 magnetic target signals; 134 impulses positive (52%), 93 dipoles (37%), 28 impulses negative (11%). The maximum of amplitude detected is 574 [nT] and the minimum is 6 [nT]; the statistic of amplitude distribution is 127 signals with 5 [nT] < A <= 20 [nT] (49%), 21[nT] <= A < 100 [nT], 101 <= A < 574 [nT]. In the survey of very high definition, where the targets are very little, the 2D and 3D maps have not very high effectiveness because it is not possible to have topographic scale fit to localize the targets with sufficient precision: a lot of dipoles or impulses have wavelength of few meters. It is standard procedure defining the targets position by the 1D products (profile) corresponding to the survey tracks. In the present case we show two maps (2D and 3D) to indicate an artificial anomaly crossing the entire survey area (Figure 5A and 5B). This anomaly corresponding to the magnetic field associated to two cables. The cables are a section of a control system of the sea area of Capo Teulada; the system is dedicated to traffic ships control in the Teulada area sea firing ground. This apparatus looks like an inductive type where the East cable (A external) is the active component (inductor) and the West cable (B internal) is the passive component (reader).



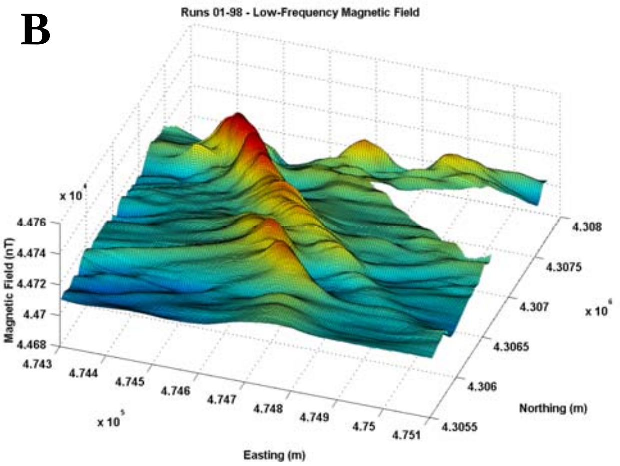


Fig. 5
A.: Total intensity field of “Capo Teulada” investigated area 2D.
B.: 3D Representation of the total intensity field.

In figure 6 we show examples of targets. T.C. 24/01-03 is a sequence of dipolar anomalies due to a series of three fish pot built in metallic net with a iron wire skeleton (more or less 2 kilos); T.C. 27/05: half iron barrel (more or less 15 Kilos); T.C. 29/06-07: the sea firing ground security system cables: 1 inductor, 2 reader; T.C. 60/01: mine MARK3 (dummy) lose in a Posidonia area during a past exercitation; T.C. 75/02-03: a sequence of two iron shell case signals (more or less 4 kilos).

T.C.	C.C.	Date	Time UTC	Ti	Tf	Fi	Ff	?F	Λ	Φ	ω
24,01	Dipole	23/05/2007	13:33:12	3303	3319	44683	44661	22	474443	4305843	25
24,02	Dipole	23/05/2007	13:34:02	3356	3410	44683	44673	10	474495	4305891	17
24,03	Dipole	23/05/2007	13:34:25	3419	3431	44582	44668	14	474520	4305913	13
27,05	Dipole	23/05/2007	15:35:26	3519	3535	44758	44698	60	475116	4306480	13
29,06	Impulse +	24/05/2007	13:58:29	5811	5858	44747	44710	37	474786	4306387	43
29,07	Impulse +	24/05/2007	14:00:16	5952	58	44762	44716	46	474680	4306290	67
60,01	Dipole	31/05/2007	10:26:36	2631	2642	45135	44601	534	474371	4306838	9
75,02	Dipole	01/06/2007	9:21:20	2116	2123	44753	44689	64	475716	4306292	5
75,03	Dipole	01/06/2007	9:21:28	2125	2132	44728	44694	34	475725	4306301	6

T.C.	N° Track Contact
C.I.	Contact Classification
Date	dd/mm/yyyy
Time UTC	Inflection of the dipolar signal detection time (or max F of the impulse signal) hh:mm:ss
Ti	UTC start signal time detection mmss
Tf	UTC end signal time detection mmss
Fi	Amplitude of field at start signal detection [nT]
Ff	Amplitude of field at end signal detection [nT]
ΔF	Amplitude of the signal [nT]
Λ	Longitude E Green [m]
Φ	Latitude N [m]
ω	Signal wavelenght [m]

Fig. 6 Examples of detection of magnetic signals after processing.

Fig. 7 shows, as an example, the MK3 training version mine (Fig.7 A) retrieved inside a Posidonia field. A photo of the mine has been taken by a ROV after its finding onto the seafloor (Fig. 7 B). The retrieving operation has been performed using the HD mag technique. The magnetic anomaly characteristic of the MK3 is represented in Fig. 7 C.

Fig. 7 MK3 training version mine retrieved inside a posidonia field in the near by of Capo Teulada coast (magnetic anomaly graph by Marine Magnetics software).

In the following some signals, grabbed during the research operation, have been reported for instance. The data have been acquired with a flying quota between sensor and sea bottom of about 15 [m]: in Fig. 8 have been represented the signals produced by three metallic cables (run 24) and by a cartridge case of a naval gun caliber 105 (run 27).

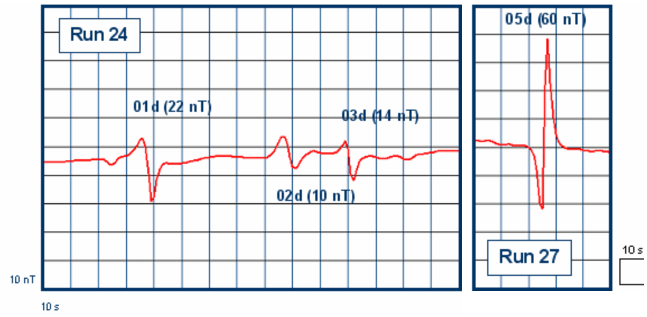


Fig. 8 Magnetic micro-target signals (graphics by Marine Magnetics software).

The comprehensive result of HD mag detections verified is reported in Fig. 9, in which white lines are the naval runs and red points are the points of interest (targets).

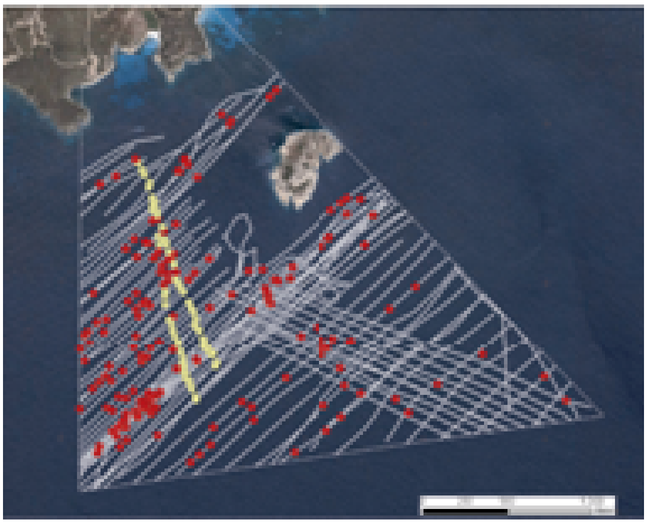


Fig. 9 Map of magnetic anomaly detected and verified (red points represent standard target, yellow points represent target due to metallic cables).

VI. Maps of Effectiveness

A basic element to qualify the effectiveness of HD magnetic survey is represented by the effectiveness maps. These documents show the ratio between the survey covered area (naval courses) and the effective covered area: greater is the density of the naval courses and smallest is the distance between the sensor and the target, greater is the target magnetic signature and the covered area is more similar to the effective covered area.

In Fig. 10 are shown the explored areas (EA, pink) compared with the surveyed areas (SA, gray), in a square of about 10m, using a flying quota between sensor and sea floor of about 1.5m for A class sources type, equal to 10-20 [nT] at this quota, for B class sources type, equal to 20-100 [nT] and for C class sources type, equal to 200-250 [nT].

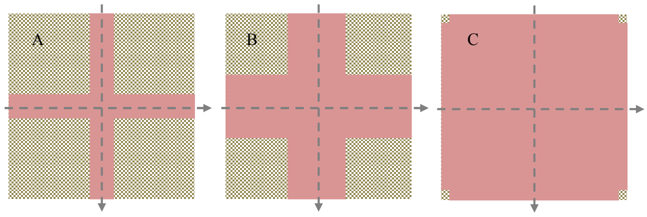


Fig. 10
A.: EA (gray) about 20% of SA (pink)
B.: EA (gray) about 50% of SA (pink)
C.: EA (gray) > 90% of SA (pink)
Gray lines represent the survey naval courses.

Applying this principle to the real survey, the explored areas map of Cape Teulada operation can be create (Fig. 11). These effectiveness maps represent the fundamental element to the evaluation of the HD technique in magnetic maritime survey for mine clearance because they give a quantitative statistical measurement of the ratio between detected object and missed target

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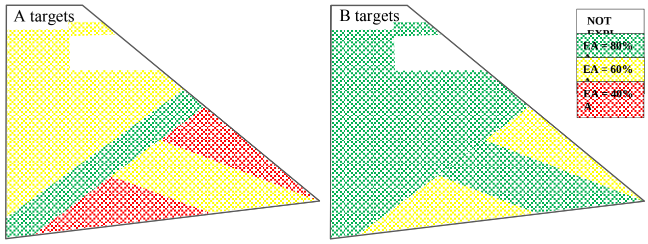

Fig. 11 Effectiveness maps of the survey for A and B classes of sources type (distance between sensor and sources equal to flying quota of the sensor 1.5 [m] 20%).

In case of necessity of a g ratio EA/SA, the maps show not only the areas to be most densely surveyed (yellow and red) but also the number of necessary naval courses. This features guarantee to the HD magnetic survey a greater reliability in operative applications.

VII. Conclusion

The magnetic survey in HD of the NATO firing range in Cape Teulada has pointed out the ability of this method to detect several targets that using the classical approaches based on acoustic and optical signal can not be detected.

This feature has been decisive especially in areas with presence of Posidonia, in which also high dimensional target resulted to be hidden (MK3 mine), and in sandy sea bottom, in which targets are often buried.

The proposed method has moreover defined with clarity the presence of two metallic cables, crossing all the survey area, which were not present in the official maritime map.

This technique proves to be a great auxiliary method to the standard approaches using in sea floor survey and detection (acoustic, optic, etc…). Analyzing the results obtained in Capo Teulada ITN has decided to carry on the research on MCM developing a multi sensorial system.

ACKNOWLEDGMENT

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