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Emergency Survey Toolkit for Naval Operations

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ABSTRACT: In order to deliver the minimum safety conditions for movement of the ships towards restricted waters, urgent survey operations are required whenever we deal with natural disasters; unreliable chart information or uncharted areas requires. In recent years, there has been a huge development in positioning and survey technology. Simultaneously, charts production techniques and GIS software are easily accessible. In this circumstance, a research project was made in order to assess the possibility of developing existing capabilities of emergency hydrographic survey. The toolkit was designed to allow the swift production of usable bottom representation and survey of navigational aids, with a focus on navigational safety, rather than bottom contour accuracy.

1 INTRODUCTION

1.1 *Context*

Occasionally and for several reasons, the navigators have to perform surveying work. In some scenarios, such as natural disasters, urgent survey operations need to be carried out in little available time, as the result of constraints from the imperative requirement to conduct ship-to-shore humanitarian relief operations. In other cases, the presence of unreliable chart information and the need to conduct amphibious operations in uncharted areas require rapid action from the fleet in order to deliver the minimum conditions for the safe passage of ships towards restricted waters.

Eventually, it may occur that the danger, infrastructure or port facility has not been surveyed and that the ship needs to collect sufficient data to be forwarded to the responsible Hydrographic Office.

Among mariners and other maritime stakeholders there is a large consensus about the existence of advantages to be derived from the implementation of Electronic Navigational Charts (ENC) and their visualization in the Electronic Charts Display and Information System (ECDIS). Simultaneously, those electronic products have paved the way for the introduction of several automatic functions which support or replace a large number of tasks carried out by the bridge officer. Therefore, the reliability of these automatic functions, which has been incorporated within the Integrated Navigational System (INS), is extremely dependent on the existence of up-to-date ENC.

From the user's perspective, this means that the presence of unreliable hydrographic information is no longer a matter of only redefining the safety margins, as it can also lead to erroneous performance of the INS, related not to some malfunctioning of the INS but to the existence of wrong data serving as basis for the automatic functions. As Andy Norris has said, these automatic systems will likely allow for an ever increasing automation of the planning process, ensuring that the information is up-to-date and of high integrity (Norris. 2011a).

In recent years, there has been a huge development in positioning and surveying technologies, which provide higher accuracy and data collection capability (IHO. 2005). Concurrently, charts production techniques and Geographic Information Systems (GIS) have evolved significantly (Lee. 2008) (Lam *et al*. 2007). More recently, the International Maritime Organization (IMO) has identified the need to investigate the best way to automate the collection of internal ship data for reporting (IMO, 2014).

1.2 *Expedite Hydrographic survey*

The purpose of expedite hydrographic survey is to support safe passage, therefore it is not necessary to produce a standard representation of the seabed. It is important, however, to provide all the details of the work and an understanding of the achieved accuracy. This principle is determinant for an assessment of existing risks and for the coming up with a final decision as to whether or not to proceed into the surveyed area.

While some manual includes information about the use of GPS receivers and recreational echo sounders, there is still plenty of space for further considerations and evaluations on how to better exploit GPS receivers and digital echo sounders, and specifically on how to integrate them with GIS applications. Additionally, some of the techniques used by professional surveyors, for instance to analyse and estimate the errors, could be explored, which might help deliver a work with a higher standard of quality.

GIS is one of the most valuable tools presently available that could offer remarkable advantages at all stages of the survey work, from the planning to the presentation of the information. On the bridge, because of the ECDIS Performance Standards requirements, it could bring other advantages. Despite the possibility to add other overlays in the ECDIS, such as RADAR, AIS and, meteo-oceanographic data, their flexibility and portrayal are limited and do not allow for the full exploration of other position-related information. “What is really required is a display that acts much more as a generic GIS, using ENC data as its background” (Norris. 2011b).

At some stage, it was expected that the research would have to cope not only with the ECDIS limitations to portray other layers but also with the navigator’s inability to use and manage ENC data on alternative systems. “A fundamental job of the human navigator today is to be the integrator of diverse navigational inputs to ensure consistency and therefore integrity” (Norris. 2011a). Ultimately, in a near future, navigators will have to abandon some of the more traditional techniques, applied on paper charts, and develop skills based on GIS tools.

1.3 *Real cases*

In 2008, when the tall ship *NRP Sagres* was entering the port of Beira, in Mozambique, the Captain had the perception that the channels had a different configuration from the one which the official nautical chart presented. Based on the existing information he decided to anchor out of the port one day ahead of schedule and to carry out his own survey with the support of the Portuguese Hydrographic Institute (IHPT). To conduct the survey, the navigator with the help of some element of the ship staff, combined a low-cost GPS receiver and a recreational echo sounder installed on a RHIB. The raw data was extracted from the equipment and sent electronically to the IHPT. Among the depth information they fixed and identified some navigational aids. The IHPT analysed the data and included some degree of corrections to account for some of the expected errors. Then, they modelled a contour layer on the same projection, datum and scale of the nautical chart. The information about the navigational aids had undoubtedly demonstrated that they were positioned in different places.

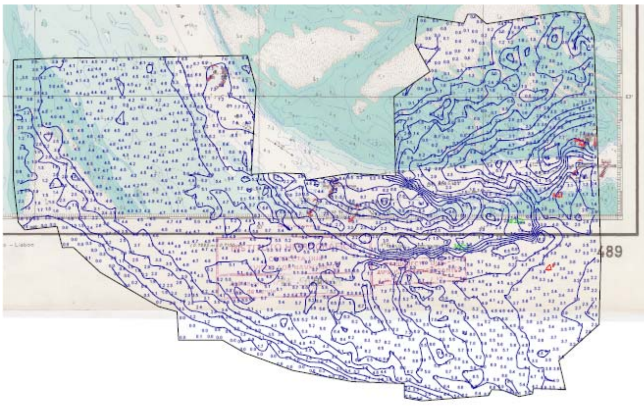

Figure 1. Geo-referenced image with a depth contour layer

As Rear Adm. Jonathan White, Commander, Naval Meteorology and Oceanography Command has said, “Hydrographic surveys are necessary in order to determine navigational hazards that could impede the egress of Navy assets involved in the relief support and enable the flow of humanitarian supplies” (NMOC, 2010). That is what happened on the island of Madeira, after the storm floods in February 2010. Immediately after the floods the Portuguese Navy ordered the IHPT to perform urgent hydrographic surveys at the port of Funchal and at other flooded places along the coast. The first objective of the survey data was to immediately detect underwater objects brought by the floods, which then served to update nautical charts and to establish the requirements for further hydrographic surveys. On the debriefing the task leader pointed out the importance of developing an integrated and deployable survey toolkit.

1.4 *Scope of the study*

David Last, as President of the Royal Institute of Navigation, has written: “As ships become larger and faster, with only one or two to operate the bridge, and as officers cease to be familiar with traditional labour intensive, highly-skilled, visual navigation, can we find ways of collecting and displaying all the information they need in electronic forms that are clear and utterly reliable?" (Last. 2008).

This research aimed to evaluate the possibility of expanding the existing capability of the Portuguese navy to carry out emergency hydrographic survey work. Present capability should be strengthened both in quantitative and qualitative terms. This means that this research should provide solutions for the following problems:

1 How to survey a larger area simultaneously, by providing the operation command with more options for the movements of the naval forces?
2 How to present nautical information with increased quality assessment?
3 How to provide the most appropriate data and presentation format for a better integration in available information systems?

The constraints for the development of the survey toolkit studied in this project were associated with:

1 The fact that on-board staff are not survey specialists;
2 The cost of the solution must be balanced with the probability of occurrence of these scenarios;
3 The time required in these situations is the most important constraint.

2 METHODOLOGY

The proposed methodology aimed to:

1 Analyse the current operational capability and the requirements for this type of operations;
2 Define evaluation criteria for the validation of the solution;
3 Study a modelled solution for collecting data, analysing it and producing paper/digital charts. This should be done by maximizing the operational use of: Low-cost handheld GPS receivers, recreational echo sounders and GIS.
4 Perform hydrographic surveys and compare the results with standard hydrographic products.
5 Present recommendations and guidelines for the utilization of the tested toolkit.

2.1 *Toolkit design*

One of the commitments of this research was to develop a hydrographic survey toolkit using handheld single frequency receivers, low-cost sensors and, if possible, software extant on-board. For budget purposes, considerations were be taken of the required maintenance contracts, specific software and the training of operators. The following factors were considered:

1 Cost;
2 Accuracy;
3 Integrated system: for positioning and sounding.
4 Training and maintenance: usable by on-board personnel, designed for outdoor usage.
5 GIS data collection software: independent software or equipment firmware;
6 Trends;
7 Maximize the applications: explore other applications for the toolkit.

Based on the above criteria, a Garmin 525s GPS, with an external antenna and a double frequency echo sounder, was used for this research. The decision on the selection of the ESRI GIS was mainly mandated by two factors: the use of an implemented system within the IHPT and the selection of a certified and standard product. No specific software was selected to capture the data, firstly to avoid further cost in software acquisition and secondly to take the advantage of the integrated GPS receiver and of the echo sounder with an external NMEA output. A laptop was used to operate the GIS and to capture the data from the equipment. For the tide measurements, a calibrated tide tape was used. It includes a visual and sound alarm for when the sensor touches the water surface.

2.2 *Experiments and evaluation criteria*

1 Tide and vertical control: to assess the quality of the tide observation, a trial during one tidal cycle was conducted next to a permanent tide gauge and a portable tide gauge, used by the hydrographic teams.
2 Planning: this was evaluated by assessing the time spent in planning and the use of a varieties of products sources and formats available in place.
3 Horizontal control: the receiver was tested at the IHPT control point; several observation time series were used to assess the accuracy of the receiver with and without EGNOS corrections.
The positions of the soundings were assessed by comparison of the bathymetry and contour data against the published hydrographic data based on surveys conducted on the same day.
4 Soundings: two trials have been undertaken to assess the soundings in comparison with Multibeam Echo Sounder (MBES) survey data.
5 Plotting analysis: some techniques were tested to establish a methodology to detect and correct errors.
6 Charting: quality checks of parameters such as conformity, scale, and orientation and position accuracy were executed.

3 RESULTS

3.1 *Tide*

A visual measurement of one tidal cycle was conducted next to the permanent radar gauge and each observation was based on the average of three readings.

A fifth order Butterworth filter was used to filter the water level data of the radar gauge. The tape gauge data was not filtered in the same way, because it had a very low sampling rate (one every six minutes) and only few observations (85 observations). Instead, a moving average filter, over five measurements, was applied twice.

Some tests were made to design a suitable and easily accessible filter; and, in the end, two filters, with two stage, were set. The first stage is the same in both filters, and consists in a moving average over five measurements. The second stage, for one filter is to run again the moving average, for the other is to use the *mathlab filtfilt* function. The selection of the filter was based on the results from the statistics. The residuals, shown on the Table I, were computed in comparison to the water level data of the reference tide gauge, which has an accuracy of 1 millimetre.

Table 1. Statistics of the residuals of tape gauge measurements and the estimated tide (cm)

	Raw data	Filter 1 (Moving average)	Filter 2 (2 x Moving average)	Filter 3 Moving (average + filtfilt)	Estimated Tide (corrected)
Mean	4.13	4.10	4.07	4.14	-11.55
Average Deviation	3.94	3.57	3.50	3.53	4.34
Standard Deviation	5.35	4.75	4.61	4.60	4.99
Maximum	18.40	15.8	15.09	15.30	-20.05
95% Confidence	15.57	14.47	14.44	14.53	-19.84

Based on tabled tide data values, a tide curve was also computed. Complementarily, a safety margin can be set to accommodate the errors associated with the vertical accuracy of the benchmark.

3.2 *Planning*

To plan the surveys, several themes were tested during the two survey trials (Sines and Setúbal), namely: depth contour data, control points, Military Charts, Nautical charts, Satellite imagery, Navigational aids data, nautical publication info.

Following the compilation of the geo-referenced information, it was necessary to set the mission objective, to collect meteorological and oceanographic information, and to assess the available resources (FIG. 2010). Held on the available information and in order to establish the best line of action for crisis response situations, a risk assessment analysis was designed, based on the following factors:

1 First stage:
  - Positioning method: accuracy, reliability, data management, autonomy, personnel's expertise;
  - Oceanographic and Weather conditions: visibility, currents, swell;
  - Survey boat: manoeuvrability, attitude, autonomy; personnel´s expertise;
  - Sounding method; accuracy, reliability, data management, autonomy, tide observation, personnel´s expertise;
  - Area to survey: best, recommended, minimum.

2 Second stage, after defining two or three line of action:
  - Land preparation time;
  - Processing and plotting time;
  - Product appropriateness.

3.3 *Digital Data collection*

All the digital data were captured using the following options:

1 A handheld GPS receiver firmware;
2 ArcMap GIS;
3 HyperTerminal: to capture the NMEA messages.

3.4 *Positioning*

Three series of static observation trials were performed at the IHPT facilities. The control point was surveyed by geodetic GPS technique, referenced to GRS80/ETRS89, with the following quality parameters:

- RMS=16.2 mm
- Horizontal precision = 0.4 mm
- Vertical precision = 0.5 mm

The data retrieved from the NMEA messages was used to compute the 2D residuals. A spreadsheets had been developed to provide the following graphic analysis:

1 Descriptive statistics about the 2D residuals;
2 Histograms about the 2D residuals;
3 Identification of the tracked satellite;
4 SNR on each channel and the average SNR;
5 Diagram combining the 2D residuals with EHPE, HDOP and PDOP;
6 Diagram combining the 2D residuals with the number of satellites used for fix.

One may verify through the statistics results (Table 2) that, to use this type of handheld receiver, it is imperative to increase the overall precision and, at some level, the accuracy by removing the gross residuals. Therefore, two approaches were applied to remove the larger residuals, one using averaged solutions over different periods of time; and another applying filters based on satellite and receiver parameters.

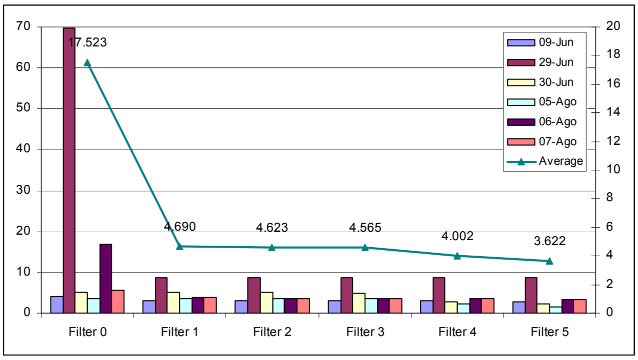

Figure 2 – Maximum residuals (m) for each filter

The average technique can only be applied for static observation, since it is based on the assumption that the GPS receiver is not moving. The second technique can be applied in both static and dynamic modes of operation, although the tuning processes vary one from another. It is important to note that there is no knowledge about the filtering processes that might exist at pseudorange computation level, prior to the delivering of the position solution.

From a practical point of view, since it is not possible to stay for a long time on the field, about 56 % of the reduction of the average error is obtained by averaging 15 minutes of data. For the second type of filters the following parameters were worked:

1 Differential solution;
2 Minimum number of satellites for fixing;
3 Maximum HDOP;

4 Maximum EHPE;
5 Velocity and acceleration over 10 seconds;
6 Velocity and acceleration over 30 seconds.

The filters were set in accordance with the values presented on the Table 3. The filter results were assessed in relation to variations of maximum residuals, standard deviation of residuals, mean residuals and the number of epochs. Filter 0 was established to accept only the differential solutions. Filters 1 and 2 were designed to remove the solutions based on only 4 or 5 satellites, with high HDOP and EHPE, which are generally correlated with positions with low precision and accuracy.

3.5 *Sounding*

The results of the calibration of the echo sounder (Table 4) shown that the echo sounder systematically provided lower depth than the real value, which was consistent with its purpose for safe navigation usage.

Table 4. Results of the echo sounder calibration

Real	Residuals (m)				
depth (m)	Max	Min	Mean	Standard deviation	95 %
1.8	0.9	0.1	0.6	0.19	0.9

3.6 *Depth reduction*

The reduction of the soundings had been carried out in the following manner:

1 Integration of the observables in a spreadsheet;
2 Correction of the positions to account for the horizontal offset between the transducer vertical and the GPS antenna.
3 Computation of the transducer beam cone radius;
4 Computation of depth uncertainty;
5 Computation of the depth referenced to water surface;
6 Computation of the reduced depth.

3.7 *Surface model*

Once the calculations of the reduced depths were concluded, the following processes were carried out on the GIS:

1 Creation of a shapefile of points, based on geo-referenced soundings;
2 Projections to UTM 29 N, WGS84;
3 Creation of a shapefile of polygons based on reduced depth (shapefile of points) and a buffer area defined by the attribute of computed beam cone radius;
4 Creation of a TIN surface;
5 Computation of surface difference, against a TIN created with the MBES depths;

The result of the surface difference calculation is a polygon shapefile, with the following attributes: volume, surface area, shape length, shape area and relative position code (above or below the reference surface).

A geo-processing model was built in order to perform the above functions with a single tool.

Table 2. Statistics of the GPS static trials

type	Time series	95.4% confidence [m]	Mean [m]	Max [m]	Min [m]	Standard deviation [m]	Variance [m]	Count [Nr]
EGNOS	08-6	32.25	19.99	32.82	4.66	9.48	89.89	5465
	09-6	2.13	1.49	4.01	1.10	0.30	0.09	10640
	29-6	21.81	4.90	69.78	0.25	7.45	55.53	6715
	30-6	1.70	1.39	5.18	0.63	0.27	0.07	14200
	05-8	1.61	0.86	3.67	0.07	0.46	0.21	14200
	06-8	3.17	1.32	16.88	0.27	1.23	1.52	14200
	07-8	2.18	1.22	5.63	0.07	0.69	0.48	14200
SPS	05-8	3.61	2.12	6.60	0.54	1.01	1.02	14200
	06-8	7.07	2.71	27.79	0.17	2.41	5.83	14200
	07-8	3.71	2.09	4.26	0.09	0.84	0.72	14200

Table 3. GPS Filter parameters

Filter	EGNOS	Number of satellites	HDOP [m]	EHPE [m]	Velocity (30s)(ms^{-1})	Velocity (10s)(ms^{-1})	Acceleration (30s)(ms^{-2})	Acceleration (10s)(ms^{-2})
0	Yes							
1	Yes	>4	<1.8	<3.3				
2	Yes	>5	<1.8	<3.3				
3	Yes	>5	<1.8	<3.3		<0.02		<0.002
4	Yes	>5	<1.8	<3.3		<0.005		<0.0005
5	Yes	>5	<1.8	<3.3	<0.002	<0.005	<0.0002	<0.0005

3.8 *Plotting and analysis - Sines results*

Generally, the bottom profile is correctly represented and most of the shoals were identified. It is important to remember that the goal is not to produce an exact representation of the bathymetry, but to identify a safe passage for the ship. This means that it is necessary to compute a surface that is, ideally, always above the true surface. Naturally, one could set a very large safety margin but this might lead to the total impossibility of the ship to move ahead towards the restricted waters.

Considering the corrections and sensors offset compensations, about 98 % of the resulting bottom surface was below the reference surface. All the areas below the reference surface were located in zones with irregular bottom surfaces, which demonstrates a limitation in the characterization of these types of surfaces. In order to quantify the offset between the two surfaces, some analyses were made, using the attributes of the surface difference shapefile. The following parameters were computed:

1 Percentage of area above and below the reference surface;
2 Volume above and below the reference surface;
3 Average offset above and below the reference surface;
4 Average offset for each shape;
5 Maximum average offset;

The computed results of the first sounding data set (data set 1) are presented in Table 5, which consolidate all the results of the Sines trial. At the next step, the soundings were reduced with an additional safety margin of 1.2m. With this data set (data set 2), the results shifted radically, since around 70% of the surface was above the reference surface.

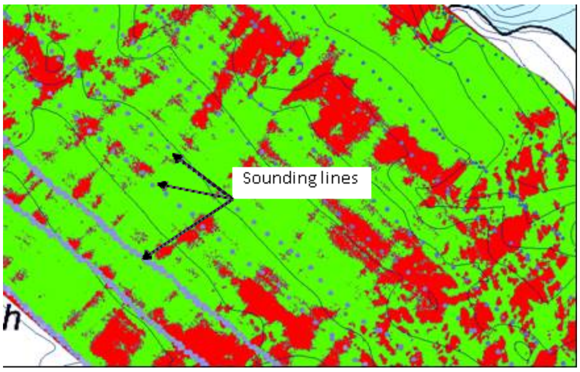

Figure 3. Surface interpolation between the sounding lines

The number of area terms provided an indication on the proximity of both surfaces, because the closer they were, the larger the number of intersection zones. Moreover, the averaging effect over the minimum and maximum values was reduced, as it was performed over smaller areas, which explains the appearance of a maximum offset below the reference surface of 4.673m. Looking at figure 3, one can observe that the areas that are below the reference surface follow a pattern associated with the sounding lines. This degradation of the interpolated surface should be reduced by using closer spacing lines and performing the survey perpendicularly to the bathymetry. Limitation which resulted from the fact that this trial was simultaneously conducted on-board the survey vessel performing a MBES survey.

Table 5.Statistics from the Sines survey trial

	Data set 1	Data set 2	Data set 3	Data set 3.1
Number of areas:	473	16355	1378	1378
Number of areas above the reference surface:	411	5494	112	112
Number of areas below the reference surface:	62	10852	1266	1332
Number of areas correlated to the TIN limit	-	-	-	34
% of area above the reference surface:	1.3%	69.8%	95.6%	95.6%
% of area below the reference surface:	98.7%	30.2%	4.4%	1.7%
% of area removed from the analysis:	-	-	-	2.7%
Average depth offset above the reference surface	0.572m	0.264m	1.036m	1.036m
Average depth offset below the reference surface	1.204m	0.606m	2.464m	0.622m
Maximum average offset above reference surface:	1.481m	0.562m	1.036m	1.036m
Maximum average offset below reference surface:	1.204m	4.673m	6.746m	2.696m

In order to consider the variation of the sounding error in relation to the increased depth, an additional term was used for the safety margin. This new term was set as percentage of the sounding, and, by approximation, the value of 5 % was set. Then, a new data set of soundings was computed with a safety margin of $[1.2m + 5\% \times depth]$.

Further analysis had shown that all the areas with more than 2.7 metres of offset were related to their interpolation with the outer limit of the TIN surface. By removing those areas from the analysis (data set 3.1), a significant reduction of the maximum average offset was obtained, and yet 2.7 % of the area still included areas below the reference surface that needed to be addressed. In order to further clarify their cause; those areas were graphically correlated with the contour bathymetry of the reference surface. As an indication, only 1.3 % of the areas below the reference surface had an offset larger than 1 m, and most of them were located between the sounding lines. Although few in number and percentage, for the purpose of their usage, they are a matter of concern which can only be reduced by carrying out surveys with closer spacing lines, and, considering that there was previous knowledge on the location of irregular bottom surface, by using depth investigation patterns. For these cases, total elimination of those areas can only be reached by carrying out a full coverage survey, for instance a sweep bar survey.

3.9 *Plotting and analysis - Setúbal results*

The area was selected in order to test the methodology over an area with bottom irregularities and a bathymetry profile range varying from 4 to 30 metres.

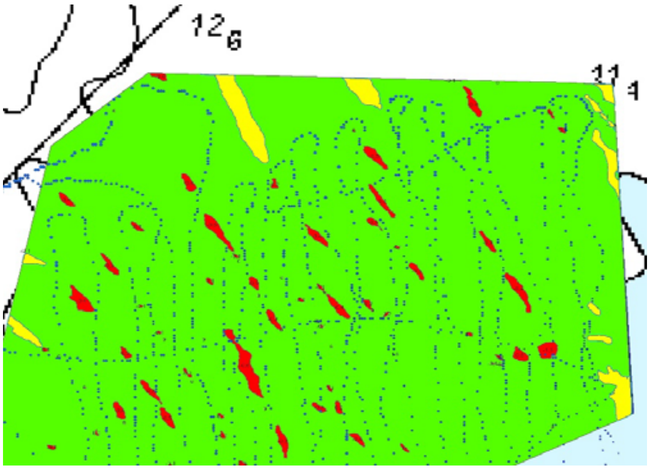

Figure 4 – Detail of surface difference and sounding of data set 3, for the Setúbal trial (yellow areas removed from data set 3 statistic results).

The results of this survey (Table 6) differs significantly from the results of the equivalent data set 1 of the Sines trial, since 65.1% of the surface was above the reference surface, against the 1.3% of Sines. This should probably due to the sounding methodology used at Setúbal, which is much more appropriate to the use of SBES.

When the safety margin of $[1.2m + 5\% \times depth]$ was applied, 14.7 % of the surface was still below the reference surface, with a maximum average offset of 1.303 metres. Subsequent adjustment were made to the variable term, and, when applying 10 %, the obtained results were improved, as it can be seen on table 6.

Table 6. Statistics from the Setúbal survey trial

	Data set 1	Data set 2	Data set 3	Data set 3.1
Number of areas:	334	391	148	148
Number of areas above the reference surface:	96	61	3	3
Number of areas below the reference surface:	235	328	144	132
Number of areas correlated to the TIN limit	-	-	-	13
% of area above the reference surface:	65.1%	84.7%	96.2%	96.2%
% of area below the reference surface:	34.9%	14.7%	3.8%	2.4%
% of area removed from the : analysis	-	-	-	1.3%
Average depth offset above the reference surface	0.776m	1.057m	1.567m	1.567m
Average depth offset below the reference surface	0.621m	0.446m	0.533m	0.383m
Maximum average offset above reference surface:	0.878m	1.058m	1.567m	1.567m
Maximum average offset below reference surface	1.324m	1.303m	1.262m	1.262m

3.10 *Charting*

The final stage of the survey toolkit was the production of nautical charts with the relevant information collected from the hydrographic survey. On the GIS, after the creation of the TIN surface, the surface contours were built with the 3D Analyst Tools. In order to check the properties of the printed chart and the GIS layer data, measurements were made on both, and checked against readings from the official nautical chart (INT 1880 – Barra e Porto de Setúbal). The measurements comprise angles, bearings, distances and coordinates. The overall result shown a very close similarity between the three formats, with no significant error induced to the user.

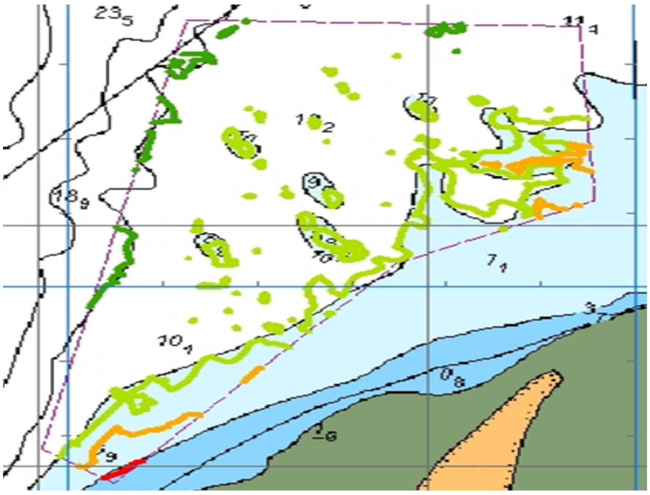

Figure 5. Detail of nautical chart with new contour lines

4 CONCLUSION

4.1 *Conclusions*

The information provided by sensors, and by other external sources, must be considered by the navigator whenever assessing the safety of navigation. So, even knowing that they might not be as accurate or precise as the one used by survey specialists, they must be used as a complement to the information provided by ENC, on a permanent basis.

GIS presents some considerable advantages in manipulating geo-referenced information, and therefore, it facilitates not only the planning process but also data collection, data analysis and chart production.

Additionally, a consistent and careful planning may mitigate a large part of the source error in this type of works, namely by assessing the estimated parameters of the satellite navigation system (Seeber. 2003), in conjunction with local environmental elements, and by implementing procedures for periodic calibrations of all the sensors.

The performance of non-professionals in the measurement of water levels, and the results were quite satisfactory, as the residual was less than 14.5 centimetres (95%).

When conducting the soundings, although the data capture process is largely improved by the use of integrated electronic systems, it is essential to complement the positioning technique with other independent navigation techniques (leading lines, hydrographic marks or other positioning system), as this is the only reliable way to reduce the uncertainty of the positions, and to detect blunders in positions, in real time.

With relatively simple post-processing techniques, it was possible to remove most of the large residuals and to slightly improve the accuracy of final GPS/EGNOS solution. Maximum residuals were reduced from 17.5 metres to 3.6 metres, and mean solutions accuracy was improved by about half a metre to 1.3 metres. For static observation, it was determined that the measuring should be carried out for a period of 13 to 15 minutes, in order to balance the available time and the accuracy improvement.

The proliferations of firmware and data formats are a challenge when considering the integration of information from different systems. In the maritime domain the NMEA standard helps to simplify this process.

The toolkit comprises skills and equipment available on board Navy ships, with no specific survey training and a specialist navigator. The toolkit also includes a set of processes and methods to plan and execute expeditious emergency surveys, as well as to produce survey outputs: a graphical representation of the sea bottom covering the area of interest.

The toolkit was designed to allow the swift production of usable bottom representation, with a focus on navigational safety, rather than bottom contour accuracy.

The results demonstrated that they fulfil some of the requirements set by the IHO (IHO, 2008) for hydrographic surveys, namely for positioning navigational aids. However, despite the fact that the IHO requirement of Total Vertical Uncertainty was not met, in both survey trials, after applying a safety margin for the depth reduction, it was possible to obtain a bottom surface with more than 95% above the true surface. To further increase the confidence level, it would be necessary to conduct complementary survey techniques, namely to carry out a seep survey.

With regard to the current methods used on-board, this methodology presents much higher levels of quality and applicability, especially as far as data processing and analysis, chart information compilation and the available format of the final product — papers or digital. For those processes, two geo-processing models were created, one for the assessment of static observation, another for processing the reduced depth into the GIS.

4.2 *Recommendations*

Amongst the uses of the EGNOS service, carrier phase observation with low-cost receivers could bring about two major advantages, already used by professional surveyors, one being the possibility of measuring attitude data, which then could provide more accurate corrections of the soundings, and additionally of opening the doors for the conductions of surveys out of restricted waters, i.e. where the swell is experienced. The second advantage would be the possibility of conducting hydrographic survey without performing water level observation.

Another possible avenue for research is the integration of other types of sensors available on-board, for instance imagery from organic helicopters or data from Autonomous Underwater Vehicles.

Finally, as was identified in the course of this project, ECDIS can no longer continue to portray additional information, as it might compromise the safety of navigation. Concurrently, the bridges are becoming crowded with displays presenting geo-referenced information, but from different systems or sources, the ship itself can collect large amount of geo-referenced data that need to be closely integrated within the prevailing system. Hence, it is necessary to develop a GIS platform, which can be flexible enough to manage all the geo-referenced data available on the bridge, and sufficiently agile to allow the navigator to establish different profiles of displays depending on the decision process and the operation in course, without compromising the minimum standard performances approved internationally.

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