Updating the Bathymetry of the Maltese Islands: a National-Scale Marine Survey Employing Interferometric Sonar

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Introduction

The ERDF project detailed a requirment for the scanning of an extensive area of 415 square kilometers employing an interferometric sonar. The process, though hampered by high wind and adverse sea conditions was completed as per contract requirements, yielding interesting new information of the bathymetric landscapes of the Maltese Islands.

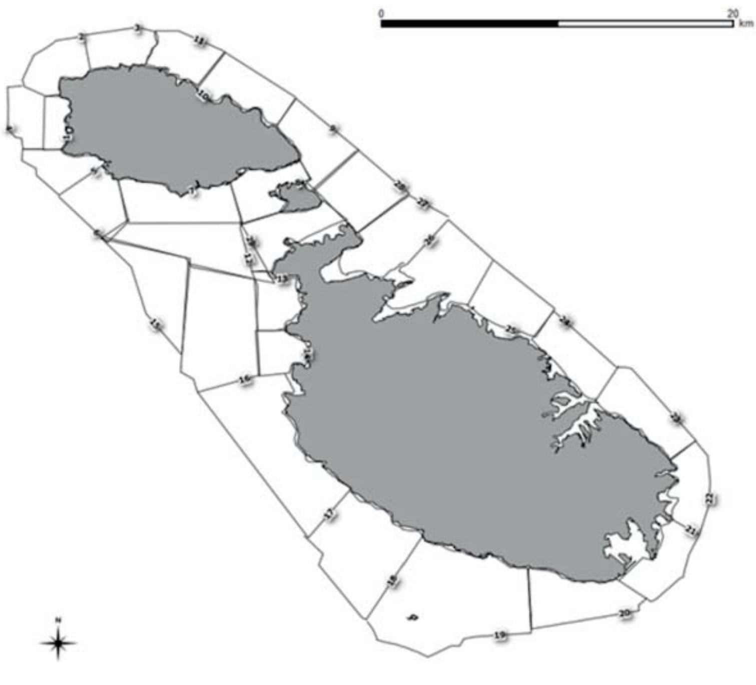
Materials and Methods

Survey designThe campaign for the bathymetric survey of the Maltese islands, carried out during the summers of 2012 and 2013, summed total area of about 415 square kilometres and covered depths between 15 and 200 m. The total survey area was divided into 28 survey blocks, laid out so each one was completed during a full day of work. This rule applied to all the blocks except for blocks 16 and 17 which were completed over the course of two days each. Each survey block was completed by running survey lines parallel to the blocks' longitudinal axis. During rough weather, lines were run parallel to predominant wave direction to minimise vessel roll. Line spacing ranged from 50 to 300 metres and was decided by a combination of the sensor's accuracy at increasing horizontal range, depth, seabed type and sea state. Crosslines were also run for each block, usually on the boundary, to allow for additional data checks between neighbouring blocks (Figure 1).

Acquisition sensor

The survey was performed with the use of a side pole-mounted SEA Swathplus-L interferometric sonar system (117 KHz). As interferometric sonar systems have demonstrated their potential for wide swath, high resolution seafloor mapping (Kraetuner et al., 2002) , the sensor was selected due to a combination of low-cost, portability and capacity to achieve the required IHO standards whilst offering wider horizontal range compared to multibeam echosounders, which translated in savings in terms of acquisition times and mobilization costs. The Swathplus-L is capable of achieving maximum horizontal ranges of 300m at 100m depths and depths up to 300m. With the sensor configuration used for this project, it was found that soft bottom sediments and sea states beyond force 3 reduced the sensor's horizontal range by around 20%. The sensor, according to the manufacturer, is capable of achieving IHO Special order at close range (up to 130 metres horizontal range at 100 metres depth) and IHO 1A at 170 metres horizontal tange at 100 metres depth. Subsequent orders are achieved at further range. The required IHO 1A standard was achieved throughout the survey.

Figure 1: Survey blocks



Auxiliary sensors

Bathymetry systems require the input from satellite positioning systems in order to geolocate each recorded sounding. In addition, vessel movement, which will have a direct influence over the direction of the sound pulses, must be recorded and offset against the each sonar ping. Finally, sound refraction through the water column due stratification must be accounted for. During this survey a Garmin differential GPS and a Hemisphere

Crescent vector differential GPS were used for positioning. Heading input was acquired from the position sensor's heading data strings. Vessel pitch, heave and roll were recorded using a SMC IMU-108 from ShipMotion limited mounted on the sonar head. Speed of sound profiles were recorded using a Valeport Mini SVP.

Vertical position and geoid

The bathymetric survey was acquired in WGS84 with soundings corrected to chart datum. Tide tables were recorded in real time inside the Grand Harbour in Valletta by Transport Malta and supplied during post-processing. Chart-datum corrected data was later merged with data from LiDAR and bathymetric LiDAR surveys undertaken during the project.

Patch tests

A total of five patch tests were carried out during the development of the project. The patch tests followed classic dual-transducer calibration procedures whereby:

- Five port/starboard overlapping lines were run to encounter and calibrate roll offsets. Roll offset lines where performed on areas of flat seabed.
- Two parallel lines running in opposite directions, preferably over sloping seabed were run to encounter and calibrate roll offsets.
- Two parallel lines running in the same direction and at speeds of 2 knots and 7 knots were over sloping seabed to encounter and calibrate timing error offsets
- Running several parallel lines close to a seabed feature were run to detect heading offsets.

Correction of offsets was performed using Swath Grid Processor, a gridding and calibration software provided by the sonar manufacturer offset values were input into the sonar acquisition software for surveying after the patch test.

Data processing

With SwathPLUS and other similar intereferometric sonars, data is processed in real time. During processing, speed of sound corrections and statistical filters are applied to eliminate outliers, backscatter noise and increase the overall accuracy of the soundings.

The statistical filters controls are managed on the computer interphase of the sonar acquisition software. Typically data is filtered for:

- Low amlitude: poor signals coming from the sound backscatter which either too distant or not valid.
- Slant range: which discards data from a given slant range value input by the operator.
- Phase confidence: SWATHplus calculates depths by looking at the phases of the

returning sonar signals at the transducers. The software uses several calculations to corroborate patters of phase response related to a particular angle of return. If the results from those calculations are not consistent, the sample is considered noise.
- Angle proximity: the angle values of a number of neighbouring samples are compared in the search for consistency.
- Median values: a filter which takes the median of a set number of samples gathered both at depth and horizontal range.
- Along-track consistency: the along track filter searches for consistency on the bathymetry as the boat moves forward. This filter looks for soundings that should "make sense" compare to recently recorded soundings. This filter is used carefully by the operator in areas with extreme underwater relief in Malta.

In addition, boresight and box (gate) filters were used at times to aggressively filter data during moments of strong external noise or to resolve extreme underwater relief manually.

Data post processing

Although real-time gathered data is useful to keep quality control underway and to ensure proper coverage, post processing was used off-site to review the data, eliminate further noise and outliers, add tide corrections and export the datasets to other file formats for further quality control. Data post processing was performed by reproducing the acquired datasets on the sonar's acquisition software and re-applying statistical filters to achieve the desired results.

Data types and formats

Data from the acquisition sensor was acquired on the sensor's proprietary formats (.sxr for unprocessed files, .sxp for processed files). Bathymetric data was exported onto gridded .xyz files for rapid mapping, survey progress checks, sensor calibration control and preliminary quality control. For final delivery, ungridded .xyza files (essentially a .xyz file containing an additional column for amplitude values) were created.

Interferometric sonar systems can also provide usable sidescan data in shallow waters, mostly due to their vessel-mounted configuration. Whenever needed, processed data was exported into sidescan .xtf for confirmation of underwater features of interest in shallow water.

Software

For data acquisition, post processing and export of ungridded data, Swath Processor from SEA was used. Generation of gridded data, grid analysis, sensor calibration and generation of raster datasets was achieved using Grid Processor, another software package delivered with the acquisition sensor by the manufacturer.

Survey planning was done using a combination of Hypack Office (www.hypack.com) and Quantum GIS (www.qgis.org). Hypack Office was used for plotting of survey blocks and survey lines whilst Quantum GIS was used for general mapping of the whole survey in both pre-acquisition and post-acquisition stages. Generation of other outputs such as sidescan mosaics, TIN models and gridded point cloud datasets were performed using Hypack Office.

Results

At the end of the survey, around two hundred survey lines were run, with additional lines used for calibration purposes, equipment testing or mapping of significant seabed features such as wrecks or underwater cliffs.

Figure 2 shows a typical low-resolution gridded raster dataset used for rapid mapping. Depending on the survey extents, grid bin size was set between 1 and 5 metres as bin size was limited by computing power. Smaller bin grid sizes were also used to develop higher definition datasets of features of interest.

Figure 2: Low resolution raster mosaic of East Malta (September, 2012). Raster datasets in this image were mosaiced in Hypack and later added as a raster layer in Quantum GIS, where they can be easily exported into other visualisation software such as Google Earth.

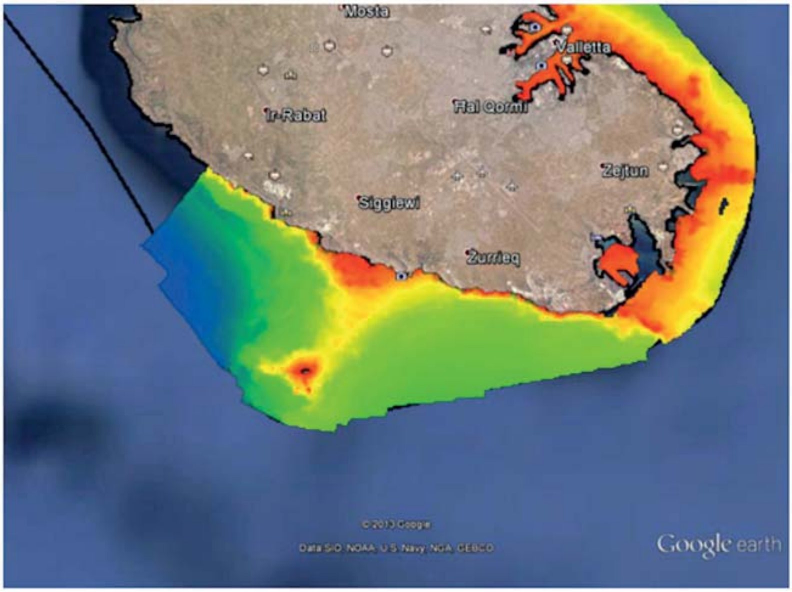
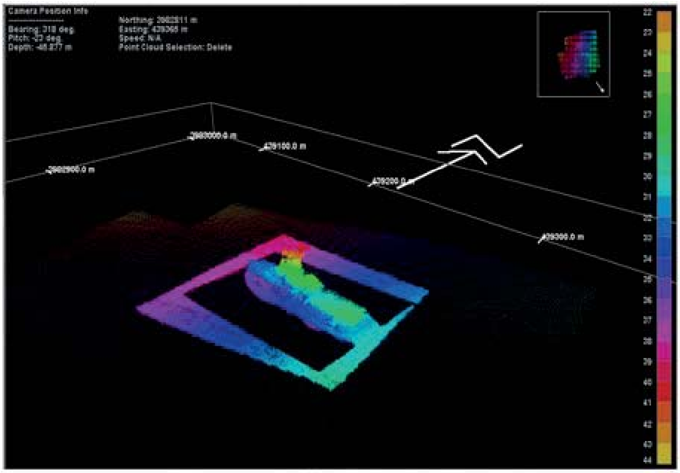
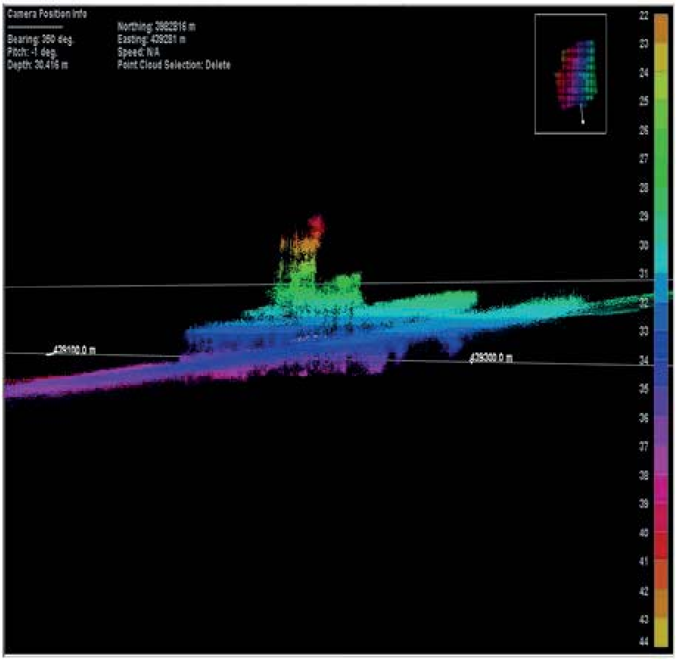


Figure 3a and 3b: The Rozi, a sunken tugboat used as an artifical reef off Cirkewwa (NW Malta). This 3D point cloud model was generated on a grid with a bin size of 80 cm.





Vertical uncertainty of the data recorded automatically by the acquisition software. This uncertainty was >1metre in most occasions. However, as interferometric wide swath sonars are essentially angle measuring instruments, it is expected that vertical uncertainties increase with horizontal range. Highest vertical uncertainties were recorded to be <2 metres at horizontal ranges between 170 and 250 metres operating in water depths beyond 150 metres.

Horizontal uncertainties are directly related to the performance of the position sensor and these were recorded to be sub-metre at all times.

Across-track coverage varied depending on the range of each sonar pulse (ping) which in turn was set up by the operator depending on sea state conditions, type of seabed, external electrical noise and water depth. Long ping ranges (>200m) resulted in across track coverage of <15 soundings per metre on every ping. On the contrary, across-track coverage was increased at shorter ping ranges. Ping ranges of <100m usually resulted in >40 soundings per metre per ping.

Along track coverage depends on vessel speed, ping repetition frequency and to a lesser extent, depth. In deeper water application (>150m) along track coverage was kept at an average of 3 metres. In shallower waters (<100m) where more coverage was required, along-track was kept, on average, at 0.5 metres.

Discussion

Interferometric wide swath sonar systems offer lower capital cost than multibeam echsounders (MBES) whilst keeping acceptable performance, especially in shallow waters. The capacity of these sensors to achieve longer horizontal ranges is translated into more survey coverage and therefore, lower operational cost.

The data produced by the sensor was able to achieve the standard for the survey after quality checks by the client, which included accuracy comparisons with bathymetric LiDAR data acquired during the course of the project carried out by Pelydryn in 2012. Interferometric sonar systems offer much higher across track resolution than beam forming sensors due to the nature of the acoustic footprint of a transmit pulse versus the acoustic footprint of a formed beam (Kraeutner et al, 2010).

However, with these types of sensors, it is known that acoustic noise and scattering of the sound pulses can increase the standard deviation between soundings and thus, the sensor's acquisition software relies on taking a large number of samples to reduce uncertainty to acceptable levels during the processing of the data. In his work, Gostnell (2004) , compares the performance of an interferometric sonar (GeoAcoustics GeoSwath) with two MBES (Reson 8125 and Simrad EM3002) and found that although standard deviations from GeoSwath were 3 to 5 times higher, a higher number of samples lead to girdded datasets of similar quality to those from the MBES.

This characteristic entitles that data accuracy also relies on the capacity of the user to perform the data processing appropriately, as the soundings are not processed by the hardware, as in the case of MBES.

Software-processed data gives the additional advantage of re-visiting acquired datasets in the case errors have been encountered during acquisition. Sensor misalignments, speed of sound profiles and tide data can be corrected post-acquisition (within a reasonable time window) with no major loss of quality. Re-visiting acquired data is also a useful tool for the operator to practice with filtering techniques that better adapt to each situation (rough weather, extreme underwater relief, detection of features).

Among the sensor's limitations, the high propensity to electrical noise was the main one. Careful arrangement of earthing wires and cable management was crucial in order to acquire data of acceptable quality. The system offers a maximum horizontal range of 300 metres and 100 metres of depth, for a total swath width of 600 metres. This performance was achieved in areas of sandy/rocky seabed (N coast of Malta) which offer a clear return of the sound pulses. Horizontal range was reduced at depths beyond 150 metres and significantly reduced (<200m) in areas of soft sediments at these depths (S coast of Malta).

Lastly, the pole-mounted nature of the system makes it prone to motion artefacts (especially roll). This will limit the use of the sensor in small vessels to Beaufort conditions of no more than force 3 and requires of careful weather observations and survey line planning to minimize vessel motion as much as possible. In general, although technically speaking the sensor can achieve depths of 300 metres, its suitability for small vessels of opportunity make this system a better performer in shallower, less exposed areas.

Conclusion

In conclusion, interferometric wide swath sonar systems provide an affordable option for mapping of large extensions of underwater territory. The simplicity of the systems make them a flexible tool for surveying on a wide variety of environments (harbours, open seas, coastal waters), albeit requiring careful attention by the user during all the surveying process. In this project, the sensor proved to reach IHO 1A accuracy requirements and provide bathymetric data of acceptable quality for the involved parties.

References

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