New Technologies For Near-shore Mapping

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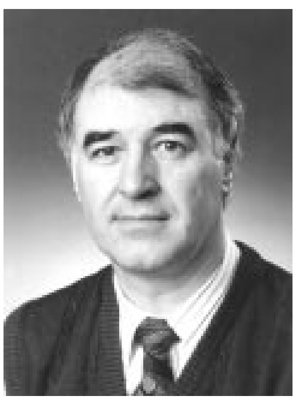

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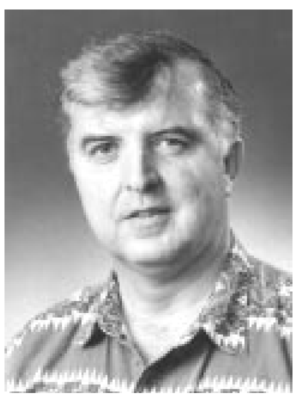

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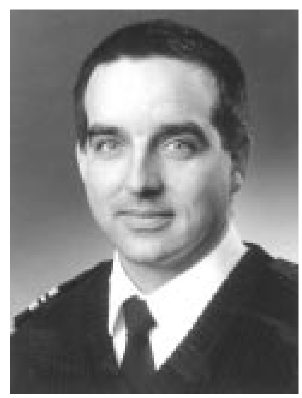

J. Bradford

Introduction

Recent improvements in acoustic transducer design and in digital signal processing have made wide-swath, multi-beam sonars (MBS) cost-effective for ocean mapping and for port and channel surveying with 100% bottom coverage. In addition, the geo-referenced, sidescan-like imagery and calibrated target-strength information from new MBS systems make them valuable for surficial geology mapping, bottom classification, and military applications, e.g., mine countermeasures.

Building on the work of the National Action Committee on Ocean Mapping (NACOM), and on recent MBS experience in larger vessels, the Canadian Hydographic Service (CHS) is planning to carry out port and corridor surveys, and near-shore mapping, using new MBS equipment on 10m launches; three are being fitted out. This approach will provide high-resolution data for chart production while being more economical and flexible than using large survey ships. The launches can be readily moved overland to a survey area and can operate with a crew of two. The launches can also be carried on a survey ship when required.

Multi-Beam Technology

Multi-beam echo sounders measure the slant-range travel time of a short acoustic pulse traveling from the sonar transducer to many points on the sea floor and back. The many slant ranges are simultaneously "sounded" across the ship's track on each acoustic ping (Fig. 1). CHS has been using first and second generation MBS systems (Simrad EM100 and EM1000) for a number of years on CSS *Matthew* and the NSC *Frederick G. Creed.* These 100kHz systems are useful in 20-500m of water, and their 100° and 150° swaths give moderate spatial resolution using 32 and 64 beams (~3° opening angle). Data from surveys carried out using these systems have produced detailed digital seafloor models for many hydrographic projects and geological investigations.

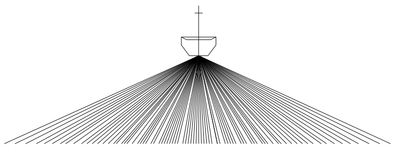

Figure 1: A typical multi-beam sonar coverage pattern

The new, third-generation Simrad EM3000 MBS now being commissioned by CHS, creates 127 separate sonar beams spanning a 120° sector which gives a sounding width about 3.5 times the water depth. Intended for water up to 75m deep, the EM3000 uses a 300kHz acoustic carrier, making the transducer (35cm diameter by 12cm high) suitable for use on a small boat. The 1.5° beam opening angle achieves high, along-track spatial resolution (~2.6% of slant range). Vertical resolution is on the order of 5-10cm.

The sounding density giving 100% bottom coverage is determined by vessel speed, beam opening angle and spacing, and ping rate. The latter depends on the two-way travel time of the outermost rays. For the EM3000 the upper limit is ~25 pings per second. This sets the maximum speed for full coverage at about 10 knots in water depths of 10m or more.

Attitude Measurement Issues. Acoustic refraction and the vessel's roll, pitch, heading and heave determine where the acoustic beams meet the sea floor. Just as in conventional surveys, factors such as tides, storm surges and vessel draft and settlement at speed are also important in MBS surveys. Position and heading are used to transform slant-ranges and ray angles into geo-referenced depths.

Accuracy standards (90% confidence level) for navigation chart depths are set by the International Hydrographic Organization: 30cm for water less than 30m deep, and 1% for deeper water. Depth accuracy for extreme, off-vertical beams is limited by errors in roll angle and sound velocity. When the error budget is allocated to all sources, the contribution from roll must be 0.08° rms or less for the EM3000, and 0.05° rms or less for the EM1000 with its wider swath.

CHS is using a new position and attitude sensor (Applied Analytics Corporation POS-MV 320) that combines two elements: a) a gyro-based, 6-degree-of-freedom, strap-down, inertial navigation sensor, and b) dual differential global positioning system (DGPS) receivers. These elements enable pitch, roll and heading angles to be measured to 0.05° rms regardless of how the vessel is being conned. Position is determined to 1m rms by blending the DGPS data (good long term accuracy) with the data from the inertial sensor (good short term accuracy) using a Kalman filter. Measurement bandwidth is 0 to 50 Hz. The combination of DGPS and inertial navigation enables the vessel position to be accurately established even during GPS outages lasting up to 1 minute.

Heave Measurement. In the conventional hydrographic sense, heave is vertical motion of the transducer relative to the average water level; it directly affects measured depths. Because of the wide frequency spectrum in the motion of the vessel and the water level, there are problems in accurately measuring heave and average water level.

POS-MV, like conventional attitude sensors, derives heave data by double integrating vertical acceleration (measured with respect to the earth's centre) and high-pass filtering the result. Filtering forces the measured heave to have zero mean-like the true heave-by removing the effects of initial conditions and zero-point drift in the electronics. However, whenever the heave spectrum has energy near or below the cutoff frequency of the filter (typically one cycle in five to ten minutes), there will be an unavoidable error in the heave measurement. This situation can occur because of oscillations in the survey area (seiches in partly enclosed bays), when operating in long-period, following seas with a fast vessel (e.g., the NSC *Frederick G. Creed*), and when the heave sensor's vertical position changes in steps due to (infrequent) changes in speed, transfer of ballast liquid, or movement of personnel (in small craft).

Normally, heave can be measured to 5 or 10cm rms, but heavy seas and the conditions noted above can increase the error to unacceptable levels. The error can be decreased by the use of DGPS in the 3-D, carrier-phase-tracking mode as long as on-the-fly (OTF) resolution of carrier phase ambiguity is possible. The height of the GPS antenna with respect to the earth ellipsoid (WGS-84) can be determined to about 3cm rms, or in real time, on post processing, thus eliminating the need for installing and maintaining temporary survey tide gauges. Tides, as well as seiche and heave effects, can all be resolved by DGPS-OTF. The approach requires spatial modeling of the present geoid-based chart datums with respect to the ellipsoid used by GPS. CHS is now using 3-D DGPS in the static mode for this modeling, and is examining the use of real-time-kinematic DGPS with OTF for multi-beam surveys.

Sound Velocity. With the phased-array beam-forming technique used in the EM3000, roll angle and the sound velocity at the transducer face control the take-off angles of the acoustic rays. The sound velocity profile (SVP) and Snell's law determine the ray paths through the water. Depth errors from typical SVP errors at non-zero roll angle are shown in Figure 2. The error budget allocated to refraction effects is typically less than 0.4% rms.

The basic accuracy (±0.3 m/s) of present-day SVP instruments is more than adequate to correct for refraction effects. But because the spatial and temporal variations in sound velocity can be ±20m/s or more over the survey area (due to solar heating, fresh water influx and tidal mixing), SVPs must be measured frequently. For the EM3000-equipped boats, CHS is evaluating a method of collecting SVP data while the launch is underway at 10 knots, by using a free-fall, sound-velocity probe and associated winch (being developed by Brooke Ocean Technology). The unit is a small-boat derivative of the larger, moving-vessel CTD (MVCTD) system developed earlier at Bedford Institute of Oceanography (BIO). It will serve to keep survey coverage rates high while giving good spatial and temporal resolution of sound velocity. (See essay by J.G. Dessureault in this Review.)

Hydrographic Impacts. Increasingly, the emphasis on navigational charting is towards site-specific, port and corridor surveys. This approach provides detailed data for the large scale charts needed by vessels entering, docking, departing, and transiting between ports.

For the past three years, CHS has utilized the Simrad EM100 and EM1000 MBS systems for corridor and harbour approach surveys, but still carried out much of its

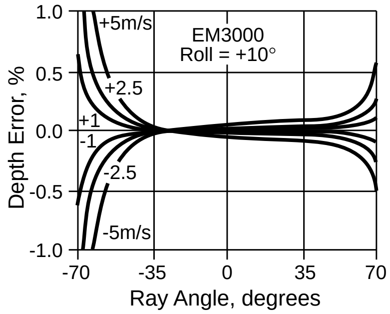

Figure 2: Depth errors at +10° roll angle for the SVP errors shown in Figure 3.

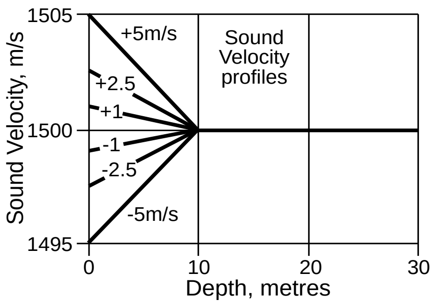

Figure 3: SVPs used in generating Figure 2. The measured SVP was erroneously taken as constant at 1500 m/s. Labels indicate surface sound velocity errors.

charting in ports and docking areas using conventional, single-beam echo sounders. In that methodology there is a risk that an obstruction or hazard will be missed between survey lines-and the task of examining shoals is time consuming. The Simrad EM3000 with POS-MV will enable these surveys to be completed more quickly, with 100% bottom coverage, and at a higher resolution and accuracy. In addition, the requirement for shoal examinations can be virtually removed, given sufficient redundant data. In areas previously surveyed using conventional echo sounders, only those sectors critical to safe navigation will require re-surveying using MBS to meet the needs of today's marine traffic.

Data Processing. The extremely high volume of data produced by the EM3000 (more than 100MB per hour in shallow water) poses a substantial data processing and management task. To date, all MBS data has been processed using the Universal Systems Limited (USL) Hydrographic Information Processing System (HIPS) and, to a much lesser extent, the Sidescan Information Processing System (SIPS). Although HIPS is functionally very powerful, and performs well for editing line soundings, position and attitude records, it is not optimized to deal with the dense data sets from the EM3000 that require interactive 3-D visualization for the rejection of outliers and for quality assurance.

A goal in MBS data processing is to process an hour of logged data in one hour or less; currently it takes several hours. To this end, CHS has recently evaluated "SEE-BED" data-editing and 3-D visualization software (Sirius Solutions Limited). The initial positive results have pointed to the desirable next step of achieving data-transfer compatibility between SEE-BED and HIPS. For the longer term, a National Working Group has been established to address the wider issues of efficient processing, archiving, and value-added re-use of MBS data by many disciplines.

Defense Applications

Navies look to route surveying to provide information on the parameters affecting mine warfare and mine countermeasures. As participants in NACOM, personnel from Maritime Command are working with CHS to examine issues and techniques related to MBS operations.

Acoustic Tag-Team. In mine countermeasures, a combination of complementary tools, techniques and data types is needed. The current technique partly involves identifying changes in "before-and-after", geo-referenced, seafloor images over a shipping route. For detecting objects the size of typical mines (see Figure 4), the vertical and sidescan imagery available from MBS is not always adequate. This is because the area of the insonified spot can be much larger than the target when the grazing angle of the beams with the sea floor is low enough to create good shadow images.

To obtain good sidescan data for route surveying, the angle of incidence should be less than ~45°. For reasons to do with power and refraction, the practice is to operate with the transducer near the sea floor in a towed body. In this mode, sidescan sonar has excellent across-track and along-track resolution. However, accurately geo-referencing the sidescan data to an accepted co-ordinate system (e.g., WGS-84) is complicated by the need to integrate towfish range and attitude with the attitude and the position of the ship, (from DGPS).

In this situation MBS can be a synergetic partner for towed sidescan sonar. The positional accuracy of salient sea floor features seen using a ship-based MBS can be an order of magnitude (1m rms vs. 10m rms) better than that from a towed sidescan. Using spatially-accurate MBS data, the registration errors of the towed-sidescan imagery can be corrected. By selecting many control points—bottom features common to both data sets—the sidescan imagery can be conformally distorted ("rubber sheeting"), so as to precisely align its features with those in the MBS data.

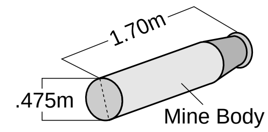

Figure 4: Dimensions of a MK36 air deployable ground mine.

High-Speed Sidescan Sonar. Simultaneous operation of towed sidescan sonar and multi-beam bathymetry systems has not been common due to a speed restriction of 2-3 knots imposed by the narrow beam-opening angle of the sidescan sonar. Current MBS systems can operate effectively at speeds of 10-16 knots. Now under development, a new generation sidescan sonar using five parallel beams operating simultaneously will overcome the speed limitation by giving a five-fold increase in towing speed. These sonars have their acoustic beams dynamically steered and focused to provide along-track and across-track resolutions down to ~12cm at ranges of 100m. As the beam pattern is designed for low-angle insonification, the blind area directly below the towfish requires interleaved data from adjacent survey lines for coverage. Real-time MBS data, collected in front by the tow vehicle, can be used to reduce the risk of the towfish colliding with the bottom.

Remote Mine Hunting. The logical follow on to an operational route survey capability is a mine hunting capability. Research and development are now focusing on mine hunting using the DOLPHIN semi-submersible survey vehicle, developed earlier for CHS. DOLPHIN, which has already been used in Canada and in the USA for multi-beam surveys using the EM100 and EM950 systems, will be used to tow a high-speed sidescan system and, potentially, to carry a MBS system. The new EM3000 is a candidate for inclusion in a remote mine hunting system.

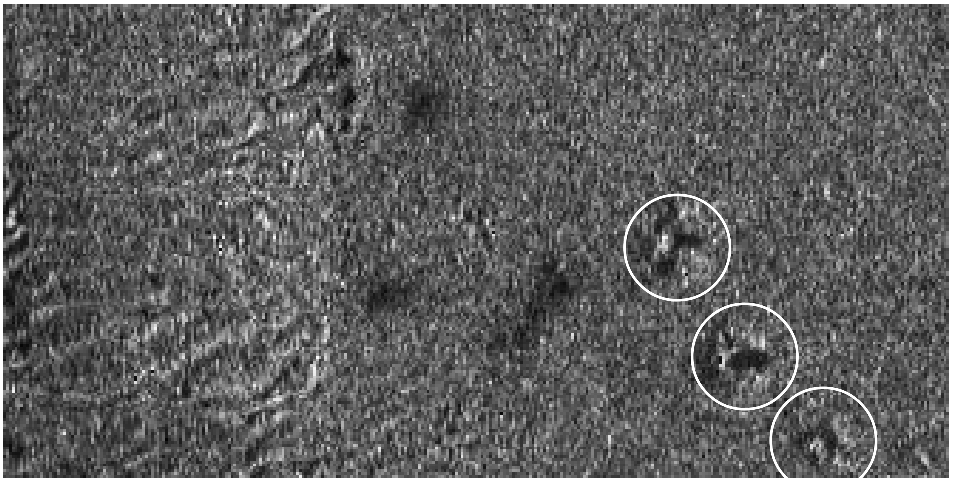

Figure 5: Segment of a sidescan sonar mosaic (30mx60m) showing three, one-metre objects at bottom right with acoustic shadows extending to the right.

Surficial Geology Uses

Multi-beam bathymetry and backscatter data provide exceptional mesoscale (100m to 1000m) information on the morphological and constitutive character of the seabed, essential for understanding its history and continuing evolution. At the Geological Survey of Canada Atlantic (GSCA), representative multi-beam data sets have now been processed from a wide range of geological environments on Canada's coastal zone. These data have been collected via Canadian Hydrographic surveys, GSC surveys on the east and west coasts and Department of Public Works activities in harbour and channel management. The data sets have been used over the past year to address short and longer term societal needs, ranging from cable route surveys, geo-hazard and seabed dumping assessments, seabed engineering studies and basic research on sediment transport in coastal embayments. This section will focus on one of these applications and the new insights derived from these activities.

Seafloor Subsidence. The GSC, in partnership with the Cape Breton Coal Development Corporation (DEVCO) and CANMET (an agency of Natural Resources Canada), have recently finished the second year of a two-year project to measure subsidence over a sub-seabed coal mine. DEVCO operates the Prince Mine, located about 3 km north of Point Aconi, Cape Breton, and they extract coal from the Hub seam positioned about 200m below the seabed. Layers of coal approximately 2m in height are removed in long narrow strips, or panels, that measure 160m in width and up to 3km in length. This coal is extracted primarily to fuel a new fluidized coal-fired power plant located nearby on Point Aconi.

As coal is removed from the panel, the 200m or so of rock above the workings collapses and the stresses associated with the collapse are transmitted to the seabed. The deformation of the seabed over the panels can be used to quantify the mechanical properties of the overlying roof rock, prerequisite information for optimizing mine operations. Before this study, the subsidence over the centre of the Point Aconi mined panels was predicted by mine geologists to be as large as 1.5m.

The objective of the two year study was to measure the temporal change in the bottom depth over the mine workings in order to ascertain seabed subsidence over new panels and, also, to study the infilling of older, pre-existing subsidence troughs. Detailed bathymetry was first measured over the panels in the summer of 1994 using a Simrad EM1000 multi-beam system operated from the Hydrographic swath vessel NSC *Frederick G. Creed.* A shaded relief image of the 1994 multi-beam data over the workings is shown in Figure 6 along with a companion image overlain with the plan of the workings. The subsidence troughs can be clearly seen at the centre of the panels in the western side of mine (north is at the top). The estimates of panel subsidence taken from the 1994 survey ranged from 1.0m to 1.5m at the centre of each trough. A collapse of the seabed was detected directly over the active working face of the mine (the eastern end of the northernmost trough). It was thought previously that the seabed collapses gradually over a year or two, after the coal has been removed, reflecting gradual deformation in the rock above the workings. The process is now viewed as one of immediate brittle failure, an important piece of information in mine design.

A second survey was conducted over the workings in 1995 with the *Creed* to measure the net subsidence above new workings over a one year period. The analysis of the second year's data set is currently nearing completion. Preliminary results show that water column sound refraction effects are now the most important source of error limiting the accuracy of the multi-beam depth data. Research conducted at the GSCA into the statistical signature of the refraction error has suggested that, with careful analysis, the repeat accuracy of the data from MB surveying systems can be reduced to 10cm to 15cm for water depths up to 50m, some three times better than the standard set by the International Hydrographic Organization. The results of this study will be released in the spring of 1996.

Conclusion

Multi-beam sonars are making a significant impact on nautical charting operations, mine countermeasures work, and marine geology investigations. New research and development activities are being driven by user demands, and current projects are focused on work in the coastal zone where delineation of seafloor features, both natural and man made, is important for navigation safety, for the Canadian military, and for commercial operations.

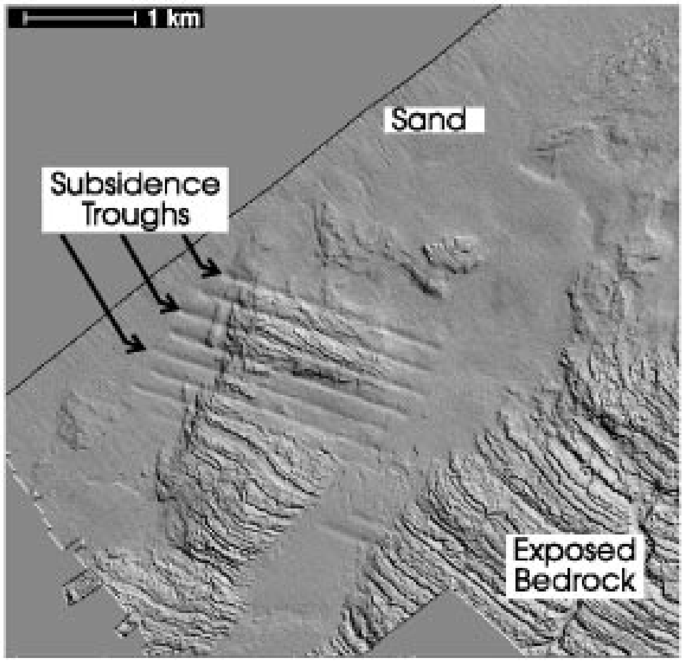

Figure 6: A shaded relief image of the seabed over the Prince Mine, derived from EM1000 multi-beam data collected in the summer of 1994 using the NSC Fredrick G. Creed. *The image shows subsidence troughs that have formed over directly over collapsed mine panels lying 200m below the seabed. The image was calculated from the data using a vertical exaggeration of 10 with the illumination shining from the northeast.*