Meeting the Challenges of the IHO and LINZ Special Order Object Detection Requirements

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Abstract

The problem of detecting objects on the seabed according to the IHO S44 Special Order survey requirements, i.e. detection of a 1m³ cube reliably, has until now not been seriously addressed by equipment manufacturers. Using the LINZ definition of the IHO requirement of a minimum sounding boresight spacing of 0.5 m, the top resolution multibeam echo sounders today are only able to achieve this to depths of about 25 m and with a coverage limited to not more than four times water depth. At larger depths the coverage and furthermore vessel speed must be severely restricted, and thus the costs of meeting object detection requirements in all navigable waters (say to 40 m depth) become very high.

A normal commercial multibeam survey would be expected to use an angular coverage of about 140 degrees at a vessel speed of 8-10 knots. Meeting Special Order object detection requirements at 40 m water depth then implies 400 soundings per swath. In addition, due to ping rate restrictions, it is necessary to derive at least two swaths per ping to meet the sounding density requirement alongtrack. The beamwidth alongtrack must be sufficiently small, 0.5 degrees, to ensure that the soundings actually detect any objects at 40 m depth. Acrosstrack the detection window length must be limited to less than 1 m in range, corresponding to an angular span of less than 0.2 degrees.

A new Kongsberg multibeam echo sounder, the EM 710, that will meet the above requirements, is now being prepared for sea trials. It is a wide-band system operating in the 70-100 kHz range allowing multi-sector transmissions and two swaths per ping. Near-field focussing is applied both on transmit and receive to retain angular resolution in shallow waters. A detailed description of the EM 710 is given in the paper.

Introduction

The latest revision of the IHO S44 standard for hydrographic surveys was approved in 1998. Its applicability is mainly to surveys intended to provide data for safe navigation, i.e. for waters not much deeper than 40 m. For critical areas, the survey must meet Special Order requirements, which will be the subject of this paper.

The Special Order depth accuracy requirement is a reduced depth accuracy with a 95% confidence level given by:

\[ \pm \sqrt{0.25^2 + 0.0075^2 D^2} \]  

(where D is depth in meters)

The term reduced depth implies that tidal and data processing errors are also to be included. Assuming that the errors have a Gaussian distribution, this translates to a depth
accuracy of 0.13 m RMS in shallow water (less than about 15 m), increasing gradually to 0.4 m RMS at a depth of 40 meters. If all error sources are independent, the total error may be derived by summing them in a root squared fashion. Thus for example with four main error sources of equal magnitude, the individual accuracy requirement is 6 cm RMS at shallow depths.

With modern high-performance multibeam echo sounders intended for shallow water use, meeting the Special Order depth accuracy is readily achievable. However, it should be noted that high-performance auxiliary sensors for determining vessel motion and position, water column sound speed profile, and sea level datum will have to be employed, and that it is essential to properly align and accurately calibrate all sensors. The main limitation in meeting the depth accuracy requirement is the vertical, and a fundamental limitation at present is the accuracy of the real-time heave measurements. Existing heave sensors only have an accuracy of 5 cm RMS, thus it makes little sense to require any of the other sensors to have better accuracy. This may of course change when and if the use of kinematic GPS can replace today’s heave sensors.

Object detection

Completely new in the latest IHO S44 specification was the requirement for detection of cubic features with dimensions larger than 1m. The intention is of course to ensure that there is nothing on the bottom for any ship to touch, but unfortunately no further clarification on what detection capability meant was given in the specification. Thus it is not known to what confidence level detections are to be obtained, to what accuracy their depths are to be measured, nor the minimum dimensions of non-cubic objects which presumably should also be detected.

Object detection has historically been the task of sidescan sonars, and the S44 indicates that it may be necessary to use sidescan to detect thin obstacles. The problem with sidescan for object detection is that one then mainly relies upon its shadow detection capability, which is only applicable at sufficiently low grazing angles. To achieve a low grazing angle requires the altitude of the sidescan transducers to be low enough, hence the need for a sidescan towfish with all the practical problems this incurs. And finally one should bear in mind that there will be a significant dead-zone with sidescan along the center of the survey line where the grazing angle is too large. Nevertheless, several hydrographic institutions do specify sidescan as their primary object detection tool, but characteristic of these institutions is that their sea bottoms are mostly flat and hence offer a benign environment for sidescan and shadow detection of objects.

Most modern shallow water multibeam echo sounders also have the capability of acquiring seabottom backscatter data with high range resolution similar to a sidescan. However, because of the multibeam’s relatively high angle of incidence this data is not usable for shadow detection. Furthermore, an object’s contrast in backscatter with respect to the bottom is often such that this data cannot be used for reliable object detection (this observation is also valid for sidescan at high grazing angles). However, backscatter information may be very useful in the quality control of the bottom detections of a
multibeam echo sounder, and is thus an important part of the data output of a multibeam echo sounder.

A discussion and proposal for how to utilize a multibeam’s bottom detections to meet the S44 Special Order object detection requirement, has been provided by John Hughes Clarke\(^1\). His recommendations have been implemented in the latest survey specifications of LINZ (Land Information New Zealand). The recommendation is mainly a specification of the required density of the soundings, i.e. requiring “a minimum of three along track and three across track strikes on a target of specified size”. Probably recognizing that while crosstrack density is easy(?) to achieve by having enough beams, LINZ adds that “the centre-to-centre distance of each ping should be no more than half the required target dimensions apart”.

What is lacking from both the IHO S44 and LINZ specifications and barely touched upon by John Hughes Clarke is a requirement for bottom detection capability, i.e. even a density of soundings according to LINZ, does not guarantee that objects will be detected. This is a matter of both the observability of some response from an object as a deviation in depth on a shallow bottom, and the capability of providing a reasonable correct depth on the object in a sufficient number of soundings hitting it.

Bottom detection in a multibeam echo sounder is usually done in two ways, either based on the amplitude variation in the range samples within a beam on near-nadir beams, or on the split-beam phase variation over a number of range samples at larger beam pointing angles. It is important to note that all the bottom detection processing is done on sampling acrosstrack within a very short distance determined by the pulse length, but that since no processing is done alongtrack, what determines a sample value is the alongtrack characteristics of the bottom or on any object on it. This implies that to ensure detection on an object within a high confidence level, the alongtrack footprint as determined by the multibeam’s transmit beamwidth, must be small enough for the object to dominate. The same observation could be made for the acrosstrack beamwidth, usually the receiver’s, but it should be recognized that it is really the length of the range window used in the detection process that determines the part of the bottom used in bottom detection, and this may be shorter than that covered by the whole beam. As a rule of thumb, we would propose that the alongtrack beamwidth and the effective detection length acrosstrack, should be not larger than say twice the dimensions of an object for it to be reliably detected. As more than one detection per object is required for it to be retained in normal post-processing, it is our opinion that this rule of thumb together with the LINZ specified sounding density, requires a maximum detection footprint of 1 by 1 meter.

A normal commercial multibeam survey would be expected to use a coverage of about 140 degrees at a vessel speed of about eight knots. Meeting Special Order object detection requirements with the LINZ specification then requires say 400 soundings per swath. At the largest beam pointing angle the above detectability criteria of a detection range window of a little less than 1 m is equivalent to an angular span of 0.17 degrees.

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\(^1\) See his home page http://www.omg.unb.ca/~jhc/ and also http://www.omg.unb.ca/omg/omg-papers.html for relevant background material.
Alongtrack the requirement is for a beamwidth of 0.5 degrees at the maximum beam pointing angle. In addition it is necessary to derive at least two swaths per ping to meet the sounding density requirement alongtrack, since the ping rate is limited to only one ping per meter at the maximum range with 140 degree angular coverage at a vessel speed of 8 knots.

**The Kongsberg EM 710 Multibeam Echo Sounder**

A new Kongsberg multibeam echo sounder, the EM 710, which has been designed to meet the IHO S44 and LINZ Special Order requirements of sounding density and detection capability as described above, is now undergoing sea trials and will be operational by the middle of this year.

The EM 710 multibeam echo sounder is a high to very high resolution seabed mapping system capable of meeting all relevant survey standards. The system configuration can be tailored to the user requirements, allowing for choice of beamwidths as well as transmission modes. The minimum acquisition depth is from less than 3 m below its transducers, and the maximum acquisition depth is up to 2000 m. Acrosstrack coverage (swath width) is up to 5.5 times water depth or 140 degrees to a maximum of more than 2000 m. The sounding density is very high, allowing even the very demanding LINZ special order survey specification for object detection to be met in full.

The EM 710 operates at sonar frequencies in the 70 to 100 kHz range. The transmit fan is divided into three sectors across to maximize range capability but also to suppress interference from multiples of any strong bottom echoes at or near nadir. The sectors are transmitted sequentially within each ping, and have distinct frequencies or waveforms. Both CW pulses of different lengths and even longer, compressible waveforms (chirps) are utilized. The alongtrack beamwidth depends upon the chosen transducer configuration with 0.5, 1 and 2º available as standard. Focusing is applied individually to each transmit sector to retain the angular resolution in the near field. A ping rate of up to 25 per second is possible. The transmit fan is electronically stabilized for roll, pitch and yaw.

The EM 710 has a receive beamwidth of either 1 or 2º depending on the chosen receive transducer. The number of beams is 256 or 128 respectively, with dynamic focusing employed in the near-field. A high density beam processing mode provides up to 400 or 200 soundings per swath by using a limited range window for the detections, which in practice is equivalent to synthetically sharpening the beamwidth. With a 0.5º transmit and 1º receive transducer the system will be able to generate two separate alongtrack swaths per ping. The system produces up to 800 soundings per ping in this mode.

The beamspacing may be set to be either equiangular or equidistant. The receive beams are electronically roll stabilized. The coverage may be limited by the operator either in angle or in swath width without reducing the number of beams. A combination phase and amplitude bottom detection algorithm is used, in order to provide soundings with the best possible accuracy across the entire swath. Integrated seabed acoustical imaging capability
is included as standard. A real time display window for water column backscatter is available. Logging of water column data and also of raw stave data (before beamforming) is a system option.

The 2 by 2° EM 710 model has an excellent accuracy, better than 10 cm RMS or 0.25% of depth (whichever is greater) as a mean across the swath. It will thus easily meet IHO S44 Order 1 accuracy and object detection requirements, but also with very good control over external sensors, Special Order accuracy can also be maintained over most of the relevant depth and coverage ranges. 100% coverage is achievable at survey speeds up to about 10 knots.

The 1 by 2° EM 710 model has a better range and depth capability than the 2 by 2° model. Alongtrack resolution is improved by a factor of two. This has a significant effect with respect to improved resolvability, giving much better seabed image quality and object detection capability. The IHO S44 Special Order object detection requirements, even with the restrictions imposed by LINZ, are thus met to a depth of about 20 m at survey speeds up to 8 knots. Accuracy is also improved so that it is easier to uphold the Special Order requirements than with a 2 by 2° model.

The 1 by 1 ° EM 710 model has an accuracy approaching a mean of 5 cm RMS or 0.15% of depth (whichever is largest) across the swath. Thus the requirements for IHO S44 Special Order should be easy to meet without any undue requirements to other sensors. Special Order object detection requirements are met to 25 m depth at up to 8 knots survey speed even with the LINZ requirements. By reducing the survey speed and/or angular coverage, they can be met to a depth of 40 m or so.

The 0.5 by 1° EM 710 model represents the utmost in multibeam capability with regards to accuracy and resolvability. IHO S44 Special Order accuracy and object detection requirements are fulfilled to a depth of about 50 m within the full coverage capability of the system. The strictest LINZ requirement for sounding density of 0.5 m both along and across is achieved in this depth range up to a survey speed of about 8 knots. This is achieved by acquiring two swaths per ping with each having about 400 soundings.

The depth capability of the EM 710 extends to about 2000 m with the 0.5 by 1° model. The transmit signal is then a pulse compressible signal (chirp) with a duration of up to 200 ms and a bandwidth of 500 Hz. With a 2 ms long CW pulse the depth capability will be in the order of 1000 m. With the highest resolution, which is achieved with a pulse length of 0.15 ms, 140° coverage is achievable to more than 100 m (depending on the model).

**EM 710 system characteristics**

The basic EM 710 multibeam echo sounder has four main units (see figure 1):

- Transmit Transducer
- Receive Transducer
- Transceiver Unit
- Operator Station
The EM 710 transducers are fully water tight units intended for many years of trouble-free operation in rough seas. The transmit and receive transducers both have a width of 224 mm and a height of 118 mm. Their length depends upon the chosen beamwidth, either 970 mm for a 1º unit or 490 mm for a 2º unit. The weights are respectively 35 and 18 kg (excluding cables). The transducers have a maximum depth rating of 250 m.

A transmit beamwidth of 0.5º is achieved by mounting two 970 mm transmit transducers together alongship. The transducers are supplied as standard with 15 m long underwater cables terminated with a surface connector directly pluggable into the Transceiver Unit.
Special underwater connectors or longer cables may be supplied upon request. Five or ten cables are used on the transmit transducer, two or four on the receive transducer, in accordance with the transducer length.

The EM 710 Transceiver Unit contains all transmit and receive electronics, and the Processing Unit which performs the beamforming, bottom detection, and motion and sound speed corrections. It contains all interfaces for time-critical external sensors such as vessel attitude (roll, pitch, heading and heave), vessel position and external clock. More than one sensor of each type may be connected simultaneously, with one in use but all logged. The Transceiver Unit comprises two 19" sub-racks contained in a cabinet designed for bulkhead or deck mounting. The number of circuit boards will depend upon the chosen transducer configuration. Twisted pair Ethernet is used for data communication with the Operator Station.

The Operator Station of the EM 710 is a high performance dual-processor PC workstation. The standard operator software is the Seafloor Information System (SIS) which comes under both Linux® and Microsoft Windows XP®. As standard, the system software includes the necessary features for system installation, testing and running the multibeam, ping related displays (including water column display) and the capability of logging the acquired bathymetry data.

The EM 710 system does not require operator intervention during normal operation, but tracks the bottom automatically while adjusting mode, gain and range dependent parameters as required. Before operation is started, the necessary external sensors, such as positioning and vessel motion sensors, are connected and calibration procedures followed in order to define the system and sensor installation parameters. In real-time the range/angle data are merged with motion sensor data and the current sound velocity profile to derive a rigorous solution for vessel motion and raybending, calculating sounding depths and positions in Cartesian coordinates relative to sea surface and vessel heading.

Quality control of the acquired data is done through graphical displays. In addition a message window and alphanumeric displays are included to allow a quick overview of the system status, indicating any interface or hardware related problems. SIS provides the graphical displays required for real-time checking of the EM 710. These include (see figure 2):

- Cross-track depth profiles
- Beam intensities and quality measures
- Time series display of beam samples and sensor values
- 3D waterfall display
- Sound speed profile display and editor
- Water column display
Figure 2 - SIS graphical user interface from early EM 710 testing

Using the SIS software, the operator will normally be viewing gridded data in a geographically oriented 2D or 3D display as his primary means of quality control of the survey. The grid has six levels of detail, allowing rapid zoom in and out. Previous survey results can be imported to allow visualization of any differences between the current and old surveys in overlapping areas. The grid may also be utilized for real-time data cleaning. Based upon a set of user defined rules, outliers in a grid cell, whether from old or new survey lines, are flagged. The flags may be retained or updated through the processing. Optionally the CUBE data-cleaning package from the Center for Coastal and Ocean Mapping Center at the University of New Hampshire is also available in SIS.

Among other features included in SIS are:
- System (sensor) calibration
- Planning of surveys
- Helmsman Display
- Full use of the chosen operating system for data export, plotting and printing

Electronic chart data can be displayed as a background in the geographical displays. While SIS is the standard solution for operator software, the system is prepared for support of third party software solutions. Such software, for example Hypack, may be used as a complement to SIS or as a replacement for SIS.
It is of the utmost importance to ensure that all survey related data is logged in a safe way. The data is always stored on disk and the geographical displays take data only from disk. In this way, what the operator sees is what is safeguarded and already stored. As standard the operator station runs two high performance SerialATA disks connected in a RAID1 array, i.e. one disk may fail without loss of data. The disks are mounted in mobile storage bays, thus they may be removed for security reasons or for transporting the acquired data. The stored data may be written to DVD at any time. Firewire, SCSI and USB interfaces may be used for transfer of data to external storage devices, such as disk or tape, according to user preferences. All data are also available on an external Ethernet. The logged data sets include:

- Raw sensor data
- Beam ranges and beam pointing angles
- Depth datagrams
- Seabed image data
- System parameter settings

The gridded data (terrain model) is also available for logging. The data formats are public and published on the Kongsberg Maritime web site, ensuring that the EM 710 is a truly open solution, allowing third party or own software to be developed for data processing.