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Small-Boat Surveys in Shallow Water

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Abstract

The Canadian Hydrographic Service (CHS) has for many years used small boats (launches) to conduct surveys in shallow water for the purpose of nautical charting. Prior to WW II, soundings would have been taken by leadline, providing depths and often some limited information about the seafloor type at each sample. For about the next half-century, soundings were acquired by single-beam echosounder, which evolved from wide-beam analogue equipment to modern digital narrow-beam sounders with capacity for classification of the returning acoustic pulse. Seabed samples (for charting purposes) were acquired in a separate operation involving either an armed leadline or grab samplers deployed using a winch. Sidescan sonars evolved from an oblique-looking single-beam transducer to modern high-resolution systems of today.

In the last decade, most shallow-water surveys have been conducted using multibeam echosounder systems (MBES); for practical reasons we limit the minimum operational depths to about 10 meters. Bathymetric (phase-measuring) sidescan sonars (BSSS) may allow us to look from this operational depth limit into the shoreline. For the moment, however, the way we collect bathymetry using these modern tools is leaving a gap between the low-water line and the adjacent survey data. More and more, the data acquired are being used not for navigational safety but for myriad other applications.

This paper considers some of the operational issues of acquiring high-resolution bathymetry and acoustic backscatter information in shallow water aboard hydrographic launches.

Introduction

This paper looks at the requirements of hydrographic offices for data collection in shallow water to support safe and efficient marine commerce and tourism. The types of sensors used require wide and varied methods of installation. The types of vessels used have an influence on the methods that can be used. Operational issues further complicate and limit how and where sensors can be deployed most effectively. There are several considerations for platform type beyond just sensor installation. All of these issues and more are discussed below.

Figure 1. Swinging the lead. Note two gentlemen near the stern, each with a sextant and a notekeeper just ahead of them. Source: NOAA Photo Library.

Background—nautical charting requirements

International standards, published by the International Hydrographic Organization (IHO) obligate hydrographic offices (HO) such as CHS to collect accurate bathymetry (depth information) and other data commensurate with that collected in other countries. These standards provide mariners with uniform expectations of data quality on paper charts and electronic navigation charts (ENC) regardless of the source agency. Other than depth soundings, mariners want to know the seafloor type, the shape and nature of the foreshore, and the location and characteristics of navigational aids (buoys, ranges, lights, etc.) and tides and currents. For a complete list the interested reader should refer to IHO publications M-13 (the Manual on Hydrography), and S-44 (IHO Standards for Hydrographic Surveys) (see Appendix for Web links).

Soundings

The legacy of all HO is the leadline survey—depths obtained from a weight suspended on a rope typically marked at fathom increments. Up until the 1950s, positions were generally obtained by two simultaneous sextant angles to fixed points on shore (Fig. 1). Since then, a steady evolution of radio-frequency and light-wave positioning systems have led us to GPS and DGPS, readily available today at very low cost, that provide reliable positions that meet or exceed all but the most demanding positioning requirements.

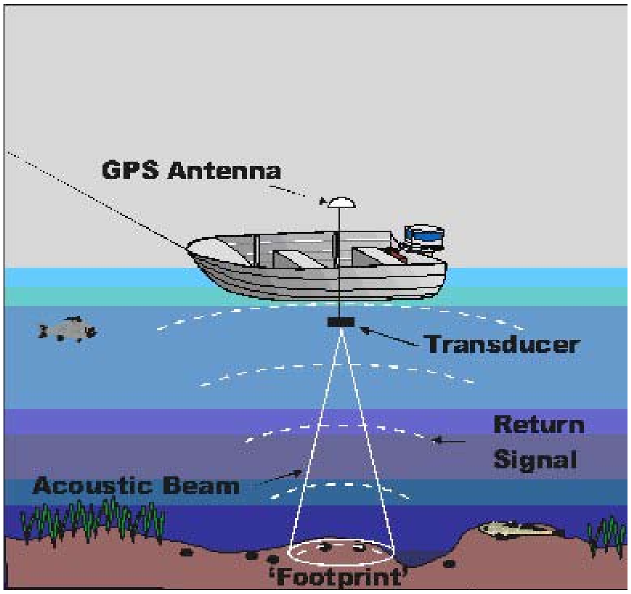

Figure 2. **Single-beam echosounder (SBES). ©Commonwealth of Australia (Geoscience Australia) 2005.**

Figure 4. **Multibeam echosounder (MBES).**

Figure 3. **FCG Smith Sweep vessel (33 SBES transducers). Source: Canadian Hydrographic Service.**

Since the 1930s, single-beam echosounders (SBES) have gradually superseded the leadline, starting with fully analogue wide-beam sounders and evolving into the fully digital display narrow beam echosounders of today (Fig. 2).

In the mid-1970s, SBES evolved into Sweep systems, where multiple transducers were placed at equal spacing along booms and in the hull(s) mounted athwartships to the vessel (Fig. 3).

These, of course, are being gradually supplanted by modern high-resolution multibeam sonars that provide a very detailed picture of the entire seafloor, within certain depth and operational limits (Fig. 4). In very shallow waters, airborne bathymetric LIDAR systems are proving very efficient and sufficiently accurate for nautical charting provided the water is sufficiently clear (nominally 2.5 times the depth at which a Secchi disk can be observed from the water surface) for the light waves to penetrate (Guenther et al. 2000). Phase-measuring BSSS also hold great potential for full coverage depth measurement up to the shoreline in waters too turbid for LIDAR to penetrate (Gostnell et al. 2006).

For most of these remote sensing systems, objects in the water column, such as weeds, eelgrass, kelp, fish, and other biota, air bubbles, etc., can cause spurious reflections that result in an incorrect measurement of the true depth of the seafloor. Sediment type plays a role in the detection capabilities of sonars and LIDAR systems, e.g., Hughes Clarke (1998) and Longenecker and Van Den Ameele (2002).

There is a big reason that high-resolution and high-density sonars (MBES and BSSS) are so valuable: more depth measurements means more redundancy and hence allows statistical and automated detection and removal of artifacts in the data. Control of systematic errors and accidental errors is made far easier through visualization techniques, and automated and interactive quality control software and methods. Redundant depths also allow us to control the growth of random error contributions, which results in greatly improved depth data for nautical charting.

There is another reason that MBES and BSSS are valuable tools in the hydrographer's tool kit: many high-resolution beams greatly increase the likelihood of detecting small seafloor targets. This is another requirement of international standards for hydrographic surveys. When SBES surveys were the norm, the only way to ensure all targets

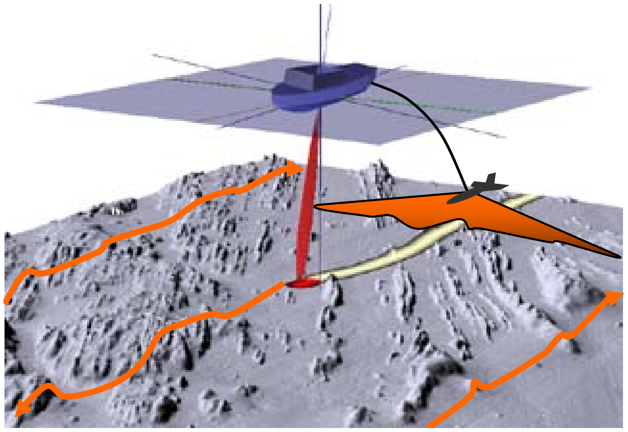

Figure 5. Towed SSS. Credit: J. Hughes Clarke, Ocean Mapping Group, University of New Brunswick.

Figure 6. Ponar grab sampler. ©www.wildco.com.

were detected, especially between the sounding lines, was by using towed sidescan sonar (SSS) (Fig. 5). These sonars also evolved from fully analogue units displaying backscatter time series on a paper trace, to fully digital units logging vast amounts of data to various storage media. While SSS provides the full seafloor picture, it lacks the precise depth and location information needed for charting, and operating alone it does not meet international hydrographic survey standards.

Bottom samples

Leadline surveys allowed us to collect a small sample of the seafloor with each sounding measurement. When SBES were introduced, seafloor sampling was conducted as a separate operation using either a leadline or some form of grab sampler (Fig. 6) on a regularly spaced grid. In recent years, various methods of classifying the seafloor based on the strength of the returning acoustic pulse (MBES, BSSS, SBES, and SSS) and some other physical parameters have been employed. These methods have, to date, required some form of groundtruth in order to associate a particular acoustic class with a well-defined seafloor type. These associations can be useful for both charting and habitat mapping, e.g., Galloway (2001).

Low-water line and foreshore type

The foreshore is that area of land between the high and low water line that is, at high tide, completely covered by water. At some point, the depth becomes zero—at the low-water line (sounding datum). Mariners need to know where the shore is for visual position reference and also what it is made of in the unlikely event that they have to beach their vessel. This information is generally collected by a combination of aerial imagery and on-the-ground (from a launch) observations—verification of correct interpretation of the imagery—and nearshore or drying soundings, when available. Foreshore type is determined by direct observation during low tide periods. High-water line is similarly important for mariners, but is also useful for inundation (due to tsunami or storm surge) mapping.

Navigational aids

While the Canadian Coast Guard is responsible for the bulk of navigational aids in Canadian waters, CHS verifies the correct (charted) position of lights, buoys (Fig. 7), and ranges and their characteristics while conducting survey operations in the area. This work is typically done from small boats, which allow a hydrographer to scramble ashore, or allow the coxswain to get the positioning system antenna close to the actual buoy position. Range line azimuths are usually confirmed by drifting across the range line at various distances from the Front Range and then plotting a best-fitting straight line through the points collected along the range. This operation is also best performed by a small boat.

Acoustic sensor installations

There are numerous ways to mount acoustic sensors on a small boat:

- Inside the hull.
- Flush mounted (using an acoustically transparent window).
- Fairings, blisters and pods.
- Hidden (moon pool).
  - Mechanical ram draws it back into the hull.
  - Requires transducer protection when deployed.
- Prone (possibly requiring debris cutters).
- Portable.
  - Over-the-bow mount.
  - Over-the-side mount.

Each has its advantages and disadvantages as discussed below.

Figure 7. Floating navigational aid (buoy). Source: www.sailingusa.

Figure 8. Examples of fairing and prone transducer mounts. Credit: G. Noll, NOAA.

Transducer mounting issues

Inside-hull installations may be faced with space constraints in the bilge of the vessel. In order to ensure the transducer is aimed vertically, some form of mounting guide will be needed for alignment. Oil-filled transducer wells are one way to ensure there is good acoustic propagation through the hull without the presence of air bubbles. The advantages of mounting inside the hull are usually the ease of access for repair or replacement and no need for holes in the hull. The main disadvantage can be the attenuation of the acoustic signal transmitting through the hull.

Flush-mounting a transducer can reduce the attenuation caused by transmitting and receiving an acoustic signal through the hull. It may require the installation of an acoustically transparent window, or a fairing around the transducer and water tight seal through which to run the cabling. Figure 9 shows an example of flush mounting in the keel, with a fairing to assist in diverting air bubbles and to create laminar flow along the keel. The cables go into the hull through a watertight gland.

Transducers can also be mounted prone from the hull as shown in Fig. 8 and Fig. 9. Usually some sort of fairing around the transducer ensures laminar flow and may also provide protection against damage cause by debris rolling under the hull, such as logs (cylindrical transducer in Fig. 9). The advantage of these installations comes in getting the transducer below the hull where there are fewer bubbles to wash across the transducer face. The obvious disadvantage is that they could be more easily wiped off the hull by shallow hazards or partially submerged debris. Lower cost forward-looking sonars (one is shown in Fig. 9) can be mounted forward of the expensive transducers as a way of mitigating the risks posed by underwater hazards. These installations still require through-hull watertight glands for the cable runs. Debris cutters may also be needed to avoid kelp, floating ropes, and nets from getting hung up on the transducer, as shown in Fig. 9 (lower right corner on leading and trailing edges of the sidescan transducer stave). Caution should be taken to avoid objects protruding forward of the active face of any transducer, as turbulence and bubbles could be introduced into the water column, thus reducing their effectiveness.

Mounting transducers in the keel usually means breaking the keel to do so. Mounting the transducers alongside the keel can mitigate this problem (Fig. 10). A fairing will be required in order to ensure laminar flow, reduce turbulence, and help protect the transducers from the elements (Fig. 11). For vessel maneuverability, pods (fairings) of equal size and shape may have to be installed on both sides of the keel (Fig. 12). Pod installations can make up for a lack of space for transducers inside the hull or in the keel.

Figure 9. Examples of in-keel fairing, prone mounts, and debris cutters. Credit: Ocean Mapping Group, University of New Brunswick.

Figure 10. Three transducers mounted in a frame alongside keel. Source: Canadian Hydrographic Service.

Figure 11. Half of pod (fairing) that protects along-keel transducer frame. Credit: Ocean Mapping Group, University of New Brunswick.

Finally, for hull-mounted transducers, any holes through the hull, changes to the structural integrity of the vessel, or changes in weight distribution that might affect vessel stability generally must go through an approval process by a ship's safety group. Recertification of the vessel's stability and seaworthiness can take time and cost money if naval architects and engineers need to get involved.

Temporary transducer mounts are also possible and useful, for example, when the sonar or vessel is on loan for only a short period. These installations can be quite ad hoc (Fig. 13) or use mechanical engineering designs meant for over-the-side (OTS) or over-the-bow (OTB) deployment. When the systems must be transported to a remote location and deployed on a vessel of opportunity (VOO), having a flexible pole-mount design with strapping for various mounting options can facilitate these installations (see Fig. 14 and Fig. 15).

As all cabling runs from the sonar head outside the hull, these systems have the advantage of not needing through-hull fittings, but one must be careful to protect the cables from damage. Often, cables are run from the transducer up the inside of the (hollow) pole.

Figure 12. View of transducers in pod from below, showing both sides of the keel. Source: Canadian Hydrographic Service.

Figure 13. Keel-mounted Benthos C3D BSSS (straps and cabling run outside hull). Source: Canadian Hydrographic Service.

Figure 14. Example of over-the-side pole-mount installation. Source: Canadian Hydrographic Service.

Mounting the GPS antenna on the top of the pole reduces the need to measure sensor coordinate offsets other than the vertical offset. The motion sensor can be mounted close to the transducer (if in a watertight container) or inside the cabin. Coordinate offsets to the GPS antenna and the sonar head will have to be measured. Clearly, all these designs would be prone to damage from debris. The OTB design has the advantage of avoiding bubbles caused by the vessel. The OTS design is probably easier to stabilize and reduce vibrations caused by increased vessel speed.

OTS mounts can also be permanent installations. This is very useful for conducting tests of new sensors where a flexible and quick installation is required (see Fig. 16 left and right). No ship's safety approvals are required as no through-hull fittings are needed and little weight is being added, so stability should not be affected. Cables can be lashed to the pole using zap straps.

For larger vessels, the transducer can be mounted on a ram such that it can be drawn up into the hull when transiting to a work location (Fig. 17). When deployed below the hull, however, such transducers can be subject to damage from debris rolling along the hull (Fig. 18). Transducer protection grids (debris diverters) of various sorts can be designed to mitigate this risk (Fig. 19).

The final consideration for transducer installation is location on the vessel. This is especially critical for flush mount installations. Some manufacturers (e.g., Kongsberg Maritime) recommend sonar installations 25-35% aft of the bow (Fig. 20). This location helps to minimize bubble washdown (aeration) from the bow when the vessel is pitching into a sea, and noise from the engines and ship's propellers. It is where laminar flow is most likely and should be the first choice for installation. Farther aft, turbulent flow is more likely. Locating the sonar close to the center of roll and pitch for the vessel can help to minimize motion-induced heave.

When several sonars will be operating at one time, synchronization of the sonars might be required to remove the possibility of cross-talk between them. Sonars with separate port and starboard arrays may alternate pinging to either side to avoid interference.

Figure 15. Example of over-the-bow pole-mount installation. Source: Canadian Hydrographic Service.

Figure 16. Permanent OTS transducer mount for new sensor testing (left = deployed; right = stowed). University of New Brunswick Ocean Mapping Group vessel *Heron*.

Figure 17. EM1002 transducer deployed below hull on ram. When retrieved, it lies inside a watertight well. Source: Canadian Hydrographic Service.

Figure 18. **Transducer deployed below watertight well showing log damage to leading edge. Source: Canadian Hydrographic Service.**

Figure 19. **Transducer protection grids that attach to pins shown in Fig. 17. Source: Canadian Hydrographic Service.**

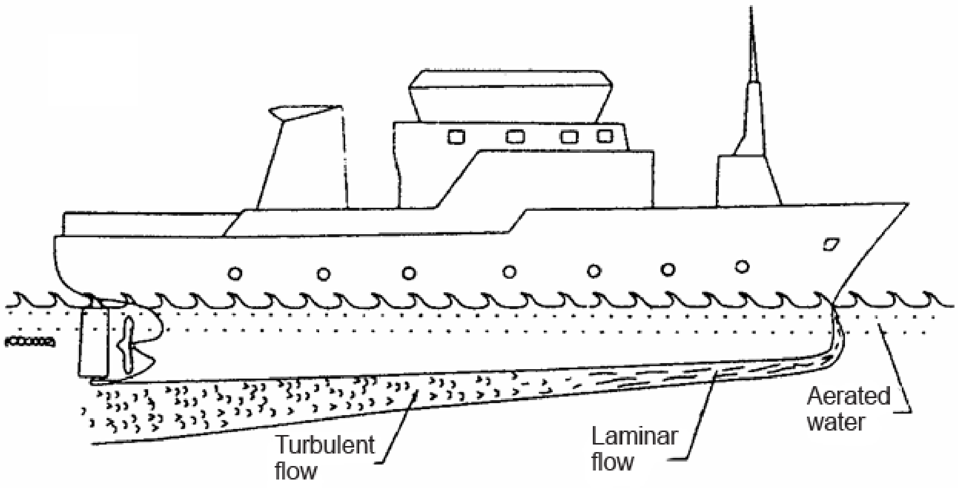

Figure 20. Location of laminar flow on hull (preferred for transducer installation). Source: Canadian Hydrographic Service.

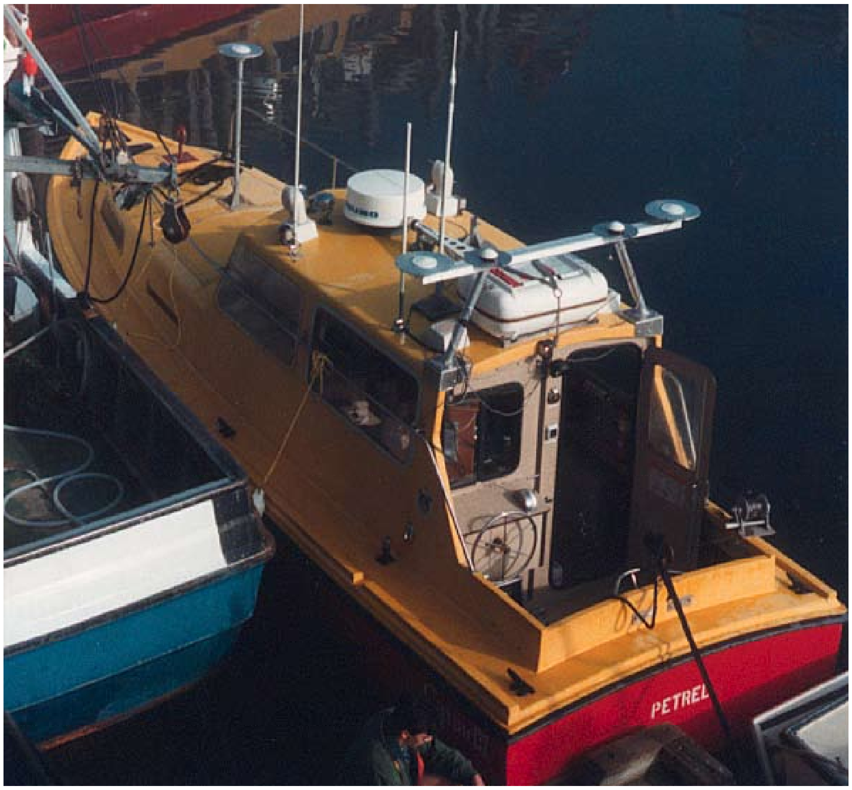

Figure 21. **Typical launch installation of positioning, navigation, communications, and safety equipment. Credit: Andre Godin, Canadian Hydrographic Service.**

Topside gear

Just as there is a need to have all acoustic sensors mounted toward the bottom of the vessel, so too is there a need to have all positioning and communications equipment mounted near the top. Fig. 21 shows an array of topside gear typical of a modern survey launch. What can be readily seen is the positioning system antennas (more than one means GPS assisted vessel orientation—roll, pitch, heading—is possible), the communications antennas (for both vessel traffic and calling and for sending/receiving data packets such as GPS corrections or real-time tides), the navigation equipment (radar, navigation lights) and the vessel safety equipment (multi-person life raft, lines, lifting hooks).

Positioning and orientation

For most modern launch data collection, GPS is a requirement for kinematic (vessel is in motion) positioning, now regularly corrected for local effects of ionosphere, troposphere, satellite clocks, and broadcast orbits; see S-44, IHB (1998). These corrected GPS positions may take the form of standard local broadcast corrections from a shore-based reference station (DGPS), modeled regional corrections transmitted usually by geostationary satellites (e.g., WAAS, wide-area augmentation system) or precise point positions (PPP) using global correctors for satellite orbits, clock behavior, earth tides, and ocean loading and the real-time Gypsy (RTG) algorithm.

The first two types, sometimes called local-area DGPS or LADGPS and wide-area DGPS or WADGPS, are provided in real time and require minimal hardware and cost to implement. For example, a WAAS-enabled GPS receiver can be purchased at many retail stores for under $200. The corrections are provided on dedicated L1 channels via geostationary satellites, which also provide additional lines of position to strengthen the accuracy of the position fix. WAAS provides coverage of USA and territories, Canada, and Mexico.

Other WADGPS implementations (Fig. 22) include a range of satellite-based augmentation systems (SBAS) such as:

- EGNOS (European Geostationary Navigation Overlay System)—Europe, Africa, Venezuela.
- MSAS (Multifunctional Transport Satellite-based Augmentation System)—Japan, Australia, Hawaii.
- SNAS (Satellite Navigation Augmentation System)—China and Asian territories.
- CWAAS (Canadian WAAS)—expanded Arctic coverage using Canadian GPS Active Control Points (ACPs).

Figure 22. **Coverage of SBAS, active and proposed. Green: North American WAAS, European EGNOS, Japanese MSAS (or MTSAS), and proposed Indian GAGAN. Blue: proposed Chinese system. White: no SBAS coverage. Source: Federal Aviation Administration.**

Figure 23. **CDGPS coverage. Source: www.cdgps.com.**

WADGPS services are also available from a few suppliers, e.g., Omnistar XP or Starfix HP from Fugro (see Web links in Appendix). Costs would have to be determined through the supplier, as would space and power requirements for the hardware that is supplied to obtain the corrected positions. CDGPS is provided by the Canadian government at no cost, but a receiver must be purchased in order to receive the corrections (about $1,500). The receiver is small and low power and has an integrated low-cost GPS receiver. The antenna does not require significant electrical grounding. Coverage of the corrections includes Canada, U.S. lower states, northern Mexico, eastern Alaska, and Greenland (Fig. 23).

LADGPS includes land-based reference stations designed to cover ground transportation networks, maritime commerce, and inland waterways. Examples include U.S. and Canadian Coast Guard radio beacon correction services (marine) and North American DGPS (NADGPS—terrestrial and inland waterways), Fig. 24. The receivers needed to acquire the broadcast corrections are reasonably low cost (less than $2,000 typically), require little space, and consume little power. Often, the corrections receiver is integrated in a single unit with a GPS receiver, sometimes including WAAS corrections. However, due to the low frequency of the Coast Guard corrections (300 kHz) a well-grounded antenna is required. This can be problematic for wooden, fiberglass, and inflatable hulls and may require the installation of a grounding plate (e.g., DynaPlate) on the outside of the hull in contact with the seawater.

Coverage for very localized areas with higher precision can be accomplished by deploying a reference station and data link for transmitting corrections at higher data rates. Such units require separate receivers for the GPS and for the corrections, at higher cost (under $20,000). Receivers are most often dual frequency and corrections must be transmitted for both code and phase on both frequencies requiring higher bandwidth. The advantage is in the very high precision achievable, especially in the vertical dimension (a few centimeters).

Precise point positioning requires special hardware that must be rented if positions are needed in real time. Costs would need to be determined with the supplier (C&C Technologies offers the C-Nav service). Size and power requirements for the equipment may also be limiting factors for smaller vessels.

All of the above methods can provide positions in real-time (real-time kinematic or RTK positioning). There are many approaches to provide precise positions in post-mission (post-processed kinematic or PPK) so that some of the hardware for receiving corrections is not needed aboard, thus reducing space and power requirements and potentially

Figure 24. North American DGPS coverage. Source: www.tfhrc.gov.

reducing costs. Usually single-point positions or WAAS-corrected GPS are sufficient for vessel navigation (keeping on station or on line). If a portable data collector (e.g., laptop with sufficient hard disk and a logging program) is aboard, all the raw GPS pseudorange and phase data can be logged to disk for post-processing back at the office. This approach has the added advantage that both forward and backward computations can be performed, unlike real-time calculations where only forward prediction is possible. Precise satellite clocks and ephemeris are available for free download from the Internet, as are free processing software packages to derive precise vessel trajectories. There are also services where you submit your raw data to a Web site and you are emailed the processed results—many of these are free.

Navigation

The study of vectors X (position), V (velocity), and A (acceleration) is called kinematics. Navigation is the kinematics of vehicles. Navigation usually seeks to answer the following questions:

- Can I get there from here?
- By which route?
- How long will it take?
- Where are we now?
- Where else could we go from here?
- What is that thing over there?

In order to find out where we are we must estimate or measure distances and/or directions to or from surrounding features (which could be satellites), and use these measurements to calculate where we are in relation to these or other features.

These tasks share a dependence on coordinates. Fortunately for us, GPS provides coordinates in a global reference frame directly. And also fortunately, maps and charts use this same reference frame: digital coverage of these maps and charts is getting better every day. Position finding is related to X, route following is related to V, and guidance is related to A.

There is software that integrates electronic maps and charts with input GPS position and velocity and, when we have it, translations and rotations for X, V, and A from other sensors. We can input where we want to go and have the software tell us which direction to head and how long it will take to get there, as well as guide us along the most direct route. Today, relatively inexpensive (less than $1,000) navigation software will run on a laptop computer.

Sophisticated integrated GPS-Inertial navigation systems can cost in excess of $100,000. Such systems provide very precise position, velocity, roll, pitch, heading, and vessel heave by integrating the best aspects of dual antenna GPS, an accelerometer triad, and a triad of angular rate sensors or ring laser gyros.

Navigation also involves the interaction with obstacles, both fixed and moving, and adherence to established rules. Radar can show the location of obstacles above water (shoreline, buoys, other vessels, sometimes logs) and forward-looking sonar can show the location of obstacles under water. Communications with other vessels and shore-based traffic management is done over standard VHF radio calling channels. Space and power requirements for these essential pieces of equipment need to be considered in order to ensure smooth operations of the primary mission. If the vessel needs to be operated at night, running lights will be required. For some operations (restricted vessel movement for example), "shapes" may need to be displayed from the mast. For operations in the fog, a horn may also be a good idea. Automated identification service (AIS) also improves situational awareness, especially in non-visible operations such as restricted waterways. Such systems improve visibility of smaller craft such as survey launches that may be working in or near major shipping channels.

Vessel and navigation safety

Should the above navigation equipment and/or personnel fail to keep you out of trouble, you may be forced to abandon ship. A capsule life raft, life jackets, and personal survival suits may be required, as well as various types of signaling devices: EPIRBs, flares, signaling mirrors, etc., and a supply of potable water and rations in a watertight container. Note that this list is not meant to be exhaustive—there are far better references for a comprehensive list of vessel safety equipment, such as your local Coast Guard office or Web site.

Other sensors

Sampling equipment, for both water column and seabed, must necessarily be mounted on deck in order to be able to deploy and retrieve sensors or grabs as needed. Figure 25 shows an installation of a small winch for taking sound speed (or other water column property) samples while underway—a moving vessel profiler (MVP), in this instance capable of sampling to 30 meters water depth while traveling at a speed of 30 knots (an MVP-30).

Figure 26 shows a medium-size launch with enough deck space for a winch or other overboarding gear, and an A-frame for deploying towed equipment. This vessel is also capable of over-the-side mounted hardware such as shallow-water MBES and BSSS.

Platforms

We have examined the types of gear one might expect to put aboard a small boat or survey launch. Now let's consider what things we need to support the collection and onboard processing of data from these myriad sensors. These things will define the type of vessel needed, or conversely, put constraints on the types of gear or areas of operation for the vessel we have available. For the platform itself, we might consider the following:

- Endurance (storage for fuel, potable water, food, etc.).
- Autonomy (its ability to work away from a support vessel—related to endurance).
- Transportability (can it be trailered or lifted aboard a larger vessel, or can it be towed safely at sea behind a larger vessel?).
- Speed (transit and working speeds, fuel consumption—related to endurance).
- Maneuverability (can it get into small wharves and floats?).
- Draft (related to maneuverability).
- Comfort (sleeping and living space, showers, heads, and refrigeration), see Fig. 27.
- Seaworthiness (related to comfort).
- Space for equipment, see Fig. 28 left.
- Power capacity (sufficient to run all the sensors, navigation, and safety equipment, plus any equipment required for comfort), see Fig. 28 left and right.
- Environmental.
- Heating/cooling (related to comfort, but also operation of equipment).
- Moisture (similar to above).
- Vibration (similar to above).
- Vessel dynamics (related to seaworthiness).

Health and safety

Safety of the vessel, the installed equipment, and the personnel aboard is of course always paramount. Regardless of where and when the vessel operates, the depth and complexity of the seafloor and the prevailing weather and sea conditions will all play a role in the safety of the vessel and its contents. In addition, there are a number of issues related to general health of the occupants, including the following:

- Availability and quality of potable water (reverse osmosis machine).
- Hot water for showers and washing dishes or clothes.
- Refrigeration to keep food fresh.
- Gray and black water holding systems and holding tanks; proximity to pump-out stations.
- Ergonomics of workstations (desks, stable and bolstered chairs, lighting, reduction of glare sources).
- Easy-to-operate equipment when the platform is rolling and pounding.
- Comfortable working temperature and humidity.
- Safe conditions on the working deck (training of personnel).
- Availability of appropriate personal protective equipment (boots, hard hats, gloves, eyewear, sunblock, ear protection, seasickness medications, etc.).
- Navigation and communications equipment in case of trouble.
- Emergency evacuation equipment and procedures.
- Sleeping accommodations (to avoid drowsiness of personnel).

Power budget

There are many sources of power draw on board (Fig. 28):

- Navigation equipment.
- Computers.
- Underwater sensors.
- Winches.
- Refrigeration.
- Pumps.
- Communications equipment.
- Lights.
- Heat.
- Air conditioning, etc.

Power budget considerations include the following:

- What type of power is needed—12 volt or 24 volt DC, 110 VAC?
- Is there a need for spike or surge protection, or uninterruptible power supply (UPS)? Once all the sources

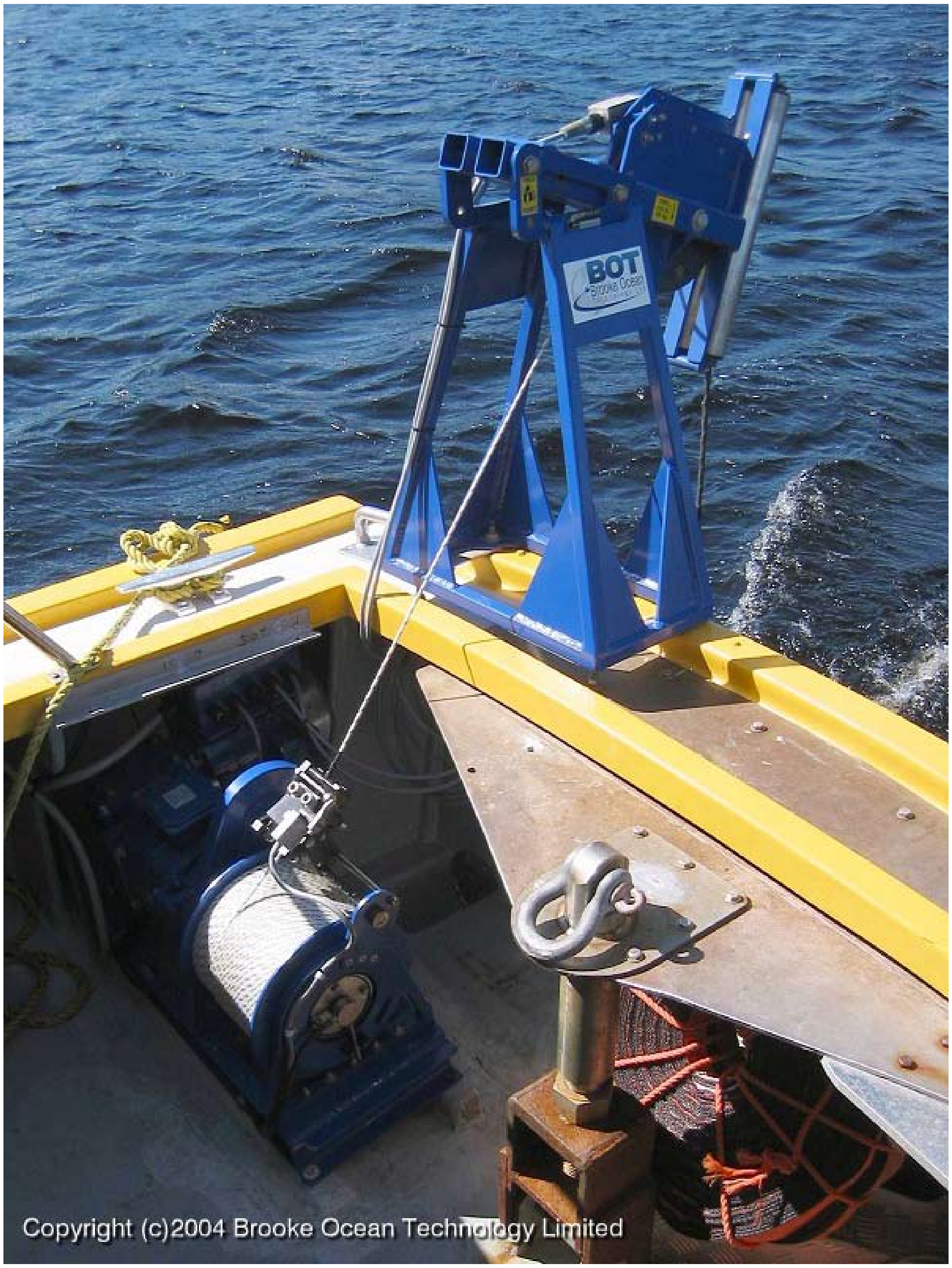

Figure 25. Installation of an ODIM Moving Vessel Profiler (ODIM MVP30™) Winch Aboard a Survey Launch.

Figure 26. CCGS Otter Bay showing A-frame and working deck for deploying sampling gear. Source: Canadian Hydrographic Service.

Figure 27. Onboard comfort is important for vessels with multiday endurance. Source: Canadian Hydrographic Service.

Figure 28. A few sources of power draw (left), and power generation (right, generator on stern of vessel). Source: left, Canadian Hydrographic Service; right, C&C Technologies.

Figure 29. There will always be a need for robust equipment. Source: Canadian Hydrographic Service.

of power consumption have been identified, an estimate of both peak and RMS power requirements should be made so that batteries and charging systems can be assessed for suitability. Consider whether the electrical panel will be sufficient to run all the equipment and if the fuses will protect it from damage in the event of an electrical system failure.

- Will power generation on board keep up with the demand (Fig. 28 at right)?
- Are the storage batteries sufficient for both charging and discharging and easy to access if they need replacement?
- Are the storage batteries properly vented so lethal gases don't build up, risking explosion?
- If a gas-powered generator is on board, is the ventilation adequate to ensure personnel won't succumb to carbon monoxide poisoning?

Noise sources

Sources of noise can be electrical, mechanical, and acoustical in nature. Noise sources can affect the quality of the data collected and can also be an irritant or even a health hazard for personnel. Taking steps to mitigate or remove noise sources will improve both quality of data and quality of life aboard. Mechanical sources of noise usually consist of the vessel's engines or generators, but could also come from low frequency (in the range of human hearing) sonars. Electrical sources of noise usually involve the engines and generators as well, and can affect sonar and positioning equipment in close proximity. Electrical sources of noise can be reduced through proper grounding (more difficult aboard vessels with non-metal hulls) and through shielding around the engine compartment. Ship radar can cause problems for GPS signal reception if the antenna is placed too close and within the main beam of the radar. Careful siting of the antenna alleviates this problem.

Acoustical sources of noise can come from the environment (ambient noise) or be introduced by vessel motions (excessive pitching in heavy seas creating bubble wash-down) or from the ship's propellers or bow thruster. Any air in the water column will reduce sonar performance to the point of failing to operate at all in extreme cases. Protruding objects in front of an acoustic sensor can cause turbulence and/or cavitation that could introduce bubbles into the water column. Sensors that put a lot of power into the water column can also cause cavitation if the negative pressure created is lower than the water pressure at the depth of installation. Also, noise can come from other sonars on board. There are mitigation measures for most of these sources of noise, largely through careful installation design as discussed above. But when poor weather causes excessive bubbles in the water column, it's best to just head for shelter. This works well for the health of many personnel as well. The quality of the acoustic backscatter will begin to deteriorate before that of the bathymetry obtained from MBES as the sea state gets rougher. When this happens, it is probably a good time to break off the survey, for the safety and comfort of the personnel and the vessel.

Logging and navigation

Logging and navigation equipment and software have to be robust and easy to use on a moving platform with possibly high humidity and temperature extremes (see Fig. 29). Working outside in the rain might require an environmentally sealed case, or perhaps using a wireless data connection to permit keeping the logging equipment inside the vessel where things are drier.

Many modern sensors come equipped with Bluetooth data links, which allows work to be conducted up to 150 feet away from the data logging computer. This also means battery packs must be maintained with the remote equipment, so either a supply of alkaline batteries might be needed or a charging system for NiMH or LiON rechargeable batteries.

Once data have been logged, they need to be backed up to secure and robust media as soon as possible and before any processing steps are carried out. Suitable media should be able to handle high humidity and temperature extremes and be of a format that can be read by virtually any type of computer. The data archiving should be redone to the latest and most trusted media on a cycle of about every five years (Rothenberg 1995).

Navigation and data collection displays need to be sufficiently bright so they can be seen in bright sunlight, but also should be dimmable so they can be viewed at night without distracting from the navigation function. These displays should be viewable from an angle so both the coxswain and the person in charge of data collection can see the important information. As with all other equipment, space and power consumption requirements will need to be considered. Robust equipment that can handle moisture, heat, shock and vibration will mean it is still operating at the end of the season as well as it was at the beginning.

Processing power

The workstation used for onboard data processing needs to have sufficient storage, clock speed, RAM, and video capability to handle the data volumes of high-resolution acoustic sensors (Gbytes per hr). Onboard networks make moving the data from collection computer to processing computer to high-speed storage units fast, easy, and secure. The ability to integrate newly collected data with existing data sets and view the results in 3-dimensional fly-throughs cannot be underestimated as a near real-time quality control tool. A dual-monitor video card is also an asset for many modern data processing programs requiring multiple windows to be open for control and graphics. Being able to ensure that high quality data have been collected and will effectively integrate with existing data sets prior to leaving the survey area will pay dividends in the long run. Having robust equipment that minimizes space and power consumption is again an asset.

Area of operations

When the area of operations is close to a hotel, vessel requirements are quite easy to meet. However, when working in remote locations, especially where the remoteness can mean many hours of travel to evacuate a sick or injured crew member, the vessel must have onboard personnel trained in wilderness first aid, good communications equipment and a complete first aid kit. If a helicopter will be needed for evacuation, where can it land and how will you get the person off the vessel and to the landing location safely?

The conditions can be quite varied where operations may be carried out from a small boat. Working on small lakes and sheltered waters is much different from an exposed coast with shallow water and breaking seas. Estuarine and riverine environments pose some unique challenges for acoustic sensors due to the variable sound speed structure that occurs in fresh/saline layers. Ice-covered waters will pose additional problems for small boats that are not designed for pushing ice out of the way. Care must be taken not to damage expensive transducers, e.g., by covering them with titanium windows. Ice can also be a source of air bubbles that get forced under the hull as the ice gets pushed aside or under the bow of the vessel.

When designing a survey, the size, shape, and location of the survey area must be considered from the point of view of most efficient use of time and vessel resources. Having standards for quality of collected data helps to optimize decisions about vessel speed, line orientation, amount of overlap, crossing check lines, choice of sonar settings, etc. For a standard hydrographic multibeam survey, the following would be considered at a minimum:

- Spatial resolution.
- Coverage.
- Speed.

Figure 30. Example of portable hydrographic system (not a product endorsement). Source: CT Systems.

Figure 31. What happens when the rock isn't where you thought it was? Source: Sam DeBow, NOAA.

- Ping rate.
- Overlap.
- Inter-beam spacing.
- Mode (and hence pulse length).
- Angular coverage.
- Target detection probability.
- Data gaps.
- Beam accuracy.
- Redundancy.
- Reliability.
- Blunder detection.
- Automated data cleaning.
- Statistical methods.
- Efficiency.

If the launch will be working in a remote location for a period longer than its endurance, a support vessel may be required to provide refueling, water, food, laundry facilities, hot showers, etc., and to rotate personnel on and off the mother vessel. While smaller vessels do have this limitation, their big advantage comes in their maneuverability and shallow draft. Outboard motors and jet drives allow small vessels to work close to shore. Twin motors and bow thrusters can add additional maneuverability. Care must be taken to protect the transducers when working in shallow waters and where unknown hazards are to be expected. Spare propellers or an ability to repair bent ones should be one of the requirements of the mother vessel.

Hull type

Hull types may be categorized by shape and material. Shapes include displacement, planing, flat bottom, deep-V, catamaran, trimaran, and SWATH (small water-plane area, twin hull). Materials include wood, fiberglass, plastic, rubber, aluminum, steel, concrete, and composite (carbon fiber for example). Most survey launches are wood, fiberglass, or aluminum.

Metal hulls have good electrical grounding characteristics, but require mechanic specialists to make modifications. They also tend to be cool and damp inside unless properly insulated. Wooden-hulled boats can be warm and comfortable inside, but are also difficult to maintain and modify. Fiberglass hulls are fairly easy to modify by someone in the ship building industry (see Fig. 8, Fig. 9, and Fig. 10). RHIBs, rigid-hull inflatable boats, make good vessels of opportunity as discussed below.

Vessels of opportunity

Sometimes the most effective way to collect the data you need is to find a small vessel of opportunity in the area of operations, or use one already on board the mother vessel. These can frequently be small fiberglass or aluminum launches or RHIBs. Rarely are these vessels designed to handle the power and space requirements of data acquisition, let alone the processing and data backup required. So the equipment needs to be highly portable, low power, very robust (completely waterproof in fact), and compact. There are many manufacturers (Read and Hart 2005) who design and build complete systems that fit into environmentally sealed plastic suitcases and can be shipped anywhere in the world by the most convenient mode of transportation (Fig. 30).

However, one should always be prepared to adapt the mounting hardware to suit the vessel (see Fig. 13). Having a credit card handy for the local hardware store to purchase miscellaneous nuts and bolts is always a good idea. Or, on board ship, be sure to make friends with the boatswain.

Once installed, system calibration will be required of course, and should be conducted at the start and end of the survey project to ensure the installation has remained stable throughout the project and all calibration parameters are confirmed.

Summary

Shallow water bathymetric surveys have a long history in CHS: we're used to wrecking props and wiping rudders off small vessels! We're use to saying, somewhat facetiously, "we find the rocks so you don't have to." Many of the things we have learned, sometimes by accident, can be applied effectively to habitat mapping surveys in Alaska waters (see Fig. 31). NOAA's Marine and Aviation Operations, and Office of Coast Survey have additional experience with small boat surveys in Alaska waters that could be of additional benefit (McGovern et al. 2007) to the habitat mapping community. North Pacific Research Board (NPRB) publication no. 154.

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Rothenberg, J. 1995. Ensuring the longevity of digital information. Sci. Am. 272(1):42-47. Updated paper http://www.clir.org/pubs/archives/ensuring.pdf. (Accessed Dec. 2007.)

Appendix. Web links

(Accessed Dec. 2007.)

CCG DGPS, http://www.ccg-gcc.gc.ca/dgps/beacons_e.htm

CDGPS, http://www.cdgps.com/

C-Nav, http://www.cctechnol.com/site51.php

M-13 (Manual on Hydrography, first edn., May 2005) http://www.iho.shom.fr/PUBLICATIONS/download.htm

Omnistar, http://www.omnistar.com/about.html

Precise Point Positioning, http://www.geod.nrcan.gc.ca/products-produits/ppp_e.php

S-44 (IHO Standards for Hydrographic Surveys, 4th edn., April 1998), http://www.iho.shom.fr/PUBLICATIONS/download.htm

Starfix, http://www.fugrochance.com/brochures.asp

USCG Boating Safety, http://uscgboating.org/

USCG DGPS, http://www.navcen.uscg.gov/dgps/coverage/Default.htm

WAAS, http://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/techops/navservices/gnss/waas/news/index.cfm