PLANNING DREDGING OPERATIONS WITH PERSISTENT BERTH DEPTH MONITORING TECHNIQUES

K.R.W. Mech[1]

ABSTRACT

Periodic hydrographic surveys by definition have elapsed time between surveys. Stakeholders conduct surveys of berths to detect change over time. However, the rate of change to berth bottoms is not constant. Shoaling and scour can be erratic and drastic due to randomly occurring storm events and flooding. Besides natural changes to bottom features, survey is needed for detection of foreign objects. Operators that lose foreign objects in berth pockets often do not disclose this to the berth owner. Recent jurisprudence in the United States places responsibility for damage due to foreign objects in berth pockets squarely on berth owners. Increasing the frequency of periodic survey becomes very expensive, and still does not capture random events occurring between surveys. Known events do not increase risks, it is the unknown events. Berth owners can mitigate these risks using persistent survey. Systems are now available that provide real-time feature detection of foreign objects and continual monitoring and reporting of changing bottom conditions. Berth operators can then use this real-time information to proactively plan appropriate interventions such as dredging or object removal, optimizing costs and resources. This paper describes one such system used for berth monitoring as well as siltation monitoring in hydroelectric dams.

Keywords: Persistent hydrographic survey, foreign object detection, siltation, dredging optimization.

INTRODUCTION

The maritime movement of goods involves two broad sets of stakeholders – those whose primary concern is safety, and those whose primary concern is commercial profit. Port authorities, the Coast Guard, Pilots, vessel insurers, vessel owners, and ship captains would ideally like absolute under keel clearance under all conditions in a berth to eliminate the risk of grounding. Often this is not possible. Terminal operators and bulk material marketers want to maximize the amount of product shipped with minimal under keel clearance while still operating safely. Each centimeter of additional draft equates to approximately 150 metric tonnes of additional cargo. These stakeholders want to load the maximum possible cargo without grounding. Excessive berth depth restrictions directly impact their bottom line. The challenge for all stakeholders is to allow economic stakeholders to maximize cargo shipped without compromising safety.

There is also a green justification. Environmentalists want vessels to carry the maximum amount of cargo possible per unit carbon emitted. Under-loaded vessels are not carbon-efficient.

As vessels get larger and drafts get deeper, virtually every port has dredging projects in planning or under way. As channels are dredged to new depths, the behavior of the new bottom is unknown unless geotechnical work is done to determine geology beneath the seabed. Will the dredged channel and berth bottom hold, or will the walls slip and subside? How often will berths and channels need to be re-dredged in estuaries subject to silting and storm events? As climate change causes more and more extreme weather events, how do these affect shoaling and scour? Port authorities have always made use of periodic hydrographic surveys to map channel and berth bottoms. These surveys are expensive and require expertise. Conducting increasingly frequent surveys becomes burdensome and costly.

Recent jurisprudence in the United States has increased the financial risk of terminal operators. "On the evening of November 26, 2004, the 60,000 dwt tanker *Athos I* struck an uncharted nine ton anchor on the river bed located about a ship's length off the CITGO Asphalt Refining Company (CARCO) berth at Paulsboro, New Jersey. The single bottom tanker was holed in her Number 7 port ballast tank and Number 7 center cargo tank, resulting in a spill of 265,000 gallons of heavy crude oil. Some 280 miles of river shoreline were affected, including 70 miles heavily to moderately oiled – resulting in cleanup costs, natural resources and third party claims totaling to $300 million." The Athos I ruling found that "CARCO had breached its "safe berth warranty," its contractual guarantee

[1] Director of Sales and Marketing, Kongsberg Mesotech Ltd., 1598 Kebet Way, Port Coquitlam, British Columbia V3C 5M5, Canada, T: 604-468-5207, Email: konrad.mech@km.kongsberg.com.

to the Athos' operator that she would be able to safely reach the dock so long as she kept her draft at less than a specified depth. As compensation, Judge Slomsky ruled that CARCO must pay the balance of Frescati's costs, $55 million, plus half of the federal government's costs, or $44 million, plus interest." (Maritime Executive, 2016). This judgement has significant implications for terminal operators. Not only must they respond to storm events to ensure safe berths, they must now take responsibility for foreign objects in their berth pockets – even if they are not aware of the foreign object - and take responsibility for resultant damages.

One way to increase confidence in the condition of berth bottoms is to increase the frequency of periodic surveys. However, the required resources and expense of continual periodic surveys very quickly become onerous. This is why persistent berth depth monitoring and reporting systems are being considered as an economical method of observing and monitoring berth bottom changes over time. Berth depth monitoring and reporting systems using dual axis echo sounders scan the berth bottom on a continual basis. This paper discusses the issues regarding site survey, installation, data processing and presentation, and integration with VTS systems. Port authorities and terminal operators can use the outputs from the berth depth monitoring and reporting systems to determine when, where and how much dredging is required.

CURRENT PERIODIC SURVEY PRACTICE

Since this conference is being held in Vancouver, let us examine the current process for bathymetric surveys in Port of Vancouver berths. The Pacific Pilotage Authority issued a Notice to Industry on June 18th 2015 with the Subject "Bathymetric Survey Standard accepted by PPA." This communication states:

> "The PPA determines controlling depths from bathymetry surveys in consultation with the British Columbia Coast Pilots, the Fraser River Pilots and the relevant Port Authority."
>
> "The PPA will review survey data and determine the controlling depths for marine terminal berths only if the bathymetry surveys are done in accordance with CHS - Standards for Hydrographic Surveys." … "Surveys not done in accordance with these standards will not be considered for updating terminal information."
>
> "Terminals submitting bathymetric survey data are kindly requested to include a letter from the entity performing the survey confirming that the survey was done in accordance with the CHS Standards for Hydrographic Surveys.
>
> The PPA would like to encourage terminal operators to consult with CHS prior to performing bathymetric surveys. Sharing of this bathymetric data might result in the production of high definition electronic navigational charts (ENCs) and high resolution docking charts that provide pilots with a high detail of information when the vessel is near the terminal, thereby enhancing safety."

CHS Standards for Hydrographic Surveys prepared by Canadian Hydrographic Service, Fisheries and Oceans Canada, June 2013, Edition 2, defines two orders of survey pertaining to berths: Exclusive Order and Special Order. It is worthwhile to consider the detailed requirements of each Order.

> 1.1 Exclusive Order
>
> Exclusive Order hydrographic surveys are based on the IHO Special Order with higher accuracy and their use is intended to be restricted to shallow water areas (harbours, berthing areas and critical channels) where there is an optimal use of the water column and where specific critical areas with minimum under-keel clearance and bottom characteristics are potentially hazardous to vessels. This order also applies to high precision engineering surveys. All error sources must be minimized. Exclusive Order requires very precise positioning systems, closely spaced lines (when target detection is required) and a rigorous control on all aspects of the surveys.
>
> The use of side scan sonar or multi-transducer arrays or high-resolution multibeam echo sounders is required to detect the feature size to be detected. In required areas, appropriate sounding equipment and methodologies must be employed in order to ensure that all features greater than 0.5m cubed are detected. The use of side scan sonar in conjunction with multibeam or multi-transducer echo sounders may be necessary in areas where pinnacles and dangerous obstacles may be encountered.

1.2 Special Order

Special Order hydrographic surveys are intended to be restricted to specific critical areas with minimum under-keel clearance and where bottom characteristics are potentially hazardous to vessels. These areas have to be explicitly designated by the agency responsible for survey quality (harbours, berthing areas, and associated critical channels). All error sources must be minimized. Special Order requires the use of closely spaced lines (when target detection is required).

The use of side scan sonar, or multi-transducer arrays, or high-resolution multibeam echo sounders is required to detect the feature size to be detected. In required areas, appropriate sounding equipment and methodologies must be employed in order to ensure that all features greater than 1m cubed are detected. The use of side scan sonar in conjunction with multibeam or multi-transducer echo sounders may be necessary in areas where pinnacles and dangerous obstacles may be encountered.

To summarize, periodic survey requires expensive sophisticated sensors that must be properly calibrated and maintained, specially trained and qualified personnel who meet criteria set by the CHS, access to the area being surveyed, and a series of reviews, checks and balances before the data is accepted for use by mariners.

What Periodic Survey Does

Periodic survey, conducted as shown in Figure 1, provides a very accurate picture of the berth bottom at the time of the survey.

What Periodic Survey Doesn't Do

Periodic survey does not capture changes occurring in a berth pocket due to environmental events or foreign objects entering the berth after a survey until the next survey is completed.

Figure 1. A typical hydrographic survey vessel.

PERSISTENT BERTH DEPTH MONITORING AND REPORTING

Persistent survey takes a completely different approach to the problem. Rather than mounting sensors on a vessel that moves over the berth, the sensors are permanently mounted in the berth in order to provide real time information continuously to stakeholders. One example of such a sensor is shown in Figure 2.

Figure 2: Dual Axis Sonar

The sensor consists of a single beam echo sounder operating at 330 kHz, mounted on a high-precision dual axis rotator, and protected by an oil-filled acoustically transparent dome. The area covered by the sonar is can be programmed to focus on specific areas or cover a wide area. Generally the area of coverage has a half-moon shape. The number and location of sensors is determined by the desired coverage of the berth pocket and local conditions such as tides, storm surges etc. Figure 3 shows a schematic of a berth pocket with four sonar heads mounted to create an overlapping area of coverage. The sensors are operated to eliminate acoustic noise between heads. The raw data from all heads are transmitted to a data processing unit where it is collated and presented in an easy format for stakeholders.

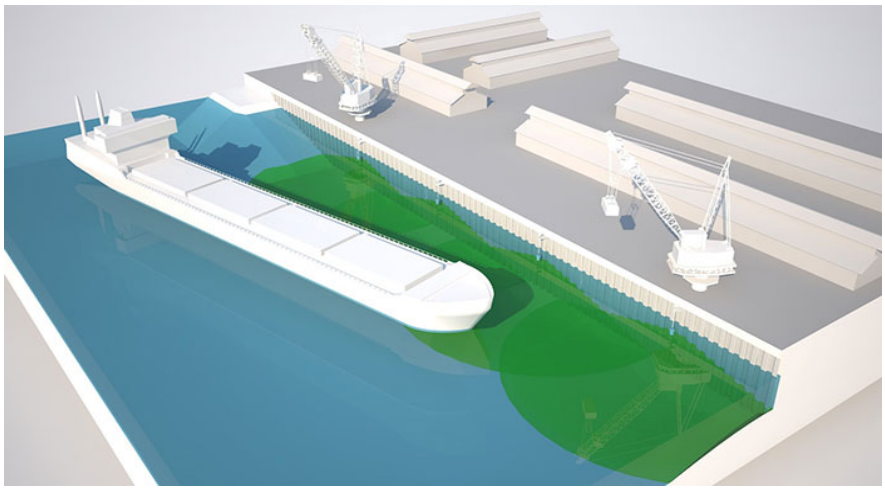

Figure 3: Berth pocket with four sonars showing overlapping coverage.

Detecting Bottom Condition Changes

The sonar produces a 3D point cloud of the berth bottom, which, when presented as a surface, is comparable to a surface from a multibeam echo sounder survey. Refer to Figure 4. In this data set, the sonar head is at the 0-0 position. The berth wall runs from upper right to bottom centre. The pink at right is to shore; the white areas are acoustic shadows cast by the supporting piles. The length of the scanned area along the berth wall is approximately 65m, and the outer reach of the sonar is 35m beyond which the grazing angle reduces the precision of the sonar. The black circle at the (-5, 25) coordinate indicates the highest point in the complete scanned area. The point cloud for this scanned area comprises 14,000 discrete soundings taken over a period of 3 hours. The sonar operates continuously.

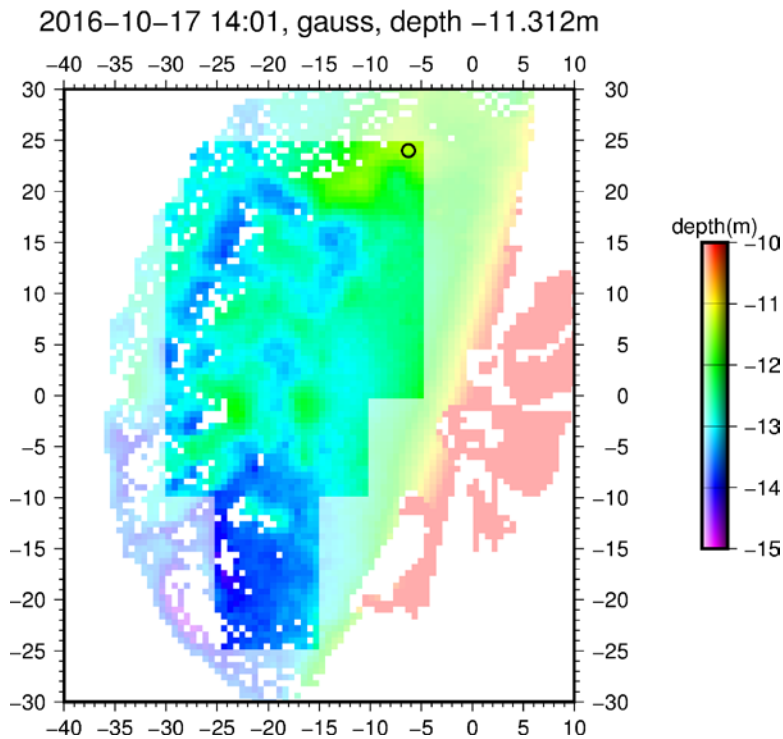

Figure 4: 3D bottom map produced by dual axis sonar.

However, this data is quite difficult to interpret for vessel operations. There is too much data for rapid decision making. A simpler presentation is shown at Figure 5. Only the critical data is presented- the minimum amount required to make good decisions. The berth datum is shown as a grey line. The published minimum safe berth depth is shown as the red line. These 2 datums are fixed. The blue line shows real time tide data (in this case from a pressure gauge located at site). The green line represents the plot of the single highest point reported in each scan – each green dot in Figure 5 plots the black circled high point shown in Figure 4.

The data is accessible via mobile devices using a web browser. If the user wishes, he or she can call up the berth plot to see exactly where the high point is. But the key economic information for operators is this: the water column between the green line and the red line shown in Figure 5 is available draft to load more cargo. This is money on the table for the shippers, and the data provides confidence to those responsible for safe operation of the vessel.

Another feature of persistent monitoring is the ability to compare data scan-to-scan. Figure 6 shows a difference plot. The difference plot shows that the change between scans is less than 0.5% of water depth.

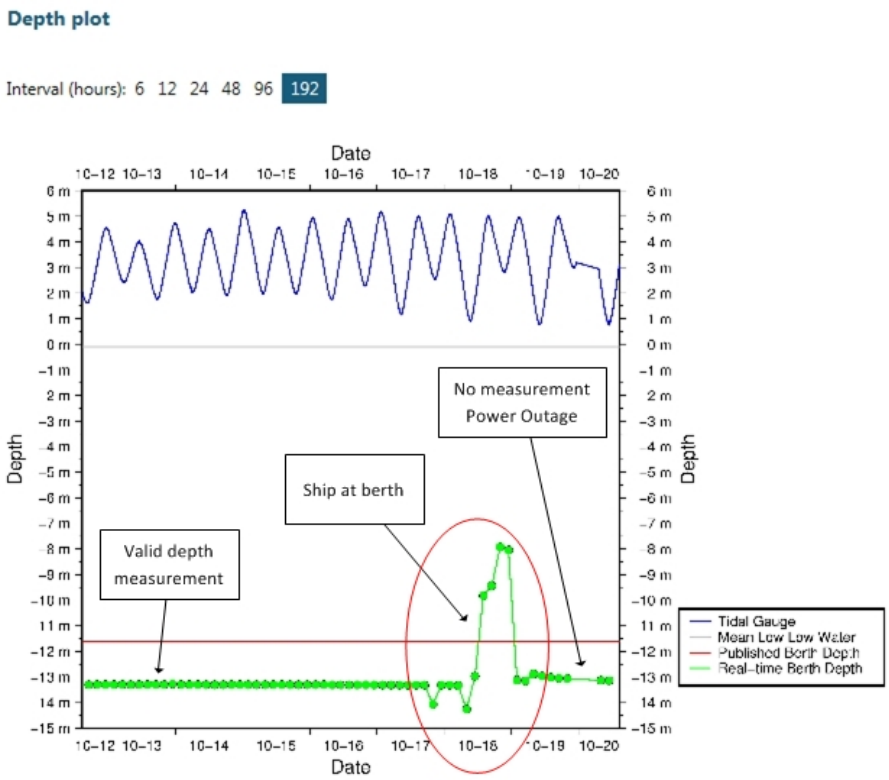

Figure 5: Example Graphic User Interface for Pilots, Captains, Load Masters

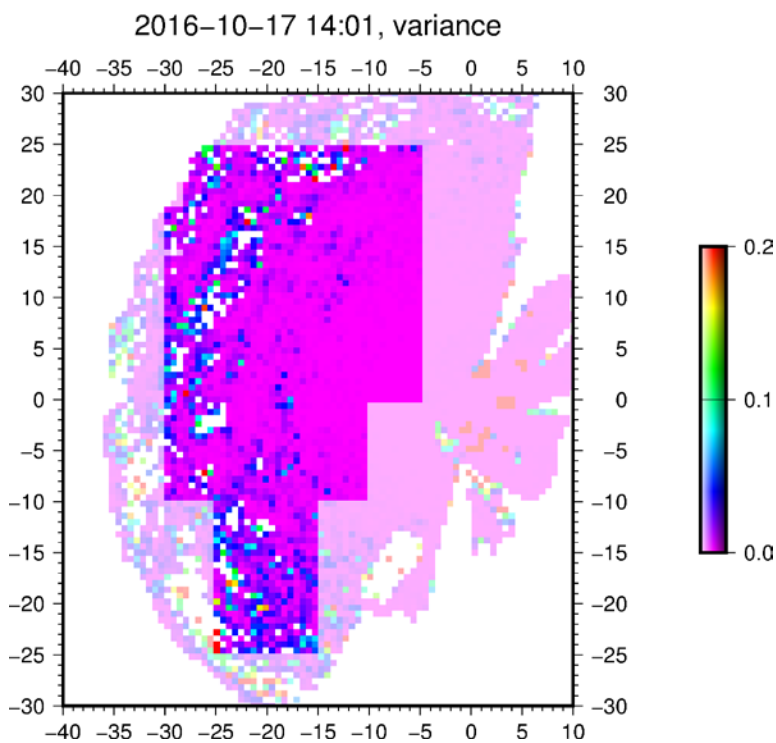

Figure 6: Difference plot - scan to scan

Detecting Foreign Objects

Changing bottom conditions due to natural events is only one part of the berth owner's challenge. The other is detecting foreign objects that end up in the berth and become hazards to navigation. To determine the capability of the dual axis sonar to detect foreign objects, a target was constructed of crab traps – refer to Figure 7. Note that IHO targets are very precisely dimensioned solid concrete targets. Crab traps are more difficult to detect as they are hollow and do not have a solid surface. Figure 8 shows the 3-D point cloud, with the target in the berth pocket. The target shows clearly with defined edges – the sonar has no problem detecting the target at all.

Figure 7: Crab trap target, 0.9m X 0.7m X 0.7m

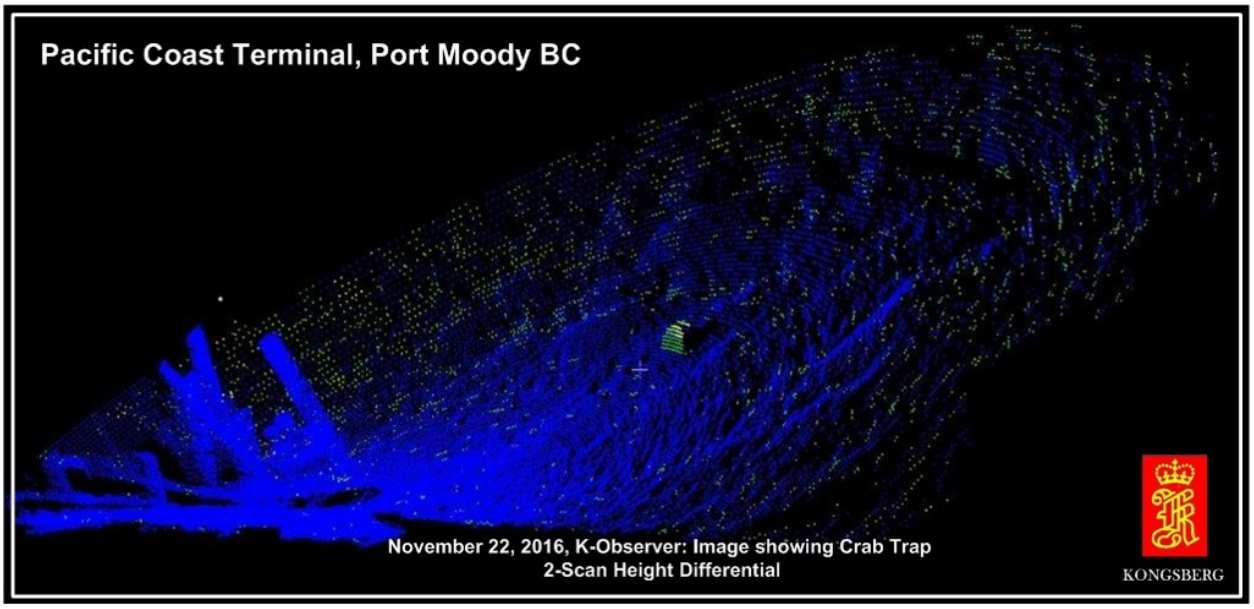

Figure 8: 3-D Point Cloud of Foreign Object Target in Berth Pocket

Figure 9 shows the Difference Plot before and after placement of the target in the berth pocket. The target again shows up clearly and unambiguously in the after scan.

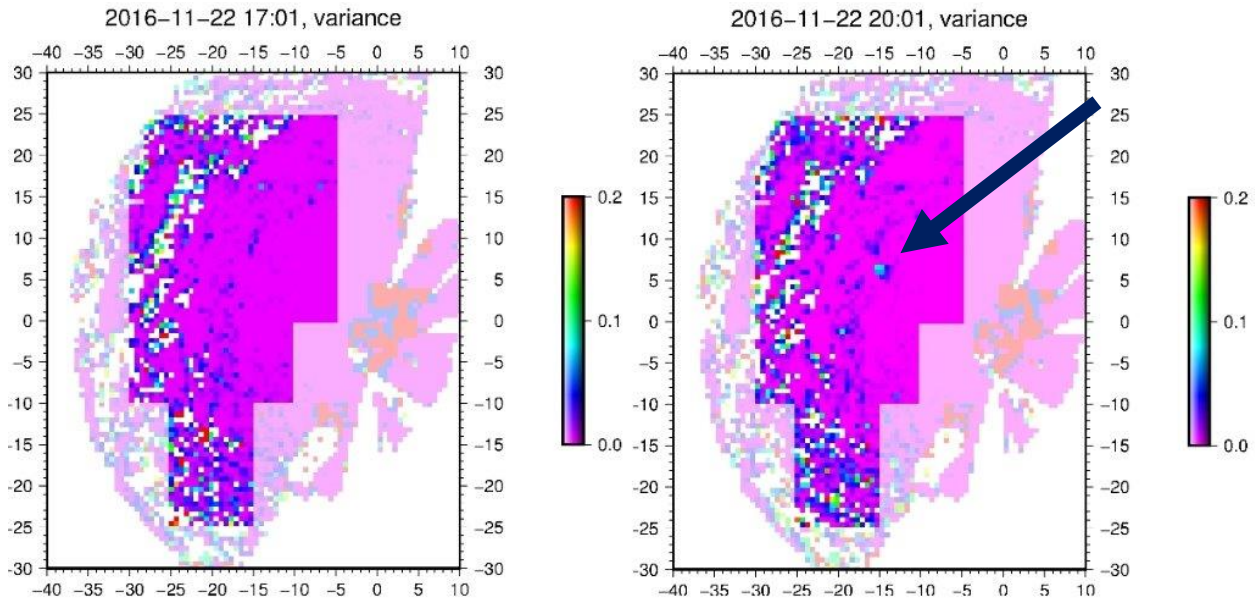

Figure 9: Difference plot showing target at (-15, 5)

What Persistent Survey Does

The benefits of persistent survey address most of the shortcomings of periodic survey.

- Continuous scanning. The scanning sonar can be operated on a continuous basis, so that a new scan starts once the previous scan is complete. This is a significant benefit in regions where shoaling occurs rapidly.
- Very precise system. The echo sounder is a very precise instrument. This increases user confidence in the data reported by the system.
- Comparable to hydrographic survey; reports changes over time. The system can be calibrated to a hydrographic survey, and the system then measures real time changes with respect to the baseline survey.
- Use a reference target to confirm accuracy. In areas subject to haloclines or other effects on sound velocity, recalibration can be achieved by capturing a geo-referenced calibration target in each scan.
- Able to detect new features (foreign objects) and report them immediately. The system is able to detect and report foreign objects in the scan area.
- Set thresholds to trigger intervention or precise surveys. The system can be programmed to provide warnings and alarms when trigger-point limits are exceeded – for instance, shoaling reaches a certain trigger point, or a foreign object compromises a minimum depth requirement. This allows decision makers to plan dredging operations and other interventions when they are needed. The data also allows for better quantitative estimates of the material to be removed, better oversight for dredging contracts and quality control after dredging.
- Web-based access to stakeholders particularly pilots. The data is accessible to stakeholders who have been issued credentials to access the data. Data may be accessed on any platform with a web browser.
- Integration to Vessel Traffic Services or Portable Pilotage Units. Providing real time data to key users allows for better planning and vessel operations particularly in conditions immediately following natural events.

What Persistent Survey Doesn't Do

- Grazing angle of the single beam echo sounder establishes an outer limit of the viable scan area. This approach can't overcome the limits of physics.
- The sonar may have difficulty providing a true bottom depth in very soft bottoms or fluffy mud.

- It isn't maintenance free. The system requires occasional maintenance to remove marine growth from the dome. Since it is a mechanical system, it requires periodic maintenance of the internals.
- It can't be left in situ in extreme winter conditions like the Great Lakes or parts of the St. Lawrence Seaway. It must be removed during the icing season.
- It isn't tamper-proof. It is a robust sensor, but it should be installed where it is protected from mechanical damage from vessel operations, vandalism or tampering.

A DREDGING CASE STUDY USING DUAL AXIS SONAR

While this case study does not involve vessel berths, it does involve loss of operating revenues due to silting and use of dual axis sonar to trigger dredging operations, and is therefore worth discussion.

"[Altagas Limited operates the Forrest Kerr Hydroelectric Facilities, which] are located in the traditional territory of the Tahltan First Nation, approximately 1,000 kilometres northwest of Vancouver. The projects capture the energy produced by the natural flow and drop of the Iskut River and its tributaries to produce and deliver clean, renewable energy. The three facilities produce an aggregate of 277 megawatts of energy to the British Columbia power grid through BC Hydro's 287-kV Northwest Transmission Line.

The 195-MW Forrest Kerr Facility redirects a portion of the flow of the Iskut River through a tunnel to an underground powerhouse that houses nine Francis turbines to generate electricity." The plant operates year round. The river carries very high solid loads including entire trees. Water from the river is diverted to desanding bays to reduce the water velocity and allow the solids to settle to the bottom. The desanding bays have large 1m diameter suction pipes with valves that are stroked to suck the solids out of the bays. The desanded water then flows over an infinity wall where it feeds into the turbine intake to generate the electric power sold to the grid. Figure 10 shows the gates controlling flow into the desanding bays in centre right, the desanding bay, and the entry to the turbines at far right.

Figure 10: Forrest Kerr Hydroelectric Plant

Early in the dam operations, the owners realized they had a significant problem. As shown in Figure 11, The silting behavior was so extreme, the operators could not determine when to stroke the valves and carry the sediment away. They had to stop generating power, drain the bays to get eyes on the situation, then dredge the solids with clam bucket dredges before restarting operations. This work cycle caused significant losses of revenue. Further, the

solids carried over the infinity wall and silted the reservoir, reducing the available head for power production. The client retained Northwest Hydraulic Consultants of North Vancouver to determine a solution. Northwest Hydraulic Consultants installed a dual head sonar into the desanding bays, and took continuous scans. The sonar was able to clearly show the development of sand waves in the bays. In Figure 12, the elapsed time between the first and last scan was only 30 hours – but the dual axis sonar produced 20 full scans during this period. Dredging operations could be conducted without having to drain the bays or the reservoir. Using this new tool, the client was able to improve the draining of solids in the desanding bays. Further, they were able to visualize the amount of dredging required in the reservoir after the infinity wall. After this intervention, Altagas was able to realize an increase of power production of $100,000 CAD per day.

Figure 11: Excessive Silt Loading in Desanding Bays

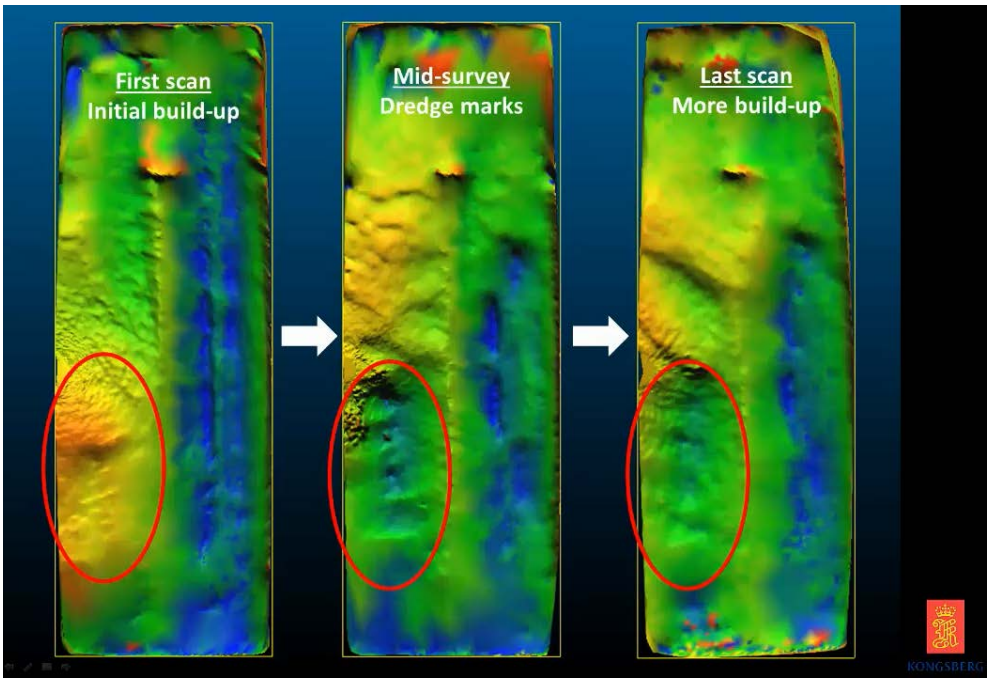

Figure 12: Dual Axis Sonar Images of Dredging Operations in Desanding Bays

OTHER DREDGING APPLICATIONS USING DUAL AXIS SONAR

Real-time monitoring of dredging operations provides benefits to contractors by ensuring they dredge the amount of material, and only the amount of material, they are contracted to remove. Failing to remove the contracted material exposes dredging contractors to penalties for non-performance. Dredging too much material is not only inefficient, it is uncompensated work. Real time monitoring allows dredgers to maximize the utilization of their expensive assets and provides proof of performance for the paying client. Figures 13 and 14 show two different dredging concepts using dual axis sonar for continuous monitoring of operations. The scanning time of the dual axis sonar was optimized to approximately 2 minutes per scan. Figure 15 shows the complete point cloud of the scanned area. This date-time stamped data becomes proof of contractual performance for both parties. Further, because the dual axis sonar is able to detect solid features, this allows the dredger to detect foreign objects and remove them prior to operations, thus reducing damage to expensive gear like cutting heads.

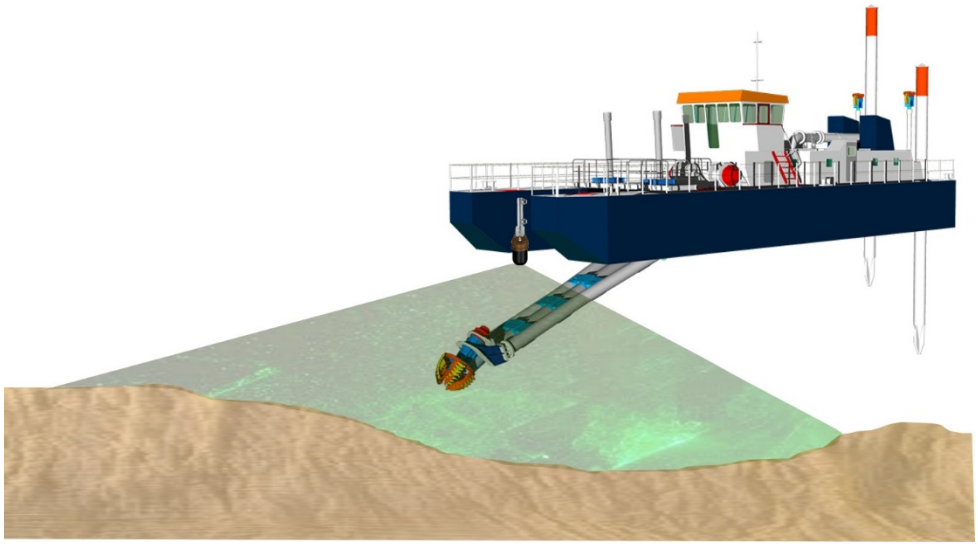

Figure 13: One dredging concept

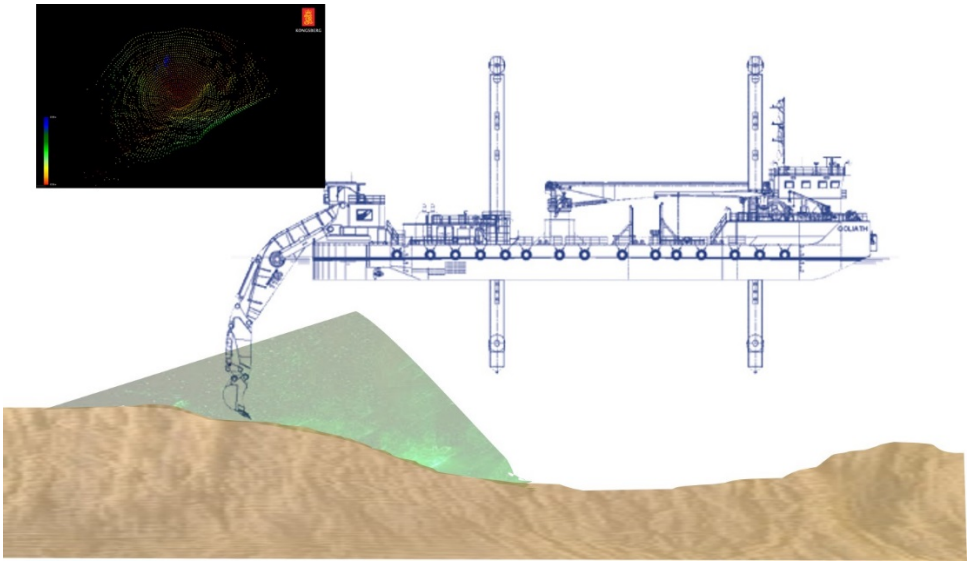

Figure 14: Another dredging concept

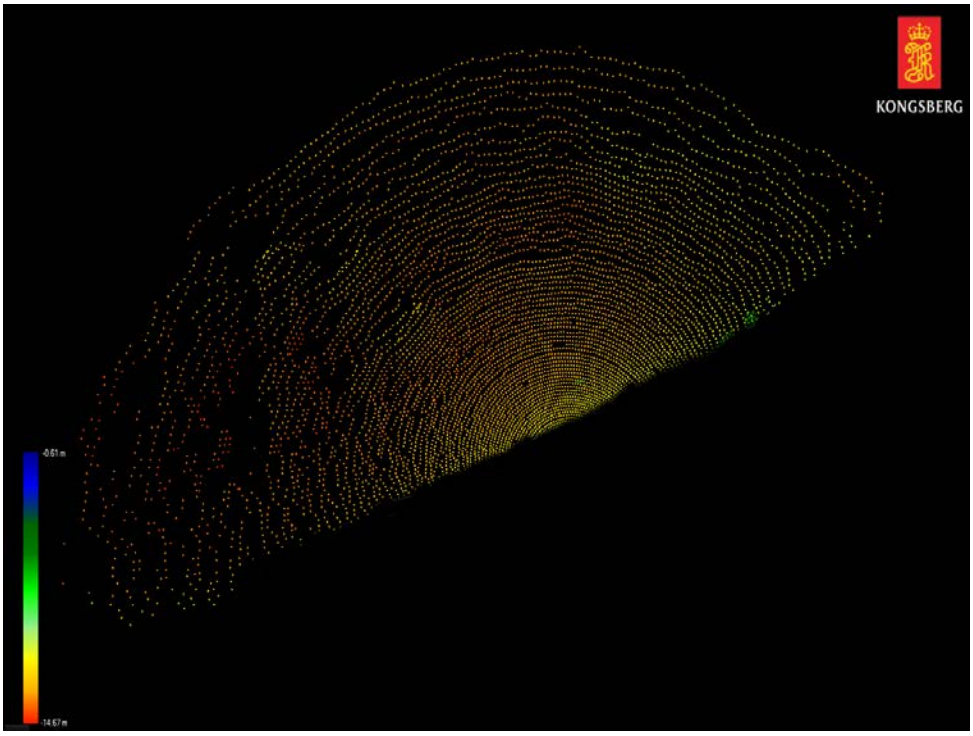

Figure 15: Post-dredging Point Cloud - a Two-Minute Scan

CONCLUSIONS

Periodic survey has served mariners well. However, a significant drawback is the inability to understand changes occurring between surveys. Natural changes do not occur at a constant rate, they occur randomly and in cases with drastically different rates, creating a hazard to safe navigation. Another significant risk to safe navigation is the presence of foreign objects that are dropped into a berth pocket or channel without the knowledge of the berth operator. Recent jurisprudence in the United States increases risks for berth owners by making them liable even for unknown hazards to shipping in their berths.

Persistent survey has emerged as a viable and reliable technology. Persistent berth monitoring and reporting systems provide stakeholders with a tool to monitor bottom conditions on a continuous basis. This information is accessible by multiple stakeholders using Internet access. This enables safer vessel operations when arriving at berths, while allowing optimized vessel loading based on real time data. Wharf and berth operators can also use this technology to better plan dredging operations for material removal. The bottom line: all stakeholders involved in the safe and economically efficient operations of vessels benefit from the implementation of this technology.

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