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The Application of a Remotely-Operated Hydrographic Survey Boat for Tailings Facility Bathymetry

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ABSTRACT

As the methods available for surveying the land portion of the mine become ever-more complex, the submerged topography beneath the tailings pond continues to be surveyed often using primitive, labour intensive and potentially inaccurate techniques. Recent application of the Z-Boat 1800 unmanned remotely-operated electric survey boat to the challenge of tailings hydrographic surveying has afforded mine operators a consistent, low cost, and safe method to gather bathymetry of the tailings facility. A GNSS (GPS) rover on the boat provides accurate position and heading, and an echosounder depth-finder simultaneously reports the depth under the boat; the combined dataset is transmitted to the operator on the shore in real time. This real time data display is used to assist the operator in guiding the boat along the survey route, which may be over 1500 m distant from the shore. Echosounders used may be basic units recording a single digital depth value under the boat, or complex echogram-enabled systems that provide advanced quality control checks of sounding data, with the applicability of each depending on local conditions and planned uses for the equipment at the site. The Z-Boat has proven successful at several mines, greatly improving water volume estimates and allowing detailed stage / volume relationships to be developed and maintained by repeat surveys with a previously impossible frequency and accuracy.

INTRODUCTION

The land surveying challenges and benefits of modern positioning equipment to meet these challenges in mining are fairly obvious; elevations of open pits and much of the mine site need to be known accurately for construction and safety. Operationally, the positions of large vehicles operating in the pit area need to be known precisely. These requirements are now intrinsically linked with GPS or Global Navigation Satellite Systems (GNSS) equipment. Land surveyors gather traditional GNSS point measurements to update topographic maps of the mine in specialized mine management software. The recent introduction of small airborne fixed and rotary wing platforms for aerial mapping of mine sites has further advanced the collection of relatively inexpensive, accurate and valuable survey data. However, one location of the mining operation that has largely remained untouched by such technological advances in surveying is the mine site hidden under the various water reservoirs.

Water management is a key discipline of overall mine management, but often there is limited knowledge about the water resources at the mine. The main reason for this is the relative difficulty in obtaining survey data for these resources - including the tailings storage facility (TSF). The environment is often hazardous, often with poor access to the water both for deploying equipment or in the event of an emergency situation, and there exists no standard method or equipment for the mine site to easily use. In the absence of a good methodology for surveying the bathymetry of these water reservoirs, mine surveyors are often forced to use methods they have devised themselves to obtain bathymetry data when it is needed. Surveyors on small boats may simply use a long pole, weighted line or recreational fish-finder to obtain approximate depth to the sediment surface at discrete positions. Traditional hydrographic surveys using single beam echosounders on dedicated survey boats might be conducted periodically to obtain high quality bathymetry, either using the mine survey equipment or a contracted surveyor, however this method requires personnel on the water and is relatively costly, reducing the potential frequency of data collection.

As the water stored in the TSF is recycled, water balance engineering models rely on knowledge of the water volume in the impoundment. Additionally, the mine may have a legal obligation to periodically report the TSF water volume. So, there exists a strong need on the part of the mine operator to understand the TSF bathymetry yet there is no conventional survey method that offers an effective way to complete this task. In order to offer mining operators a safer and less manpower-intensive option for TSF bathymetry collection, an unmanned remotely-operated survey boat manufactured by The Oceanscience Group (San Diego, USA) has been adapted for use in the TSF environment. The 24V battery-operated boat accommodates a GNSS system to give continuous position measurements, and an echosounder depth-finder that precisely measures the depth under the boat. The sonar “ping” (or more accurately up to 20 “pings” per second) travels down from the transducer in the boat hull, reflects off the bottom and is received back at the transducer a certain time later; this time is directly proportional to the depth under the boat. The sonar and GNSS measurements are combined and transmitted over a radio link in real time to the shore operator who uses a navigation display to navigate the boat during the survey from a safe and convenient location. Important considerations for design and operation of this remote survey system are discussed in this article.

METHODOLOGY

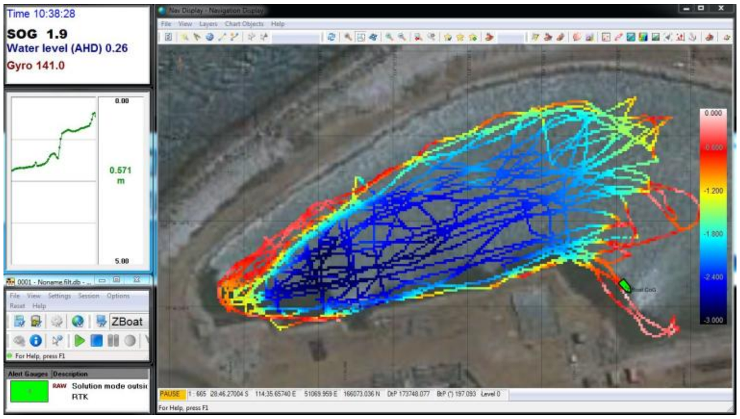
The Oceanscience Group's Z-Boat 1800 remotely-operated hydrographic survey boat has been in use for remote hydrographic data collection since 2008, and is operated in many countries around the world. The boat was originally developed in 2007 for the United States Geological Service (USGS) to allow remote collection of river discharge (velocity) and bathymetry measurements during conditions that were potentially hazardous for people to be out on the water. Only in 2012 has the Z-Boat come to the attention of mining operators for their TSF surveying challenges.

Remotely-Operated Surveying

A remotely-operated survey boat requires three specific components:

1. **Navigation control signal from the shore to the boat.** A 2.4 GHz frequency hopping spread spectrum radio system is used up to a range of about 1500-2000 m. Control of the boat is achieved by a joystick operation on the shore. This system also provides telemetry of the boat's main battery power level to the shore unit.
2. **Data transmission from the boat to the shore operator.** As the boat may be out of visual range for much of the survey, its position and depth data should be visible to the operator in real time. This is achieved by an on-board telemetry module (CCM) that accepts up to three RS232 serial inputs - GNSS position, depth soundings, and boat heading from a magnetic compass. These data streams are recorded on an internal memory card in the order they are received, and simultaneously transmitted to the shore using either an industrial Bluetooth or high power Freewave (Boulder, USA) spread-spectrum radio. On the shore PC, a serial COM port is used to receive the NMEA0183 format messages.
3. **Data display and acquisition software on the shore PC.** Readily available hydrographic surveying software can be used to manage the remotely-operated boat survey workflow. An example screenshot of the shore PC during a Z-Boat 1800 survey is shown in Figure 2.

Figure 1. Z-Boat 1800 measuring sediment accumulation in Queensland, Australia.


Time 10:38:28
SOG 1.9
Water level (AHD) 0.26
Gyro 141.0

PAUSE 1 : 665 28:46.27004 S 114:35.65740 E 51069.959 E 166073.036 N DtP 173748.077 BtP (°) 197.093 Level 0

Figure 2. Real time data display showing the boat position on the shore laptop.

The typical TSF environment presents a unique hydrographic surveying challenge, and after several mining companies became interested in using the Z-Boat system for their tailings ponds, it was appropriate to investigate the key requirements and specifications for a remotely-operated survey boat such as the Z-Boat 1800 for use at mine sites. The topics evaluated were: echosounder selection, GNSS positioning systems, radio telemetry, and materials of construction.

Echosounder Selection

The TSF is usually characterized by relatively shallow water over much of the area, with gentle gradients and fairly uniform bottom topography. This situation is beneficial for echosounder selection, as relatively wide beam-width inexpensive echosounders can potentially be used. As shown in Figure 3, for a sharp gradient such as on the right hand side image, a wide beam echosounder may report biased and inaccurate depth readings compared to a narrow beam unit. One such location where a wide beam echosounder may be useless is in a steep-sided deep pit lake, where reflections from the side walls can distort the bathymetry dataset.

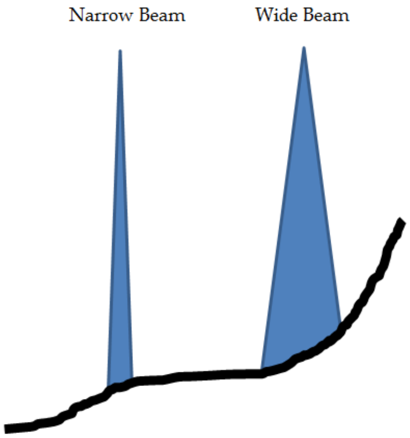


Figure 3. Narrow vs wide beam echosounder footprints.

The main characteristic of the TSF relating to echosounder operation is its gradual decrease in water content and associated increase in solids content with depth through the sediment, along with the potential for fine tailings to be suspended above the bottom. Shallow water echosounders usually operate at a sonar frequency of 200 kHz, which does not penetrate far into the sediment; the sonar ping may even be attenuated by suspended tailings leading to an inaccurate depth reading. Having the capability to adjust the bottom detection algorithm inside the echosounder may allow accurate data to be collected even with suspended solids layers. Therefore, although inexpensive sonars are viable candidates for the remotely-operated TSF survey boat, care must be exercised to ensure that potentially avoidable erroneous results are not recorded. For the most secure bathymetry data quality from the Z-Boat surveys, it is possible to use a 200 kHz or dual frequency 33 kHz & 200 kHz echosounder that records a full echogram "picture" of the sonar response for each ping. The echosounders that have been tested on the Z-Boat in the TSF environment are shown in Table 1.

Table 1 Echosounder types tested.

Echosounder Type	Relative Cost	Beam Angle (deg)	Minimum Depth (m)	Bottom Detection Adjustments	Quality Control
Airmar Smart Sensor DT800 200 kHz	$	15	0.5	None	None
Seafloor Systems SONAR M8 200 kHz	$$$	4	0.25	None	None
CEE HydroSystems CEEPULSE 200 kHz	$$$	9	0.25	Pulse width Sensitivity	None
CEE HydroSystems CEESCOPE 33 kHz & 200 kHz	$$$$$	8	0.15	Pulse width Sensitivity	Echogram record

GNSS Positioning Systems

The position of the Z-Boat on the TSF is determined by GNSS. The accuracy of GNSS receivers is largely dependent on the access to real time differential corrections that allow the rover to compute its position with consideration of the ionospheric errors that are present. As every region of the world has varying access to these differential correction services, a "one size fits all" approach could not be taken. Mine sites operate their own RTK (real time kinematic) differential correction networks and so the Z-Boat 1800 configuration ensures that any of the site's existing GNSS receivers may be used on the boat, or a new GNSS rover can be selected based on the particular location's requirements.

Radio Telemetry

For a remote survey vehicle, reliable radio telemetry is a critical requirement. The TSF presents a large area to survey; the boat may be outside adequate visual range, and there may be earthworks hindering line-of-sight. Hence, radio power is particularly important for TSF operation. Although the shore computer display is usually used to assist navigating the boat even on small areas, this becomes the only reference for larger surveys. For TSF surveys, increasing the range of the ***navigation*** (vessel control) system to 1500 m can be achieved using a high gain 9 dbi onmi-directional antenna on the boat. For surveying up to 2000 m distant, a flat 14 dbi plane antenna can be used on the shore side instead of the standard transmitter antenna. The ***data*** radio transmit range is 600 m when using industrial Bluetooth, but this can be increased to over 2000 m using Freewave 900 MHz or 2.4 GHz spread spectrum radios which are essential for larger TSF surveys.

Figure 4. TSF surveying in Democratic Republic of Congo – view at 250 m range.

Materials of Construction

The survey boat should be resistant to aggressive water, usually corrosive low or high pH. Fortunately during surveying, the total immersion time per exposure is relatively short so corrosion and degradation can be minimized. The use of acid-resistant ABS plastic, stainless steel, and Viton seals for the motor's rotating shafts ensure that the Z-Boat demonstrates good resistance through two weeks of acid immersion as shown in Figure 4. The echosounder transducer is not exposed to the water outside the hull, but is instead sealed in a propylene-glycol filled cavity inside the hull.

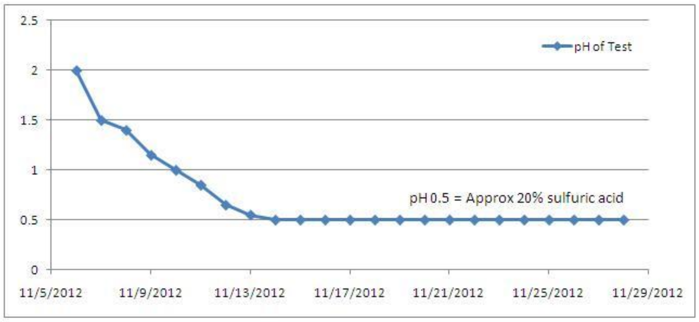


Figure 4. pH during Z-Boat acid resistance testing.

RESULTS AND DISCUSSION

The various GNSS options used on Z-Boat 1800 systems deployed on several TSFs showed no deviation from the expected behaviour. All GNSS rovers can be configured to output generic NMEA messages that are compatible with the Z-Boat. However, surveyors used to operating the rover on a survey pole were required to become familiar with the configuration software to switch the rover operation. The radio telemetry requirements for TSF surveying led to relatively poor results with the limited range industrial Bluetooth systems. The more robust Freewave-based radio can be positioned practically anywhere around the TSF and receive the incoming data, allowing for maximum flexibility in survey control locations.

Overall survey results have been positive with the echosounders tested; even the most inexpensive echosounder (Airmar DT800) has proven effective albeit with most of the surveys characterized by a relatively well defined water / solids interface. Figure 5 shows a map of the Z-Boat track and color-coded depth soundings from <60cm to over 10m for a location in the South-western US. The TSF is about 1.3 miles across with the survey conducted from three locations on the west side. Over several tests, the DT800 was somewhat unreliable shallower than 60 cm depth, unlike the other echosounders that continue to output accurate results up to the draft of the Z-Boat (25 cm).

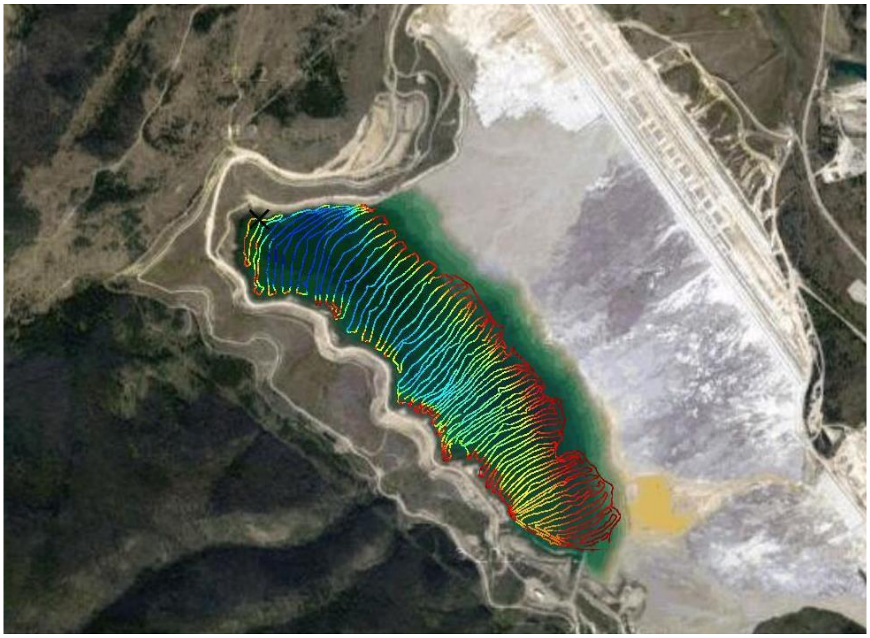


Figure 5. Z-Boat TSF survey completed in November 2012 using the Airmar DT800 with Trimble R8 GNSS.

The CEEPULSE and SONAR M8 echosounders offer hydrographic survey grade results to a stated 1 cm accuracy courtesy of their better transducers and more advanced bottom following algorithms. Although the DT800 performed satisfactorily, selecting a survey grade echosounder remains the prudent choice. Conventional hydrographic surveying calls for not simply the depth record, but a supporting echogram “sonar image” so the surveyor can visually inspect the results. This inspection allows erroneous data to be manually deleted or adjusted. The CEESCOPE 200 kHz echosounder fitted to the Z-Boat allows this echogram record to be inspected in real time or after the survey is completed, and represents the most error-proof configuration for TSF surveying. The image shown in Figure 6 is a slice through the water column along several metres, and resuspended material is clearly visible above the bottom on the left side. Without this ability to check sonar results the suspended matter may be falsely reported as the bottom on a "digital only" echosounder. Adding a second, 33 kHz sonar channel to the CEESCOPE allows the operator to work in deeper more turbid environments where the 200 kHz signal may be attenuated, and also investigate surface sediment thickness. The 33 kHz sound penetrates several meters into deposited sediment, allowing qualitative measurement of solids deposition.

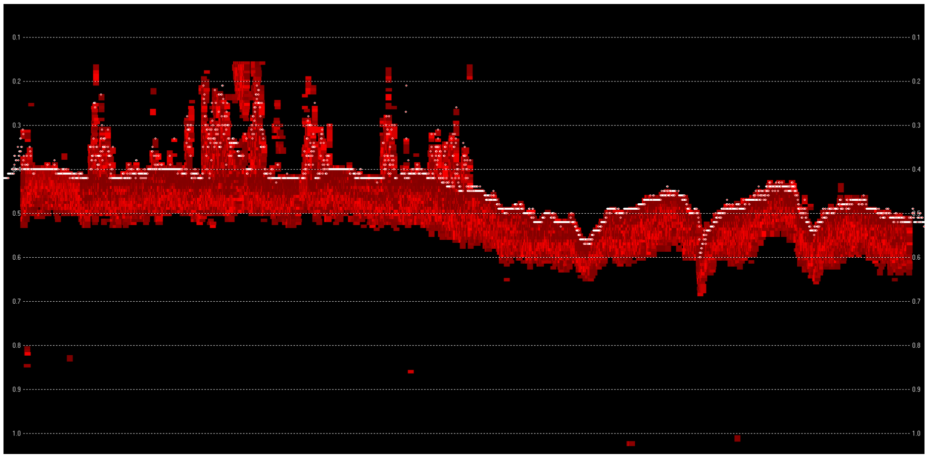


Figure 6. Real time output from Z-Boat with CEESCOPE 200kHz echogram recording sonar

CONCLUSION

The Z-Boat has already proven to be a successful tool for TSF surveying at several mine sites. With an echo sounder ping rate set at 2-10 Hz, it presents a step forward in survey coverage of the TSF compared to point shots using a sounding pole or a rudimentary sonar system. Not only is there far better accuracy, but confidence in the calculations that are based on this dataset increases significantly. Upon completion of the survey, depths may be converted to elevation and the data set imported into ArcMap (ESRI), MineSight, AutoCAD, or other mine management software. The bathymetry dataset can be merged with existing land survey topographic data to generate stage / volume / area curves for the TSF, offering engineers accurate existing water volumes and available storage above the existing water, along with identifying deposition patterns in the TSF. The stage-volume-area curves are vital pieces of information of site-wide water balance models. Engineers know how much water is sent out to the TSF, and how much is pumped back (through flow meters) but often evaporation, seepage, and void loss are estimated. Because these models are used to evaluate water security risks, not knowing the volume of recoverable water in the TSF can be a big data gap. A remotely-operated survey boat such as the Z-Boat allows the operator to overcome surveying constraints and bridge the data gap while at the same time contributing to safety improvements; some locations will inherently have more risks concerned with mine pond and specifically TSF surveying than others, but in every single case, getting people off the water in an industrial setting is a step in the right direction.

ACKNOWLEDGEMENTS

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NOMENCLATURE

GPS	Global Positioning System. The US government operated satellite positioning system.
GNSS	Global Navigation Satellite System. The overall satellite positioning system including but not limited to GPS. Also includes Galileo, GLONASS, Compass satellite constellations.

REFERENCES

No references.