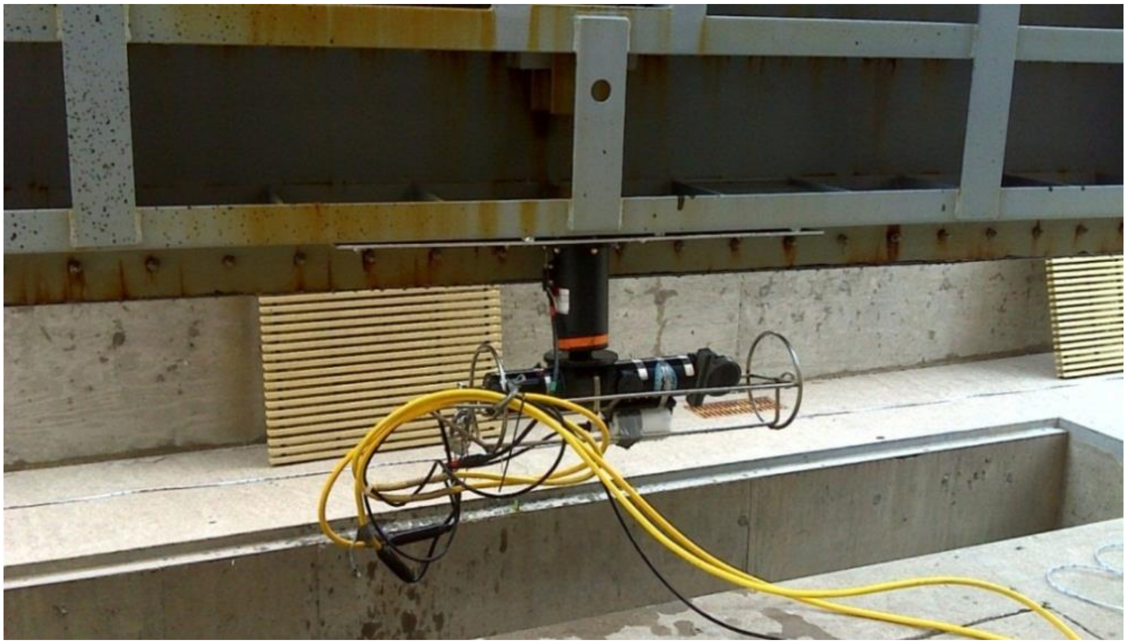
RECLAMATION

Managing Water in the West

Report DSO-2014-06

Scanning Sonar Technology Development

Dam Safety Technology Development Program



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Tracy B. Vermeyen, P.E.

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14. ABSTRACT
The problem with performing underwater inspections of hydraulic structures using divers or remotely operated vehicles is that visibility is often poor, which increases the time the inspection takes and reduces the inspection quality. Commercially available scanning sonar systems can be used to overcome this limitation because sonar works in highly turbid water to produce detailed images of underwater infrastructure. Scanning sonar can also collect survey grade bathymetry and three-dimensional (3-D) point clouds of underwater features. Point cloud data can be used to develop 3-D computer models or to compute estimates of lengths, areas, or volumes. Typical scanning sonar applications include inspections of scour, undercutting, concrete abrasion, exposed rebar, and accumulation of sediment around or debris on intakes. A scanning sonar system is currently being used for a variety of projects, which is critical for developing experience with sonar operation and interpretation of sonar images. This experience includes developing deployment techniques for inspecting features unique to large hydraulic structures such as embankment and concrete dams. The first few applications revealed the need to upgrade the sonar system with accessories to improve data quality, data collection efficiency, and the quality of geographic position data. This report describes the system enhancements and deployment improvements that have been achieved.

15. SUBJECT TERMS
scanning sonar, underwater imaging, bathymetry, three-dimensional point clouds, underwater inspection, hydraulic structures

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Prepared by:

Tracy B. Vermeyen, P.E.

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

BUREAU OF RECLAMATION

Dam Safety Technology Development Program
Hydraulic Investigations and Laboratory Services Group, 85-846000

DSO-2014-06

Scanning Sonar Technology Development

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Prepared by: Tracy B. Vermeyen, P.E. Date
Hydraulic Engineer, Hydraulic Investigations and Laboratory
Services Group, 86-68460

10/27/2014

Technical approval: Robert Einhellig, P.E. Date
Group Manager, Hydraulic Investigations and Laboratory
Services Group, 86-68460

10/27/2014

Peer review: Joseph Kubitschek, PhD, P.E. Date
Hydraulic Engineer, Hydraulic Investigations and Laboratory
Services Group, 86-68460

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Digitally signed by EVANS.JAMES.A.1230767870
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Date: 2014.10.27 09:46:15 -05'00'

External Peer review: James A. Evans Date
Senior Engineer, US Army Engineer Research and Development
Center, 3909 Halls Ferry Road, Vicksburg MS 39180

REVISIONS					
Date	Description	Prepared	Checked	Technical approval	Peer review

ACRONYMS AND ABBREVIATIONS

CCTV	closed-circuit television
DC-AC	direct current to alternating current
DGPS	differentially corrected global positioning system
GPS	global positioning system
MRU	motion reference unit
NMEA	National Marine Electronics Association
Reclamation	Bureau of Reclamation
ROV	remotely operated vehicle
RTK	real-time kinetic
VAC	voltage alternating current
2-D	two-dimensional
3-D	three-dimensional

Symbols

°	degrees
±	plus or minus

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BACKGROUND

The problem with performing underwater inspections of hydraulic structures using divers or remotely operated vehicles (ROVs) is that visibility is often poor, which increases the time the inspection takes and reduces the inspection quality. Commercially available scanning sonar systems can be used to overcome this limitation because sonar can "see" through highly turbid water to produce detailed images of underwater infrastructure. Scanning sonar can also collect survey grade bathymetry and three-dimensional (3-D) point clouds of underwater structures. Point cloud data can be used to develop 3-D computer models or to compute estimates of lengths, areas, or volumes. Typical scanning sonar applications include inspections of scour, undercutting, concrete abrasion, exposed rebar, and accumulation of sediment around or debris on intakes. The Bureau of Reclamation's (Reclamation) Hydraulic Investigations and Laboratory Services Group recently acquired a scanning sonar system and is developing operational protocols, which includes deployment techniques for inspecting features unique to large hydraulic structures such as embankment and concrete dams. The first few applications revealed the need to upgrade the sonar system with accessories to improve data quality, data collection efficiency, and the quality of geographic position data.

OBJECTIVE

The primary objective of this project has been to develop enhancements to a Kongsberg Mesotech Ltd scanning sonar system to improve data quality and data collection efficiency as well as to develop new applications that are relevant to dam safety related inspections. For example, scanning sonar can be used to image/survey underwater structures without having to dewater or reduce release flows. Likewise, scanning sonar can be used to inspect underwater construction, conduct search and recovery operations, and provide support for dive team inspections.

INTRODUCTION

Reclamation has an inventory of 476 dams, 53 hydropower plants, 2,015 bridges, and 8,100 miles of canals, all of which require regular inspections. These facilities contain many features that are underwater, which presents difficulties obtaining timely, reliable, and cost-effective access for inspections. Reclamation's Comprehensive Facility Review program requires periodic dam safety and operation and maintenance inspections to ensure facilities are operated and maintained in a safe and reliable manner. Historically, periodic diver inspections have been conducted over the life of a structure to assess condition, detect damage and schedule preventative maintenance. More recently, remotely operated vehicles (ROVs) with video cameras have been used for underwater inspections. In many cases, these inspections were conducted under challenging environmental conditions (i.e., strong currents, extreme depths, poor visibility, or excessive debris accumulation), which can limit video quality. An ongoing concern for diver and ROV inspections is obtaining accurate and repeatable documentation in the inspection reports. Reporting inconsistencies can occur when using different dive contractors or variable inspection techniques. Consequently, the facility manager may not get reliable condition assessments for their underwater infrastructure, which can result in costly unscheduled outages for repairs.

This report summarizes experiences using scanning sonar technology that can improve the repeatability and quality of underwater inspections.

WHAT IS A SCANNING SONAR?

SONAR is the acronym for SOund NAvigation and Ranging. Active sonar systems transmit sound pulses through the water and receive the reflected sound waves which can be recorded and post-processed for various purposes. With scanning sonar an image is made using the reflected acoustic signal strength to provide information about the objects or surfaces that reflect the acoustic pulses. Typically, strong reflectors are represented with bright colors, and dark colors are used to denote poor reflectors. The sonar transducer is attached to a precision stepper motor that rotates the transducer at increments as small as 0.225° (degrees). The scanning sonar system can be operated in three modes including two-dimensional (2-D) imaging which uses a 0.9° by 30° fan beam, 2-D profiling (point measurements), and 3-D point cloud. The sonar imaging mode uses a fan beam with a 30° fan beam angle (field of view). The sonar profiling and 3-D point cloud modes use a 1.7° wide conical beam to measure points. Point cloud measurements require a mechanical rotator to add a second plane of rotation. In the following sections, examples of the three operation modes are presented.

SONAR IMAGING TECHNOLOGIES

Prior to purchasing a scanning sonar system, available sonar technologies were evaluated for inspecting hydraulic structures and included side-scan, forward-looking, and multibeam sonars. Side-scan and multibeam sonars are typically used to image large areas from a moving platform. While forward-looking sonars can be used with either moving or stationary platforms, they do not have scanning capability. Conversely, scanning sonars are typically used from a stationary platform, which allows the user to collected images at different resolutions (ranges) and to adjust system settings to capture the highest quality image.

Subsequent inspections can be made from the same location to produce images that can be compared with previous images to detect changes. Furthermore, scanning sonar systems have an integrated stepper motor that precisely locates the sonar head. Pitch, roll, and heave sensors are used to compensate for system movement during data collection. An electronic compass allows the collection of georeferenced images by providing the magnetic heading when coupled with the geographic position of the sonar system.

In 2011, Reclamation acquired a scanning sonar system from Kongsberg Mesotech Ltd. The 1171-Series sonar system is capable of imaging underwater infrastructure in zero visibility water, in strong currents, and at depths up to 500 feet. The sonar features a 675 kHz acoustic transmitter with a range of up to 450 ft. When deployed properly, this scanning sonar can produce repeatable and dimensionally accurate images of underwater structural features with a range resolution as low as 0.06 ft (depending on sonar range). Reclamation engineers are currently developing deployment methods and inspection techniques for a wide range of applications. In general, scanning sonar can produce plan, front, and side view images depending on the instrument’s orientation with respect to the area of interest. Scanning sonar can also be used to measure profile points in a plane (vertical or horizontal) that can be used to build 3-D point clouds of bathymetry or structural features (similar to terrestrial laser scanning applications). Sonar images and profiles can be analyzed to determine bearing and range to a feature and to measure area, perimeter, or object height. It is important to note that high-resolution scanning sonar systems are capable of producing images with excellent detail; however, sonar images are not photographs, and their interpretation requires an experienced operator.

Acoustic Imaging

Acoustic images are collected by submerging the scanning sonar instrument and rotating the acoustic fan beam to cover the area of interest. Images from multiple locations can be combined to create a mosaic image of large areas. The sonar has an acoustic range of up to 500 feet and can be used at depths up to 9,000 feet (it was designed for deep ocean applications). The image resolution depends on the range and instrument configuration. High-resolution configurations can detect offsets greater than 1.2 inches and measure distances to within ±1 inch. The sonar can also detect changes in materials because the acoustic reflection strength will vary with material properties. For example, water stop joints in a concrete structure will appear darker than concrete because the softer material will absorb some of the acoustic energy (see figure 1). The sonar’s orientation will depend on whether a plan view or front view is desired. The sonar will collect a 2-D image normal to the long axis of the transducer housing. A horizontally-oriented sonar will produce a front view of a vertical surface like a concrete dam face or stilling basin wall. A vertically-oriented sonar will produce a plan view of a flat surface (or sloped) like a stilling basin floor.

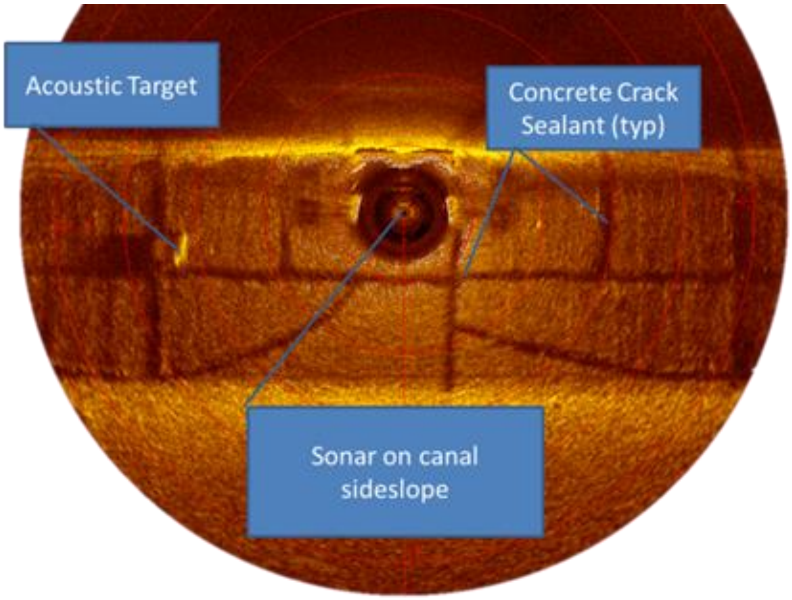


Figure 1.—Sonar image of a concrete-lined canal bank repaired with flexible crack sealant.

Acoustic Profiling

Similar to terrestrial laser scanning, scanning sonar surveys can be used to create 2-D profiles along underwater surfaces or structures. Additional profiles can be acquired by rotating or relocating the sonar. All data collected below the water line can be tied into the project datum using a real-time kinetic (RTK) global positioning system (GPS) and the sonar system electronic compass. Figure 2 illustrates how an horizontally mounted sonar can be used to profile a powerplant tailrace structure.

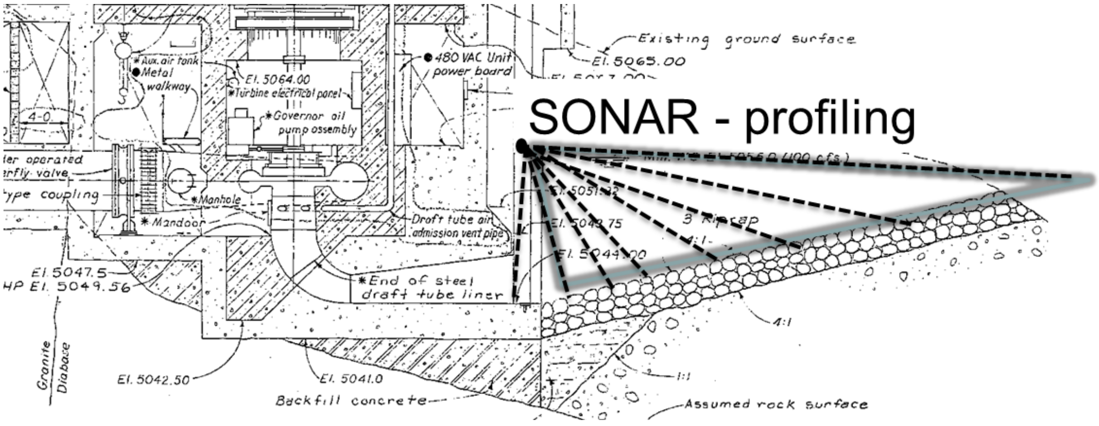


Figure 2.—Section view of a sonar profiling application at a powerplant and tailrace.

Point Cloud Surveys

Adding a precision mechanical rotator to the scanning sonar system allows for efficient collection of 3-D point cloud survey data. Point clouds can be imported into commercial software to create 3-D models of an underwater structure and surrounding bathymetry. The 3-D data can be combined with abovewater laser scanner point clouds to create a complete 3-D model of a hydraulic structure. This sonar application will allow Reclamation facility managers to document the condition of their structures. Comparisons with subsequent point clouds can be used to decide if divers are needed to verify any observations of concern. An example point cloud dataset was collected in a pump sump at our hydraulics laboratory in Denver, Colorado. Figure 3 shows a photograph of the dewatered pump intake sump and a high-resolution 3-D point cloud of the water-filled sump. These types of datasets can be used for condition monitoring or documenting as-built dimensions.

Figure 3.—Left – Photograph of a pump sump in Reclamation's hydraulics lab in Denver, Colorado. Right – 3-D point cloud of the water-filled sump (over 100,000 profile points) overlaid on the photograph.

Bathymetric Surveys

This scanning sonar system can be used in echosounder mode with a RTK GPS system to collect survey-grade bathymetric data. Kongsberg’s echosounder data processing software, BathyXYZ, can be used for coordinate conversion, projection, and datum adjustments. Figure 4 is an example of a bathymetric survey of the reservoir side of an embankment dam. The survey area covered about 8 surface acres and over 45,000 survey points, which were collected in about 4 hours.

A unique feature of using imaging sonar for bathymetric surveys is that the data file contains images along with the profile points. The images can be reviewed to confirm anomalies in the echosounder data. For example, when fish causes a false bottom detection. Likewise, the echosounder images can be used to located

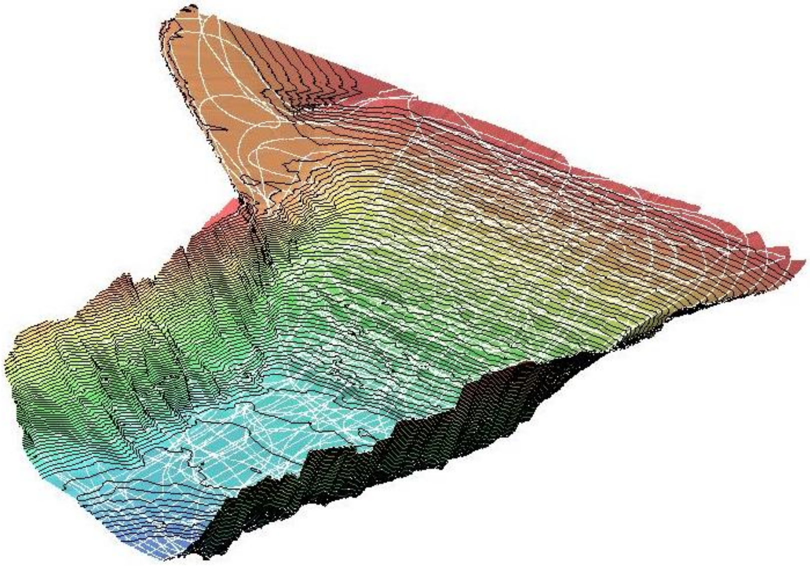
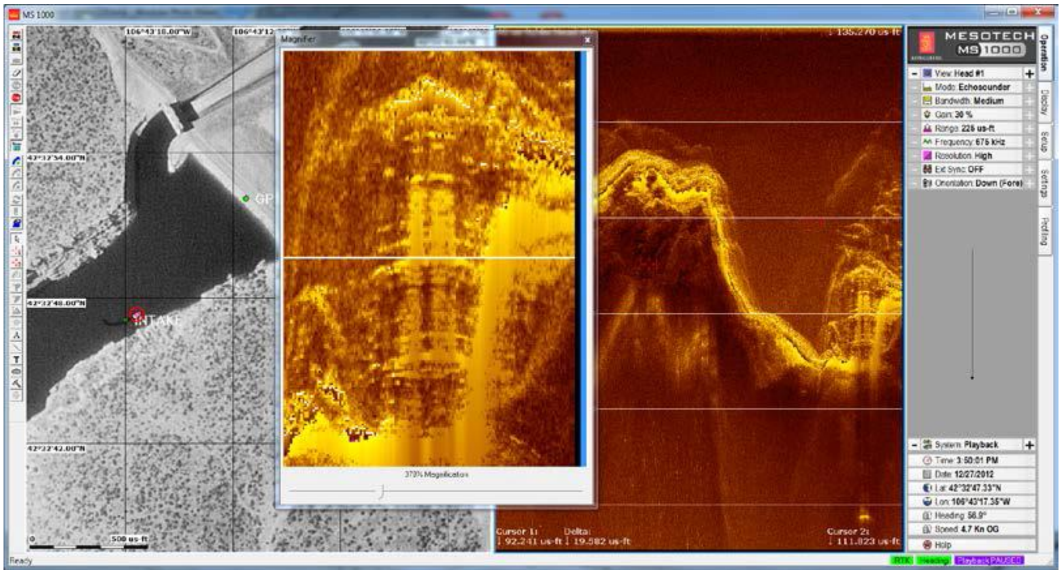


Figure 4.—Forebay bathymetry upstream of an embankment dam. A boat-mounted sonar and RTK-GPS system were integrated to collect this detailed survey data. The white dots are the echosounder profile points and the black lines are the elevation contours.

submerged features, such an intake tower, in the reservoir bathymetry data file. For example, during the bathymetric survey mentioned above, the intake tower was located and imaged (figure 5). Without sonar imaging capability, it would have been difficult to ascertain the intake from the canyon wall.



View: Head #1
Mode: Echosounder
Bandwidth: Medium
Gain: 30 %
Range: 226 us-ft
Frequency: 675 kHz
Resolution: High
Ext Sync: OFF
Orientation: Down (Fore)
System: Playback
Time: 3:50:01 PM
Date: 12/27/2012
Lat: 42°32'47.33"N
Lon: 106°43'17.35"W
Heading: 56.9°
Speed: 4.7 Kn OG

Figure 5.—MS1000 display with trackplotter (left panel) and sonar image (right panel) as the survey boat passed over the intake structure. The intake structure is magnified in the center panel, which shows concrete beams and some horizontal trashrack spacer bars.

SONAR SYSTEM ENHANCEMENTS

After completing several sonar projects, it was clear that sonar system enhancements were needed to improve the quality and efficiency of sonar inspections. For example, attempts to collect several 2-D profiles to develop a 3-D model of near-structure bathymetry were very time consuming, and the results were unacceptable. Data quality suffered from having to relocate the sonar at the same depth and orientation at adjacent locations. Each location had unique pitch, roll, heading, and depth offset that had to be accounted for in data processing. Using a mechanical rotator to position the scanning sonar would help eliminate the difficulty in obtaining 3-D point clouds. Furthermore, the sonar system's electronic compass, pitch, and roll sensors do not function properly when the sonar was horizontally mounted. To compensate for this limitation, an external motion reference unit (MRU) is needed to compensate for pitch, roll, and heave. An MRU can also include an electronic compass to provide heading information to the sonar's data processing software.

Mechanical Rotator

Adding a precision mechanical rotator to the scanning sonar system facilitates the collection of point cloud data that can be used to create high-resolution 3-D models of underwater features and hydraulic structures. Underwater point clouds can be combined with laser scanner point clouds above the water surface to create a complete 3-D representation of a hydraulic structure.

In 2013, a Kongsberg Mesotech Ltd single-axis, heavy-duty rotator (part number 806-00360000) was acquired to add a second axis of rotation to the scanning sonar system (figure 6). The high precision rotator has a torque rating of 65 foot-pounds and is capable of rotating loads up to 150 pounds. The rotator has a user-defined angular step size (ranging from 0.45 to 18°), which is used to control data density in the point cloud.

Figure 6.—Kongsberg Mesotech Ltd single-axis mechanical rotator with communication/power interface unit.

The rotator system is easily integrated into the MS1000 data collection software. The rotator requires its own interface unit – the MS1000 USB Rotator Interface Unit (part number 901-60270000), which provides an isolated interface between the USB port of a laptop PC running a MS1000 software processor. The rotator interface is powered with 110 VAC, which requires a DC-AC inverter when running the system using 12-volt batteries. Specification sheets for the rotator and USB interface are included in attachment A of this report.

The MS1000 software is used to set up the sonar and rotator for 3-D data collection. During data collection, the software plots the profile points in a 3-D viewer in real-time, which is useful for monitoring data quality.

Kongsberg's BathyXYZ software is an echosounder data processing utility that can be used to review and filter point cloud data. In addition, there are many third-party software packages that can be used to post-process point cloud datasets. Post-processing is commonly used to merge multiple point clouds, compare point clouds to find dissimilarities, change coordinates systems, or adjust vertical datums.

Motion Reference Unit

An MRU is designed to accurately measure pitch, roll, heading, and heave for surface and underwater applications with static or dynamic conditions. The digital compass in the Kongsberg scanning sonar system measures pitch, roll, and heading, but it only works while the sonar is vertically oriented. To accommodate other mounting orientations, an external MRU is required to provide reliable data to the MS1000 data acquisition software.

A Think Sensor Research TSR-100 MRU was acquired in 2012. This MRU consists of the sensor package and a communications/power interface (figure 7). The MRU was also equipped with pressure and temperature sensors, which are data required to compute the speed of sound in water. Specification sheets for the TSR-100 are included in attachment A of this report.

The TSR-100 MRU can be mounted in any orientation on vessels, ROVs, fixed deployments, or other structures to support scanning sonar data collection for sonar imaging along with bathymetric and point cloud surveys.

For the MS1000 software to import MRU data into the sonar data file, the MRU system must be able to output data strings in NMEA 0183 format (a standard for data communications published by the National Marine Electronics Association). NMEA strings are transmitted into the laptop via a USB to a RS485 communications connection.

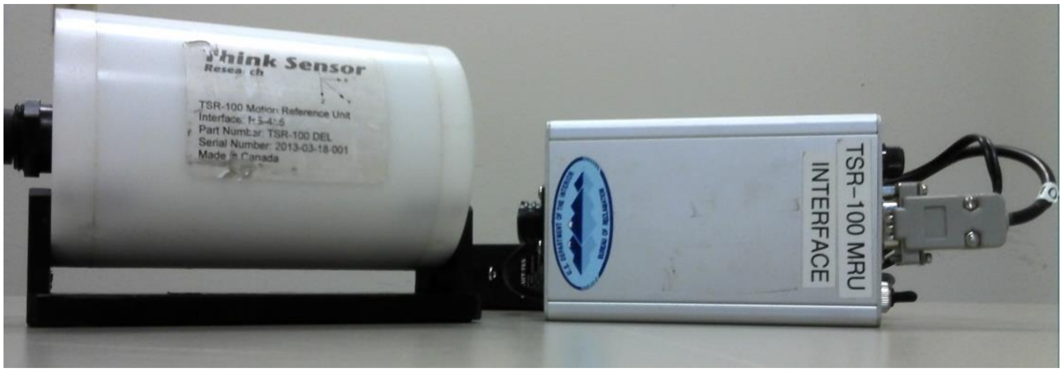


Figure 7.—Think Sensor Research TSR-100 MRU (left) and a communications/ power interface.

Robotic Crawlers

Reclamation's Technical Service Center has been using closed-circuit television cameras (CCTV) on robotic crawlers for video inspection and evaluation (Cooper 2005) of toe drains, pipelines, siphons, and penstocks. CCTV inspections can be hindered by turbid waters, which limit visibility. A scanning sonar system can be used in turbid water for both imaging and profiling the conduit surface. A proof of concept test was conducted in our hydraulics laboratory to confirm that a crawler can effectively move the sonar along a flat, concrete channel. The scanning sonar was attached to a VersaTrax crawler (parallel system) and lowered into a rectangular concrete reservoir. Figure 8 is a photograph of the crawler, camera, lights, and scanning sonar system as tested in the hydraulics laboratory water reservoir. For this simple test, the crawler easily moved the sonar back and forth along the channel bottom. The scanning sonar profile images were monitored to navigate the crawler so that it stayed on the channel centerline while the camera was pointed forward. When visibility is poor, the video camera and lights can be removed to lighten the payload. The crawler with a sonar setup can be used in pipes with diameters greater than 20 inches and has a 500-foot maximum travel length (limited by the sonar cable length).

GPS Systems

To date, RTK and differentially corrected GPS (DGPS) systems have been tested to provide geographic positions to the MS1000 data acquisition software. A Trimble R6 system was used for RTK-GPS projects, and a Trimble Pathfinder ProXT® system was used for DGPS projects. Using RTK-GPS is more time consuming to set up, requires more effort to post-process the data, and it can be difficult to transport all the components – GPS receivers (2), radio (1), tripods (2), batteries (2), and antennas (3). On the other hand, the Pathfinder ProXT fits in a small equipment case that can be easily transported to and set up at the project site.

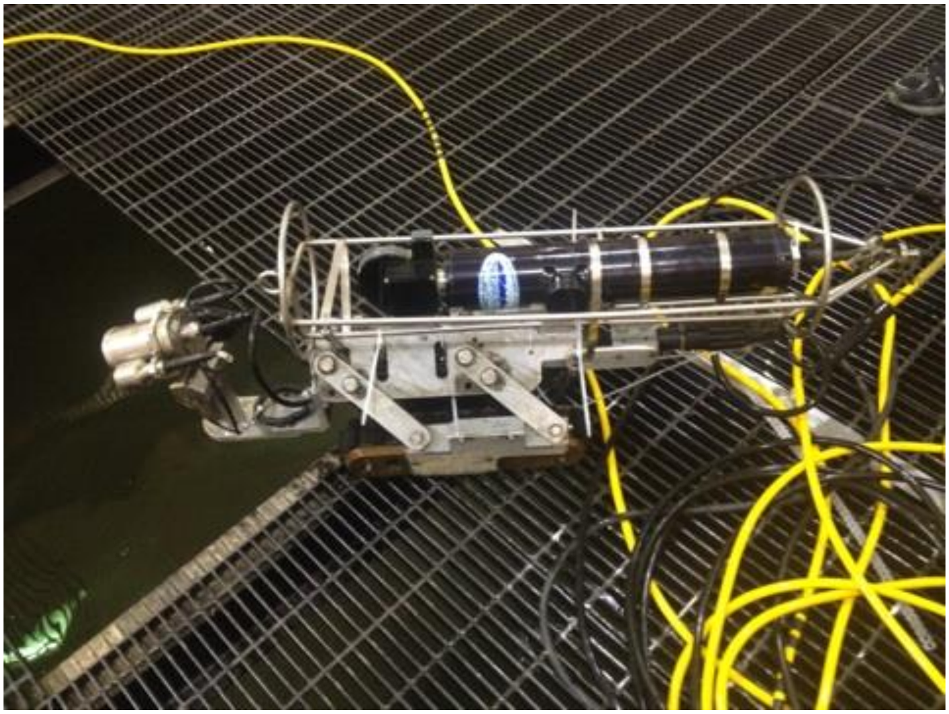


Figure 8.—Photograph of VersaTrax crawler with a scanning sonar attached. The crawler also has a camera and lights attached (left side). As shown, this system requires two cables to deploy the crawler and sonar.

RTK and DGPS with post-processing can provide position data with horizontal uncertainties of 5 and 50 centimeters, respectively. When possible, RTK-GPS should be used for bathymetry and point cloud surveys because these surveys are likely to be repeated in the future, and having accurate horizontal positions and elevations will facilitate survey comparisons. Furthermore, if water surface elevation measurements are an important component of the survey, RTK-GPS must be used to obtain sufficiently accurate elevations. In most cases, elevations tied to a Reclamation project datum are computed using the reservoir water surface elevations at the time of the survey. In addition, RTK-GPS can provide an accurate measurement of heading for moving boat applications. GPS headings can be used to post-process bathymetry data if the MRU compass malfunctions or drifts out of calibration.

For sonar imaging projects, a DGPS may provide position with sufficient accuracy to document the sonar locations when images are mosaicked manually in software packages like Adobe Photoshop or Microsoft Powerpoint. However, third-party software packages that use sonar images tagged with GPS positions to automatically create a mosaic of the image area will perform better and require less editing time if RTK-GPS positions are used rather than DGPS.

For the MS1000 software to import GPS data into the sonar data file, the GPS system must be able to output GPS data strings in NMEA 0183 format. NMEA strings are usually transmitted into the laptop via a RS-232 serial communications connection.

Laser Range Finder

Figure 9.—TruPulse 200 laser range finder. (Image courtesy of Laser Technology, Inc.)

For a few scanning sonar projects at Reclamation dams (e.g., Olympus and Crystal Dams), GPS data could not be reliably collected because the close proximity to the dam face resulted in poor satellite coverage or created multipath errors. For areas with poor GPS conditions, a Laser Technology Inc. TruPulse 200 laser range finder (figure 9) was used to measure distances from the sonar location to a prominent feature that appears in the sonar image. For example, at Crystal Dam a corner of a powerplant structure was always visible by the sonar when the tripod-mounted sonar was deployed at several locations. The sonar distance measuring tool can be compared to the laser distance measurement to confirm the sonar relative position. The TruPulse 200 has a distance measurement uncertainty of ±1 to 3 feet depending on the target quality.

SONAR DEPLOYMENT SYSTEMS

Successful collection and interpretation of scanning sonar images requires the system be deployed so sonar position and orientation are known. Likewise, keeping the sonar stable during data collection will produce the highest quality images and profile data. When working around hydraulic structures, it is recommended that the design drawings (preferably as-built) be reviewed in advance to assist with the proper deployment and real-time interpretation of the sonar images.

The following sections will briefly describe several scanning sonar deployment systems and their operational limitations.

Vertical Orientation

Sonar images collected with the sonar in a vertical orientation (typically deployed on a tripod, figure 10) will represent a 2-D plan view of the area below the sonar. The tripod should be equipped with a gimbal connection that ensures the sonar hangs vertical if the tripod is placed on an uneven surface.

Figure 10.—Gimbal-mounted scanning sonar on a tripod. This tripod system will produce a vertical orientation on an uneven or sloped surface.

Examples of tripod-mount scanning sonar applications include:

- Imaging spillway and stilling basin floors to detect damaged concrete, exposed rebar, and sediment/debris accumulation. Figure 11 is an example of a stilling basin inspection at Olympus Dam near Estes Park, Colorado.

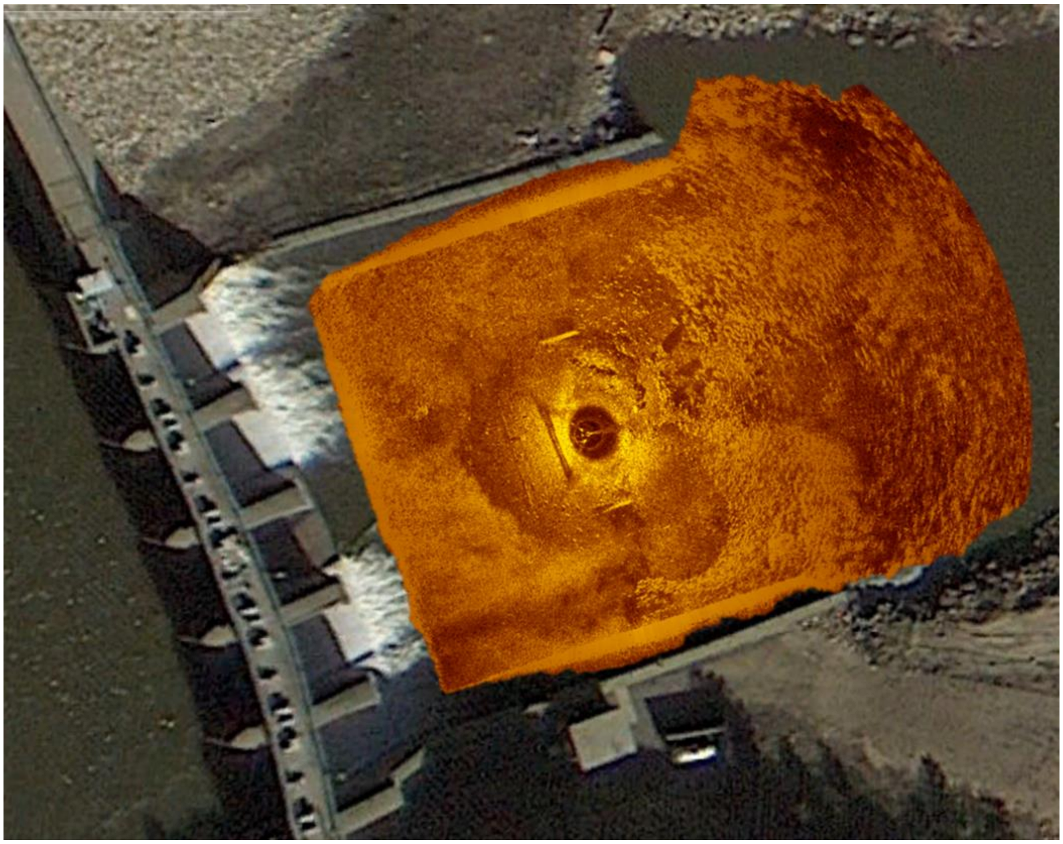


Figure 11.—Acoustic image of the Olympus Dam spillway apron using a 120-foot acoustic range. The acoustic image is not to scale so the spillway walls can be referenced to the walls in the aerial photograph.

- Imaging streambeds to detect scour or sediment deposition around hydraulic structures such as fish screens or diversion dams.

- Profiling of vertical shafts or intakes to assess concrete or steel liner condition at multiple elevations.

Figure 12 is an example of using the measurement tools to document underwater features that were observed in the Olympus Dam spillway. The geographic position of two outfall drains, located on either side of the sonar (dark oval), were documented with the dimensioning utility along with the GPS coordinates of the sonar position. Likewise, estimates of the sediment deposition area and perimeter (2,143 square feet and 314 feet, respectively) were determined with an area measurement utility.

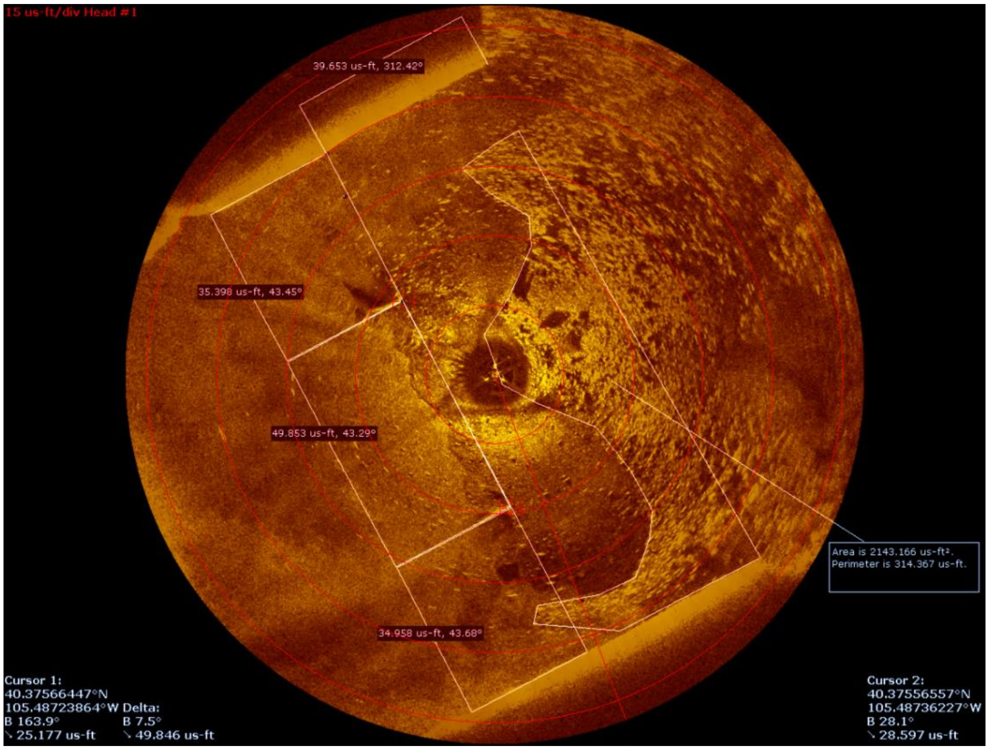


Figure 12.—Annotated acoustic image of the Olympus Dam spillway apron using a 90-foot acoustic range. The GPS coordinates for the lower split-drain outfalls are noted by cursor 1: @ left block and cursor 2: @ right block. The lower split-drain outfalls terminate about 40 feet from the spillway's end sill. This image also contains estimates of the debris pile area and perimeter, which are 2143 square feet and 314 feet, respectively.

In general, these similar applications can be performed on any sloped surface, like a concrete-lined canal bank, by deploying the sonar perpendicular to the surface using a wheeled cart (figure 13). A recent project was successfully imaged by lowering the sonar down the dam face using this method (Vermeyen 2013a). The scanning sonar was used to collect a front view image of the concrete dam face and canyon walls in an effort to determine if the penstock intake tower was partially covered with rock. An analysis of the image indicated that the intake trashrack was in fact covered with debris. Figure 14 is the sonar image, which clearly shows the river outlet trashrack, but shows a debris pile where the penstock intake trashrack is located.

Figure 13.—Custom wheeled cart that is used to lower the sonar down a sloped concrete surface to image the canal lining.

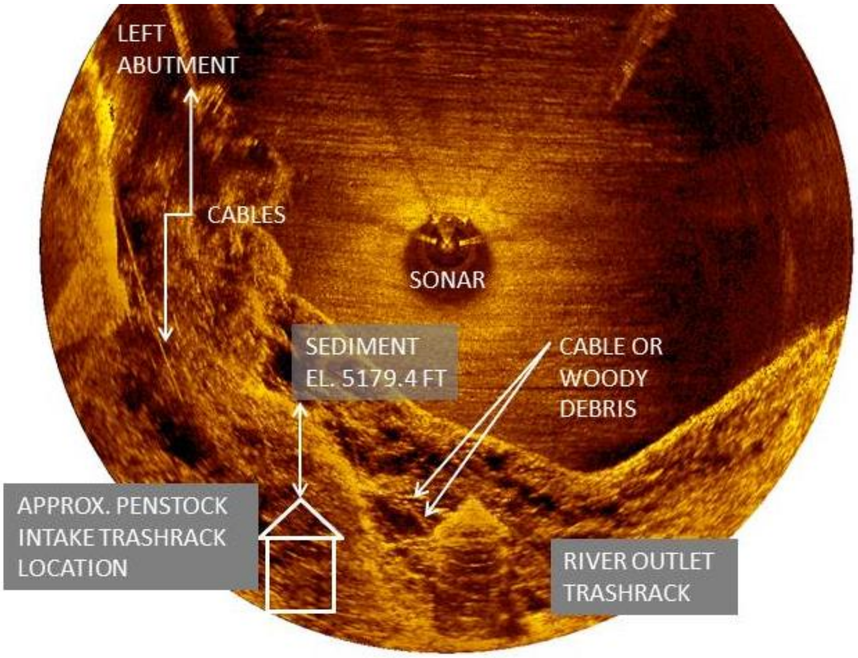


Figure 14.—Scanning sonar image (front view, looking downstream) of a concrete dam face (smooth, darker area around the sonar) and upstream sediment accumulation (uneven, yellow area below the sonar) that has covered the penstock intake trashrack (Vermeyen, 2013b).

Horizontal Orientation

Sonar images collected with the sonar in a horizontal orientation (typically deployed from a pole mount, figure 15) will represent a 2-D front view of a vertical surface around the sonar.

Example applications include:

- Imaging walls, concrete dam faces, slide gates, trash racks, and fish screens.
- Bathymetry surveys with the scanning sonar configured as an echo sounder.
- Side-scan sonar survey with the sonar head fixed at some angle to the water surface.

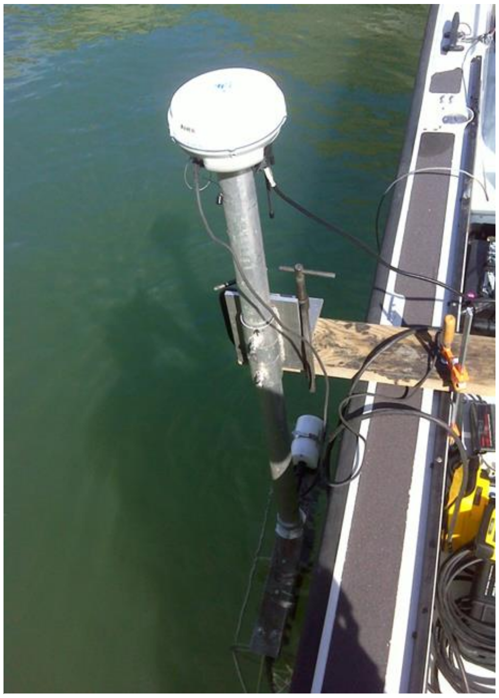


Figure 15.—Photograph of a pole-mounted sonar with an external MRU (white cylinder) that was used during a bathymetric survey.

- Point cloud surveys can be done in either orientation, but a horizontal mount is more practical for most applications. For these applications, an external MRU must be used to get accurate position information for x, y, z points. This is especially critical if multiple point clouds are going to be combined to form a large-scale 3-D model of the area.

A recent 3-D point cloud survey was conducted to document concrete damage in a powerplant tailrace. The scanning sonar and rotator were mounted to the bottom a bulkhead gate (figure 16). The bulkhead gate was lowered until the sonar was submerged. The 3-D point cloud survey acquired 23,800 profile points in 2 hours. Figure 17 is a contour plot of the draft tube and tailrace apron that was developed using the 3-D point cloud.

Figure 16.—Photograph of the KML MS1000 scanning sonar system with a rotator (cylinder located above sonar) mounted to a tailrace bulkhead gate. The bulkhead gate was lowered to the desired elevation with the powerplant's gantry crane.

As previously described, a scanning sonar image was used to confirm debris accumulation around a penstock intake trashrack (see figure 14). A followup bathymetric survey was conducted to describe the debris accumulation in the canyon upstream of the dam. Working in the steep canyon environment resulted in poor RTK-GPS data quality because of the low number of visible satellites. As a result, near-dam bathymetry data were not obtained for the penstock intake. To obtain the required bathymetric data near the dam face and narrow canyon, the scanning sonar, rotator, and MRU were set up on a wheeled cart and lowered down the dam face. This setup was used to collect a 3-D point cloud of the forebay. The sonar was configured with a 300-foot profiling range that covered the canyon width, maximum depth, and distance from the dam to the canyon entrance. A high-resolution point cloud survey was completed in 2.5 hours and produced 19,000 raw profile points. The point cloud dataset was post-processed

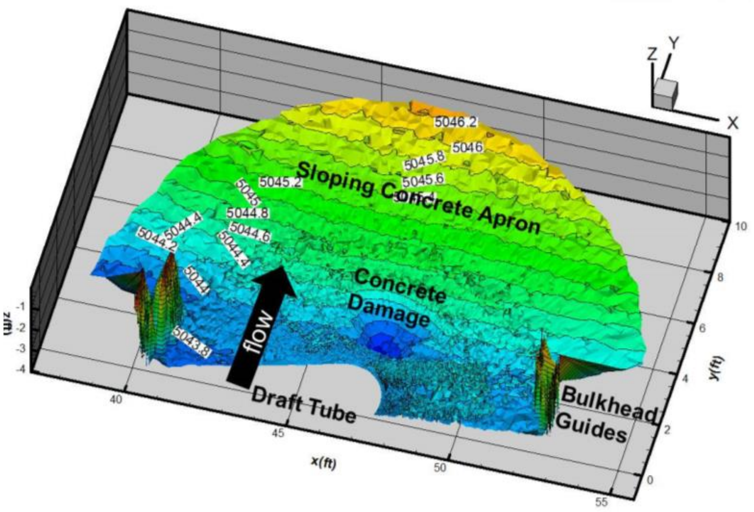


Figure 17.—Contour plot of the concrete damage in a powerplant tailrace. Data from a 3-D cloud survey was used to create the contours.

to remove extraneous profile points and a 2-foot resolution contour map of the near-dam bathymetry was created (figure 18). These survey data were tied to the Reclamation project datum using the sonar position (northing and easting) and elevation in the bathymetry data processing software. This sonar project is a good example of how a bathymetry survey can be done when using RTK-GPS is not possible.

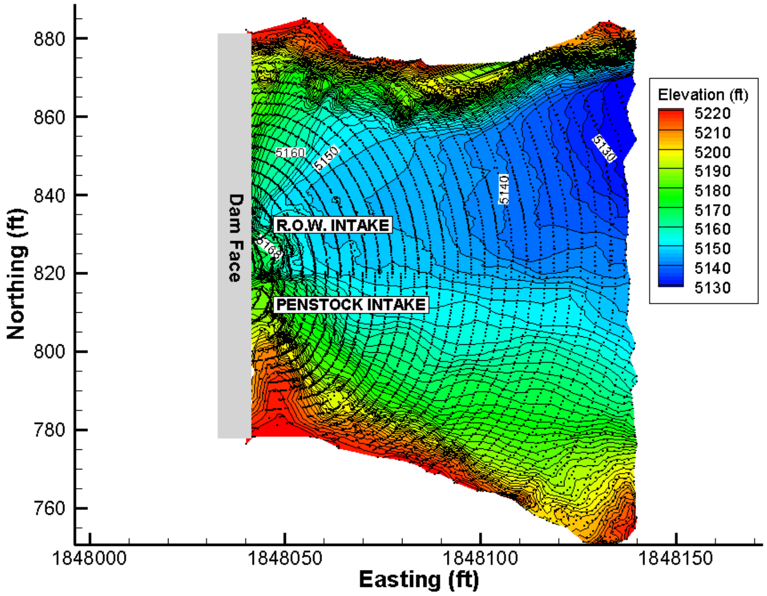


Figure 18.—Near-dam 2-foot contour map developed using 3-D point cloud data collected with the sonar deployed down the dam face on a wheeled cart.

CONCLUSIONS

Scanning sonar technology has many inspection and survey applications for water resource projects. In the future, it is likely that facility inspection programs will require sonar images of features that cannot be inspected by divers. While sonar imaging will not supplant the need for dive inspections, it could reduce the number or duration of dive inspections by identifying areas of concern and concentrating the dive inspections at those specific locations.

Scanning sonar systems can produce detailed acoustic imagery of underwater features when other methods of inspection are impractical because of poor visibility, strong currents, unsafe access, or excessive depths.

During this technology development project, the scanning sonar system was successfully upgraded with a mechanical rotator and motion reference unit to improve the efficiency of point cloud data collection and the quality of the acoustic images.

Scanning sonar systems can be used to collect repeatable bathymetric surveys in areas where GPS systems do not work because of poor satellite coverage or multipath errors.

While funding and travel restrictions prevented participating in a dive inspection, a scanning sonar system should be evaluated as a pre-dive inspection tool to evaluate environmental and potential entanglement hazards to minimize risks during dive inspections.

Scanning sonar projects require careful planning for a successful outcome. A review of design drawings can assist with deployment planning and interpretation of real-time imagery. A successful project depends on careful attention to sonar alignment, providing a stable platform, documenting sonar positions, and taking detailed notes on the system configuration.

Scanning sonar technology is rapidly evolving with the recent development of variable frequency transducers, which improve image resolution over a wide range of scanning distances. It is recommended that scanning sonar technology be re-evaluated in the near future.

This project provided the opportunity to test and improve deployment methods for a wide range of scanning sonar applications. Reclamation’s hydraulics laboratory proved to be a valuable initial testing ground for scanning sonar technology development. Laboratory testing to verify that all system components were properly configured was critical for successful field demonstration.

REFERENCES

Cooper, Chuck R., 2005. "Closed Circuit Television Inspection of Outlet Works and Spillway Conduits and Toe Drains." Association of State Dam Safety Officials Annual Conference.

Vermeyen, Tracy B., 2013a. Scanning Sonar Survey Report- Buffalo Bill Dam River Outlet and Powerplant Intakes, Bureau of Reclamation, Technical Service Center, Hydraulic Laboratory Technical Memorandum, PAP-1072, January 2013.

_____, 2013b. "Sonar Scans Reveal Sedimentation Issues with Shoshone Powerplant Intakes" in *Hydro Review*, Vol. 32, No. 4, May 2013.

ATTACHMENT A

Product Specifications

SCANNING SONAR SYSTEM

3000 m “High Resolution”
Geared Fan/Cone Sonar Head
Digital Telemetry

KONGSBERG

P/N 974-23050000

This version of the 1071-Series Sonar has been specifically designed to produce the highest resolution scanning sonar images possible with 675 kHz. Its design is targeted at bottom clearance, body recovery, underwater construction, pipeline inspection, cable route survey, bridge/pier inspection and applications where data clarity supercedes any other requirement.

This sonar head should also be considered in conditions where the in-water temperatures are lower than 4° C, or higher than 20° C. Domed, oil-filled heads may acoustically defocus beyond these temperature ranges. This sonar head incorporates the electronic advantages of increased sampling rates, wider receiver bandwidth, increased power output, and a very narrow horizontal beam pattern with the fan transducer. The telemetry is RS 485 and RS 232 compatible, and is automatically sensed and configured. The transducer is of a bare-shaft design, but the motor-end is oil compensated to prevent water ingress into the main electronic stack via the transducer shaft.

The sonar head is compatible with the MS1000 and MS900D Surface Processors. To take full advantage of the advanced features and high resolution this head has to be operated with the MS1000 processor.

Operating Frequency	675 kHz
Beam Width	0.9° X 30° Fan/1.7 X 1.7° Cone (nominal)
Range	0.5 - 100 Metres typical; 150 Metres obtainable
Range Resolution	≥ 19 mm (@ 1500m/sec speed of sound, 25 µs transmit pulse)
Sampling Resolution	≥ 2.5 mm
Scan Angle	360° continuous
Mechanical Step Size	≥ 0.225°
Scan Speed	nom 11 sec/360° @ 10 m and 1.8° step size (@ 230 kbits/sec.) nom 36 sec/360° @ 100m and 1.8° step size (@ 230 kbits/sec.)
Transmit Pulse Lengths	25 - 2500 µs
Transmit Power	OFF, 50 W nom, 500 W nom
Receiver Bandwidth	12/100 kHz
TVG Control	-20 to +100 dB
Telemetry	RS 485/RS 232 auto switching asynchronous serial data
Telemetry Rates	Downlink: 9600 Baud Uplink selectable: 230K, 115K, 57K, 38K, 19K, 9600 bits/sec automatic (to suit cable telemetry)
Power Requirements	33W, 22 - 60VDC
Temperature Ranges	-10 to +40° C operating -30 to +40° storage
Operating Depth	3000 meters
Connector	Seacon RMG-4-BCL (optional connectors; inquire to factory)
Materials	Aluminum 6061-T6, 300-Series SS
Dimensions	Diameter 3.5”/89 mm Length 22.4”/569 mm Transducer width 5.5”/140 mm
Weight	In air 13.5 lbs/6.1 kg, In water 6.5 lbs/2.9 kg
Options:	-7801 Built-in Security Key

MECHANICAL ROTATOR

Positioning Devices

KONGSBERG

Single Axis Heavy Duty Rotator

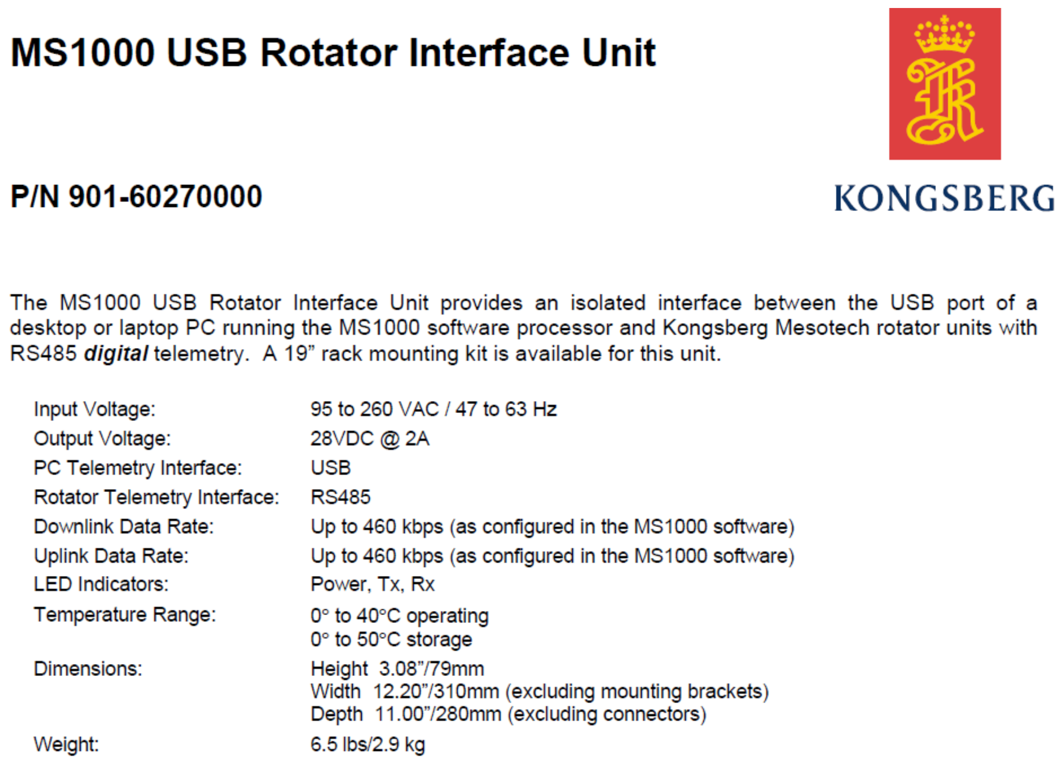
(***SEACON 5-pin, FAWL-5P-MP Series Connector*** **configuration)**

P/N 806-00360000

This Single Axis Heavy Duty Rotator is a powerful positioning device. This device offers torque ratings up 65 ft-lbs and is able to position heavy loads with ease and high accuracy. It has a corrosion resistant underwater housing with a relatively small footprint.

Electrical	
Input Voltage	15-30 VDC
Maximum Drive Current	300 mA – 2.2 A (load and speed dependent)
Maximum Static Current	300 mA – 1.2 A
Maximum Output Torque	65 ft-lb (88 Nm)
Maximum Payload	150 lbs (68 kg)
Output Speed	0.5 to 35 deg/s
Position Feedback	12 bit resolution (approx 0.1°)
Communication	RS-485
Connector	Seacon FAWL-5P-MP
Mechanical	
Gears	Precision strain wave gearing
Backlash	<36 arc minutes (approx 0.5°)
Dimensions	4.62 in OD x 9.7 in long (117 mm OD x 246 mm long) 6.75 in (171 mm) Flange OD
Weight in Air	15.5 lbs (7.1 kg)
Weight in Water	9.9 lbs (4.5 kg)
Pressure Compensator	Internal diaphragm
Position Limits (optional)	+/-175° (other configurations available)
Environmental	
Operating Depth	Up to 10,000 ft (3000 m)
Temperature Range	-20 °C to +50 °C (-4 °F to +122 °F) operating -30 °C to +60 °C (-22 °F to +140 °F) storage
Housing Material	Anodized 6061-T6 Aluminum
Fastener Material	316 Stainless Steel

MECHANICAL ROTATOR INTERFACE



MS1000 USB Rotator Interface Unit

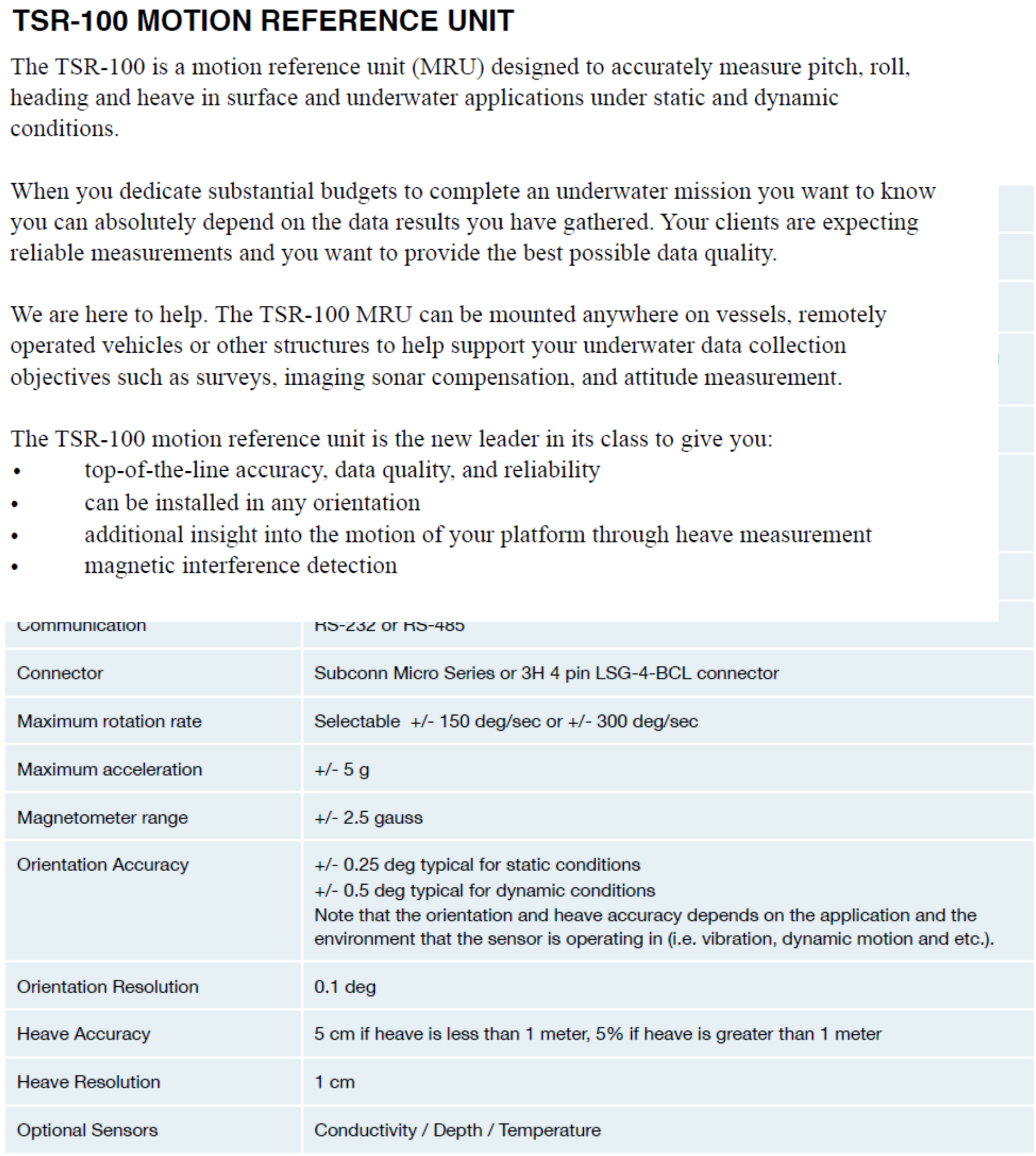
KONGSBERG

P/N 901-60270000

The MS1000 USB Rotator Interface Unit provides an isolated interface between the USB port of a desktop or laptop PC running the MS1000 software processor and Kongsberg Mesotech rotator units with RS485 ***digital*** telemetry. A 19" rack mounting kit is available for this unit.

Input Voltage:	95 to 260 VAC / 47 to 63 Hz
Output Voltage:	28VDC @ 2A
PC Telemetry Interface:	USB
Rotator Telemetry Interface:	RS485
Downlink Data Rate:	Up to 460 kbps (as configured in the MS1000 software)
Uplink Data Rate:	Up to 460 kbps (as configured in the MS1000 software)
LED Indicators:	Power, Tx, Rx
Temperature Range:	0° to 40°C operating 0° to 50°C storage
Dimensions:	Height 3.08"/79mm Width 12.20"/310mm (excluding mounting brackets) Depth 11.00"/280mm (excluding connectors)
Weight:	6.5 lbs/2.9 kg

Motion Reference Unit



TSR-100 MOTION REFERENCE UNIT

The TSR-100 is a motion reference unit (MRU) designed to accurately measure pitch, roll, heading and heave in surface and underwater applications under static and dynamic conditions.

When you dedicate substantial budgets to complete an underwater mission you want to know you can absolutely depend on the data results you have gathered. Your clients are expecting reliable measurements and you want to provide the best possible data quality.

We are here to help. The TSR-100 MRU can be mounted anywhere on vessels, remotely operated vehicles or other structures to help support your underwater data collection objectives such as surveys, imaging sonar compensation, and attitude measurement.

The TSR-100 motion reference unit is the new leader in its class to give you:

- top-of-the-line accuracy, data quality, and reliability
- can be installed in any orientation
- additional insight into the motion of your platform through heave measurement
- magnetic interference detection

Communication	RS-232 or RS-485
Connector	Subconn Micro Series or 3H 4 pin LSG-4-BCL connector
Maximum rotation rate	Selectable +/- 150 deg/sec or +/- 300 deg/sec
Maximum acceleration	+/- 5 g
Magnetometer range	+/- 2.5 gauss
Orientation Accuracy	+/- 0.25 deg typical for static conditions +/- 0.5 deg typical for dynamic conditions Note that the orientation and heave accuracy depends on the application and the environment that the sensor is operating in (i.e. vibration, dynamic motion and etc.).
Orientation Resolution	0.1 deg
Heave Accuracy	5 cm if heave is less than 1 meter, 5% if heave is greater than 1 meter
Heave Resolution	1 cm
Optional Sensors	Conductivity / Depth / Temperature