Performance Analysis of the EdgeTech 6205 Swath Bathymetric Sonar

Lisa Nicole Brisson, Lead Bathymetry Product Engineer, EdgeTech, Boca Raton, FL
Damon Wolfe, Lead Bathymetry Sales Engineer, EdgeTech, Wareham, MA

Introduction

High frequency phase differencing bathymetric sonars, or interferometric sonars, have recently become a popular tool for shallow water surveys and now form an integral part of the surveyor’s toolkit. The interferometric sonar can be considered a multi-stave side scan, collecting a wide swath of bathymetry and sonar amplitude data with the angle of arrival of the seabed returns determined by phase comparisons between the receive staves.

A-priori theoretical error models of interferometric systems are complex and have been difficult to reconcile with observed system performance. A reliable system error model is required in order to apply sophisticated post processing techniques, for example the Combined Uncertainty Bathymetric Estimator (CUBE) algorithms developed at University of New Hampshire (UNH), and to determine the uncertainty indications to use on data sets and charts. Direct empirical measurements of system uncertainty can be used to refine and verify the sonar models and ensure that the Total Propagated Uncertainty (TPI) applied in the data processing is consistent with real data as collected.

Understanding the performance of these sensors is a critical step in the deployment of these systems. In addition, algorithms that can be applied to mitigate large errors and improve numerical stability must be evaluated for efficiency and robustness given the high computational complexity.
Statistical techniques for analysing and optimising the performance of swath bathymetry systems have been used for several decades, especially in the analysis of Multibeam Echo Sounders (MBES). A well-used technique is to compare a single line of test data against a reference surface to determine the sonar depth repeatability and consistency across the swath. [1]

Once a reference surface has been generated and deemed free of systematic biases, a separate survey line is recorded over the test area providing a dataset with which to assess the performance of a particular sonar system. Statistical analysis of the difference between the reference surface and the test line will provide a good indication of the accuracy and repeatability of the sonar and its ancillary sensors in a single pass as a function of three-dimensional positional accuracy across the entire swath. The benchmarking and accuracy assessments utilizing this method require the use of high-quality sensors that can serve as a basis for evaluating the various levels of accuracy achieved. Due to the expanded swath coverage of interferometric sonars, the core suite of sensors includes high-end inertial navigation systems utilizing dual frequency carrier-phase GNSS receivers with tidal correction capabilities and accurate heading determination. These ancillary sensors minimize positioning errors of the directly geo-referenced bathymetry point data, especially in the outer swath regions, as most of the corrections are angular in nature. In late 2013, these techniques were applied to analyse the performance of a pole-mounted EdgeTech 6205 Swath Bathymetry and Dual Frequency Side Scan Sonar System. The results of this analysis are presented in this paper. [2]

Methods

The EdgeTech 6205 Swath Bathymetric Sonar System is a combined, fully integrated, swath bathymetry and dual frequency side scan sonar system that produces real-time high resolution three-dimensional maps of the seafloor while providing coregistered simultaneous dual frequency side scan and bathymetric data.

Figure 1: Side scan image (left) with coregistered bathymetry (right) of debris lying on the seafloor. Red circle and crosshair indicate real acoustic data of the debris at nadir.

The 6205 uses 10 receive elements and one discrete transmit element in a pair of transducer heads. The high number of channels enables enhanced rejection of multi-path effects as well as reverberation and acoustic noise. EdgeTech’s Full Spectrum® processing techniques provide complete coverage in the nadir region, while meeting International Hydrographic (IHO) Special Publication No. 44, National Oceanic and Atmospheric Administration (NOAA) and United States Army Corps of Engineers (USACE) specifications for feature detection.

In early November 2013, a shallow water data set was collected using a traditional MBES system and an EdgeTech 6205 deployed on a retractable bow pole mount aboard the USACE Survey Boat SB-46.
The area chosen was the nominally flat navigational channel, which was in approximately 10 meters of water, sheltered from swell and weather, and was of sufficient size to allow 16 orthogonal sets of 200 meter lines at 15 meter spacing. Repeat surveys were run over the dredged navigation area with a MBES in the St. John’s River, Jacksonville, FL, with the aim of generating a reference bathymetric surface. The MBES reference surface was acquired using 200% coverage with a boustrophedonic lattice pattern, consisting of 16 N-S lines and 16 E-W lines, and only logging the highest quality data, or 90 degree swath. A test line was then collected over this reference surface using the EdgeTech 6205. The test line was acquired using the full field of view (200 degree) which amounts to 12 times water depth or more.

A patch test area to the northwest of the survey area was identified. It consisted of a flat area and a channel edge which enabled roll, pitch, yaw, and latency calibrations. The final surfaces were corrected for tides, delayed heave, and sound velocity variations within the water column.

The 6205 utilizes EdgeTech’s latest electronics package and arrays resulting in an extremely lightweight, modular design required for shallow water applications and vessels of opportunity. The 6205 sonar
electronics and arrays are mounted onto a streamlined body that is deployed over the bow of the survey vessel via a pole. Alternatively, the sonar can be hull-mounted, mounted on a side pole, or configured for ROV or AUV deployment. The standard configuration for the 6205 includes an integrated sound velocity sensor and the system interfaces with standard DGPS/RTK systems, MRUs, SVPs, CTDs, altimeters, and gyros. The sonar data is transferred from the transceiver at the sonar head to the processing unit in the survey cabin via an Ethernet network interface. In the Jacksonville tests, a POS-MV from Applanix and a Trimble HPD450 Radio were used for position and attitude, with the POS-MV applying lever-arm corrections from the GPS and IMU to the transducer head. While the real-time survey data was collected using real-time kinematic (RTK) tides, the height control in final processing of the two surfaces was achieved using POSPac post processed kinematic (PPK) GPS data (supplied by Matthew Staley of the US Army Corps of Engineers).

The data was collected using EdgeTech’s Discover Bathymetric software and Hypack’s Hysweep Survey software, which has a real-time interface for collecting 6205 interferometric data. Post processing was carried out in the office using Hypack Hysweep Editor (also known as MBMax). The 6205 also interfaces to many other third party acquisition and processing software packages, such as SonarWiz, and QINSy. CARIS can also be used to ingest and post process the native EdgeTech JSF files.

To create the reference surface, the data from each MBES survey line was processed and filtered separately to remove outliers and water column hits (e.g. wakes and fish). Care was taken to visually inspect the lines to check for outliers, blunders and other erroneous data points, and cross-check lines were utilized to identify and eliminate calibration and offset errors. The full filtered data from all the reference lines were then combined to create a cleaned reference surface. This was then gridded by averaging to a cell size of 1m x 1m and extracting the median for export as a final digital terrain model (DTM). The final reference surface is shown on the left in Figure 4.

The individual EdgeTech 6205 test line was acquired at 12 times water depth using the middle line of the reference surface (track shown in Figure 5). In post processing the raw data file was virtually untouched and only corrected for tides, sound velocity changes within the water column and calibration offsets (i.e. roll, pitch, and yaw). The test line was then gridded using the same parameters as the reference surface (1m x 1m and extracting the median) and exported to a final DTM. The test line is presented to the right in Figure 4. This was done to demonstrate the cleanliness of the system’s raw data output and what is realistically achievable by the system.

![Figure 4: MBES reference surface (250m x 250m) gridded to 1m cells (left); the EdgeTech 6205 250m test line, untouched, gridded to 1m, and collected at 12 x water depth (right). Both have been plotted using the same colour scale shown and rotated counter clockwise so that cross profiles are perpendicular to the vessel’s track.](image-url)
To compare the reference surface with the 6205 test line, a mean difference surface was created and exported as a separate DTM (Figure 5). To generate the statistics for analysis, two methods were used. The first compared the entire test line to the reference surface by producing one large cross profile orthogonal to the vessel’s track over the total swath and along the length of the entire line. Then three separate cross profiles 50 meters long, again taken orthogonal to the boat heading along this line, were compared to show the consistency of the data.

Figure 5: Top view of the EdgeTech 6205 test line differenced from the MBES reference surface with the vessel’s track designated by the arrow. Notice new colour scale and difference surface deviates around zero (light orange).

Results

To demonstrate the overall system performance, the above methods provided a set of profiles across the test swath which revealed the difference between the test line and the reference surface. These profiles were analysed to find the mean and standard deviation of the differences between the test line and reference surface. Figure 6 illustrates the results obtained over the total swath, or roughly 12 x water depth, and along the entire length of the test line, while Figures 7 through 9 show the results obtained when 50 meter along track sections were used.

The mean difference shows the depth residual, or static offset, and the standard deviation is a measure of the cell-to-cell repeatability of depths at their respective swath position. Figures 6 through Figure 9 are drawn using approximately 120 meter swath, or roughly 12 x water depth, and demonstrates the approximate limit beyond which the signal amplitude is too small to reliably provide a bathymetric solution in the depths and environmental conditions found within the region.

Note that in order to aid in determining whether or not the system can meet hydrographic standards the error bars in Figures 6 through 9 illustrate two standard deviations above and below the mean, which corresponds to the 95% confidence level. The IHO Special Order criterion was then used as the performance metric. According to the IHO Standards for Hydrographic Surveys, 5th Edition, Special Publication N°44, the Total Vertical Uncertainty (or TVU) is computed as
$$TVU = \pm \sqrt{a^2 + (b \times d)^2}$$

where, 
- $a$ represents that portion of the uncertainty that does not vary with depth,
- $b$ is the coefficient which represents that portion of the uncertainty that varies with depth,
- $d$ is the depth, and
- $(b \times d)$ represents that portion of the uncertainty that does vary with depth.

The maximum allowable uncertainty in depth includes all inaccuracies due to residual systematic and system specific instrument errors including. This includes the speed of sound in water, static vessel draft, dynamic vessel draft, heave, roll, and pitch, and any other sources of error in the actual measurements process, including the errors associated with water level (tide) variations (both tidal measurement and zoning errors). [3]

For IHO Special Order surveys the variables $a$ and $b$ are defined as $a = 0.25$ meter and $b = 0.0075$. Using the equation above and the variables stated previously, the TVU in 10 meters of water was calculated as $+/-26.1$ centimetre. This TVU for IHO Special Order was then drawn as a red line on the plots in Figures 6 through 10.

![Figure 6](image)

Figure 6: Mean depth difference across the swath (approximately 12 x water depth) between the entire test line and the reference surface. Error bars show 95% confidence level.
Figure 7: Mean depth difference across the swath (approximately 12 x water depth) between the test line and the reference surface at along track section 50m to 100m. Error bars show 95% confidence level.

Figure 8: Mean depth difference across the swath (approximately 12 x water depth) between the test line and the reference surface at along track section 100m to 150m. Error bars show 95% confidence level.
Figure 9: Mean depth difference across the swath (approximately 12 x water depth) between the test line and the reference surface at along track section 150m to 200m. Error bars show 95% confidence level.

To further demonstrate the EdgeTech 6205’s performance the 95% confidence level was plotted as a function of water depth (Figure 10). A blue line was fitted to these values for visualization purposes and again the TVU for IHO Special Order surveys was drawn in red.

Figure 10: Swath confidence as a function of water depth for a nominal water depth of 10m. IHO Special Order shown by the red line.
Discussion

The mean depth residuals are considered to represent systematic errors or biases in the depth results. The standard deviations are caused by random error sources from the sonar combined with other dynamic error sources which change rapidly over the time taken to collect the test line (~100 seconds). Two times the standard deviation corresponds to the 95% confidence level and can be used to indicate the uncertainty of the measurements. Knowing this, several features are apparent from the plots:

1. Figure 6 represents the typical performance of the 6205 in 10 meters of water depth, while Figures 7 through 9 display how consistent the data is within the shown sections, only deviating slightly due to topographical differences.

2. Figure 7 shows the mean depth residual and uncertainty computed for the seafloor between sections 50 meters to 100 meters. From this region it can be seen that a slightly larger mean depth residual and uncertainty are produced on the starboard side, which can be attributed to the dredge mark that resides on the starboard side as shown in Figure 4. In this section, the sonar is looking down into a deeper section out at a far range, where noise tends to pick up.

3. Figure 8 provides the mean depth residual and uncertainty calculated for the seafloor between sections 100 meters to 150 meters. Figure 4 illustrates that the seabed is relatively flat for this portion of seafloor, only sloping slightly downwards on the starboard side. Figure 8 presents a more consistent result across the swath, only deviating slightly more on the starboard side due to this topographical change.

4. Figure 9 gives the mean depth residual and uncertainty derived from the seafloor section between 150 meters to 200 meters. Figure 4 illustrates that this portion of the seabed is also relatively flat and sloping slightly on the starboard side. This corresponds to an evenly distributed mean depth residual for both port and starboard sides, but the standard deviation, or uncertainty, increases as the outer portion of the starboard side is reached.

5. Figures 6 through 9 show the random variation in the mean depth residual over the swath demonstrating that there are no consistent systematic errors in the depths across the swath.

6. Figures 6 through 9 also demonstrate that the mean depth residual at nadir is similar in amplitude to that of the depth residual in the outer portions of the swath. This also illustrates that the 6205 nadir data is indeed usable, which is quite contrary to most interferometric systems as they typically do not produce data at nadir at all.

7. From reviewing Figures 6 through 9, it can be seen that beyond approximately 45 to 50 meters from nadir the random error (at the 95% confidence level) rises to approximately 0.50 meters, showing the limits of the swath width achievable using the 6205 in this type of environment.

8. Figure 10 displays that the depth consistency of the test line is within IHO Special Order standards (TVU of 26.1 centimetre at the 95% confidence level) out to about 9 times depth, or a 90 meter swath, and only just exceeds this criterion after the 9 times depth limit is reached.

9. Figure 10 also shows that the data produced by the 6205 is within Order 1a (TVU of 0.5 meters at the 95% confidence level) out to a total of 120 meter swath (12 times water depth).

Navigation sensors are of paramount importance to the absolute accuracy of each sonar ping. These sensors provide the absolute orientation of the bathymetric swath. As mentioned in the introduction, the two fundamental components of the navigation system are the IMU and GPS sensors, which (in most applications) are further integrated using a state estimation filter. Additionally, corrections such as DGPS...
and RTK are often used to augment the real-time navigation solution. As such, it is to be noted here, that the data used to generate the above plots will have many sources of error included, both from the sonar and the ancillary equipment so it can be considered as a reasonable proxy for the total propagated errors of the survey system. These plots will be expected to overestimate the TVU contribution from the sonar alone and should only be used as a guideline for performance. [4]

Conclusion

The EdgeTech 6205 Swath Bathymetric Sonar System was tested in a nominal 10 meters of water and the data consistency between a reference surface and a test line was within IHO Special Order specifications to a swath width of approximately 9 times water depth. The data was within IHO Order 1a specifications to 12 times water depth. The shape of the mean depth residuals compared with the magnitude of the random errors indicates that there are no significant systematic error sources, and that this technology has finally come of age. The statistical analysis techniques applied here provided valuable information about sonar performance and helped measure the data quality that can be obtained from the sonar system. The total vertical uncertainty values obtained here will help inform sonar users and aid in the use of advanced post processing algorithms with this data. These attributes, combined with the ability to validate three-dimensional point data utilizing the co-registered side scan imaging capabilities of most interferometric systems, provide a reliable survey tool for the hydrographic community.

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References


Author Biographies

Ms. Lisa N. Brisson is the lead Bathymetry Product Engineer at EdgeTech with experience in Underwater Acoustics and Hydrographic Surveying. Brisson graduated with a B.S. in Ocean Engineering in 2009 from Florida Atlantic University. After graduation, she continued her studies there and developed a detection and classification algorithm for forward look sonars, and later graduated with a M.S. in Ocean Engineering in 2010. Following that, she joined EdgeTech and has been involved in the design and development of swath bathymetry sonars for the last 4 years. Currently, she is refining, testing, installing and providing training for hydrographic systems.

Mr. Damon Wolfe is the lead Bathymetry Sales Engineer at EdgeTech with background in Geodesy and Hydrographic Surveying. Wolfe graduated with a B.S. in Geomatics from the University of Florida. After graduation, he went to work with the Army Corps of Engineers as a Geodesist, where he worked extensively to support their positioning, navigation, and dredging requirements. Damon now works for EdgeTech and currently focuses on EdgeTech’s bathymetric sonar systems.