# AQS-20 Through-the-Sensor (TTS) Performance Assessment

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*Abstract* - Performance of existing and planned mine hunting sensors is dependent on the environment. When the seafloor is a flat smooth hard sandy surface with no mine like clutter on it, then sensor performance is outstanding and acoustic mine hunting is relatively easy. Introduce clutter, a rough seafloor and a soft muddy bottom, sensor performance is seriously degraded making mine hunting operations extremely difficult to impossible. One must know the environment to know sensor performance.

Historical environmental data is important but not sufficient. In spite of painstaking efforts to collect, process and disseminate data, historical information is often missing, outdated or in error. To know sensor performance, near realtime environmental data must be collected to verify, supplement and refresh historical holdings.

This paper describes the results of two near real-time endto-end Through-the-Sensor (TTS) demonstrations conducted in FY05 using AQS-20 data. Critical environmental parameters were extracted from the raw tactical data stream using a TTS approach. Data collected by the AQS-20 was processed for bathymetry, sediment type and % burial. Supplemental data was fused with historical information on scene and used to calculate doctrinal bottom type in NAVOCEANO's Bottom Mapping Workstation. The information was passed to MEDAL where track spacing and hunt times were calculated. NAVOCEANO, in a fast reach back mode using TEDServices, examined the data, added value, and returned it. The impact to the mine warfare community is a true sense of sensor performance.

### I. INTRODUCTION

NRL is developing Through-The-Sensor (TTS) techniques that utilize the tactical data stream from mine hunting sensor systems to also extract ocean environmental measurements for near real-time use in decision aids.<sup>1</sup> Under sponsorship by the Oceanographer of the Navy and SPAWAR PMW 180 management, TTS environmental data collection from the AQS-20 was demonstrated.<sup>2</sup> The technical objectives of the current effort, under ONR, NRL and CNO N7C sponsorship, are to automate data processing, develop data fusion techniques and distribute the data using web services.<sup>3</sup>

Due to the temporal and spatial variability of vast littoral regions, accurate real-time environmental information assimilated with available historical data is required to adequately characterize the Mine Warfare battle space. Demonstrated repeatedly in numerous Mine Counter Measures (MCM) exercises, near real-time characterization of the seafloor can significantly impact the MCM Commander's decisions allowing him to bypass geographically challenging areas, alter routes, breach an area and achieve MCM goals in less time. Current MCM doctrine uses a measure of bottom composition, estimated percent mine case burial, bottom roughness and bottom clutter density to determine the bottom category for a given location. Doctrine provides a listing for probability of detection values associated with each of these bottom category descriptions. The probability of detection values along with sonar detection widths derived from sound velocity profiles determines the MCM track spacing to achieve the required clearance level. The AQS-20 sensor suite is capable of measuring all of the necessary environmental data types needed to determine bottom category value.

NRL conducted two End-To-End TTS demonstrations using AQS-20 data. End-To-End includes sensor data collection, processing, fusion with historical data, distribution, and use in tactical decision aids. The first demonstration took place in a laboratory setting at NAVOCEANO using data that had been collected 3 to 6 The second was performed near the months earlier. helicopter hangar at Naval Surface Warfare Center Panama City using data collected that day. In both demonstrations raw AQS-20 Volume Search Sonar (VSS) data was processed, fused, and delivered to the Mine Warfare Environmental Decision Aids Library (MEDAL) Tactical Decision Aid (TDA).

## II. DEMONSTRATION #1 AND #2

The first demonstration was conducted in a laboratory setting at NAVOCEANO in their Mine Warfare War Room during the period of 13-17 Dec 04. A simple operational scenario was chosen for the demonstration that was centered on the previously collected (3 to 6 months earlier) AQS-20 data from two flights. The scenario included a beach objective, an assault lane, and an inner transit area. The goal was to determine AQS-20 sensor performance. AQS-20 high-speed data was processed, fused with historical data delivered in the right formats and used in the MEDAL decision aid. Virtual Natural Environment-Net Centric Services (VNE-NCS formerly TEDServices) was used to send and receive sensor data in a reach-back mode to NAVOCEANO.

The second demonstration took place 21-25 March 05 at NSWC-PC. This demonstration included three AQS-20 "Volume Mode" flights flown in the Panama City Operating Area during the demo. A more complicated scenario was used with a much longer transit lane and several transit areas.

The goal was the same as in the first demo, but this time a comparison was possible between predicted sensor performance using solely historical data versus performance using TTS data. Thus the impact of using the new techniques can be determined. NRL's SeaBED (Seafloor and Bathymetric Environmental Data) software was used to process the AQS-20 Volume Search Sonar data for bathymetry and sediment parameters, and fuse it with historical holdings. In addition to using the VNE-NCS Gateway in a reach-back mode, it was also used to send TTS data to the mine warfare decision aid.

# III. DATA

Historical bathymetry and bottom surface sediment type for the Panama City area were provided by NAVOCEANO. Surface sediment data are from the geophysical databases and historical bathymetry came from the Oceanographic and Atmospheric Master Library (OAML) Digital Bathymetric Data Base, DBDBV. AQS-20 TTS data was collected in small areas of the region, and typically at much higher resolution than the historical data. The first demo used data of opportunity from AQS-20 flights from May and November of 2004. Specific flights were flown for the second demonstration in March 2005. These flights were flown in exercise areas to support analysis of AQS-20 sensor performance. Table 1 shows the AQS-20 data types collected for the demonstrations.

TABLE 1 --- Summary of AQS-20 Data Collected

AQS-20 Data					
Mode & data type	Date Collected	Minutes of Data	Field Depth	Multibeam Soundings	Sediment Points
Volume Mode					
High Speed & Mission Data	6-May-04	24	200m	38,220	1,417
Mission Data Only		109	200m	6,500	n/a
High Speed & Mission Data	2-Mar-05	80	200m	130,275	5,550
"	18-Mar-05	133	30m	208,000	8,281
"	23-Mar-05	121	30m	188,292	6,993
"	24-Mar-05	40	200-30m	66,560	2,472
Single Pass Shallow Mode					
Side Scan sonar	12-Nov-04	48	30m	Imagery	n/a

# IV. END-TO-END DATA FLOW

The End-To-End data flow is achieved through components in NRL's SeaBED Software. The software is an integrated set of modules used to manage AQS-20 data. It is designed to be a component in NAVOCEANO's Bottom Mapping Workstation (BMW), and is a template for the software architecture that could be used with a host of other TTS systems. Functional modules support handling of raw data, display of intermediate results in the processing scheme for quality control, automated editing, fusion of products with historical databases, and reach-back capability to other users. SeaBED is a centralized system that can be interactively managed using the SeaBED Data Manager (SeaBED DM) application. The connectivity of these systems facilitates data sharing at the sensor, local, and global levels in near real-time. A diagram of the primary components is shown in Fig. 1.



Fig 1. SeaBED Data processing components and data flow.

Two resolutions of data are available, low-resolution mission data and high-speed recorder (HSR) data. Multibeam bathymetry and sediment data are available only in the HSR Volume Mode data. When HSR data is unavailable, single beam bathymetry can be extracted from the mission data.

Multibeam bathymetry processing uses the deconvolved baseband time series from the preprocessing step. The travel time through the water from the sonar to the bottom is determined from the data using a weighted mean time algorithm for beams that do not exceed 45 degrees from the nadir (downward looking beam). Beams exceeding this limit have too high grazing angle for this technique. These data are combined with towbody pressure depth, towbody attitude corrections, towbody position, and water column velocity profile to determine the total water depth and position for each sounding.

Soundings are passed back to the SeaBED Data Manager for further corrections and fusion with historical data. An optional automatic data filter is applied to trim erroneous data values from a dataset similar to manual editing. Optional tidal corrections are also made available using NRL's PC\_TIDES. Correction to mean sea level can be important in the fusion process with historical data.

Sediment processing also uses the deconvolved baseband time series from the preprocessing step. The data manager feeds the time series data into the automated Acoustic Sediment Classification System (ASCS)<sup>4, 5</sup> and 6 software

imbedded in SeaBED. Acoustic impedance is determined for each ping and empirical relationships are used to convert impedance values to bottom type (mud, sand, rock) and mine impact burial potential. These properties are combined with the VSS sonar ping location. The resulting sediment points are passed back to the SeaBED Data Manager for fusion with historical data.

SeaBED includes three fusion algorithm options. For bathymetry datasets the OAML Feathering algorithm is used, although a Generic Mapping Took Kit Nearest Neighbor Interpolator can also be used for quick looks at point data for quality checks. The Feathering algorithm is a twodimensional interpolation routine<sup>7</sup> adopted by NAVOCEANO as a standard technique for feathering grids of different resolutions into a single continuous grid.<sup>8</sup> When the fusion algorithm completes the process, a new fused grid is stored in the local Geophysical Data Base Variable-grid (GDBV). During the demonstrations AQS-20 data from multiple flights was fused with historical data and the resulting grid was sent to the mine warfare decision aid.

A Kriging technique was used to fuse historical impedance data with AQS-20 impedance data. Kriging will yield an interpolation that optimizes (minimizes) the variance in the surrounding measurements; however, it requires subjective interpretation of the variances (creating a "best fit" variogram), and is therefore optimal in only a subjective way. More importantly, the resulting Kriging interpolation has associated with it uncertainties such that estimates of the impedance at varying distances away from the track line can be assigned a finite uncertainty. Areas where the impedance is slowly varying result in high confidence levels, while estimates far away from the track line result in low levels. Conversely, rapid variation along the trackline degrades confidence in the impedance estimates off the track line. The output of the Kriging algorithm is an evenly spaced impedance grid that is converted to impact percent burial categories and used in the computation of doctrinal bottom types.

The SeaBED data fusion algorithms are controlled and executed from within the data manager. The SeaBED Data Manager also controls all communications between the Bottom Mapping Workstation and the VNE-NCS Gateways. From the SeaBED Data Manager the user can submit files (any format) to a particular VNE-NCS Gateway. Also, the user can retrieve data from a VNE-NCS Gateway as a 3D Grid object. The SeaBED DM also allows the user to create a data order on a VNE-NCS Gateway forcing it to execute automatic subscriptions to a particular data type on another VNE-NCS Gateway. The data order feature is used to receive grids that are placed on the NAVOCEANO VNE-NCS Gateway automatically.

The BMW is based on a standard installation of Slackware Linux (currently version 9). The BMW includes NAVOCEANO's Unified Sonar Image Processing System (UNISIPS) software package. UNISIPS is a software suite used for processing raw acoustic imagery from multiple types of side scan sonars to produce digital mosaics, and seafloor characteristics including clutter density and roughness<sup>9</sup>. In bottom provincing, areas of like bottom roughness are digitized by hand and assigned a roughness category based upon Mine Warfare doctrine. The digitized polygons are written out in ESRI's Shape file format. CEAS is an ArcInfo based GIS package used for deriving doctrinal bottom type<sup>10</sup>. CEAS was used in the demonstrations to combine the roughness with %burial and clutter information to produce mine warfare doctrinal bottom types.

VNE-NCS was used to distribute fused and supplemental data to local and remote locations. This new technology provides environmental data via subscriptions and is designed to ensure a common, current environmental view while minimizing bandwidth limitations.<sup>11</sup> In the AQS-20 demonstrations, VNE-NCS Gateways were installed on the BMW system and at NAVOCEANO to demonstrate the reach-back capabilities. Raw bathymetry datasets were sent to NAVOCEANO where the hydrographic experts edited and gridded the point data and returned it. The Mine Warfare Environmental Decision Aid Library (MEDAL), the primary tactical decision aid used in Mine Warfare, was modified to receive environmental objects from VNE-NCS. In the second demonstration, this interface was used almost exclusively to pass data between the BMW and MEDAL due to its ease of use.

## V. HISTORICAL AND NEW ENVIRONMENTAL DATA

Data used for the demonstrations were collected off the coast of Panama City, Florida. The area is the site of numerous exercises, survey operations, and test activities. Consequently, considerable historical data exists and the environment is well understood, and significant differences between historical data and new data collected by the AQS-20 sonar were not expected; however, some differences were recorded. Generally, the environment is characterized as relatively benign, comprised of areas that are moderate to easy for mine hunting.

Bathymetry data from the December demonstration were fused with historical data. Fig. 2 shows the National Geophysical Data Center three-second bathymetric data for the Panama City, Florida area. Near shore, where the density of the data collected is greater, the contour lines are more defined and complex. Farther offshore, where the density of the data collected is less, the contour lines are smoother, actually drawn between single beam profiles taken several miles apart. The AQS-20 data is circled in the figure. Fig. 3 is a zoom into the area. Here the fused historical data contour lines are relatively straight and smooth, indicating a lower data density. However, the contour lines are better defined and complex where AQS-20 data were collected indicating the higher density bathymetry. Differences in the bathymetry between the historical data and the TTS data are approximately one half to two meters. The difference does not appear to be significant; this is most likely attributable to the relatively flat bottom characteristics in the region and to the hydrographic and AN/AOS-20A sensor accuracies.



Fig. 2. NGDC 3 second bathymetry data for the Panama City area



Fig. 3. Zoom in of AQS-20 bathymetry fused with NGDC 3 Second bathymetry data

Inspection of sediment data from the December demonstration indicated an impedance difference of approximately 0.2 to 0.4 between AQS-20 data and historical data. Due to the good agreement of the historical with the new data there was no change in the time required to conduct mine warfare operations. The data is relatively consistent in the area with impedance is in the range surrounding 2.4 indicating predominantly sand. However the TTS data appears to be composed of a mixture of various grain sizes bordering the mud-sand categories, reflecting slightly finergrained, more watery sediment than shown in the historical data. The difference is minor and does not affect mine warfare doctrinal bottom type.

TTS sediment data from the March demonstration showed some differences with the historical data. Three data sets were used: regional historical sediments; high-resolution historical sediments along a narrow track; and the AQS-20 TTS data.

Regional historical data was converted to impedance and compared to the TTS measured impedance data. The difference does not result in a change in mine warfare doctrinal bottom type, which is attributable to the relatively consistent data in the area.

However high-resolution historical sediments were derived in an exercise area using available side scan sonar imagery. The lower impedance (lighter color) from the TTS data corresponds to the lighter areas in the high-resolution data in Fig. 4. Northeast of the light areas indicates an area of higher impedance (darker color) for all three types of data, which is to be expected. However, southwest of the light area the TTS data indicates a lower impedance, which is consistent with the enhanced data but not with the highresolution historical data.



Fig. 4. Historical and Measured Sediment Comparison

There is an empirical relationship between impedance and percent burial that has been determined experimentally by NRL. From that relationship percent burial, one of the parameters used to determine mine warfare doctrinal bottom type, is computed. The difference between historical % burial and TTS % burial is shown in Fig. 5. The difference is not as significant as it appears. The primary reason for the difference in % burial is due to NAVOCEANO currently including subsequent burial into the calculation for sandy bottoms. Only impact burial was considered in calculating TTS % burial during the demonstration.



Fig. 5. Historical and Measured %Burial Comparison

## VI. SENSOR PERFORMANCE

Mine hunting sensor performance is determined from mine warfare doctrinal bottom type. If the bottom is hard, flat, and has no clutter, then the bottom type is good for hunting. Add softer bottoms, rougher terrain and lots of boulders, then conditions become difficult to hunt for mines. Mine hunting is conducted to achieve a specified percent clearance of mines. As environmental conditions degrade the track line spacing for mine hunting sensors gets less, and the time required to hunt a given area to the same percent clearance increases.

Thus sensor performance for mine hunting depends on the environment. If the environment is different or has changed from the historical data, then performance will be incorrect. Either too much time will be spent hunting the area, or worse hunting is done too quickly, and there is a false sense of mine clearance. Neither condition is optimum so one needs to get the environment right by measuring it in the field.

In demonstration #2 mine warfare doctrinal bottom type was calculated using just historical data, and compared with calculations using TTS data. In the comparison the doctrinal bottom type using TTS data was more favorable for hunting. Part of the difference is due to increased accuracy of the bottom composition from TTS data, although part is also due to the method used to compute doctrinal bottom type. More indicative of the increased accuracy provided by data collected TTS is the higher resolution data.

Fig. 6 illustrates the time and number of mine hunting tracks required to achieve 80 percent clearance as computed by the mine warfare decision aid MEDAL using historical data and TTS data. To achieve 80 percent clearance required 24.45 hours and 50 tracks using historical data. To achieve the same percent clearance required 14.73 hours and 30 tracks using TTS data. Computing a more accurate

characterization of the bottom from data collected TTS resulted in a 40% reduction in both timelines and number of tracks.



Fig. 6. Historical and Measured Timeline Comparison

Had the TTS data detected conditions that were less favorable than the historical then time lines would have increased. It is important to underscore that the value added by data collected TTS is not necessarily a reduction in timelines or number of tracks, but getting the environment right. The value of Through-The-Sensor data is resolving the difference between the expected and the actual environment. Once resolved, the Mine Warfare Commander can employ optimal tactics, determine asset utilization and calculate more accurate mission plans.

### VII. SUMMARY

Characteristics of the seafloor determine the performance of mine hunting sensors. Historical data is great for planning, but often lacks currency and needed density. Measuring the environment in near real-time allows operators to verify historical data, refresh data holdings, and acquire new data.

The AQS-20 is capable of accurately measuring the environment in addition to tactically hunting for mines. The Navy has developed the SeaBED software to automatically process, fuse and disseminate sediment and bathymetry data needed to determine sensor performance. NRL successfully conducted two demonstrations to show that environmental data collected by the AQS-20 could be processed, fused with historical data, and disseminated to decision aids in near realtime.

In the demonstrations discussed, a reduction of 40% in the timeline was achieved to "hunt" an area to the same percent clearance because the measured seafloor was different than the historical. The time could have just as easily been increased by the same amount if conditions were degraded from the historical. The important thing is to use the best environment possible so that sensor performance can be more accurately determined. Accurate sensor performance then yields realistic timelines and a true sense of mine clearance.

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## REFERENCES

- W.E. Avera, M.M. Harris, D.J. Walter, L.D. Bibee, and D.N. Lambert, "Through the Sensors Concepts to Refresh the Environmental Picture; <u>NRL Review 2003.</u>
- [2] M.M. Harris, W.E. Avera, L.D. Bibee and J.M. Null, "Environmental data collection from the AQS-20;" Journal of the Society for Counter-Ordnance Technology, 27 May 2002.
- [3] M.M. Harris, W. Avera, L.D. Bibee, C. Steed, J. Sample, M. Null and J. Hammack, "Environmental data collection, sensor to decision aid," 6<sup>th</sup> International Symposium on Technology and the Mine Problem, Monterey, 9-13 May 2004.
- [4] D.N. Lambert, D.J. Walter, D.C. Young, M.D. Richardson, "High resolution acoustic seafloor classification system for mine countermeasures operations," International Conference on Underwater Acoustics, U. of New South Wales, 5-7 December 1994.
- [5] D.N. Lambert, "An evaluation of the honeywell ELAC computerized Sediment Classification System," NORDA Report # 169, 1988.
- [6] J.A. Hawkins, W.T. Wood, D.N. Lambert, and D.J. Walter, "The characterization of near-surface sediments with high-frequency acoustic pulses," The 128<sup>th</sup> Meeting of the Acoustical Society of America, 28 November – 2 December 1994.
- [7] W.H.F. Smith and P. Wessel, "Gridding with continuous curvature splines in tension," *Geophysics*. 55, 293-305, 1990.
- [8] C.A. Steed and W.E. Rankin, "OAML Feathering Algorithm Overview," Naval Research Laboratory, NRL/FR/7440--03-10,052, May 16, 2003.

- [9] S. Lingsch, "Processing, data basing and product generation of acoustic imagery for naval applications," Proceedings, Ocean Imaging Conference 2000, Newport, RI, 2-5 May 2000.
- [10]S.C. Lingsch, K.W. Grossman, S.M. Mesick and W.C. Lingsch, "A GIS application supporting mine warfare," Proceedings, 18<sup>th</sup> Annual ESRI Interantional User conference, San Diego, CA, 27-31 July '98.
- [11]E. Warner, R. Ladner, U. Katikaneni and J. Shea, "New developments in internet-based delivery of MetOc data to warfighters," Proceedings of the *MTS/IEEE Oceans* 2003 Conference, San Diego, CA, September 24, 2004.