Innovative Partnerships for Ocean Mapping: Dealing with increasing data volumes and decreasing resources

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Abstract

The US Naval Oceanographic Office (NAVOCEANO) has recently updated its survey vessels and launches to include the latest generation of high-resolution multibeam and digital sidescan sonar systems, along with state-of-the art positioning, attitude, and ancillary sensors. This has resulted in NAVOCEANO possessing a tremendous ocean observing and mapping capability. However, these systems produce massive amounts of data that must be validated prior to inclusion in various bathymetry, hydrography, and imagery products. It is estimated that the amount of digital data to be processed will increase by an overwhelming 2000 times above present data quantities.

NAVOCEANO is meeting this challenge on a number of fronts, first by embarking on a series of hardware and software improvements. Existing processing software was run primarily on Unix workstations, and the initial hardware improvements included migrating to dual-processor PCs running the Linux operating system with a large local disk drive. This has resulted in a significant improvement of many of the computationally intensive applications and improved data access through the avoidance of pushing huge amounts of data across the network.

The key to meeting the challenge of the massive data volumes was to change the approach that required every data point be viewed. This was achieved with the replacement of the traditional line-by-line editing approach with an automated cleaning module, and an area-based editor (ABE) integrated with commercial off-the-shelf (COTS) software packages. The approach includes three important elements: (1) the development of a unique data structure that enables the direct correlation between the full-resolution data (including Generic Sensor Format (GSF), Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) format, etc.) and the area-based view (including a direct interface to target files and imagery "snippets" from mosaic and full-resolution imagery), (2) the development of an automated filter used to identify fliers in the data, and (3) the integration of these capabilities with a complete analysis package and a 3D visualization package.

The massive amounts of data to be processed offer tremendous opportunities in terms of visualization and analysis, and interactive 3D presentation of the complex multi-attribute data provides a natural complement to the ABE processing. Georeferenced

complex data sets can be presented in a natural and intuitive manner that allow the operator to rapidly identify the data requiring further analysis.

NAVOCEANO has a unique requirement because of the sheer volume of data that must be continually processed, but it was essential that the tools developed also take advantage of the best elements of complementary COTS applications available. To achieve this, NAVOCEANO entered into two Cooperative Research and Development Agreements (CRADAs)-one with Science Applications International Corporation (SAIC), Newport, RI, USA, and another with Interactive Visualization Systems (IVS), Fredericton, N.B., Canada, to integrate the ABE with SAIC's Survey Analysis product and IVS's Fledermaus 3D visualization product.The work under the CRADAs will result in integrated packages that will allow NAVOCEANO to use COTS products that are tailored to these unique requirements.

Introduction

The inclusion of high-resolution multibeam and digital sidescan sonar systems, along with state-of-the-art positioning and attitude sensors and other ancillary sensors on our ships and Hydrographic Survey Launches (HSLs) has provided the US Naval Oceanographic Office (NAVOCEANO) with the finest-equipped survey fleet in the world. Along with this tremendous increase in bottom-mapping capability comes a corresponding increase in the amount of data that must be validated prior to inclusion into the various shallow and deep water hydrography, bathymetry, and imagery products that NAVOCEANO produces. With our ships operating 24 hours a day, 7 days a week, and 10 months a year or more, NAVOCEANO will soon continually collect more data than anyone else in the world. If maximum data rates are used, we could face a potential of a 22-fold increase in the amount of bathymetric data to be processed-a maximum of over 2.75 terabytes per year versus the present level of 125 gigabytes per year. This figure rises to an overwhelming 2400 times the present data quantity (roughly 300 terabytes per year) if multibeam imagery and digital sidescan sonar are included. Figure 1 depicts the expected increase in future bathymetric/hydrographic data volumes and the amount that has been collected over the years that NAVOCEANO has been collecting multibeam data. Notice the prior 30 years of multibeam data barely registers on the graph!

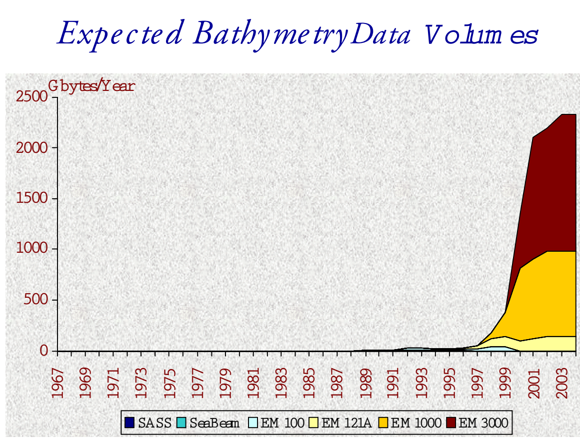

Figure 1

We've got to change the way we do business!

In an attempt to begin dealing with the increased data volumes, the Seafloor Data Division at NAVOCEANO embarked on a series of short-term hardware improvements and longer-term software improvements for both shipboard and in-house validation. The short-term improvements were intended to quickly improve existing processes while the longer term solutions were being developed. The Bathy/Hydro Post-Processing system (BHPP) is a suite of in-house and contractor-developed software that consists of over 400 programs and 1 million lines of code utilized to quality control, validate, and produce bathymetric and hydrographic products. In-house software has been used for over 30 years to process both single and multibeam sonar data. With the decreasing amount of information technology personnel available to develop and maintain this in-house suite of software, alternatives to in-house software development and maintenance had to be investigated. The solution had to allow incorporation of state-of-the-art technology and reduce the training and maintenance "tail" that accompanies maintaining software resources. Until recently, BHPP was primarily operated on Hewlett-Packard Unix workstations. After analyzing the personnel resources available for quality control and validation of the bathymetry data, an initial goal of 4:1 (collection time:processing time) for a new processing system was identified just to be able to keep up with the amount of data being collected with the new sensors. COTS products available at present provide approximately 1:1.

Hardware improvements

The hardware improvements included migrating to a dual-Pentium 600 (we're using 800s now) PC-based processing system that uses the Linux operating system with a large local disk drive. In addition to being much more powerful than existing processing hardware, these PC workstations are about one-third the cost of the workstations they are replacing. This first-step solution was chosen because of several factors:

1. Implement quickly to effect improvements as soon as possible.
2. Speed up the process by speeding up the hardware. Test results showed this hardware improvement alone increased the speed of some of the more computation-intensive application programs by a factor of 6.
3. Allow for rapid utilization of existing software. Utilizing the Linux operating system enabled the majority of existing Unix-based software to be converted easily and quickly to run on the new hardware.
4. Decrease network traffic. Operators interactively editing data spent much of their time competing for resources over the network. By localizing the processing and data storage on the PC workstations, this network slowdown was avoided.

Software improvements

Due to the tremendous increase in data we are facing, the key to making major improvements in processing throughput is to change the way we do business–***we can no longer look at every data point***! But, we must have confidence that real hazards to navigation are not invalidated in shallow water and we must have the capability to examine every data point if necessary. The software improvements planned include three major components: (1) an Area-Based-Editor (ABE), (2) an automated data cleaning module, and (3) the incorporation of these two capabilities with COTS software packages to provide a complete integrated data processing solution. These components are designed to work in conjunction to produce the 4:1 system.

The automated data cleaning module is intended to quickly and automatically invalidate random and systematic outliers in the data. This filter will not invalidate targets identified by sidescan or any other source and will mark as "suspect" any data that cannot be positively identified as an outlier or good data. The filter will run as the data are being loaded into the ABE and utilize the information obtained in the area-mode from overlapping swaths of data collected at different times. When the ABE is used with datasets for which sidescan imagery is not available or with datasets that do not have significantly overlapping swaths, the filtering step may optionally be bypassed.

The ABE has replaced the current labor-intensive line-by-line interactive editing module, called "*geoswath*". Using this line-by-line editing procedure, operators cleaned the data by manually reviewing every data point and interactively flagging outliers invalid–the majority of time was spent scrolling through good data. One of the disadvantages of this method is that full-resolution, overlapping data cannot be viewed. While this module was a big improvement over previous editing methods, NAVOCEANO hydrographers and bathymetrists were not able to keep up with the increase in data volumes by reviewing every data point in this manner. The ABE allows a scientist to view and edit all the data in an entire area simultaneously and directly retain those edits in the full-resolution native data files. The goal is that the operator will only spend time looking at data in question and not review good data. Jan Depner developed the unique "PFM" (Pure File Magic) data structure and I/O libraries that enable the direct correlation between the full resolution data and the area view of the data. He also developed a prototype Editor Graphical User Interface. The ABE also interfaces directly with the target files and "snippet" images generated by the Datasonics Digital sidescan sonar file and the mosaic and full-resolution imagery generated by the UNISIPS (Unified Sonar Imagery Processing System) was developed and is maintained by the NAVOCEANO Geophysical Techniques Division.

With the filter and the ABE working in conjunction, scientists now review the data in an area mode and spend time only on the "problem" areas. These "problem" areas are easily identified from the various views in the editor or indicated by high standard deviations of the depth measurements or estimated error values.

Two Cooperative Research and Development Agreements (CRADAs) are now in place-one with Interactive Visualization Systems (IVS) of Fredericton, N.B. and another with Science Applications International Corporation (SAIC) of Newport, RI - that will integrate NAVOCEANO's tools with each company's commercial product(s). This will allow NAVOCEANO to migrate toward a COTS product that meets our specific requirement. Under the CRADAs, SAIC's Survey Analysis product and IVS's Fledermaus product will both be integrated with NAVOCEANO's ABE. These products allow the scientist to view the PFM data geographically, review and assess the quality of the fliers identified by the filter, compare bathymetry with other types of data, and perform interactive editing. This approach will provide the scientist with a seamless transition between the full-resolution swath-oriented data, geographically oriented presentations of the data, and interactive 3D visualization of the data. The link between the software packages will be the PFM file structure as shown in Figure 2 and will allow users to move easily and quickly between the visualization surface and the full-resolution data.

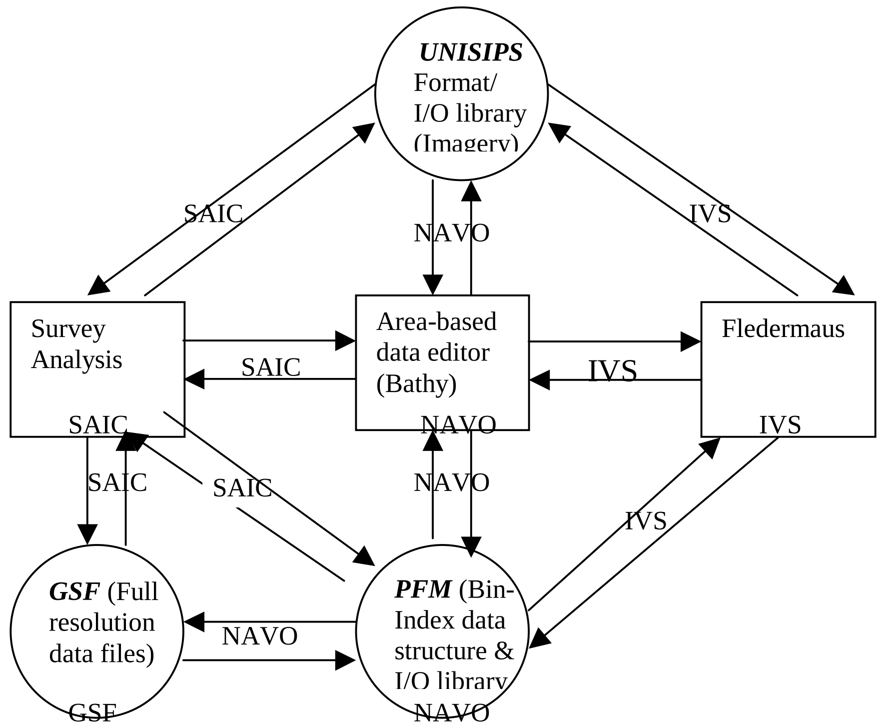

Figure 2. CRADA Interfaces

Cooperative Research and Development Agreements (CRADAs)

CRADAs are legal agreements between a government laboratory and a Non-Navy Partner to jointly conduct research and development in a given technical area and share in the technical results. It can save in both industry and government laboratory costs and in valuable time to achieve mutually desirable results.

CRADAs can be initiated through common technical interests and frequently revolve around existing intellectual property, used directly or expanded upon, as a result of the CRADA. Determination of intellectual property rights for the intellectual property must be made before the issuance of the CRADA and for the intellectual property developed as a result of the CRADA.

A commercial partner can provide facilities, equipment, personnel, and funding to the CRADA. The government partner can provide the same things except for funding; otherwise the research and development would be considered a contract and then come under control of the Federal Acquisition Regulations.

The Navy uses a standard CRADA format and clauses to identify and describe the research and development to be carried out by both the Navy and Non-Navy partner.

When each CRADA partner approves the terms of the agreement, it is signed by the government laboratory commander and the Non-Navy partner. The Navy has developed and participated in over 1,000 CRADAs since 1990.

Area-Based Editor (ABE)

Figures 3 and 4 are samples of the functionality of the ABE in the "Area" view and "Editor" views, respectively.

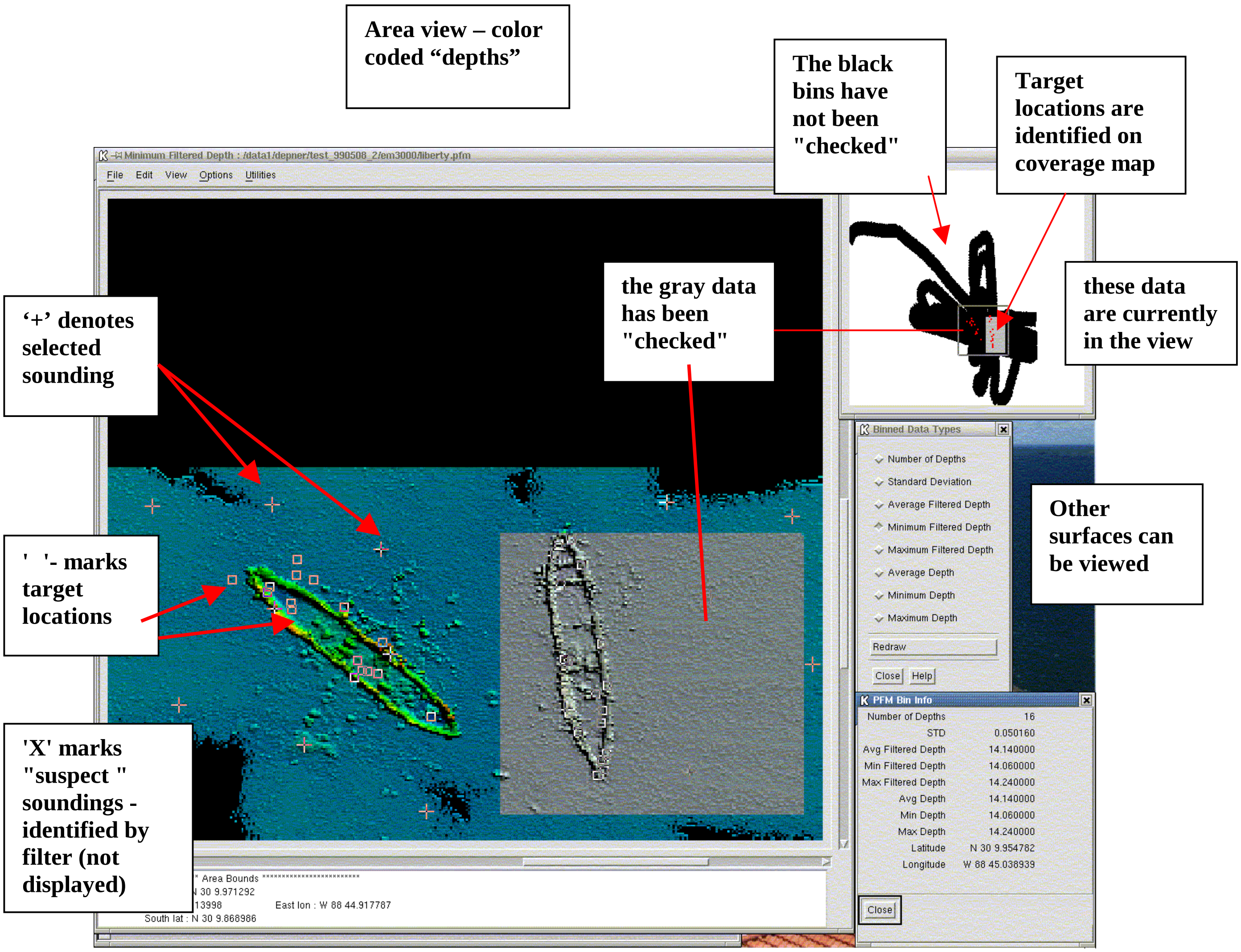

Figure 3. Area View with coverage map

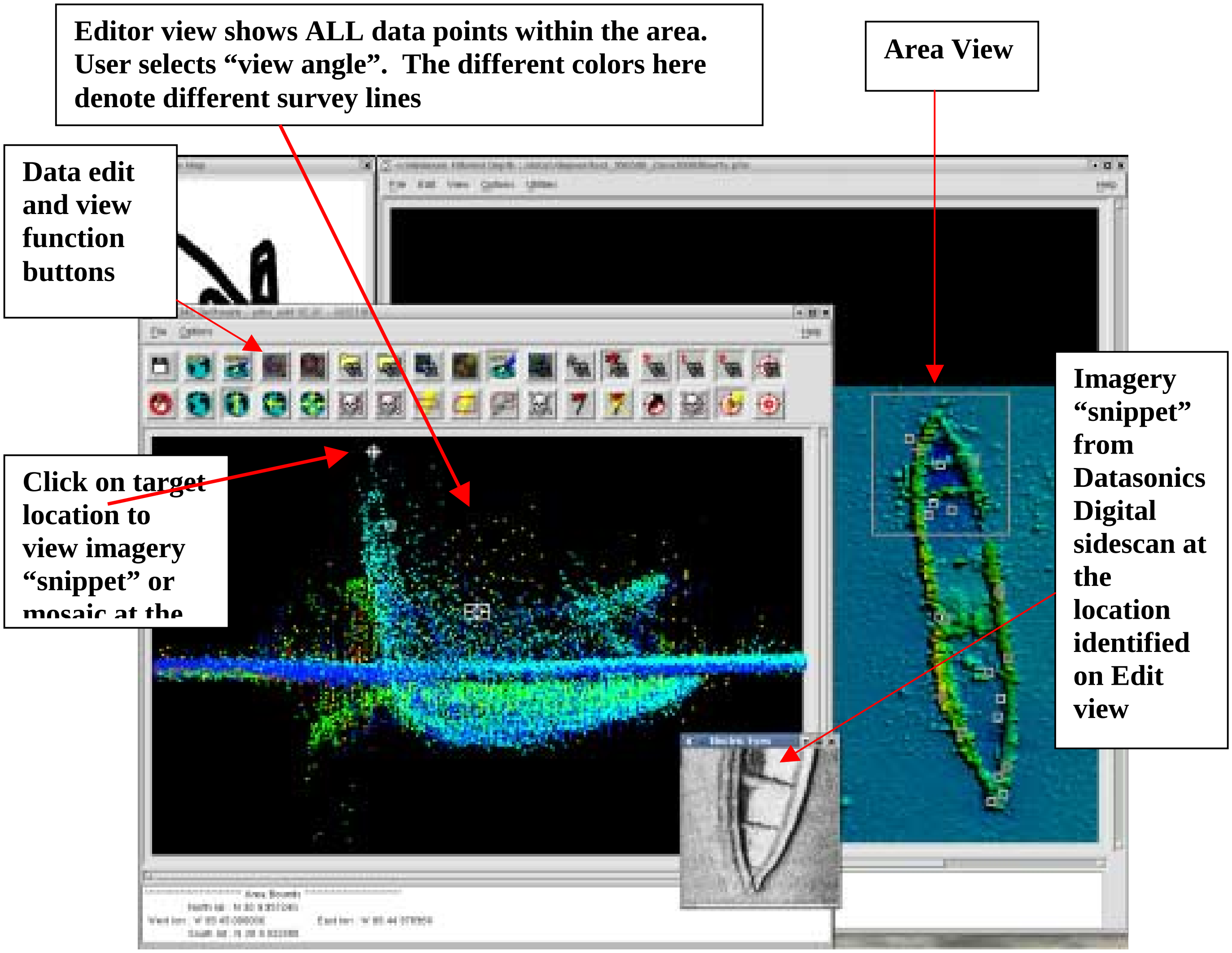

Figure 4. – Editor View with Imagery "snippet" interface

An easily accessible interface with targets identified by the sidescan sonar and imagery data is crucial in aiding the operator when making decisions about the bathymetry data. It is critical that the operators easily view all available imagery data when making these decisions. Another important function of the editor is the ability to view all the information about the individual data point contained in the full-resolution data file.

A prototype of the ABE along with the new Linux workstations was successfully deployed with the USNS HENSON (the filter was not deployed) when she did the first hydrographic survey with the new HSLs. As with any prototype, there are still rough edges to be smoothed out, but without the new editor, the survey crew would have been completely overwhelmed with data.

Airborne laser bathymetry data from the US Army Corps of Engineers' Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) system has been integrated into the ABE. The user can view the laser waveforms along with the full-resolution data.

Data Types supported

It is important to note that PFM data "loaders" and "unloaders" are easily written for almost any native type of data format. In order to load and unload a data type you must be able to extract latitude, longitude, depth, and some form of status information from the data. You must also be able to directly address each individual data record in the native format file. Status flags are available in the PFM format to allow data to be marked as manually edited, filter edited, selected, suspect, contact, class 1, or class 2 (user defined parameters). Translation of these flags to and from the native format is the function of the "loaders" and "unloaders." In the simplest case, such as for ASCII XYZ data, the only status indicator available in the native format is a valid/invalid flag, so the edited flags are mapped to the valid/invalid flag. Only status information is actually written back to the native format on "unload." At present the supported data types are multibeam or single-beam data stored in ***Generic Sensor Format (GSF)*** [1], single-beam data stored in NAVOCEANO's "merge" format, SHOALS Lidar data in the Optech .out format, and various types of data provided in ASCII XYZ format. Data formats that are not presently supported by IVS and SAIC can be added by the end user since the PFM API (application programming interface) library is provided with Fledermaus and the Survey Analysis Toolkit. Documentation describing the PFM format and API will be provided with the IVS and SAIC products. A loader/unloader typically takes about 2 hours to implement for most native data formats.

Survey Analysis

SAIC's Survey Analysis product provides a state-of-the-art hydrographic and bathymetric data analysis software package. Survey Analysis is the post-processing component of SAIC's Integrated Survey System (ISS2000), which, in addition to post-processing and charting capabilities, offers mission planning, and real-time data acquisition and survey control components. Survey Analysis is designed to process hydrographic and bathymetric data in support of nautical charting surveys, seafloor characterization surveys, cable route surveys, and search and locate surveys. [2], [3], [4], [5]

Survey Analysis provides an intuitive approach capable of handling today's large seafloor datasets in a rigorous and efficient manner. The approach supports a standardized processing flow to ensure the consistency of results across a spectrum of analyst capabilities. Quantitative quality assurance is provided to fully characterize processing results. All of these factors support the objectives of streamlining the effort required to produce data products and minimizing survey rework when these processes are applied in the shipboard environment.

Figure 5 illustrates the graphical user interface (GUI) for SAIC's Survey Analysis product. The data displayed in figure 6 were acquired and processed by SAIC under contract with National Oceanic and Atmospheric Administration (NOAA) to survey Salem, MA Sound. The minimum depths of approximately 1.5 meters are displayed in red, and the maximum depths of approximately 19 meters are displayed in blue.

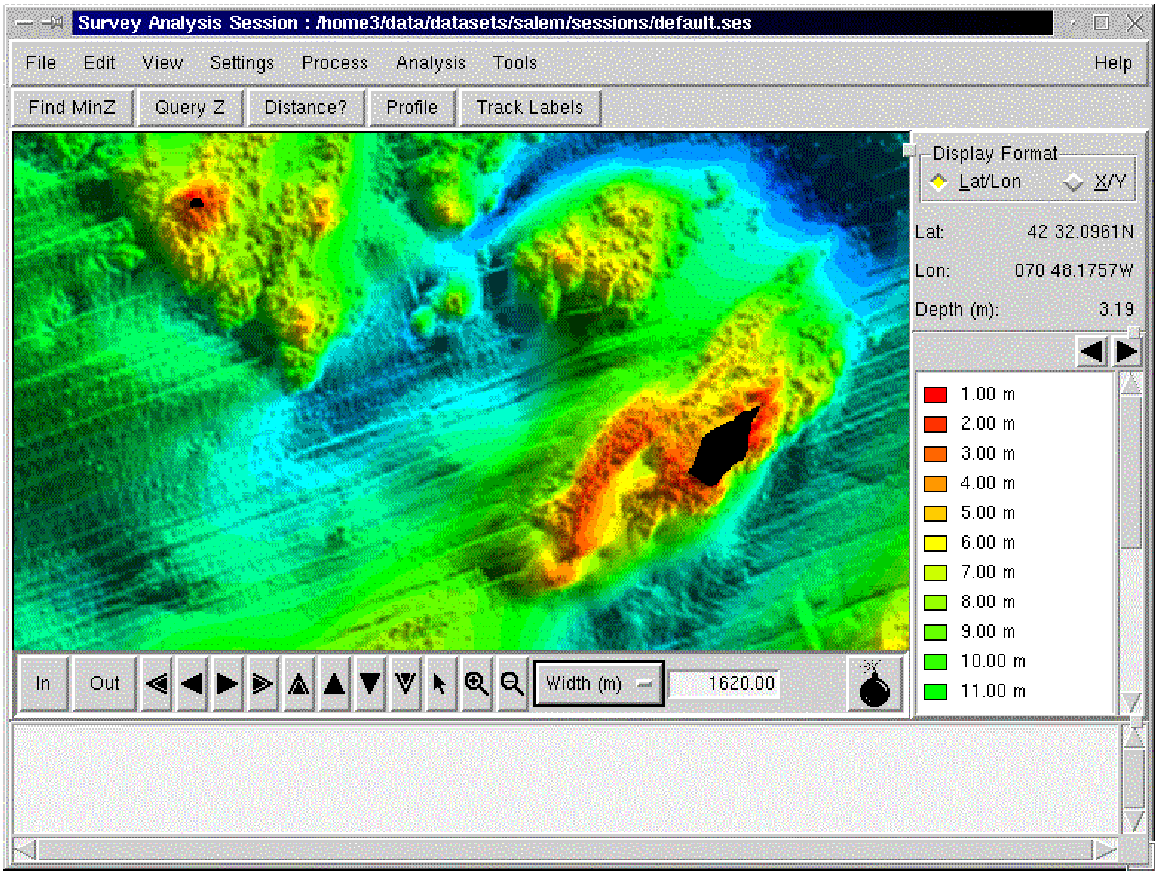

Figure 5. – Survey Analysis Graphical User Interface

This user interface provides the focal point for the product's geospatial data analysis. From this user interface various geospatial data layers may be superimposed for visualization, and analysis. Supported data layers include planned survey transects, tidal zoning, sheet boundary definitions, coastlines, various formats of vector data, gridded bathymetry, contours, sidescan mosaics, targets, survey tracklines, selected soundings, junction statistics, and raster nautical charts.

The menu structure for Survey Analysis is organized to follow typical data flow through post processing. Swath oriented bathymetry and sidescan imagery data may be georeferenced immediately following acquisition for initial processing. The geospatial gridded bathymetry files may be created in Survey Analysis's internal grid file format or, as a result of the CRADA, in the PFM format. The various layer selections available in PFM may be selected for display.

Enhancements resulting from the CRADA agreement include the ability to use the editor shown in figure 4 by selecting an area from the gridded data surface. A coverage view is available to show the areas of the gridded surface that have been reviewed and to highlight those areas that have not been reviewed.

A complete suite of swath-oriented and navigation processing tools are available to assist with data editing and post-survey corrections on an as-needed basis. Survey Analysis uses the GSF file format to read and process bathymetry data. Use of the GSF format provides full traceability for all corrections and edits to the data. This is a key feature necessary to ensure that all required corrections to the bathymetry data may be re-applied in post-processing if necessary. This complete level of traceability is maintained from initial data acquisition through the final selected soundings for all edits and corrections to the bathymetry. In the shipboard environment, new data can be incorporated into Survey Analysis as they become available. The data can be edited as required, used to assess coverage, and used to assist with the planning of fill-in transect lines to ensure adequate bottom coverage.

Surface ship and sub-sea navigation processing tools include the ability to identify and invalidate fliers in the position data. A forward/backward Kalman filter may be used for driving down residual errors in the raw navigation data and, if appropriate, bridging short outages. For sub-sea navigation, complete reprocessing from the raw acoustic ranges, including application of appropriate calibration values, is supported.

Targets that have been identified from sidescan sonar or other imaging systems may be imported and layered over the bathymetry for contact analysis. Contacts can be organized, associated with other contacts, and related to the most appropriate bathymetry sounding to assist with the determination of contact significance.

Once editing and final corrections have been completed, tools are available to assist with quality assessment. Junctioning of the bathymetry data may be performed at cross line to main scheme line intersection and sheet-to-sheet intersection. A statistical report is provided to quantify the results. Shaded relief display of the bathymetry data using operator-selectable azimuth and elevation angle of the light source may be used for quality assessment.

Survey Analysis provides a geospatially oriented sounding reduction algorithm. The approach takes into account the sheet scale and all appropriate input data. The sounding reduction results may be used to attribute the GSF data files. Sounding selection results may be displayed as a layer on top of a gridded depth layer, or on top of a raster chart for further quality assurance.

Figure 6 shows a zoomed in view of a selected soundings layer displayed on top of a NOAA raster chart. These data were acquired and processed by SAIC under contract with NOAA to survey Salem Sound. The soundings shown in blue are the selected soundings, resulting from a 100 percent bottom coverage survey using a Reson 8101 multibeam sonar. The area labeled as Bowditch Ledge is viewable as the shoaling area in the upper left-hand portion shown in figure 6.

Survey Analysis also provides the capability to support channel engineering operations. This includes the ability to compare the results of a channel survey to the channel design and the computation of volume of dredged material. Additionally, the software provides marine cable engineering functions, including design of route position lists and the production of alignment charts.

SAIC’s commercial Survey Analysis software has been used to efficiently and rigorously process and analyze large shallow water hydrographic datasets. These datasets have varied in size, in excess of one billion soundings for a single sheet. Full traceability is maintained from data acquisition through the final product generation.

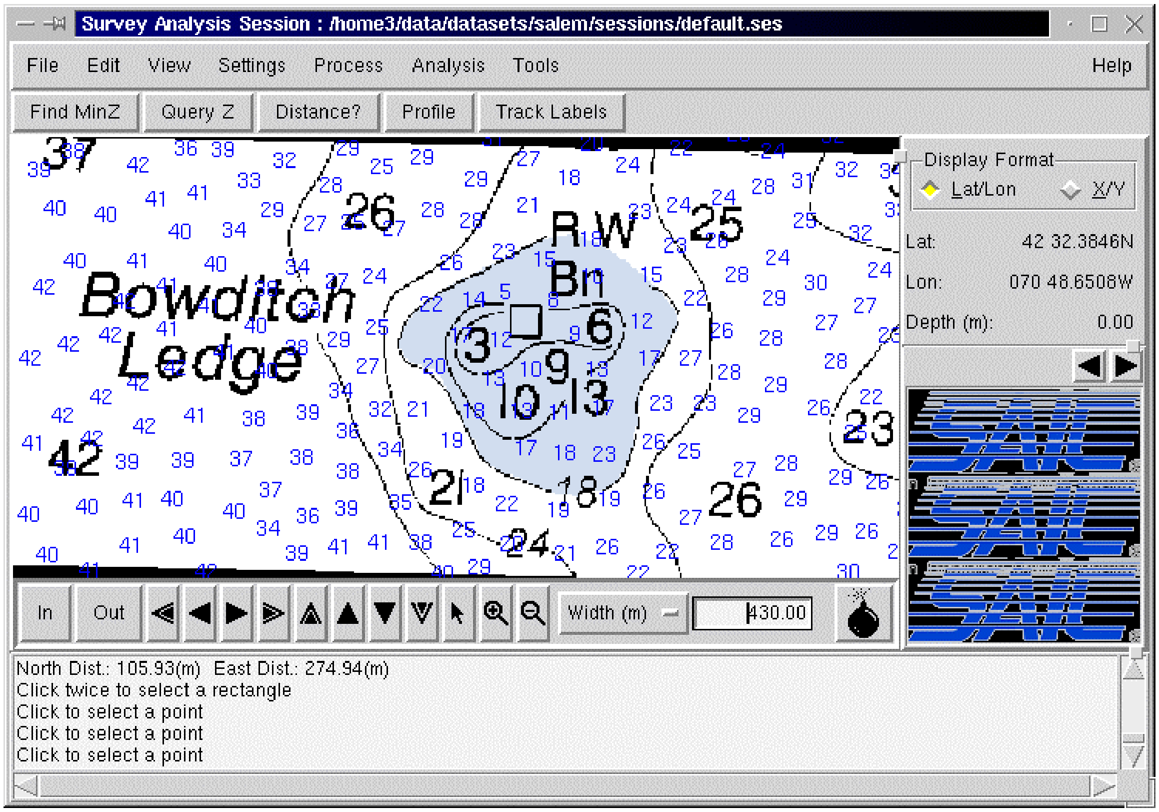

Figure 6. – Sounding Selection Comparison with Raster Chart

Fledermaus 3D visualization and editing

The massive amounts of data that NAVOCEANO vessels are producing with the new systems present many challenges; the establishment of the quality of the data acquired and then the interaction, integration, interpretation, and presentation of the data. If properly handled, the inherent density of the data available also presents tremendous opportunities. Integrating interactive 3D visualization into the overall processing system allows the operators to take full advantage of this data density and, in doing so, allows them to interact with, explore, and analyze, complex multidimensional data. When properly geo-referenced and treated, these complex data sets can be presented in a natural and intuitive manner that allows the simple integration of multiple components from various sensors without compromise to the quantitative aspects of the data.

The human visual system has an enormous capacity for receiving and interpreting data quickly and efficiently and therefore must be an integral part of any effort to understand complex data. The key is to be able to present the data in as intuitive a fashion as possible. The more intuitive the presentation, the more rapidly data are interpreted and the more new information can be extracted from that data. These elements have been incorporated in the Fledermaus interactive 3D software application. Figure 7 illustrates one of the 3D views colored by the density of data and a selected profile “cut” through the data.

Some of the unique features of Fledermaus are the methods for exploring 3D data spaces. The most innovative of these uses a special six degree-of-freedom mouse (the "Bat") that allows the user to rapidly "fly" through the data by using simple hand motions. You can explore your data by simply moving your hand in the direction you want to move. To move forward you move your hand forward; to turn right you turn your hand to the right. Thus natural gestures allow you to quickly view large data volumes in a natural fashion that greatly facilitates the interpretation of the visualized data.

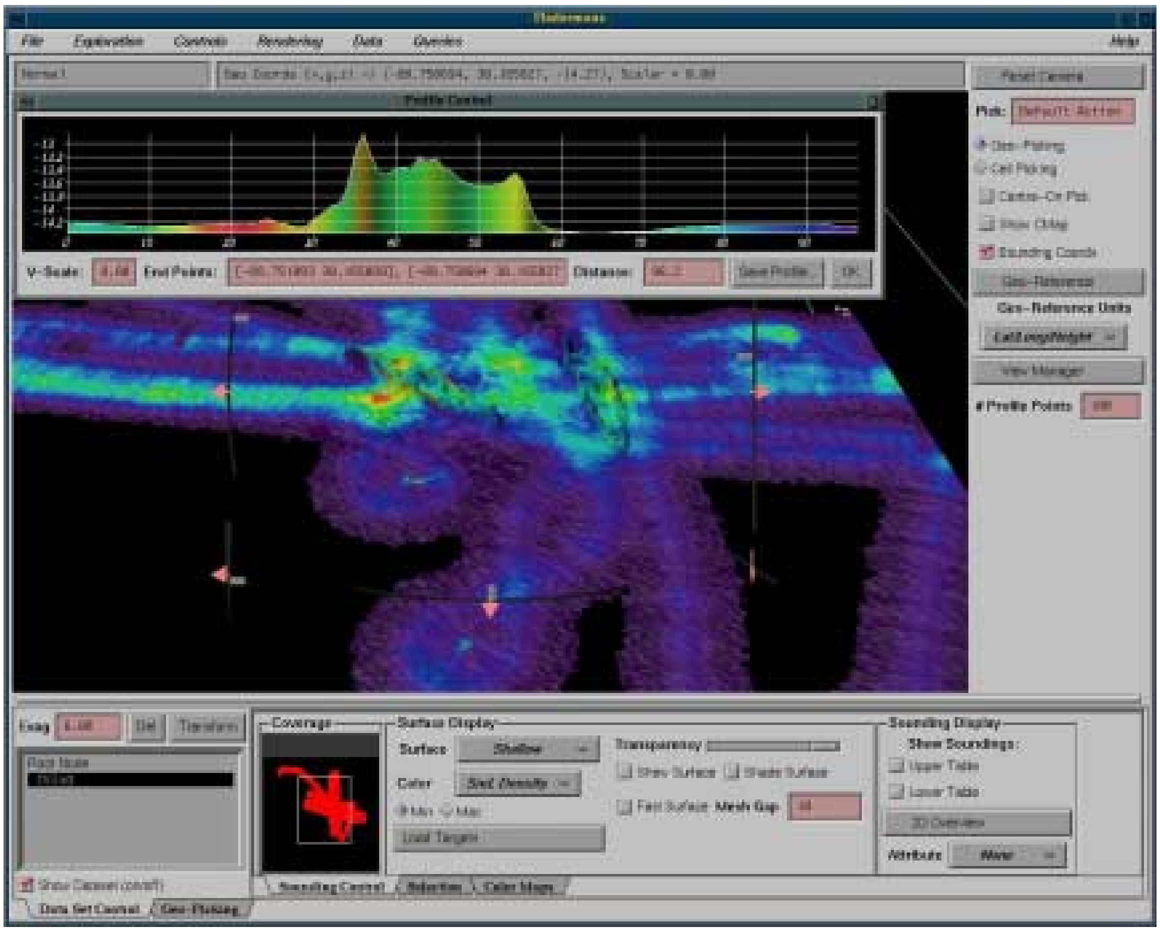

Figure 7. - Surface of sounding class data colored by the density of data and profile interactive profile.

The software package allows the import of a variety of data types, either gridded or ungridded, from common mapping applications, as well as ASCII data and/or a range of image file types. For the NAVOCEANO integration, the unique sounding class data structure of Fledermaus was modified to support the NAVOCEANO PFM data structure. This combines the power and benefits of viewing a gridded surface but also allows full access to all the data in the individual native format data files contributing to the PFM bins.

Using this unique approach, the operators are able to load the PFM data based on a geographic area of the survey and interactively analyze the data in the 3D environment from the total overview of the survey down to selected regions of interest. They are able to view the data surface based on various parameters (shallow, average, deep, filtered, or unfiltered) and highlighted by various attributes (bin density, standard deviation, class, etc.). Operators also have the option to display target files generated during acquisition and bring up “snippets” of the sidescan sonar associated with each contact. Figure 8 illustrates this target interface with the 3D display.

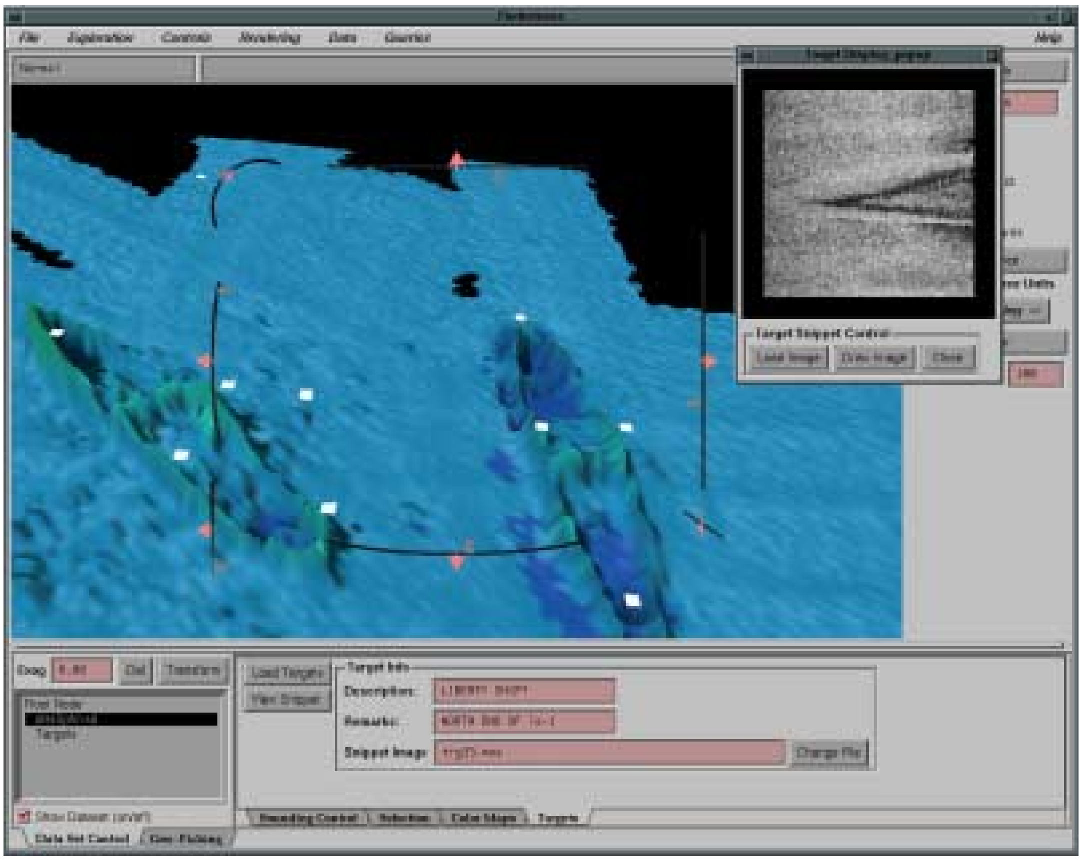

Figure 8. – 3D surface of Liberty shipwrecks with target locates indicated by white squares. An associated “snippet” of the sidescan is shown in the upper right.

If the operators identify an anomaly, they can select an area of the 3D surface and then view all the individual data points from the GSF data files, either directly in the 3D environment or in a linked window of the ABE. Any edited data are then dynamically updated in both the PFM file and the data visualized in the Fledermaus 3D environment.

In addition to the processing with the PFM data files, operators can utilize the normal functionality and data types in Fledermaus. Texture mapping permits the draping of georeferenced, high-resolution datasets (i.e., nautical chart, other geographic imagery, or sidescan sonar imagery) over lower resolution DTM without the need to up-sample the DTM or downgrade the imagery. Additional queries include profiling across the surface or surfaces in the 2D and 3D environment, interactive contouring of the surface in the 3D environment, and calculation and analysis of differences between surfaces from either overlapping lines of soundings or from previous surveys in the same area.

The challenge of the ever-increasing data volumes makes it essential to become more efficient. 3D visualization is a significant element of meeting this challenge, and when integrated in the overall process, can produce value in areas such as efficiency, accuracy, completeness, integration, and communication. Variations in the accuracy of a survey, from either systematic or random errors, are clearly defined. This provides an assessment of whether the survey meets requirements. Early detection of any out-of-limits condition not only will improve the accuracy of the survey but also will provide greater efficiency by limiting the requirement for re-surveying. Visualization provides the complete picture of all the data gathered during the survey or available from other sources, and it is inevitable that without the complete picture, maximum value will not be obtained from data and errors will be made in the processing.

Product Generation software

NAVOCEANO utilizes CARIS chart production software to generate both Digital Nautical Charts (DNC®) and Electronic Navigation Charts (ENC). The CARIS software modules include the CARIS Object Manager for DNC® (CARIS DOM) and ENC (CARIS HOM), Digital Terrain Model (CARIS DTM), Geographic Information System (CARIS GIS), and CARIS Suppress Soundings. These tools are used mainly in compiling the soundings, creating and editing bathymetric contours, and rearranging the geometry of linear features to achieve proper topology. The output of the sounding selection. module of the ABE goes directly into the CARIS chart production software. On 15 November 2000, a Memorandum of Agreement was signed between the National Imaging and Mapping Agency (NIMA) and NAVOCEANO under which NAVOCEANO would assume the responsibility to compile specific DNC libraries. These libraries consist of those directly affected by NAVOCEANO surveys, either with Navy survey platforms or with survey vessels cooperating under the Hydrographic Cooperation (HYCOOP) Program. Upon completion of the DNC library compilation using the CARIS software and after rigorous quality control using the NIMA VPF Validator software suite, the libraries are sent to NIMA for general dissemination as part of the NIMA chart maintenance and update program. The major objective of co-production is to provide quality DNC products to the Warfighter that meets their high-priority navigational and operational requirements in the shortest possible time. Also, the NAVOCEANO compilation may be used to produce an ENC in partnership with HYCOOP and foreign host nation hydrographic offices.

Conclusion

NAVOCEANO has unique requirements, in part because of the sheer volume of data that must be continually processed. Obviously, the data rates are going to continue to increase, and we must continually push our throughput rates and decrease the turn-around time from data collection to generation of a product. These software improvements are the first step in improving those processes, and we must include R&D efforts in such things as artificial intelligence to make the next jumps in progress. Integration of NAVOCEANO's ABE with SAIC's Survey Analysis and IVS's Fledermaus will produce a significant improvement over prior capabilities. The resulting tools will be mutually beneficial and will provide NAVOCEANO with a COTS solution that addresses our requirements for data throughput and product generation turnaround time.

Partnerships with industry–particularly the CRADAs with IVS and SAIC-have enabled NAVOCEANO to move toward COTS packages while utilizing the benefits of over 30 years of government data processing experience.

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