Quality Control of Hydrographic Multi Attribute Data by Interactive 2D and 3D Visualization

Peter Johnson, Royal Australian Navy Hydrographic Service, Wollongong, Australia.
Lindsay Gee, Interactive Visualization Systems, Inc., Fredericton, Canada.
Scott Elson, Nautronix Ltd., Fremantle, Australia.

Abstract

The Royal Australian Navy Hydrographic Service's (RANHS) Laser Airborne Depth Sounder (LADS) was introduced in the early 1990s and is now a well established system used for routine hydrographic surveys of the coastal zone. LADS primary use has been the conduct of surveys for the production of nautical charts of the Great Barrier Reef, off Australia's northeast coast. These areas have extremely complex seabed topography and when combined with the enormous quantities of data produced by LADS it made quality control (QC) of the surveys difficult and very labor intensive.

Previously the only LADS data that could be used for nautical charting were those plotted on 1:25,000 fairsheets. These soundings were manually checked and contoured. During a typical three month survey, LADS may produce fifteen or more such A0 size fairsheets. LADS acquire data on a ten meter grid and the soundings shown on the fairsheets represent only 0.5 percent of those collected.

In 1998 the AHS initiated a program to improve the QC process through the acquisition of a 3D interactive visualization system that would enable a much greater quantity of digital LADS data to be used for nautical charting. The Fledermaus 3D visualization application was selected and combined with the latest Silicon Graphics Octane workstation. The system supports interactive, stereo, three dimensional 'fly through' of the very large data sets, with the ability to pick any sounding and query any of twenty or more attributes. By creating a visualization model of the entire area, any sounding data problems are immediately apparent with other tools allowing the further investigation or editing of the data.

The system also allows the import of multiple data sets and types, in addition to LADS, and these can have different levels of resolution. All the data sets are geo-referenced and spatial queries allow for measurements and interactive interrogation of XYZ and any other attribute. Texture mapping permits the draping of geo-referenced high resolution data sets (e.g. raster charts or high resolution sidescan) over lower resolution bathymetry. Gradients and difference surfaces can also calculated in the 3D environment to support the QC process.

Introduction and Background

In 1946, an Australian Government decision established the Royal Australian Navy Hydrographic Service (RANHS) as the national charting authority, with the objective to ensure safe navigation for all vessels sailing Australian waters. Australia has a charting responsibility exceeding 11 million square nautical miles and half the continental shelf is less than 50 meters deep. A significant amount of the inadequately surveyed areas is in the strategically important northern waters. A large section of this is includes the shallow and complex reef areas of the Great Barrier Reef. [1]

Earlier work in the Great Barrier Reef area had been primarily restricted to delineating the outer reef and the main inner shipping route. A number of other shipping routes had been surveyed to allow transit through the Barrier from significant ports to the Coral Sea. Survey work in the unsurveyed areas of the Reef was constrained by the dangers to vessels in shallow waters and the slow speed required. The use of single beam echosounder and towed sidescan sonar in the extremely complex reef areas resulted in a slow rate of progress for surveys in the Great Barrier Reef.

Early investigation of other remote sensing system showed the limitations of passive techniques restricted their use to reconnaissance and the identification of suitable areas to operate survey vessels. Suitable survey acquisition for nautical charting relied totally on the use of surface vessels. In the early 1970's the possibility of using an airborne scanning laser was investigated, and after proving the feasibility a program was initiated to continue the research and develop an operational system. [1]

Figure 1. *- Diagram of LADS coverage (Image courtesy LADS Corporation)* [2]

The current RANHS Laser Airborne Depth Sounder (LADS) system was contracted in 1989 and after an extensive set of functional trials in various areas of the Australian continental shelf, was accepted into service by the RANHS in 1993. Since being accepted the LADS system has surveyed more than 60,000 square kilometers of the continental shelf, at an average rate of 10,000 square kilometers per annum. This annual rate of coverage has been approximately the same area as that surveyed by all the RANHS survey ships combined.

The LADS system was developed as a completely self-contained hydrographic data collection, processing and analysis system, capable of operating in the relatively remote locations of northern Australia. It has the ability to acquire data in sorties up to eight hours duration and covering over 50 square kilometers per hour. The data acquisition and processing is undertaken in two subsystems; the Airborne Data Acquisition Subsystem (ADAS) and the Ground Analysis Subsystem (GASS). The ADAS comprises the navigation, data acquisition and data logging elements. The ADAS is highly automated and allows the operators to monitor the depth sounding and equipment performance. Data is recorded in this system and apart from monitoring the raw depth all processing and analysis is undertaken in the GASS.

The first step in the GASS is the automatic processing of the raw data on a line by line basis into primary soundings. This takes about the same time as the data acquisition. Primary soundings have normally then been reduced to secondary soundings at a density related to the traditional plotted fairsheet together with an associated Final Survey Data file output. This reduction identifies the significant shoal soundings of the primary data, and was undertaken to assist in the more effective review of the data during validation and checking. During validation the waveform for every sounding is available for review by the operator to assist in identifying outliers.

Figure 3. *- Typical hardcopy contour output. (Image courtesy of LADS Corporation)* [2]

Review of the combined secondary data from various lines, on an area basis, could then only be done using hardcopy plots of the soundings. In a typical three month survey fifteen or more of these A0 size fairsheets will be produced. It was at this stage in the processing that a slight bottleneck was identified where any anomalies found in the hardcopy plots required reversion to the original line by line processing for correction. The GASS tools available to the operators were the same for validation and checking and it was considered that an improved approach with an independent application could be implemented to assist in the overall processing life cycle. In addition, because the process was reliant on the scale of the hardcopy sounding plot, less than 1% of the data was undergoing final checking resulting in approval by the charge surveyor for use in the nautical chart product.

In 1998 the RANHS initiated a program to improve the Quality Control (QC) process through the acquisition of an interactive 3D visualization system that would simplify the QC process and improve the efficiency of this stage of processing. It also provided the added benefit of allowing QC of more than just the soundings that were plotted on the fairsheets.

The following sections describe firstly the general application of 3D visualization to the analysis of high-resolution geographic data and the specific use of visualization for the quality control stage of the LADS data processing.

Data Visualization

High-resolution data sets that result from huge volumes of survey data (surveys can now run into gigabytes per day), render traditional evaluation methods obsolete. The traditional presentation approach has been the 2D plot, either on a computer screen or a hard copy. This type of plot has some major disadvantages. It is not possible to show both regional coverage and detailed information in the single presentation. Also, the underlying data are normally heavily reduced and cartographic techniques, such as colors and contours are used to graphically enhance the derived information. The scale dependence of this approach also limits the variety of information that can be shown and the analysis that can be undertaken.

The human visual system has an enormous capacity for receiving and interpreting data quickly and efficiently and therefore should be an integral part of any effort to understand complex data. It has been estimated that well over half of the brain is absolutely dedicated to things we see, and there is the enormous capability of the human brain to detect patterns in data. [3]

The often used quotation that "the purpose of computing is insight, not numbers" neatly encapsulates the purpose of the discipline of scientific visualization. [4] The key is to be able to present the data in as intuitive a fashion as possible with the purpose to gain new insight. It has been found that the more intuitive the presentation, in the way that we perceive the real world everyday, the more rapidly new insight can be gained and the more new information you can extract from that data. [3]

3D visualization is used in various areas of the analysis of geographic data. It has been shown that it can produce value in areas such as efficiency, accuracy, completeness, integration, and communication. [3]. The hydrographic surveyor has no choice but to become absolutely more efficient because the number and size or surveys and the types of data that has to be processed and interpreted are increasing rapidly. Compare the progression in recent years from the profiles of single beam echosounder surveys, to the small number of beams in early swath systems, to the current technology where some systems now have thousands of beams per swath. In addition, some systems provide other attribute data simultaneously that requires processing and interpretation. It is a certainty that the number of people available to process the data will not increase, and that pressure will remain to process the data in the same amount of time. 3D data visualization is part of the solution to meet this challenging processing and analysis problem. It is inevitable that without the complete picture, maximum value will not be obtained from data and errors will be made in the processing.

A significant area for visualization is the preview of data. Currently, it is common to only use 3D data visualization in the latter stages of processing once it is believed that the data are clean and ready for final analysis. This is under-utilizing the power of 3D data visualization and not improving the efficiency of the processing pipeline. The use of visualization of the data on an area basis, instead of the normal line by line process, in the early stages of processing provides the general character and structure of the sea floor that has been mapped. It also intuitively shows the areas that will be more difficult to process and any areas of importance. In this fashion, preview assists in the planning of data processing and analysis.

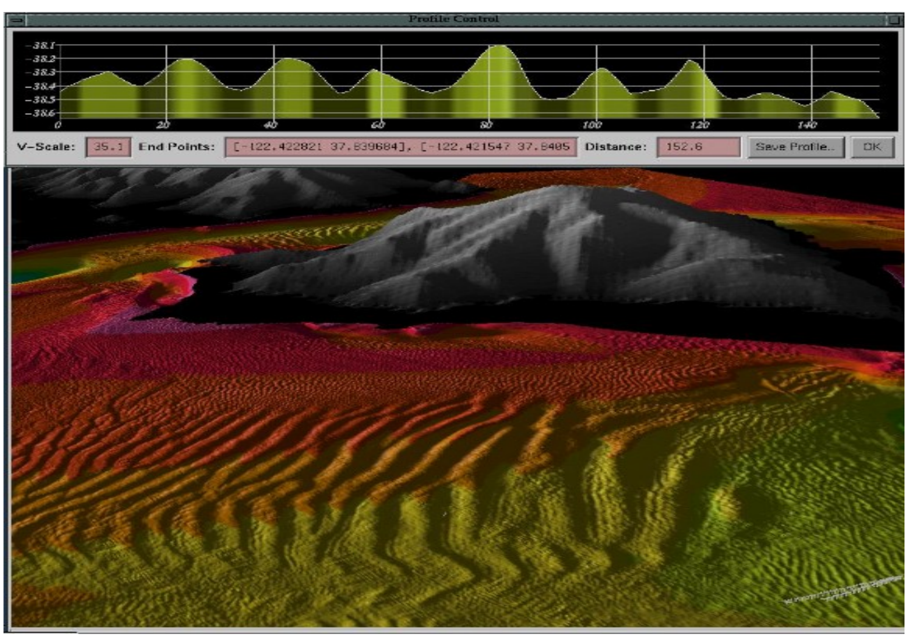


Figure 3. *- View of the area adjacent to Angel Island in San Francisco Bay – swath bathymetry combined with the terrestrial DEM and profile of sandwaves. (Data courtesy of Jim Gardner, USGS)*

3D visualization also improves the accuracy of data processing and analysis. 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 will not only improve the accuracy of the survey, but will provide greater efficiency by limiting the requirement for re-surveying. Visualization provides the complete picture of all the available data gathered during the survey or available from other sources.

When making judgements about the relationships between objects in a 3D scene, it is important to provide as many 3D spatial cues as possible. These cues help make surface features of digital terrain and other objects clear. Thus, the spatial relationships in the visualized data are easily perceived. Interactivity provides a dual benefit. Being able to move around the 3D scene and view it from any position or orientation, further aids in the interpretation of the scene. Motion also assists in extracting information from the data. If the objects can be analyzed while they are in motion, the observer will see more information than if the image is static. [5]

If we consider surface data, there are several techniques that are commonly used to visualize data. These include pseudo-coloring, illumination and shading.

Pseudo-coloring is the process of assigning a sequence of colors to a sequence of data values. When the colors are mapped onto the depth data, the result is a color contour map of the sea floor. By selecting different color maps, appropriate features of the surface can easily be highlighted. While the color sequences are often mapped to depths, any other variable, such as multibeam backscatter, gravity and magnetic intensity can also be mapped.

Another visualization technique commonly used is illumination and shading. Here a light source is added to the scene and the surface is shaded accordingly. Applying a lighting model to a surface greatly enhances the features of the visualized data, which makes for more effective analysis. The image also appears more "real" if true shadows can be cast on the surface.

All the above aspects of visualization have been implemented in the Fledermaus software application from Interactive Visualization Systems that has been delivered to the RAN as part of the upgrade to the LADS processing. Fledermaus is used for the interactive 3D visualization and analysis of data and incorporates a number of sophisticated rendering, viewing and data manipulation tools. What is perhaps most important is the fact that these tools are combined in a highly interactive integrated package. [6]

Fledermaus has three distinct 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 just 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. This flying interface provides visual feedback about velocity and rate of turn in the form of a predictor.

Through the use of different object classes, multiple, individual data sets with different levels of resolution can be easily combined, geo-referenced, and displayed. Thus land-based DEMs with one level of resolution can be combined with multiple bathymetric data with different levels of resolution sets (LADS, multibeam, etc.) without the need to re-grid at a common scale. All of these are geo-referenced and spatial queries allow for measurements and interactive interrogation for position, depth/height or any other attribute. If necessary, as with the case in full analysis in the LADS QC Tool, the data underlying the DTM can be viewed along with the derived surface.

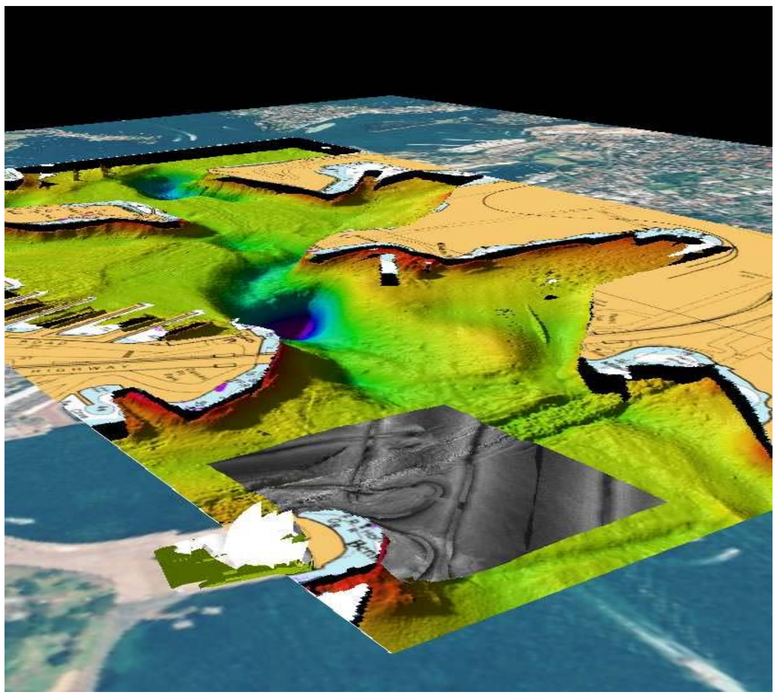


Figure 4. *– Image combined data sets from Sydney Harbour including swath bathymetry, raster chart, and orthophoto. (Data from DSTO Shallow Water Survey Conference, 1999)*

Texture mapping permits the draping of geo-referenced, high-resolution data sets (i.e. nautical chart, other geographic imagery or sidescan sonar imagery) over lower resolution DTM without the need to upsample the DTM or downgrades the imagery. Gradients, slopes, difference surfaces and volumes can also be calculated in the 3D environment.

In addition to the exploration of the data contained in the computer's virtual 3D environment, Fledermaus also provides a true 3D stereoscopic display. Normal human stereoscopic vision only works over a limited range and optimal stereoscopic viewing is between 0.5 and 2 meters. Fledermaus incorporates a stereo viewing algorithm that automatically adjusts the stereo viewing parameters so that stereoscopic depth is obtained even for scenes that are at large (virtual) distances. Fledermaus is unique in that, these parameters are constantly adjusted so that even while 'flying' through a virtual data environment, stereo depth cues are always available.

LADS QC Tool

The primary requirement for the LADS QC Tool was to enable the visualization and QC of the Final Survey Data (FSD) before it was approved and forwarded after each survey to the Hydrographic Office for inclusion in the main hydrographic database. A second system was also delivered to the Hydrographic Office to be used for final verification prior to the data being used for nautical charting. Both systems were delivered on Silicon Graphics Octane MXE workstations that were subsequently upgraded with the addition of a second monitor. The Hydrographic Office system has subsequently been used for the assessment of the performance of the new multibeam systems being delivered to the RANHS under the new Hydrographic Ship Project – SEA1401.

The principal data to be used was the LADS FSD. This is a unique multi-attribute format that was established with the development of the system and includes for each data point the position and depth plus over twenty attributes. These include:

- Run, frame, scan and sounding information,
- Date and time, and tide correction and method,
- Sounding status (accepted, anomalous, deleted, etc.) and
- Primary and secondary confidence values.

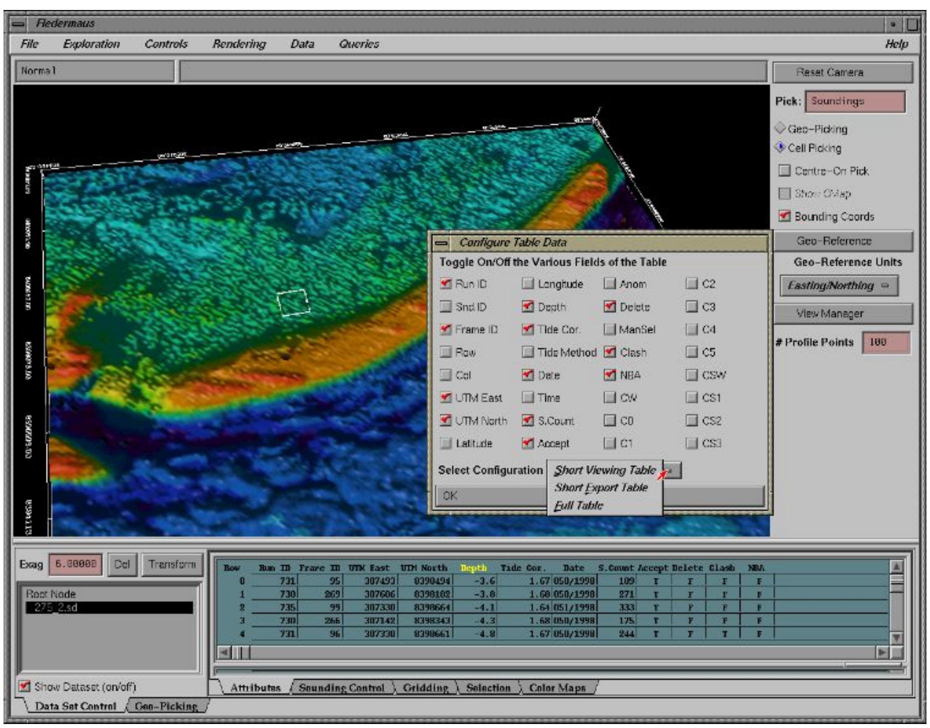


Figure 5. - *Screen capture showing single object and the attribute table and configuration options.*

In addition the system was required to handle a number of other data types to assist in the QC process, including:

- The generic RAN Hydrographic Transfer Format (HTF),
- ASCII xyz sounding data,
- GeoTIFF images, and
- Ability to exchange data with the other units of the RAN Hydrographic Service.

Fledermaus supports over twenty object data classes, (such as gridded surfaces, line and point objects, solid objects, subsurface profiles, planes, grids, and cable objects) and a number were used specifically for the LADS QC requirements. The depth data could be prepared and analyzed in both the 2D and 3D applications as a prepared gridded surface. As noted above, this display should not be underestimated in identifying a significant number of line and scan based outliers.

However, the LADS QC requirement was to be able to identify the anomalies and then directly access the underlying XYZ and associated attributes for each data point. This was combined with the requirement to be able meet stringent performance requirements for the import and update of displays. The traditional hydrographic approach to ensuring that all data points are evident in any 3D display is to use the Triangular Irregular Network (TIN) approach. This is not suitable for the volume of data associated with the LADS system unless the data is reduced in volume by some method. Reduction of the data by thinning or processing by smaller area defeats the purpose of being able to visualize the data from a regional view down to the individual data points. This is also no longer relevant with the high data density of multibeam sonars where the TIN approach is completely inefficient and also can hinder the analysis by hiding outliers or features in the system noise.

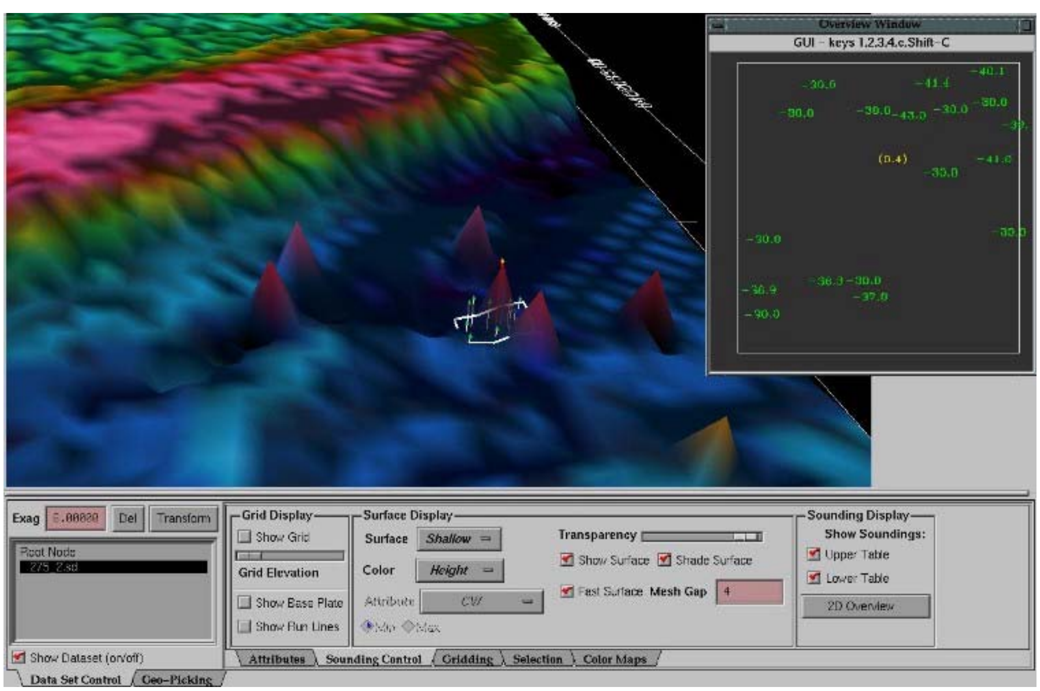


Figure 6. *- Screen capture showing selection of outliers and the linked 2D display.*

The requirements for the LADS QC Tool could be satisfied by a couple of unique features of the Fledermaus application. Primarily the sounding class allows the user to benefit from the speed of viewing a gridded surface, but also provides full access to all the underlying data contributing to each data cell. In the 3D environment the sounding class allows the surface to be:

- Interactively re-gridded with various cell size, selection criterion and status,
- Coloring the surface by various attributes – depth, density, confidence, standard deviation, etc.,
- Interactively re-shaded with varying illumination and shadow length, and
- Apply automated processes to the data to identify outliers, cells of high variance, surface gradients, etc.

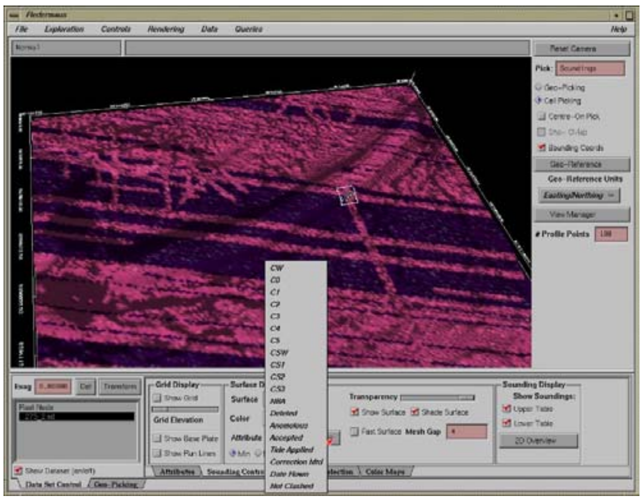


Figure 7a. – Selection of attribute to color surface.

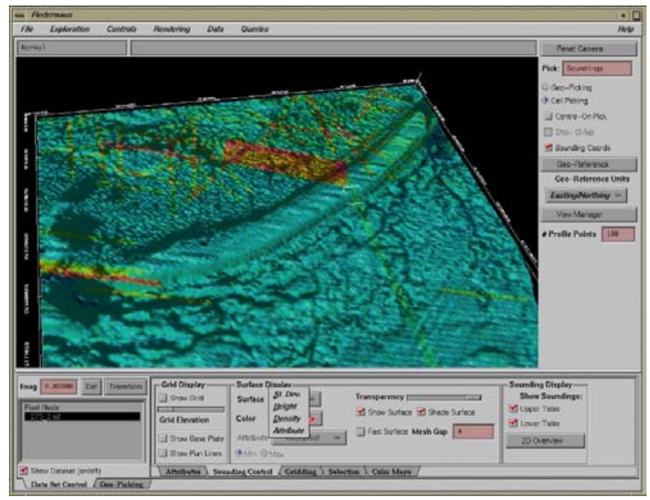
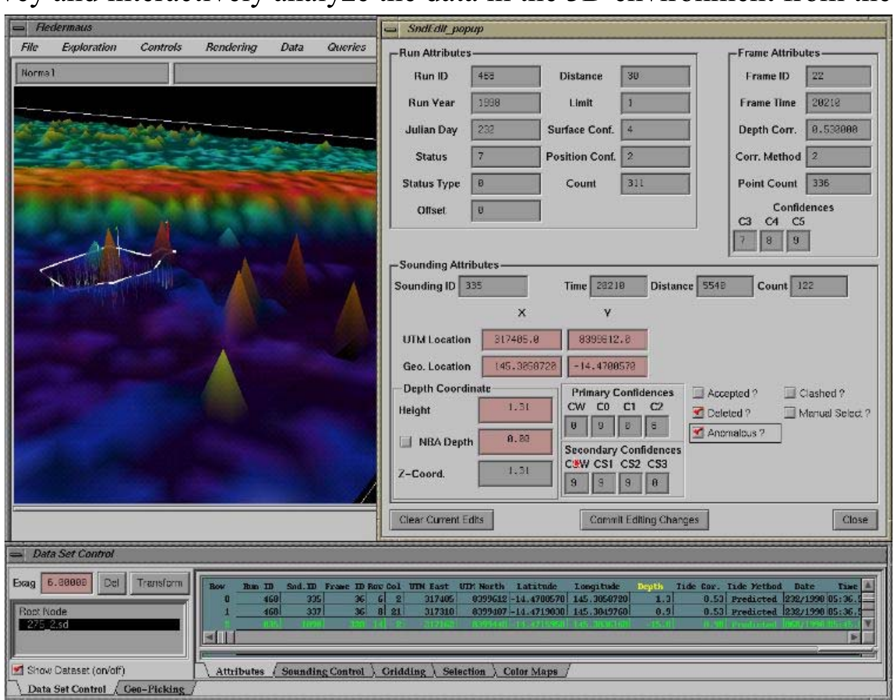


Figure 7b. – Surface colored by density of data

Using this unique approach with the system provided, the operators are able to load all the FSD from a survey and interactively analyze the data in the 3D environment from the total



overview of the survey down to each data point that has been imported. If the operator identifies an anomaly they can select the cell in which it is located, plus any number of surrounding cells, view a separate linked 2D display and access the full details of each point with all attributes in a linked table. Also at this stage of processing any anomalous data can also be edited and this is stored in the FSD with an audit trail of any changes.

Figure 8. *– Screen capture showing the selected soundings and the editing dialog box.*

Additional queries utilize the normal functions of Fledermaus including:

- Picking of points on any surface,
- Profiling across the surface or surfaces in the 2D and 3D environment,
- Interactive contouring of the surface in the 3D environment, and
- Calculation of differences between surfaces from either adjacent lines of sounding, or from previous surveys in the same area.

A number of output products can be produced to support the final reporting including screen captures, scaled map output, recorded movies of a "flight" across the data, output of the attribute tables and a number of standard export formats of the selected data.

Conclusions

The Fledermaus interactive 3D visualization tool is now an accepted part of the quality control process in the RANHS LADS Operational Unit. The application permits the exploration of the data in both multi-attribute and geographic space and allows combined and complex data sets to be interactively explored in a 3D environment. The area based visualization of the survey data complements the normal line by line based processing and improves the overall efficiency of the QC of Final Survey Data. In addition, it has provided the capability to significantly increase the percentage of LADS data approved for nautical charting.

LADS is one type of swath mapping system and the approach described has been successfully used on a number of other projects for the QC and analysis of both acoustic multibeam sonars and topographic laser mapping systems.

Reference:

1. Setter, C.[1], and Willis, R.J.[2]: "LADS – From Development to Hydrographic Operations", presented at 1994 US Hydrographic Conference, Norfolk, USA. [1]BHP Engineering Pty Ltd, [2]Hydrographic Office RAN.
2. Sinclair, M.[1], "Airborne Laser Bathymetry – Acceptance grows in 1998/99", presented at 1999 DSTO Shallow Water Mapping Conference, Sydney, Australia. [1]LADS Corporation.
3. Dorn, G.[1] "Applications of Visualization in the Oil and Gas Industry," presented at the 1998 Visualization Summit, Oslo, Norway, May 6-8. [1]ARCO Exploration and Production Technology.

4. Hamming, R. W.: Numerical methods for Scientists and Engineers, McGraw-Hill, New York, 1962.

5. Zeitlin, M.[1] "Texaco Visualization Technology: Corporate Visualization Center," presented at the 1998 Visualization Summit, Oslo, Norway, May 6-8. [1]Texaco.

6. Mark Paton[1], Larry Mayer[2], Colin Ware[3], and Lindsay Gee[4]: "Interactive 3-D Tools for Offshore Engineering Development". Presented at the 1997 Third Australasian Hydrographic Symposium, Fremantle, Western Australia, December 1-3. [1]Interactive Visualization Systems. [2]University of New Brunswick Ocean Mapping Group. [3]Uuniversity of New Brunswick Human Computer Interaction Lab. [4]Nautronix Ltd.