Multi-Dimensional Water Column Analysis as a Catalyst for Sustainable Hydrographic Survey

COLLINS, Corey, P.Eng., CARIS, 115 Waggoner’s Lane, Fredericton, New Brunswick, Canada.

ABSTRACT

With the ever-increasing availability of CPU processing power and data storage, multibeam sonar systems used for shallow water surveys are now capable of collecting full water column imagery data. This imagery is being used by post processing software as a way to supplement bottom detection results, often for the purpose of detecting the shoalest parts of sunken ships. The incorporation of water column data with bathymetry also provides a more complete representation of the submarine landscape as a whole and as such has the potential to allow multibeam data to be used for many non-traditional applications.

This paper will describe how water column imagery can be interrogated as part of an integrated bathymetric processing workflow. It will highlight tools and techniques that can be used in conjunction with standard swath analysis for the purposes of least depth detection. Perhaps more interestingly it will also describe how water column imagery can be represented in a 3D environment using the latest point cloud processing and visualization techniques. By representing water column imagery as a point cloud it becomes much easier to determine, shape, extent and volume of features in the water column with a view to more accurately and efficiently classifying the information.

Multi-dimensional water column analysis presents an opportunity for the surveyors of hydrographic data to provide additional value from the information that is being collected, as well as making the day job more efficient and robust. In these times of economic prudence being able to use data for multiple purposes e.g. marine science, fisheries and oceaneering, presents a sustainable strategy to justify the practice and development of ocean mapping and hydrographic survey. The tools and techniques highlighted in this paper aim to suggest how processing data in new ways can help sustain the industry.
INTRODUCTION

Within the last three to five years, computer hardware and disk sizes have increased to the amount where it is possible to constantly log backscatter data throughout the whole water column, known as Water Column Imaging (WCI). Research, as well as real world experiences, has shown the possibilities of the use of Water Column Imaging for hydrographic and oceanographic purposes. Demand is increasing for the analysis of water column data in more and more survey projects. Multibeam data processors are increasingly required to interrogate the water column data as well as the seafloor bathymetry and imagery, which was the catalyst for CARIS’ tightly integrated implementation in the existing HIPS and SIPS application and workflows.

Further to the acknowledgment that WCI is of importance to the hydrographic community, it can also be seen that WCI presents an opportunity to provide additional value from the information that is being collected, as well as making the day job more efficient and robust. The ability to provide additional value to the data collected is also the ability to help sustain the industry.

The goal of this paper is to describe how water column imagery can be interrogated as part of an integrated bathymetric processing workflow. It will highlight tools and techniques that can be used in conjunction with standard swath and area based analysis, describing how the data can be used in 2D as well as a 3D environment. Furthermore, the paper will discuss how water column data can be utilized, as well as leveraged, to help create a sustainable hydrographic industry.

WATER COLUMN IMAGING

With the commercial availability of hydrographic-grade multibeam echo sounders that are able to log Water Column imaging data, it has become apparent that there is a desire and need to access this data post collection. Even though water column imaging was originally developed primarily for fisheries, today’s technical and financial pressures to extract as much information as possible from hydrographic data makes water column data an obvious fit in the industry. Access to this data in post processing software provides significant advantages for hydrographic data quality control [Hughes Clarke et. al., 2006].

With the ever increasing processing power of computers, the decreasing cost of disk storage, sonar manufacturer’s now have the ability to record water column imaging information to raw data files. Software vendors can now access this data and provide the tools to view and potentially interrogate it in post processing. This data, being what sonar manufacturers run through their complicated and proprietary bottom detection algorithms, is of potential significance in post processing.

With the release of HIPS 7.1.1, there is now support for the reading and the displaying of water column Imagery. Initial support for WCI includes Kongsberg (.all, .wcd) sonars and Reson 7K (.s7k) sonars. The data can be read and displayed as a curtain image in Swath Editor, as well as read and displayed as a 3D point cloud in Subset Editor. The data as displayed can then be used to help aid the Processor in making decisions with regards to the bathymetric data. Whether it is
the ability to verify valid or invalid data or the ability to identify areas of additional interest in regards to further investigation or even re-survey.

CARIS HIPS

With a proven reputation of being a comprehensive bathymetric data cleaning and validation tool, it is only fitting that CARIS HIPS allow users to read and visualize WCI data in a multi-dimensional environment. With proven automated data cleaning filters and algorithms, which assist in today's high data volume environments, WCI is a great addition to the workflows currently available in the application.

When first approaching this initiative, the goal was to implement Water Column Imaging within HIPS in such a way that it would be useful for a variety of applications. Examples include, quality control of bottom detections, least depth determination, 3D visualisation of water column data, volume calculations, environmental monitoring, detecting gas seeps, etc. Due to the size and complexity of the development effort, the initiative was broken down into five phases:

1) Read water column data as logged by Kongsberg and RESON sonars
2) Display WCI data in Swath Editor
3) Display WCI data in Subset Editor
4) Ray-trace water column data
5) Least depth determinations, intelligent filtering, volume calculations, etc.

With the release of version 7.1.1, Users will see the implementation of the first three phases. Realizing that different users have different needs, HIPS employs a variety of options for incorporating these new capabilities into existing workflows. In order to allow users to absorb the changes at their own pace, the traditional workflows are still available. Phases 4 and 5 will be tackled in future development and released to the users as they become available.

READING WCI DATA

With the sheer volume of data that is present in the recorded WCI files, coupled with the fact that this information may or may not be of interest by all Users in all situations, it is important to be as efficient as possible in reading and presenting the data. With past processing implementations in HIPS (Geocoder), it was realized that the information could be extracted directly from the raw data file itself for processing, therefore eliminating the need to convert the data. With this experience gained, the WCI tools as implemented in HIPS, read the WCI data on demand from the raw data files themselves. The data extents as defined by the Editors dictate what and how much data gets called and presented for display. During normal conversion of bathymetric data, the raw data files as required for WCI display are referenced within the project and, at if any point that location changes, the User will be presented with the ability to re-locate the data. This is to ensure that the User is always able to maintain reference to the raw data. To further increase efficiency, background threading techniques are utilized to read and display the WCI data. Due to the large volumes of data that potentially could be requested, this will allow the User to continue processing in the application without being locked out by the data load. The WCI data can be
loaded and viewed both in the Swath Editor as 2D curtain images and the Subset Editor as a 3D point cloud. Additional WCI tools are presented to the User if it is detected that water column data exist for the bathymetry being interrogated.

**SWATH EDITOR**

Over the last five to ten years we have seen a decrease in the line by line editing techniques and a dramatic increase in the directed editing approach within post processing software. With the increased reliability of multibeam sonars, there is less of a need to look at each line of bathymetry one by one or even ping by ping, not to mention the time required to investigate the large amounts of data as produced by modern day systems. However, there is still value in having access to a line by line editor, such as the Swath Editor in an effort to QC and troubleshoot the data when issues arise. With that said the ability to view the WCI data in a 2D line by line editor is seen as beneficial and is a great addition for quality control and detailed investigation.

In order for the WCI data to be viewed in Swath Editor, the data as recorded in the raw data file has to be mapped into a two-dimensional near-vertical plane with respect to the transducer. This involves transforming the data from polar to Cartesian coordinates (Figure 1). This type of display is familiar to RESON Seabat Users as a real-time, sonar-referenced display of the polar intensity plot has always been available for quality control purposes [Hughes Clarke, 2006].

![Polar Coordinates (left), Cartesian Coordinates (right) [Hughes Clarke, 2006].](image)

With the ability to read the WCI and the transforming of the data to Cartesian coordinates, Swath Editor now has the ability to display individual polar plots (across track image) of WCI data associated with a specific profile. Furthermore, with the construction of the across track image, it is also possible to construct an along track image of an individual beam. Two new views have been added to Swath Editor to display this information; an Across Track view, as well as an Along Track view as seen in Figure 2. As noted previously, the water column data is read on demand from the raw data file itself. The data to be read, as well as the amount of data to be read, is dictated by the profiles that are currently displayed in the Plan view of the Swath Editor. As the number of profiles in the Plan view is changed, the amount of water column data available for viewing is changed. All things related to the loading of the data is carried out using background
threading techniques so as to allow the User to continue to process bathymetry without locking the application.

Figure 2: Across Track and Along Track views of WCI data as seen in the Swath Editor [Kongsberg, 2006].

The user is able to step through these WCI images, in the Across Track, on a profile by profile basis. The view can also be stacked where all images are stacked one on top of the other with the highest intensity value showing through. This option provides a representation of all WCI data within the Plan view as opposed to one profile at a time. The Along Track view can be stacked as well, where all beams within a profile are stacked one on top of the other with the highest intensity value showing through.

Figure 3: Stacked WCI views [Kongsberg, 2006].
These views can be utilized to validate what is being presented in the bathymetry. To add to these views, the bottom detections can be displayed, which allows for easy comparison of how the bathymetry relates to what is present in the water column imagery. This could potentially highlight what the sonar missed in the water column, as well as aid the decision of whether the bathymetry is valid or not.

Basic filtering is also present in the Swath Editor to allow the User to filter the WCI data based on intensity values. These filters can be used to apply a minimum and maximum restriction on the intensity values that are being displayed in both views.

All existing options and functionality within the current Swath Editor, where relevant, have been connected with the WCI views to keep work flows consistent and familiar. Functionality such as colouring, selection of bottom detections, querying of bottom detections and editing of bottom detections can be carried out in both the WCI views. Furthermore, all views update to indicate changes made in other views.

**SUBSET EDITOR**

With the shift of data editing from a line by line approach to an area based directed editing approach; it was deemed critical that the WCI data could also be displayed in 3D space with the bathymetry. The Subset Editor, like the Swath Editor, also has the ability to load and display Water Column data, but in this case, as a geographically referenced 3D point cloud. Since CARIS has implemented a sophisticated 3D point cloud data structure that can store billions of multi-attributed 3D points, a perfect container for the WCI data in 3D space already existed. This technology has been leveraged to load and display the water column data seamlessly into this area based editor [Masry et. al., 2009]. By representing water column imagery as a point cloud, it becomes much easier to determine shape, extent and volume of features in the water column with a view to more accurately and efficiently classify the information.

As with the Swath Editor, the Subset Editor has the ability to call and load the WCI data on demand. Within the Subset Editor there is a new Water Column node in the layer tree within the editor tab. This node allows the user to load and open the water column data in the 3D view, as well as the 2D view of the editor. The geographic extents of the defined subset dictate the WCI to be loaded. Similar to the Swath Editor, all things related to the loading of the data is carried out using background threading techniques so as to allow the User to continue to process bathymetry without locking the application.
The key to displaying the data in 3D space is to translate the water column data from a vessel referenced 2D plot to a 3D geographically referenced point cloud. This has been done by taking the WCI data and automatically pushing it through the standard processing workflow (vertical adjustment, svc and merge) to reference the data geographically with respect to the same coordinate system as the bathymetry. The translation from a vessel fixed coordinate frame to geographically referenced data as related to vertical datum is completed during the load of the water column data. The initial approach to ray tracing the water column data is to apply a static sound speed of 1500 m/s in an effort to account for as much refraction as possible without overburdening the application when the subset is loaded. This is completed in an effort to account for as much beam refraction as possible, without overburdening the application with processing times on load. One of the most taxing processes in HIPS with regards to bathymetry is the Sound Velocity Correction process. Combine this with orders of magnitude due to the volume of WCI data, and it is quickly seen that the current SVC approach would not be workable.

While the User is viewing bathymetry within the Subset Editor, they have the ability to load the WCI data on demand and have that data loaded into the 3D and 2D views. Upon loading the data, the user will be able to filter the data by intensity, as well as by a minimum slant range at nadir. This will allow the User to minimize the loading of irrelevant WCI data, while identifying anything in the water column that the sonars’ bottom detection algorithms may have missed. Akin to bathymetry, the User will be able to enable and disable the specific lines of WCI information.

All existing options and functionality within the current Subset Editor, where relevant, have been connected with the WCI display to keep workflows consistent and familiar. Functionality such as colouring, point size, etc. can be used to alter the display of the bathymetry as well as the WCI data.
SUSTAINABLE HYDROGRAPHY

With the ever increasing financial pressures associated with collecting good quality hydrographic data and the downturn in today's economy, ship time has become a premium. It has become evident that in today's hydrographic surveying operations, the concept of "collect once, use multiple times" is of great importance. With the availability of WCI data in a post processing environment, it is apparent that this type of data could be used for purposes other than least depth detection.

With abilities to extract more information from data collected by precise and accurate multibeam sonars, it is seen that the data is lending itself to a wider range of decisions, interpretations, and even predictions. Already capable of accurate bathymetric mapping and backscatter analysis, the sonar's ability to log WCI allows the processor to see what the sonar collected in full. The availability of this information creates the capacity for use beyond the realm of bathymetry. With water column data it is very easy to see the benefits in least depth determinations. However, what can be considered about other aspects of the data? For years we know this type of information has been used in the fishing industry. In recent years we have seen the information used in assessing and predicting the consequences of disasters such as the Deepwater Horizon oil spill. Can the use of this data be carried even further? Can it be used to aid the oil and gas industry in regards to locating and identifying gas seeps from the ocean floor? Being in these times of economic prudence, being able to use data for multiple purposes presents a sustainable strategy to further justify the practice and development of ocean mapping and hydrographic survey.

Further to the idea of WCI being a catalyst to a sustainable hydrographic industry, there is potentially another aspect to this statement other than the concept of collect once use multiple times. With the full mapping of the water column now possible, the potential of being able to collect less data could make survey time more cost effective. It is seen that in situations of minimum under keel clearance determinations, time consuming and expensive measures are currently employed to accurately determine the shallowest depth. In the example of a ship wreck survey, it is typical that at least seven passes with a high resolution multibeam sonar is needed to expose as much information as one pass of a multibeam sonar with WCI data enabled (Figure 5). The potential for time saving in this type of situation is of great significance and would allow surveys to be carried out more efficiently and cost effectively.
Multi-dimensional water column analysis presents an opportunity for the collectors of hydrographic data to provide additional value from the information collected, as well as making surveying practices more efficient in both operations and costs.

FUTURE DEVELOPMENT

With the release of 7.1.1, phases one through three have been realized in an effort to allow the User to view the WCI information as an aid to the existing bathymetric cleaning and decision making processes. As mentioned previously, there is a need for a more sophisticated yet efficient approach to ray tracing the water column data. CARIS sees this as the primary focus for the next phase of implementation. This will allow users to interrogate the water column information and carry out such analysis as least depth determinations. These determinations will take place on collections of water column samples from multiple survey lines where analysis can be carried out both statistically and comparatively in an effort to isolate and indentify a minimum depth.

In the final phase, users can expect emphasis on intelligent noise filtering, use of WCI as a supplement to existing bathymetry, least depth determinations, clustering techniques, volume computations and temporal analysis. It is apparent through the display of WCI in 3D space that intelligent noise filtering will be required to isolate groupings of water column samples. When the raw WCI data is loaded into Subset Editor, noise with a high backscatter tends to corrupt the visualization of the data of real interest. Most common noise is caused by specular echoes, digitizer noise and outliers. The ability to intelligently filter this noise is of great value and will allow more thorough analysis of the WCI. With the ability to filter the noise from the data of interest, it will be possible to allow the user to intuitively select groupings of water column data to use as a supplement to collected bathymetry. This is seen to be more than just least depth determinations but also the ability to provide a more complete representation of targets such as ship wrecks.

Further to this, the addition of tools to carry out clustering, volume computations and temporal analysis are identified as beneficial in the analysis of water column data. With clustering, the goal
would be to divide the loaded point cloud into clusters (i.e. seafloor, plumes, fish schools, and noise). Proven clustering methods as used for fisheries acoustic applications could be suitable, these methods include the DBSCAN (Density-Based Spatial Clustering of Applications with Noise) method and the NJW (Ng, Jordan and Weiss) method. DBSCAN is based on data density (higher density indicates coherent objects) whereas the NJW method is based on K-means. With the clustering of data the user will then be able to determine the volumes of these clusters. In addition, with the isolation of clusters from multiple survey lines, the ability to carry out temporal analysis of these clusters could also be possible. The user would be able to identify things such as plumes or seeps from clustering and then use this isolation temporally to study the behavior of these entities as affected by their environment.

These areas are a work in progress, and as individual items are completed they will be released to the HIPS and SIPS user base.

CONCLUSION

With the use of WCI by post processing software such as CARIS HIPS, it is apparent that this data can be used in a way to supplement bottom detection results. As this paper describes, the incorporation of water column data with bathymetry also provides a more complete representation of the submarine landscape as a whole and as such has the potential to allow multibeam data to be used for many non-traditional applications.

This paper has described how water column imagery can be interrogated as part of an integrated bathymetric processing workflow in CARIS HIPS. It also describes tools and techniques that can be used in conjunction with standard swath analysis for the purposes of visualization and quality control. It has also been shown how water column imagery can be represented in a 3D environment by using the latest point cloud processing and visualization techniques. Representing water column imagery as a point cloud has the potential to make it much easier to determine, shape, extent and volume of features in the water column.

Furthermore, multi-dimensional water column analysis presents an opportunity for hydrographic surveyors to provide additional value from the information that is being collected, as well as making the day job more efficient and robust. It is expected that the tools and techniques highlighted in this paper suggest how processing data in new ways can help sustain the industry.

With the areas of work identified as well of areas of interest and need, CARIS can now move forward confidently in the continuation and improvement of its WCI implementation in HIPS.


Kongsberg, EM2040 Dataset (2011), Data provided courtesy of Canadian Hydrographic Service.

Kongsberg, EM3002 Dataset (2006), Data provided courtesy of John Hughes Clarke, OMG UNB, Canada.
