Note

Multibeam Processing – The End to Manual Editing?

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Introduction

Multibeam sonars have been around now for some 40 years and their use in shallow waters for the last 14 years. Hardware and software have managed to leap frog each other for most of that time but in recent years the volume of data gathered by shallow water multibeam systems operating at up to 40 pings per second has threatened to overwhelm the software and hence the data processor. An acquisition to processing ratio of 1:1 is achievable at best. Software manufacturers have attempted to cope by decimating the data based on complex spline algorithms, but this negates the additional benefits of the multibeam systems, such as backscatter that require complete seabed coverage. For nautical charting surveys where the identification of critical shoal soundings is essential for the safety of navigation an algorithm should also point the data processor to these areas of concern. What has been required is a robust, best surface estimator which works quickly and is at its best with greater data densities. This algorithm should also work inside a data storage structure that easily handles these large datasets, provides fast access and allows for changes to the surface to been seen instantly.

The CUBE algorithm (Combined Uncertainty and Bathymetric Estimator) (Calder, 2003) creates a series of estimates at node points in a regular grid. CUBE selects one as being the correct value, retains the other estimates and also gives a guide to how well it thinks it achieved it by outputting the uncertainty of the depth, the number of times the hypothesis ran and the strength of that hypothesis. The uncertainty, number of hypothesis and hypothesis strength values guide the hydrographic surveyor to those areas where CUBE thinks that the result is dubious and hence needs further validation.

Fledermaus, the 3D visualisation software developed by Interactive Visualisation Systems (Fredericton, New Brunswick) has an area based editing data storage format called PFM (Pure File Magic). PFM was jointly developed by the Naval Oceanographic Office, IVS and SAIC as part of a Common Research and Development Agreement. PFM allows for an unlimited amount of data to be stored in a spatially referenced, fast access data structure. Links are maintained between the soundings and the surface bins so that changes made to either the surface or the soundings are updated are incorporated instantly in both. The visualisation is used to colour the surface by various parameters such as standard deviation, sounding density as well as depth. When CUBE is run during the build process the surface can also be coloured by the uncertainty, number of hypothesis found and the strength of the hypothesis. The 3D visualisation

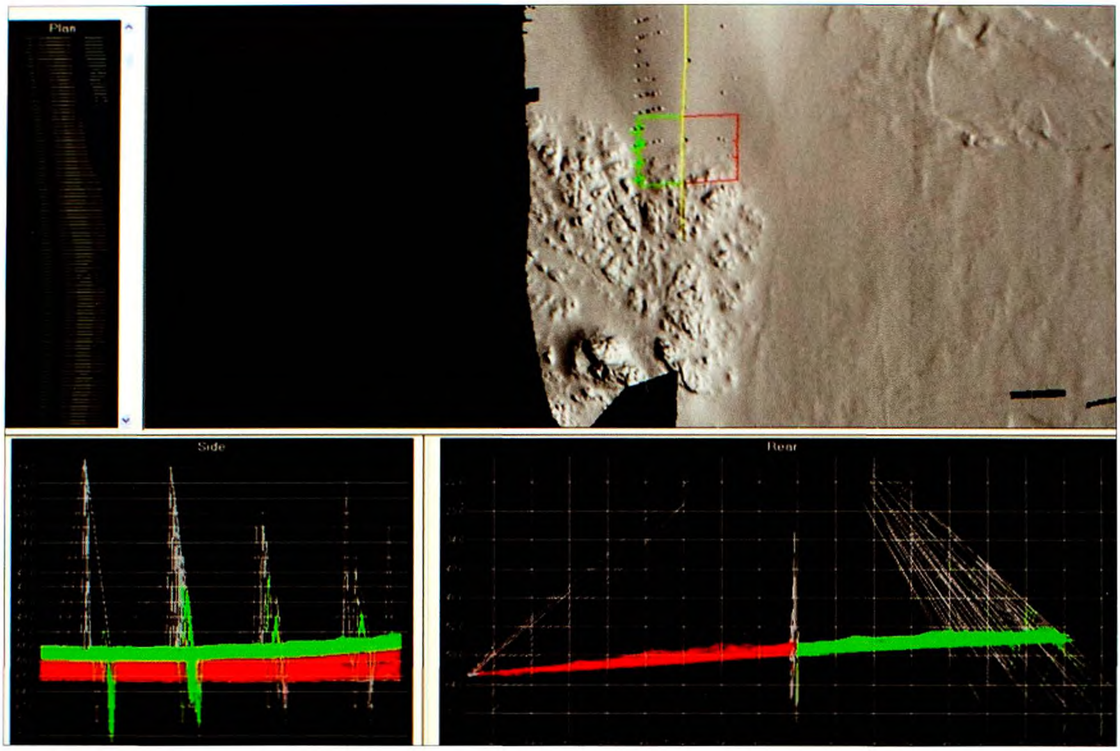

Figure 1: Line-by-line editing.

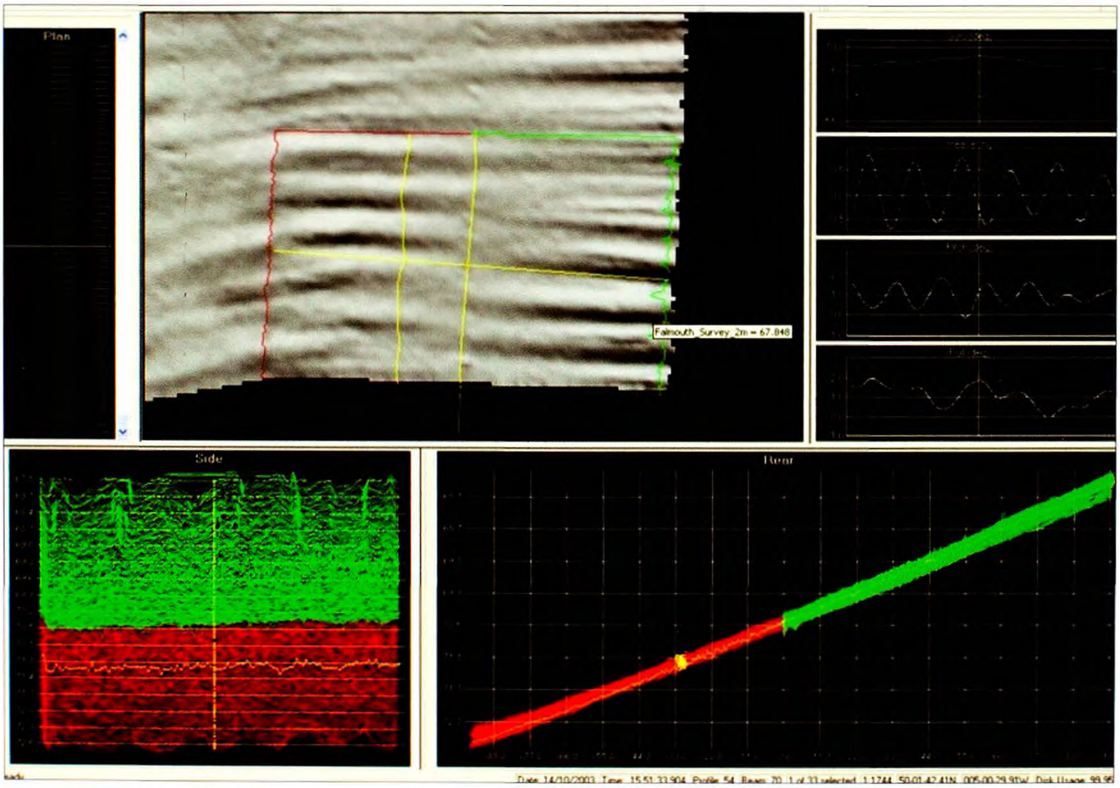

Figure 2 : Error checking.

guides the data processor to the areas of concern. The surveyor therefore does not have to look at those data points that are valid and in an area of high certainty.

The initial trials on board NOAA vessels (Calder, 2004) and subsequently operationally by NetSurvey have shown that acquisition to processing ratios of 40:1 are now achievable. This will have a dramatic and fundamental impact on the data processing workflow. It is the authors' opinion that far from making the hydrographic surveyor redundant the processing flow actually steers the processor to make the judgements like: "Is this a feature or noise?", which are often overlooked in their attempt to get the data cleaned in time. It will enable the surveyors to achieve far higher quality products in the field, minimise the chances of fundamental errors occurring that require re-survey, allow for the processing of backscatter and seabed classification on board the vessel and the integration of other scientific data types such as sidescan and sub-bottom seismic for geophysical interpretation that can be analysed in offshore, not in the office, allowing for 'on-the-fly' decision making.

This paper will outline how the hydrographic surveyor used to process multibeam data, how the processing pipeline is followed with these new tools and the additional QC controls, enhanced processing and greater variety of products that can be produced straight off the vessel. It will also demonstrate how the hydrographic surveyor will use his spatial and analytical knowledge to make judgements and how the working knowledge of the surveyor will start to encompass more of the oceanographic/temporal knowledge that has been lost with the concentration of purely bathymetry.

The 'Traditional' Multibeam Data Processing Pipeline

The traditional method that is still in use today by numerous software applications is based on a line-by-line processing approach. That is to say that one line of multibeam data is loaded and then a section of that line is investigated for artefacts and outliers, which are then manually edited out accordingly. Automatically filtering for a depth window, by beam number, slope between points, quality flags and recently by whether the beam's error is outside the IHO order for the survey are a number of ways in which the line-by-line approach has been accelerated. The fundamental flaw to this approach is that you cannot see adjacent lines and how they match up. Therefore any tidal errors, sound velocity issues and whether a seabed feature shows up on more than one line (beam validation techniques), are impossible to see.

There are occasions however, when the line-by-line approach is best. Examples are when you want to see what sensor is causing a specific artefact in the data, or when you are surveying a quay wall or some other structure that requires absolute precision.

Area based editors were developed by some software manufacturers to aid the hydrographic surveyor in their task of validating soundings. Typically the survey area would be gridded and a sun-illuminated image, either grey scale or coloured by depth, would then be displayed in 2D. A subset would then be selected of a portion of the dataset and this can be analysed, colouring by line to show adjacent swaths. Sound velocity issues and tidal errors are easily identified and quantified in this way. Prominent wrecks can be seen in the 2D sun-illuminated display and the outliers over the wreck discounted by ensuring the features seen are visible in more than one swath and follow a trend. This method, like the line-by-line approach, while entirely valid, involves having to look at every single beam to ensure that the data is clean. This is incredibly time consuming and not one hundred percent reliable as the outliers are not readily apparent. Once the outliers have been edited the entire dataset must be re-gridded to show the new surface. This again is very time consuming for a large dataset.

Methods for tiling the dataset based on criteria such as number of soundings in the tile and vertical difference within the tile were created. The tiles then allowed for statistical cleaning within the tile. This process is very depth and system dependant and like the area based editing the survey data processor had to look at all the points to ensure that the correct data was retained, that outliers were deleted and most importantly, that good data (especially over wrecks) was not deleted.

To see outliers more readily the surface must be visible in 3D and the surface itself must be selec-

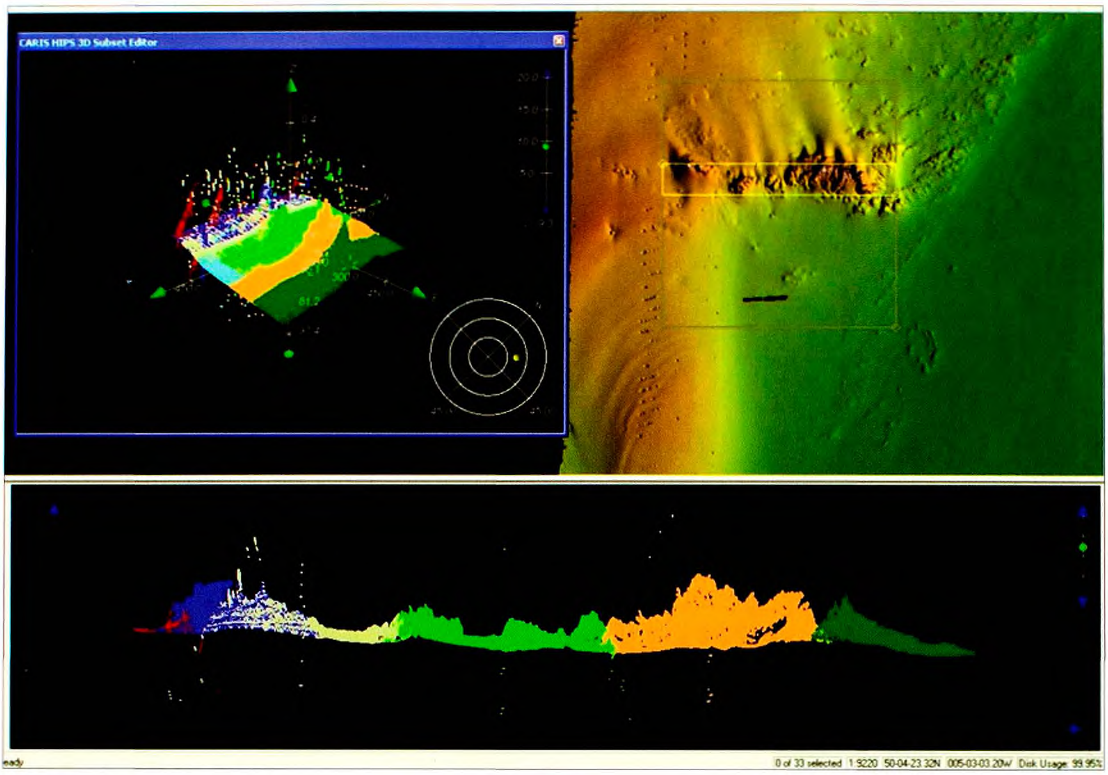

Figure 3: Area-based editing.

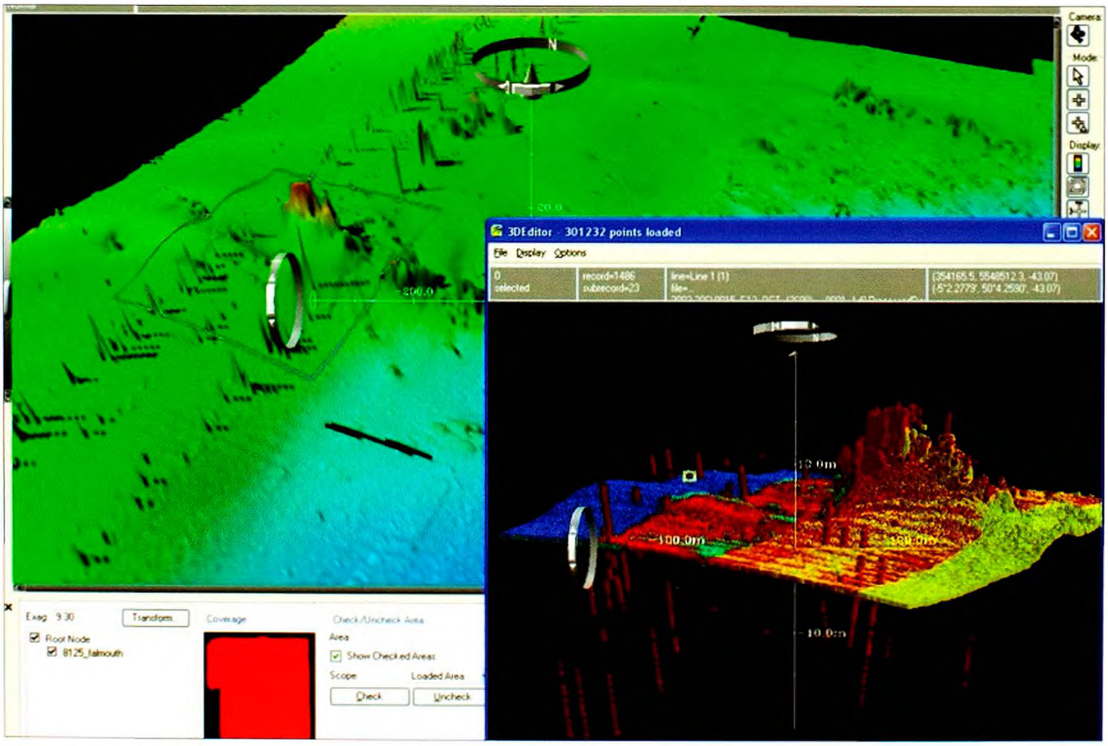

Figure 4: Area-based editing with 3D surface.

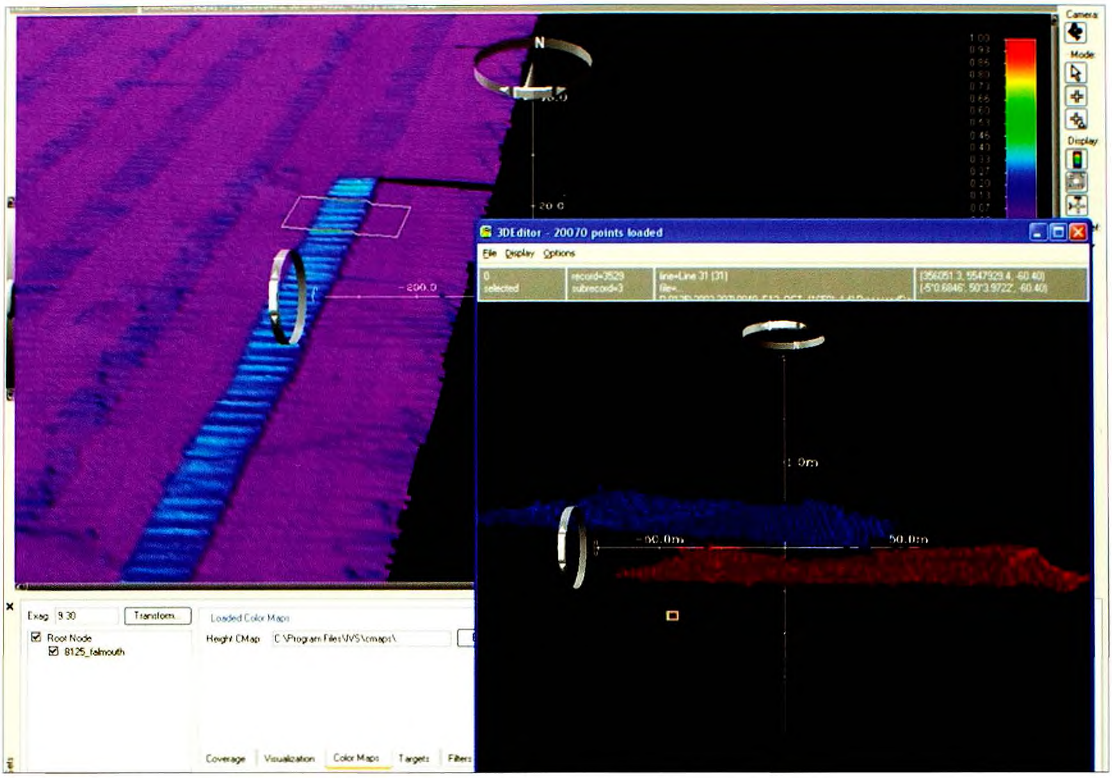

Figure 5: Surface coloured by standard deviation showing tide error.

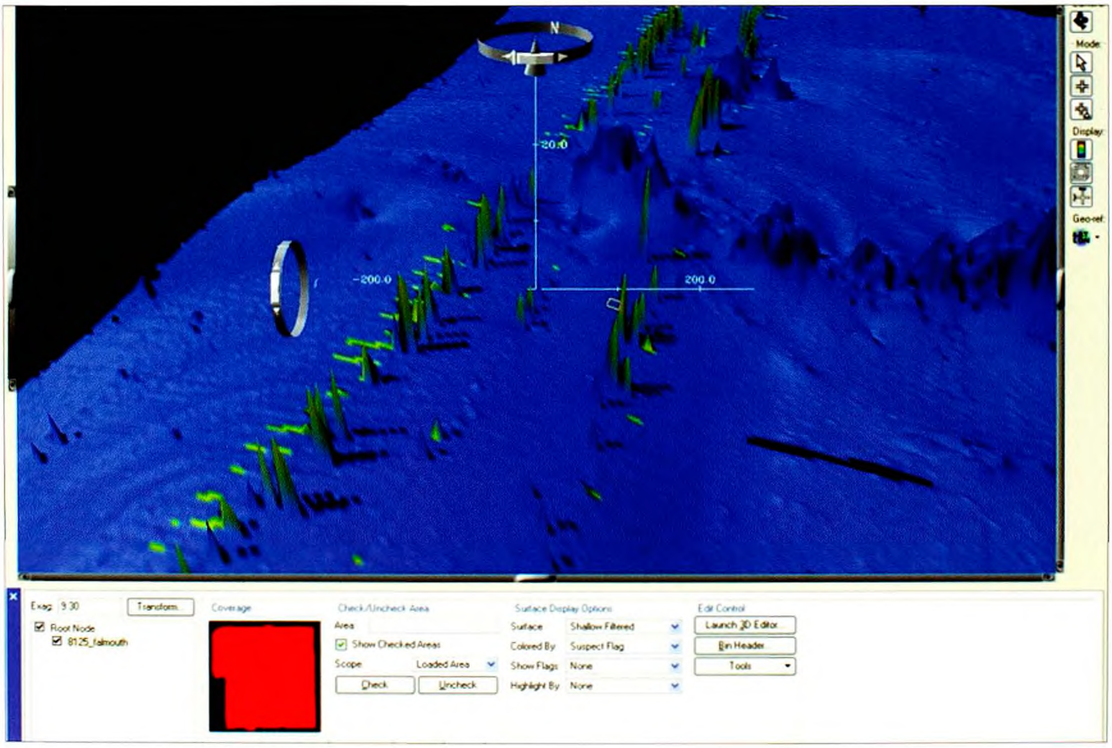

Figure 6: Surface coloured by suspect soundings.

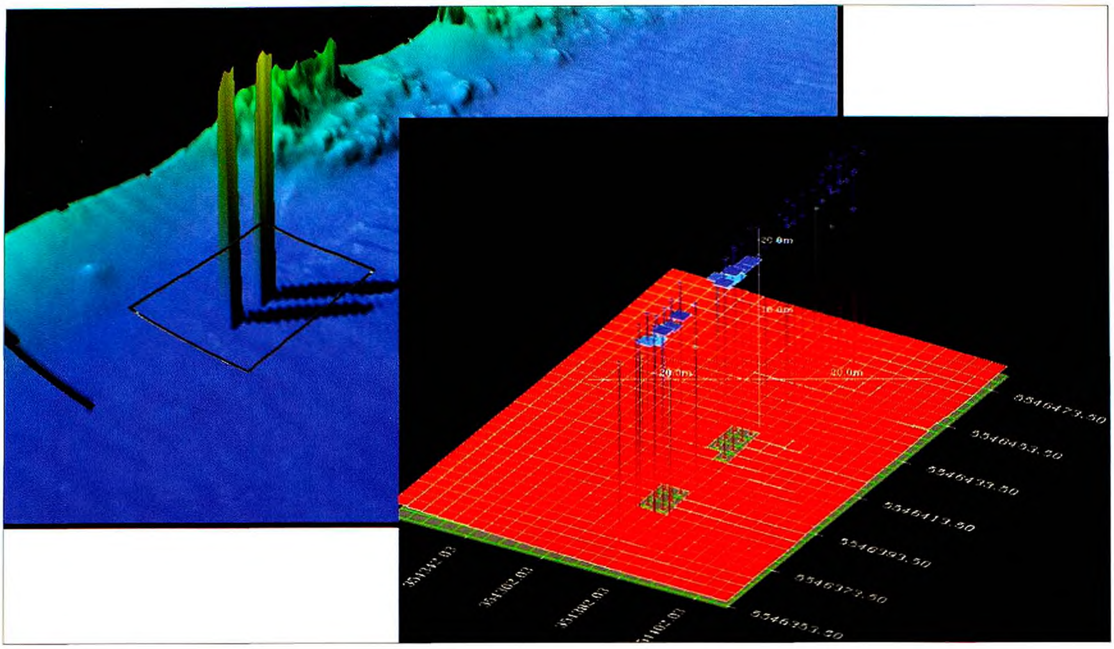

Figure 7: CUBE hypothesis as a surface and also the CUBE hypotheses coloured by depth in the 3D editor. Small plates indicate alternative hypotheses and large plates indicate the hypothesis CUBE has chosen as correct. The user can select hypotheses either individually or by grouping hypotheses so that the initial hypothesis is overridden to the correct hypothesis.

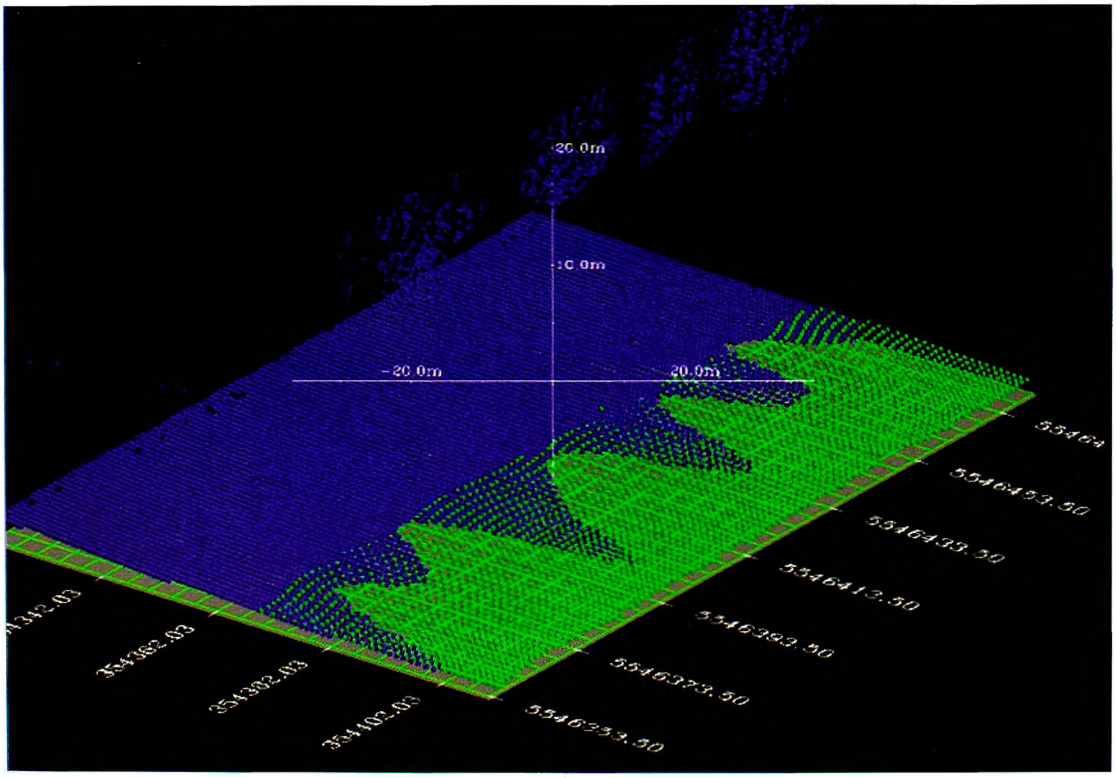

Figure 8: Validating outliers by colouring by line.

table from Shallow biased to Deep biased. In this way outliers 'jump off the surface'. Colouring the surface by statistics such as standard deviation and sounding density will highlight problems with the data. Once the outlier has been deleted the surface should automatically be adjusted and the statistics re-computed. The PFM data architecture was developed and integrated into Fledermaus to enable this approach. It allows for selection of smaller areas to process (and even multiple users to edit the same area). Shallow biased, average depth and deep biased surfaces can be displayed and those surfaces coloured by standard deviation, sounding density and user enabled variables. A suspect sounding filter was developed which would highlight soundings that deviated off the surface by more than the user stated distance. The surface could be then be coloured to show the distribution of the suspect soundings. The user would then select the area around the suspect soundings and bring all the soundings for the area up into a 3D point editor. This was the start of focused editing. It sped up the data processing pipeline but it still involved the deletion of soundings either by filtering or manually and is a time consuming process.

The 'Modern' Multibeam Data Processing Pipeline

What was required to take the processing methodology one stage further was a process that robustly produced a best-fit surface but that also derived other possible surfaces. The data processor would then be guided to the areas of concern identified by the algorithm and the correct surface would be identified and selected by the data processor. The CUBE creates a best-fit surface with a guide to how well it thinks it achieved it.

The fundamental differences between the CUBE approach and the previous methods are that the CUBE algorithm does not actually flag as deleted any soundings at all and that the hydrographic surveyor edits a surface (actually the CUBE hypotheses) rather than soundings. Soundings can still be viewed to ensure that the CUBE hypothesis chosen is based on valid soundings. Once the correct surface has been selected the soundings are then flagged as invalid if they are a function of standard deviation off the surface.

The CUBE method is to statistically calculate the most likely height (a hypothesis) for the surface

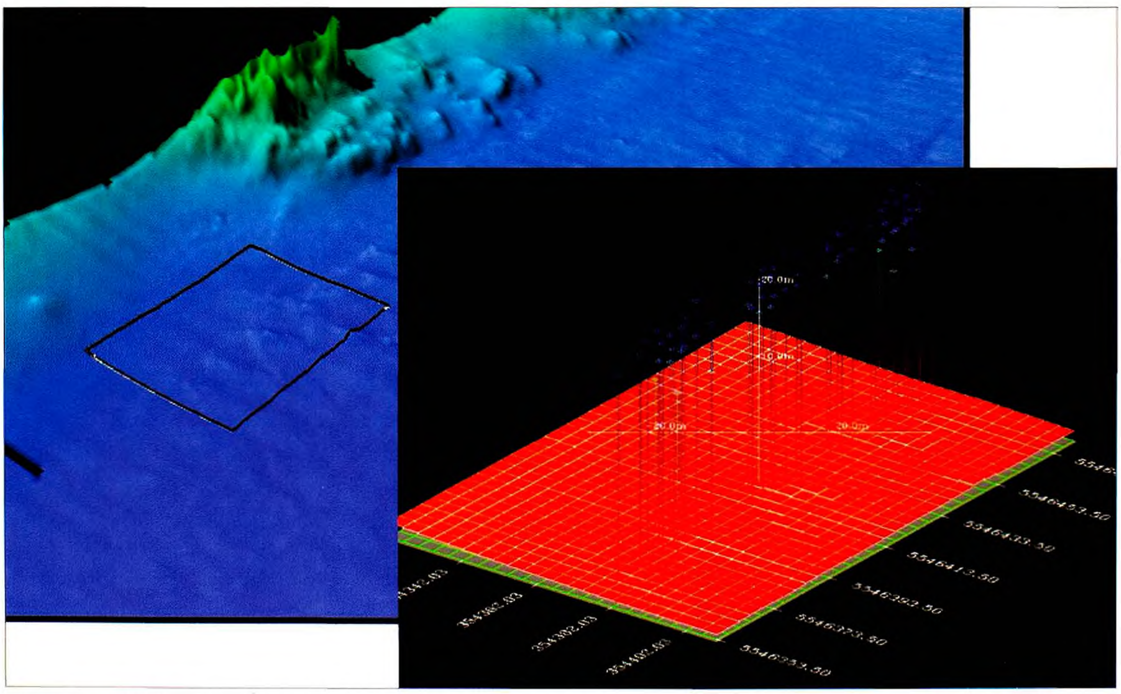

Figure 9: CUBE hypothesis as a surface and also the CUBE hypotheses coloured by depth in the 3D editor after user corrections have been made. Note that in the 3D editor the shallower hypothesis are now all small plates indicating alternative hypotheses but not those chosen as correct.

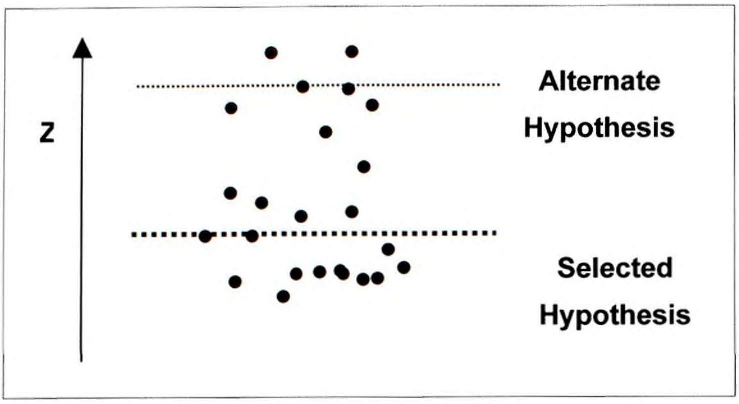

Figure 10: CUBE hypotheses.

using all of the known information. This calculation takes into account the uncertainty for individual soundings – less certain soundings make less contribution to the surface and more certain soundings make more contribution to the surface. In some cases the data may support different hypotheses (for example, when a burst error occurs). Figure 10 displays a possible situation where two different hypotheses would be created.

When the CUBE algorithm is run, a list of all possible hypotheses is generated and the algorithm attempts to choose the best hypothesis. The chosen hypothesis is called the *selected hypothesis* and the other hypotheses are called the *alternate hypotheses*. This system simplifies the amount of work required from a surveyor since the surveyor must only verify that the correct hypothesis is chosen in areas where more than one hypothesis exists. The hydrographic surveyor then interactively chooses the correct hypothesis.

This process reduces the processing time substantially, commonly by as much as 40 times in NetSurvey's experience. The surveyor can now use his analytical and spatial skills to ensure that the correct surface is chosen. Soundings that designate masts or shoal features can be selected as 'golden soundings' or 'designated soundings'. This ensures that the surface is kept at the depth of these soundings regardless of the resulting chart scale to ensure safety of navigation.

It is the authors belief that freeing up the surveyor's time to use their trained skills rather than their mouse skills, will result in a much higher standard of product that is produced much more quickly and on board the vessel.

The Additional Benefits of Reduced Cleaning Time

We have already mentioned about the higher standard of on board product, but by using the surface colouring options on the cleaned dataset the Surveyor-in-charge on the vessel can ensure that the survey performed is fully compliant to whatever survey specification is appropriate. For instance, to meet the IHO Order 1 target detection criteria of 9 soundings in a 2m cube for up to 40 metres of water, the surface can be coloured from 1 to 9 if the bin size is 2m (or ratio thereof for differing bin sizes) and at a glance all the areas that are coloured red, for example, are within specification and anything other than red is outside the specification and required additional survey work. Having to re-mobilise a vessel when it becomes apparent in the office that the survey is not up to specification is a very expensive exercise.

One of the outputs from a multibeam system that is normally forgotten about because it would involve yet more data processing is the acoustic backscatter intensity of the individual beams. The University of New Brunswick and University of New Hampshire are both working on ways of producing calibrated backscatter. This will enable us to use the backscatter in the same way as we use bathymetry to track sediment movement and enable historical comparisons. It will also lead to a better understanding of fish habitat by being able to identify areas of differing fish diversity by the backscatter strength and hence allow for the selected or targeted trawling and harvesting of sea life with respect for the environment. It will also be possible to calculate the seabed shear strength (very important for pipe and cable engineers) without actually having to take samples.

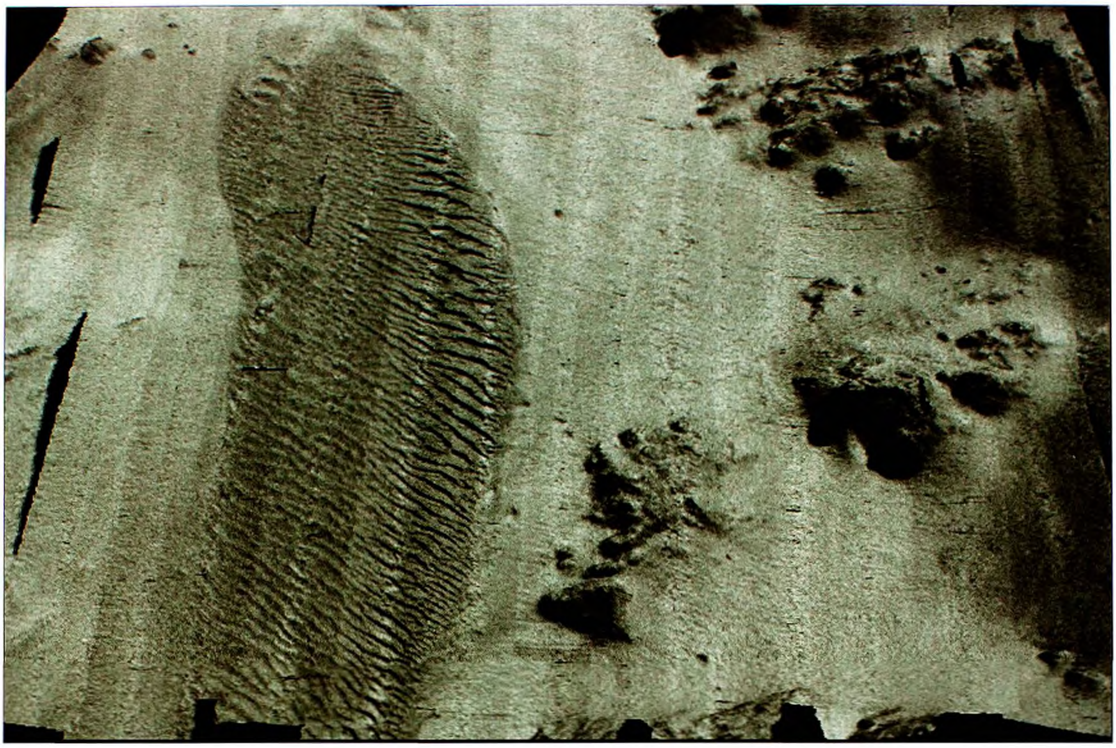

Figure 11: Backscatter draped over DTM.

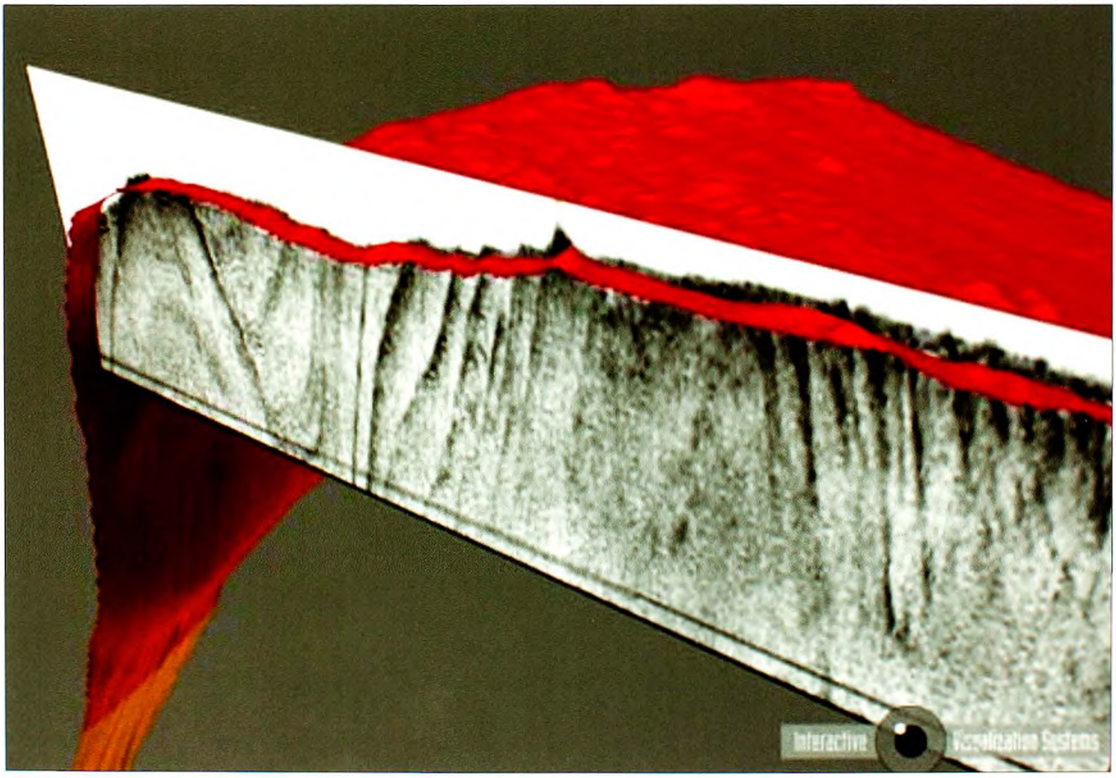

Figure 12: Geohazard analysis (courtesy Dr Jim Gardner, USGS).

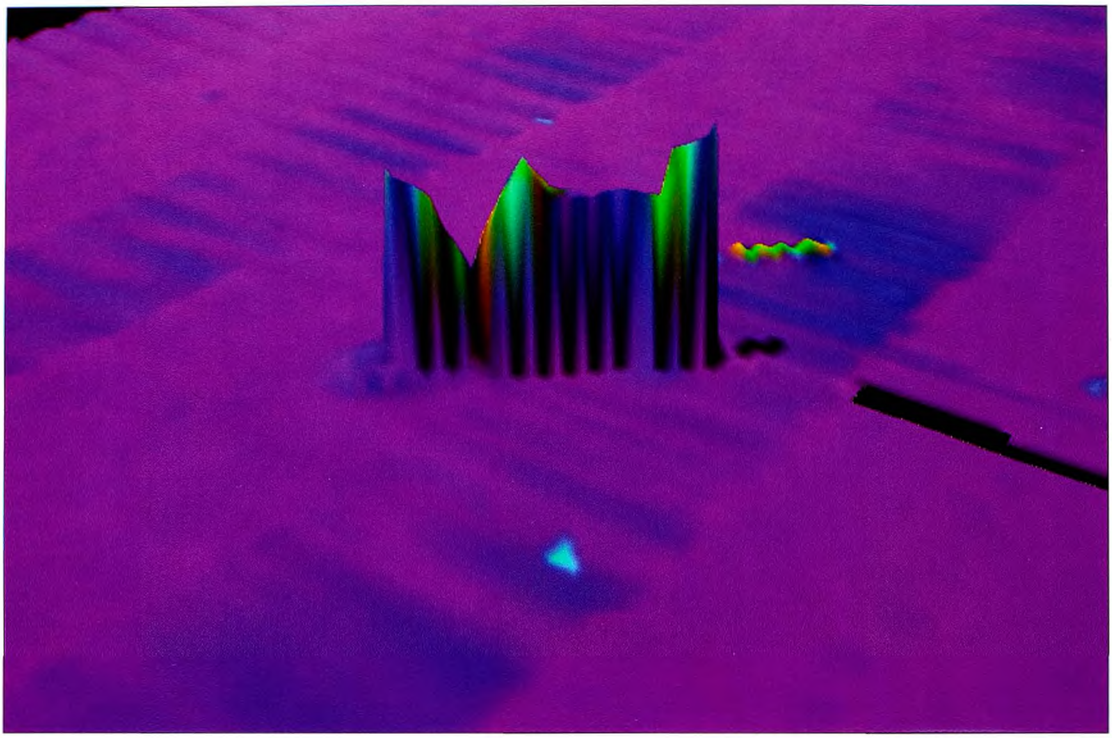

Figure 13: CUBE surface coloured by uncertainty showing wreck.

Processing this on board the vessel for nautical charting surveys will enable grab samples to be taken in selected location due to bottom type rather than the norm at present for a 2km grid of sample locations. Grab sampling is a time consuming process and this will free up more vessel time for survey work. Seabed classification software will be used in conjunction with the backscatter software to produce quantifiable results.

Being able to process bathymetry data with a 40:1 ratio will lead to new techniques for the GeoHazard survey industry. Certain oil companies now routinely combine bathymetry, sidescan and sub-bottom data together offshore to make decisions for pipeline, cable route and platform location planning. With a vessel travelling at 5 knots the sooner a problem with the initial route can be identified the shorter the transit distance back to survey for a new route and hence the less survey time is lost. Processing bathymetry data is always the bottleneck for this process. By decreasing the processing time it will enable in-field decisions to be made much more quickly.

By combining CUBE's uncertainty results with the 3D visualisation, wrecks are easily identified. Identifying them quickly ensures that further wreck investigation lines can be performed while the vessel is still on location, thereby reducing transit time and increasing survey time.

Conclusions

Robust surface estimators and 3D visualisation will change the role of the hydrographic surveyor from one of data processor to one of data validator. It will enable them to use their spatial and analytical skills with which they have been trained in validating their surveys.

Far from making hydrographic surveyors redundant, this new processing method will increase the scope and variety of their work. They will gain new knowledge and interest in how the seabed is made up and what factors affect it. The hydrographic surveyor of the past was much more knowledgeable on oceanographic matters as it affected their survey methods greatly. In recent years the hydrographic surveyor has been focused heavily on positioning accuracies and bathymetric accuracies. By taking the burden of processing off the human interaction and onto the computers and enabling the processing of other types of deliverable, today's hydrographic surveyor will once again be able to become more much knowledgeable about the whole oceanographic processes.

As Kapoor and Kerr (Kapoor and Kerr, 1986) state: "Hydrography has been defined as the science of measuring and depicting those parameters that are necessary to describe the precise nature and configuration of the seabed, its geographical relationship to the landmass and the characteristics and dynamics of the sea. The parameters encompass bathymetry, geology, geophysics, tide currents, waves and certain other properties of seawater."

Freeing the processing burden will return the offshore surveyor back to a hydrographer.

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