(ALUIZIO M. Oliveira Jr. and JOHN E. Hughes Clarke – published in Sea-Technology Magazine - JUNE 2008)

Extending the multibeam angular sector to improve seafloor classification

A three-step process to explore the outermost beams of multibeam backscatter

Backscatter imaging using multibeam sonars is being used to complement bathymetric data. Differing approaches have been employed to characterize the backscatter data, ranging from average properties (mean and angular response) to textural methods (gray-level co-occurrence matrices and spatial spectra).

Average properties are very sensitive to calibration and proper reduction for geometric and radiometric artifacts. Textural methods have had more success with imperfectly calibrated sonars as the attributes of the spatial patterns are less sensitive to absolute signal level. The textural methods, however, work best with low aspect ratio data such as that derived from sidescan sonar. Multibeam sonar geometry, in contrast, usually has a higher aspect ratio. This article discusses an alternate approach to handling multibeam backscatter that takes advantage of lower grazing angle data.

Due to a focus on bathymetric data quality over backscattering imaging quality, multibeam angular sectors greater than +/-60 ^{o} are rarely used in hydrographic surveys. Wide angular sectors are prone to refraction and motion sensor errors, and the along-track sounding density is reduced, thereby compromising target detection. For the purpose of seafloor classification using power spectral analysis however, the wider sectors provide significant advantages.

The Brazilian Navy has routinely been operating an EM1000 sonar in the Hydrographic ship NHo Taurus. The sonar was used in the equiangle beam spacing mode (EABS) using a roll-stabilized +/-75 ^{o} angular sector (~7.5x the water depth) with 200% coverage. This configuration allowed a swath coverage nearly twice as wide as most other hydrographic agencies, which have been using primarily narrower (+/-60 ^{o}) angular sectors.

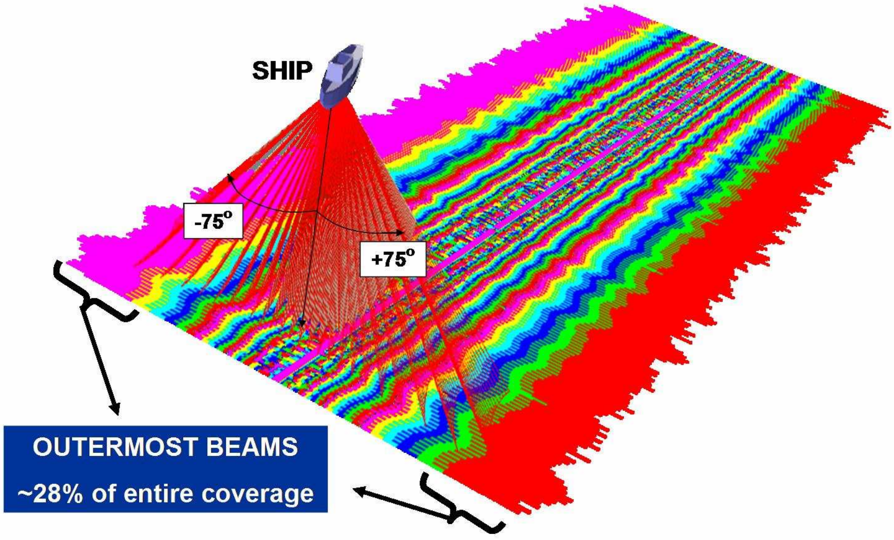
In this experiment, a series of software has been implemented by the first author to explore the backscatter data logged in this extended across-track coverage. Processing steps included compensation for outermost beams artifacts, development of an alternative mosaicking technique and implementing a textural seafloor classification scheme, which automatically accounts for the continuously changing outer sector geometry.

Step One - Processing beams

During the bottom detection processing the raw intensity time series for each beam is recorded well before and beyond the projection of the half-beam width (-3 dB limit). When the data are subsequently stored, overlapping inner beams have redundant data and thus usually only the data within the -3 dB limits are generally retained. If, however, an inner beam is dropped, the beam traces on either side are lengthened just enough into the intervening time gap to ensure a continuous coverage. For the outermost beams, however, for which there is never an adjacent beam outboard, the full beam trace outboard is retained, resulting in potentially a much wider available backscatter swath. EM1000 system logs the outermost beams intensity time series well beyond the half beam width. Usually, this data is not incorporated because of pronounced beam pattern issues. Herein, software has been developed to compensate for the pronounced beam pattern to take advantage of this extra coverage beyond the last beam resulting in up to 28% increased area coverage. As well as increased coverage, the percentage of the swath at the low grazing angles, most suitable for textural classification, is markedly increased.

The raw outermost beams backscatter intensity values reflect the directivity of the receive beam. Using the imaging geometry, each intensity sample was associated with the angle with respect to the beam boresite. For the outermost beam, samples intensities variations were greater than 10 dB. These variations must be reduced, such that the backscatter strength fluctuations represent only inherent properties of the seafloor. In this manner, they represent a useful signal for the task of seafloor characterization. To achieve this aim, a least squares fitting method was used to calculate the quadratic equation that best matches the samples intensities variation by angle. This equation has been used for artifact normalization.

Results from this implementation demonstrated that typical outermost beams “rolling-off” intensities artifacts, which are present in original sonar image data, could be properly reduced. The resulting better quality backscatter signal could now be applied in the next two steps.



The 60 beams coverage areas and the extended area of the outermost beams.

Step two – Mosaicking

Maps of both seabed bathymetry and backscatter are generated using multibeam data from multiple survey lines with overlapping swaths. A method needs to be defined to handle that overlap. For the case of bathymetry, a surface fitting technique is used that generally favours nearer nadir beams as the accuracy and data density is usually better. For the case of the backscatter mosaic, the issue is not the data accuracy; rather it is the useful information for the purpose of seabed characterization. For the purpose of textural classification it is the outermost beam, low grazing angle backscatter data that is most useful.

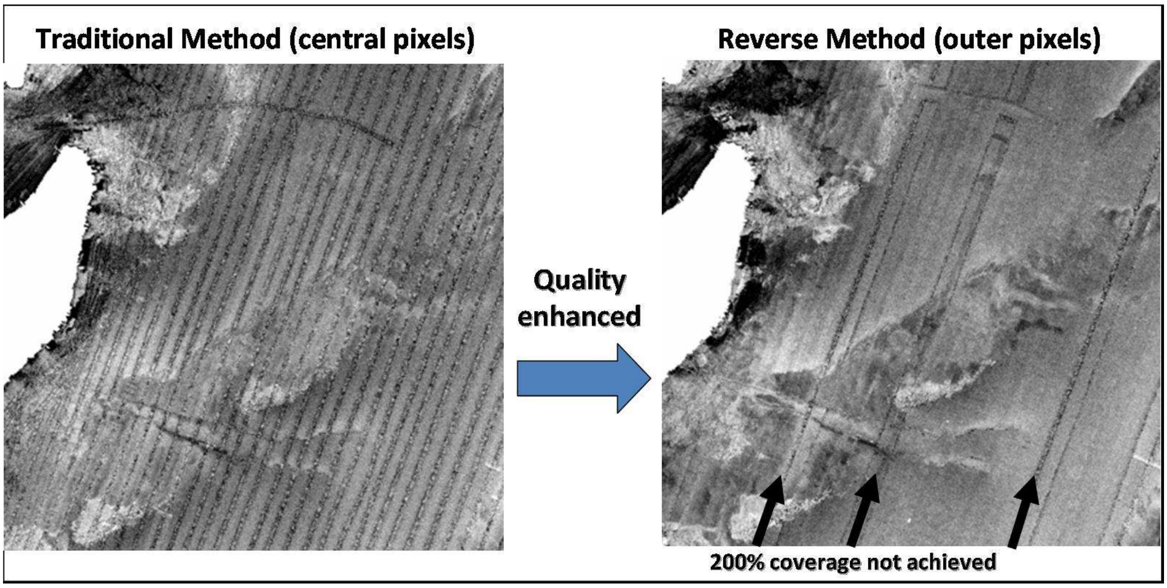
During the mosaicking process, in the overlap region, when different pixels occupy the same geographic position, one has to decide what pixel will remain in the image. In this case of 200% coverage, half the data is suppressed.

Different approaches are used in this step, but most of them tend to, by default, give higher priorities for the central (near-nadir) pixels. In this manner, central beams would be retained and outer beams would be discharged. For normal sidescan mosaicking, the positional confidence of the outermost pixels is the poorest and this data tends to be corrupted by thermocline and noise artefacts. In this case, however,as the quality of the outer beam intensities have been improved and due to the rigid integration of multibeam systems the outermost beams don’t suffer from poor positioning, this study used the reverse of the traditional priority. Outer pixels were attributed the higher priorities.

When testing both mosaicking methods:

The traditional method (central pixels having higher priority) presents the dominant “nadir stripe”. Although the average variation in beam pattern across the swath has been compensated for, there is a markedly different texture at nadir that still draws the eyes. Part of the problem is that the shape of the near-nadir angular response curve is highly sediment dependent and thus averaging that over a survey line (crossing multiple sediment types) fails to account for local changes in the angular response. Also, the slope of the angular response curve is so steep, that small changes in seafloor slope, switch the echo from specular to oblique. This characterisitic pattern of backscatter fluctuations is unique to the nadir region and its statistics have no resemblance to the texture of the same sediments at lower grazing angles. Thus for the purposes of textural characterization, they are least wanted.

The reversed method (outer pixels have higher priority) enhances the mosaic quality. Because available backscatter coverage has been extended through outer beam trace recovery, the outermost swath data of the adjacent line is available to cover (replace) the noisy nadir region. A markedly-reduced contrast in the along-track striping in the image is evident. The line spacing, however, is not always achieving 200% coverage and occasional near-nadir data is retained. In this situation, along-track artefacts can remain in final mosaic image.



Backscatter mosaics using two different priority methods.

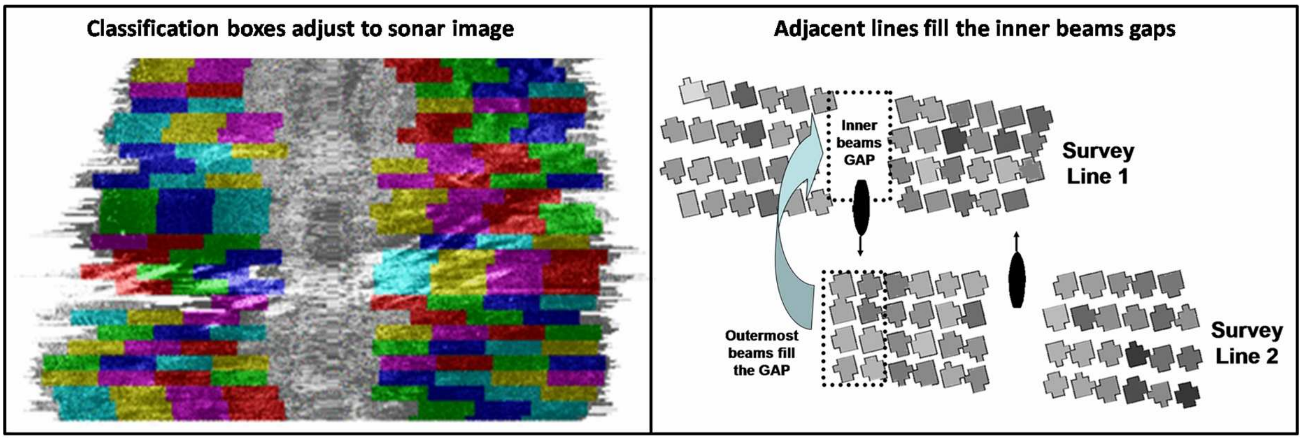
Step three - Seafloor classification

The Ocean Mapping Group at UNB has previously developed a seafloor classification software to work with sidescan sonar backscatter using power spectral analysis[1]. The algorithms require selection of a finite area, which corresponds to a box defined by a series of adjacent radial range-series of intensity. The size of these boxes is defined by the maximum desired spatial wavelength to investigate. A limitation is that within this finite dimension, there may be change in the seabed type. Classification boxes size can be chosen by the user. In this implementation, they were approximately 19 m x 19 m (16 pings along-track x 128 pixels across-track). Pixel size was adjusted to 0.15 m radial dimension in order to match the sonar pulse length that determines the across-track resolution. Along-track size was calculated using vessel speed (4 m/s) and ping rates (3.3 pings/s).

Within these boxes, statistical and power spectral analyses are performed upon the backscatter intensities inside each box. Statistical analysis produces the average and standard deviation. Power spectral analysis uses Fourier transform to decompose backscatter into 7 spectral wavelengths including the fundamental (19.2 m) and its harmonics.

Classification can then proceed based on the relative ratios of spectral energy between the different wavelengths similar to prior work using sidescan trace data. Key to this classification is that the spectral ratios should be similar for differing across-track distances. Clearly, close to nadir the textural pattern is corrupted by the sparser backscatter traces distribution. A method was therefore developed to restrict the box selection to the lower grazing angles, favoring the outermost part of the swath where the rate of change of grazing angle is lowest. Because the outermost beam trace data has been recovered, this region is now more extensive.

Because the box dimension must remain fixed, yet the swath width is defined by the depth and the fixed angular sector, the number of classification boxes will be depth dependent. Therefore, new software has been developed to accommodate multibeam geometry, which has higher depth oscillations than sidescan and also has varying outer range. The software detects the maximum outer beams range to become the start point of the classification boxes creation and user can limit the inner sector to avoid the higher grazing angle noisy inner beams. For a single swath, there is a resulting gap in the inner region. But, with the designed 200% coverage, extended through outer beam recovery, higher quality outer beams of the adjacent survey lines are able to fill these gaps of the noisy inner beams. Therefore, classification boxes can fill the entire survey area.

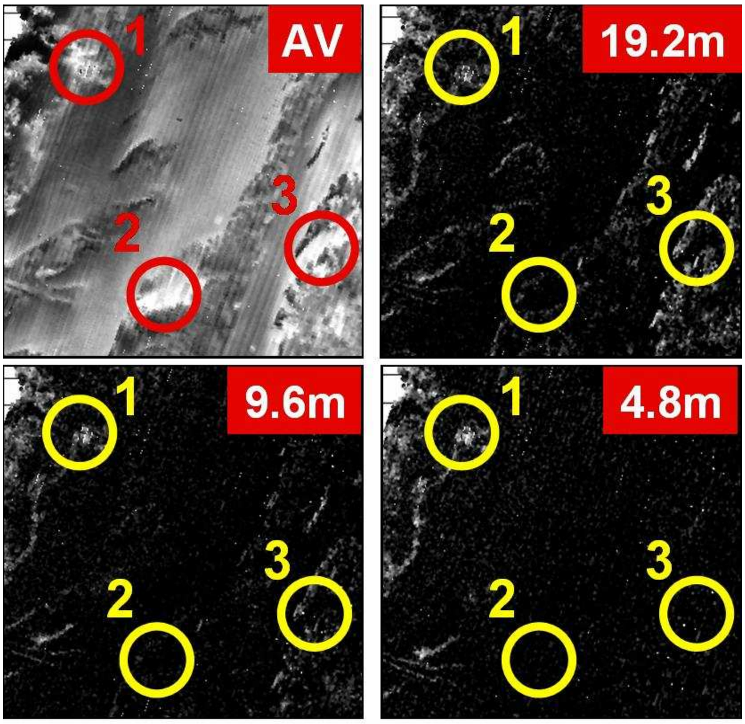

Classification boxes adjust to sonar image

Adjacent lines fill the inner beams gaps

Classification boxes positioning scheme had to be adjusted to the multibeam geometry.

By using 2 statistical maps and 7 spectral maps, the capacity to segment different seafloors was increased.

The series of maps were able to provide more degrees of freedom for the seafloor classification task.



Areas 1,2 and 3 have similar average backscatter, but not the same sediment types. With the aid of spectral maps (19.2, 9.6 and 4.8m wavelenghts), each area could be segmented when comparing their energy contents.

Future Applications

Newer sonars (e.g. EM710) are going to use multiple across-track swaths per ping cycle, which gets around the actual requirements of narrowing the angular sector (+/-65 °) to achieve tight along-track coverage. So, wide angular sectors (+/-75 °) can be used without compromising hydrographic requirements for target detection.

The same software developed for the EM1000 has been adopted to work with the EM710. Data has been collect in 2006 with the Canadian Coast Guard Ship (CCGS) Matthew with the EM710 with 1 ° x 0.5 ° wide beams. First experiments (still using 1 swath per ping at this time) demonstrate these sonars present similar patterns for the outermost beams.

Conclusion

The aim of this project was to demonstrate the efficacy of utilizing low grazing angle available backscatter data, not normally collected in hydrographically-driven multibeam operations.

Results demonstrated that outermost beams (which are able to log backscatter amplitudes beyond the range of the beam centre limits) can improve both mosaicking and seafloor classification.

This method[2] represents an improvement in the processing capabilities of the Brazilian Navy to handle data collected with the EM1000 in the equiangle (EABS) +/-75 ° mode. Furthermore, it demonstrates the future potential for the newer sonars (e.g. EM710) with multiple across-track swaths per ping cycle.

References

1 - Pace, N.G. and H. Gao, 1988, "Swathe Seabed Classification", IEEE Journal of Oceanic Engineering, vol. 13, no. 2, p. 83–90.

2 - Oliveira Junior, A.M (2007). Maximizing the Coverage and Utility of Multibeam Backscatter for Seafloor Classification. M.Sc.E. thesis, Department of Geodesy and Geomatics Engineering, University of New Brunswick, Fredericton, NB, Canada.

Aluizio Maciel de Oliveira Junior

Lt. Cmdr. Aluizio M. Oliveira Jr. is the chief of the Bathymetry Division in the Directorate of Hydrography and Navigation (DHN). He has a B.Sc. in Electronics and M.Sc. in Geomatics. He is currently a Ph.D. student, studing marine Geophysics at Universidade Federal Fluminense.

John E. Hughes Clarke

John E. Hughes Clarke is the Chair of Ocean Mapping at the University of New Brunswick, Fredericton. With a background in marine geology and oceanography, his prime interest is in taking advantage of the limits of resolution and accuracy achievable with both the bathymetry and backscatter from swath sonar systems to examine marine sediment transport.