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Geocoder: An Efficient Backscatter Map Constructor

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ABSTRACT:

The acoustic backscatter acquired by multibeam and sidescan sonars carries important information about the seafloor morphology and physical properties, providing valuable data to aid the difficult task of seafloor characterization, and important auxiliary information for a bathymetric survey. One necessary step towards this characterization is the assemblage of more consistent and more accurate mosaics of acoustic backscatter. For that, it is necessary to radiometrically correct the backscatter intensities registered by these sonars, to geometrically correct and position each acoustic sample in a projection coordinate system and to interpolate properly the intensity values into a final backscatter map.

Geocoder is a software tool that implements the ideas discussed above. Initially, the original backscatter time series registered by the sonar is corrected for angle varying gains, for beam pattern and filtered for speckle removal. All samples of the time series are preserved during all the operations, ensuring that the full data resolution is used for the final mosaicking. The time series is then slant-range corrected based on a bathymetric model, in the case of sidescan, or based on beam bathymetry, in the case of the multibeam. Subsequently, each backscatter sample of the series is geocoded in a projected coordinate system in accordance to an interpolation scheme that resembles the acquisition geometry. An anti-aliasing algorithm is applied in parallel to the mosaicking procedure, which allows the assemblage of mosaics at any required resolution. Overlap among parallel lines is resolved by a priority table based on the distance of each sample from the ship track; a blending algorithm is applied to minimize the seams between overlapping lines. The final mosaic exhibits low noise, few artifacts, reduced seams between parallel acquisition lines and reduced clutter in the near-nadir region, while still preserving regional data continuity and local seafloor features.

ACOUSTIC BACKSCATTER AND GEOCODER STRUCTURE

The acoustic backscatter acquired by multibeam and sidescan sonars carries important information about the seafloor geomorphology and physical properties. With the proper radiometric and geometric correction, acoustic backscatter mosaics can aid in the mapping of surficial seafloor features and facies, an important task toward remote seafloor characterization. Backscatter mosaics can also provide important auxiliary information not only for marine geological and environmental studies but also for hydrographic surveys.

The acoustic backscatter registered by sidescan sonars is normally logged as two long time series of intensity values, one for the port side the other for the starboard side, recorded at the reception transducer (Tyce, 1986). On other hand, multibeam sonars register the acoustic backscatter in three different forms: 1) one measurement of average backscatter strength for each beam; 2) one time series of backscatter strength around the detection point of each received beam; 3) two long time series of backscatter strength (port and starboard) for each received ping, which will generate data very similar to a sidescan backscatter (Beaudoin, 2002).

Geocoder is software tool conceived to accept all these different sources of acoustic backscatter and to construct more consistent and more accurate mosaics with the processed data. The data processing starts with the raw acquisition data, that is, the original data registered during the survey, without any additional processing. So far, the system can process Simrad, GSF and XTF formats. The implemented algorithm radiometrically corrects the backscatter intensities registered by sidescan and multibeam sonar, and then geometrically corrects and positions each acoustic sample in a final backscatter mosaic in a well-defined projection coordinate system.

The Geocoder system is implemented with an interactive graphical user interface that allows the visualization of the navigation tracks and the backscatter mosaics, and is structured using object-oriented methods. The main objects of its data structure are the sonar lines, the sonar mosaics and the backscatter cells. The sonar objects have information about the sonar equipment, the navigation, the transducer attitude, the gains and the sidescan backscatter samples. The sonar mosaic objects have information about projection, resolution and histograms of the final mosaic. A mosaic object is defined as an array of backscatter cells objects and not just pixels. One cell object can store up to two sidescan samples, each sample consisting of the backscatter value, the sample source (the acquisition line) and the sample quality. In order to define quality, samples closer to the nadir and far off nadir are attributed low quality values, while samples in the mid-range are attributed higher values. The cell structure has an important function during the mosaicking procedure when multiple sidescan samples are mapped into the same mosaic cell. In Geocoder, instead of storing only the last mapped sample, or averaging all the samples inside one cell, the data structure stores the two most significant samples, with the two highest sample quality values. Finally, the mosaicking procedure is defined as the method that maps multiple sonar objects into one mosaic object.

SLANT RANGE CORRECTION

Slant-range distortions are inherent to backscatter acquisition geometry, and are a result of the echo return being registered in time and not in horizontal range to the transducer. Another related source of distortion is the water column data. Some sidescan systems start recording the backscatter time series just after the transmitting pulse, so that there is a period of time in which the echoes are coming from the water column and not from the seafloor. In Geocoder, the water column data is removed based on the depth of the first return and the knowledge of the sampling rate. In the case of backscatter time series from sidescan sonars, a typical slant-range correction is applied to the data (Miller et al. 1991). For that, a flat bottom is assumed and the transformation from slant range time samples to horizontal range distances is computed by simple geometry, depending only on the value of the sound speed. If a bathymetric model is available, the average slope in the across-track direction of each ping replaces the flat bottom assumption for the slant range correction.

In the case of acoustic backscatter from multibeam sonars, the backscatter time series for each beam is added based on the time and range of each detection point, in order to assemble a time series equivalent to a sidescan trace (Hughes-Clark et al. 1996). During the assemblage of this time series, if two samples arrive at the same time, the preference is given to the sample closest to a detection point. The final beam solutions of multibeam sonars include the detection time and the horizontal range to the transducer, so this information can be used to compute a more accurate slant-range correction. In Geocoder, multibeam backscatter time series can be slant-range corrected by parts, as the ranges for a certain number of samples (at the detection time of the beams) are known. The horizontal ranges for all samples are then computed by linear interpolation between consecutive beam solutions or by splines. This same procedure is used to slant-range correct sidescan datagrams registered by multibeam sonars, as the acquisition time of the sidescan samples can be synchronized to the detection times for the bathymetric beams. When processing average beam backscatter, the same rationale is used, with the limitation that the number of samples is restricted to the number of beams (one average backscatter per beam), and no interpolation is necessary.

RADIOMETRIC CORRECTIONS AND SPECKLE REMOVAL

In Geocoder, the processing sequence starts with the original acquisition data, so that all the logged parameters will be considered for the radiometric correction. Each raw backscatter sample is then corrected for the removal of variable acquisition gains, power levels and pulse widths, according to manufacturer's specifications. The backscatter strength is calculated per unit of area and per unit of solid angle, so that the actual footprint area of the incident beam should be taken into account for proper radiometric reduction. During acquisition, logging systems normally simplify the geometry by assuming a flat bottom for the incident beams, which causes a radiometric distortion in the data. With this flat bottom assumption a simple Lambert's law correction in normally applied during acquisition to reduce the angular dependency of the backscatter.

In Geocoder, the backscatter values are corrected to the true footprint projection area, as the detailed bathymetry is known from the multibeam time-of-flight beam measurements. For each beam footprint, the along and across track slope are calculated with respect to a bathymetric model. The effective area of insonification is calculated based on these slopes, the transmit and receive beamwidths, pulse length and range to the transducer. In a similar manner, the effective incident angle is calculated from the scalar product of the beam vector (form the transducer to the footprint) and the normal to the bathymetric surface at the footprint. The effective incident angle is used for correcting the Lambert's law correction applied during acquisition. In the case of sidescan backscatter, due to the absence of beam bathymetry information, an external bathymetric model is used for the footprint area and slope corrections. Finally, a residual beam pattern correction is removed in a ping by ping basis, by calculating a moving average of angular responses around the each ping (typically 500 pings).

The acoustic backscatter signal sampled at the transducer head is subject to stochastic fluctuations that produce a speckle noise in the registered backscatter data. The removal of the speckle noise improves considerably the interpretability of the data and aids the process of seafloor characterization. For the speckle removal Geocoder implements a morphological median filter with a percentile threshold (Fonseca, 1996). After applying all these corrections, the acoustic backscatter values from different acquisition lines are reduced to a common scale of scattering strength, and so prepared for mosaicking.

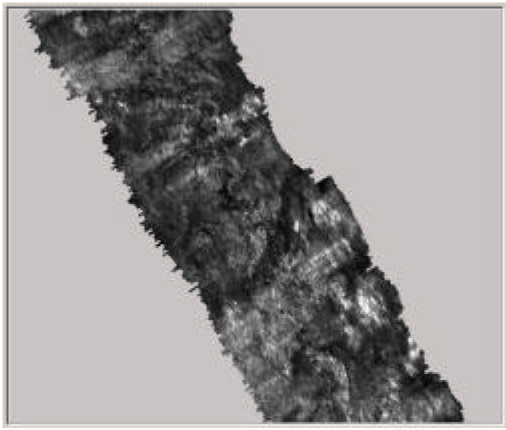
GEOMETRIC CORRECTIONS AND HOMOGRAPHY MAPPING

Geometric distortions of a sidescan image are caused by a number of different sources, mainly the slant-range distortion, as the backscatter is sampled in time and not in horizontal range. Distortions also result from refraction of rays in the water column, as well as variations in trajectory, speed and attitude of the transducer (Cobra, 1992). The actual geometric correction starts with the algorithm for slant-range correction of the backscatter time series. However, the final geometric correction is applied only when a backscatter sample in the ship track coordinate system is mapped to a mosaic cell in a projection coordinate system. For that, the logged values of navigation, heading and attitude (pitch, row and yaw) are interpolated in time for each ping transmit time and reduced in space to the location of the transducer. With this information, the location of each slant-range corrected sidescan sample in the mosaic coordinate system can be directly calculated by straightforward geometric mapping.

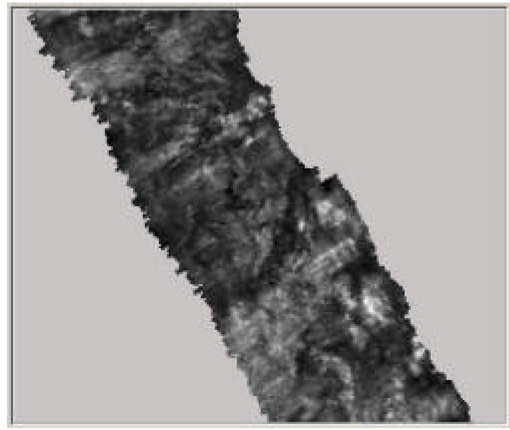
In Geocoder, the mapping from backscatter samples to cells in the mosaic space is not done in a sample-by-sample basis. Instead, it uses an interpolation scheme that resembles the acquisition geometry. For that, the system maps two sonar pings at a time, and every four adjacent samples are mapped simultaneously thought a homography mapping. In this mapping, a rectangle in the track coordinate system is transformed to a quadrilateral in the projection coordinate system. The vertex of the quadrilateral is assigned to the backscatter values of the vertex of the original rectangle (Malinverno et all, 1990). The pixels inside the quadrilateral are assigned to an interpolated value calculated by average of the vertex values weighted by the inverse of distance to the vertex.

ANTI-ALIASING

When the spatial resolution of the mosaic is significantly smaller than the spatial resolution of the sidescan samples, the final mosaic will be affected by spatial aliasing. As the aliasing problem is due to low resolution, a simple but expensive solution is to assemble a high-resolution super-sampled mosaic and then to apply a low-pass filter to smooth and to sub-sample the mosaic in a lower resolution (Crow, 1981). Geocoder implements an alternative approach called inverse mapping with pre-filtering. For that, the corners of each cell in a low resolution mosaic are inverse-mapped to the sonar track coordinate frame. In cases where one cell corresponds to more than a certain number of sidescan samples, a Gaussian filter is applied to average the contribution of the samples. As the cell-object structure stores two values of mapped backscatter, the final mosaicking can blend these contributions in the sub-pixel level, reducing the aliasing effects. With this implementation, it is possible to assemble a low-resolution backscatter mosaic that preserves the general features on the seafloor and that is less affected by aliasing problems (Fig. 1). This feature can be important when the bandwidth used to transfer the mosaic is a limiting factor, as in the case of the link between an AUV and the survey vessel.



a)

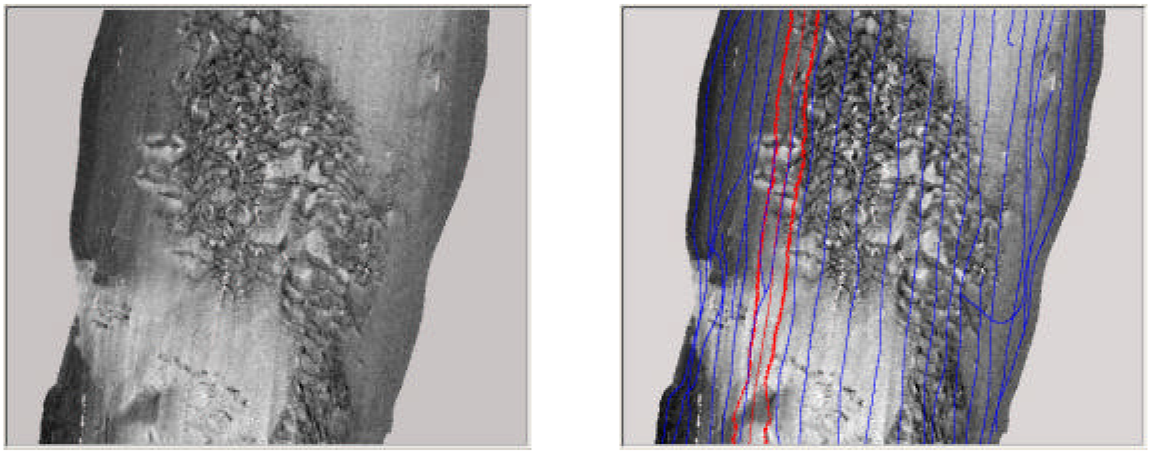


b)

Fig. 2- a) Reson 8150 backcatter from East Bering Sea mosaicked at a cell size of 8m, which is compatible to the time-series sampling resolution, generating an image of 5523 by 3938 pixels b) The same data mosaicked at a cell size of 80m, generating an image s of 552x393 pixels. Notice the absence of aliasing artifacts and that the main features were preserved in the lower resolution mosaic.

OVERLAP AND FEATHERING

Multibeam and sidescan surveys always include overlap between adjacent acquisition lines. During the assemblage of the mosaic, it is necessary to decide how to handle this data redundancy. The quality factor stored in the cell objects can be directly used for this decision. As discussed, the mosaic is an array of cell objects, and each cell has information about the backscatter strength, source and quality, which is used as a weight factor. When displaying or printing the mosaic, each cell will have to provide a pixel value to the output image. The natural selection for the pixel value is the backscatter value with the highest quality, preserving therefore the most reliable sample. The disadvantage of this approach is the sharp seam artifact that will be present in transition between two overlapping lines. In order to reduce this seam artifact, Geocoder implements a variant of a technique called feathering (Rzhanov et al. 2002). The feathering algorithm chooses the highest quality factor unless the difference between the two quality factors is smaller then a threshold and the samples come from different sources (acquisition lines). In this case the area is defined as a buffer zone between two overlapping lines, and the result pixel will be an average between the two backscatter values. With this approach, the sharp seam artifact between overlapping lines will be considerably reduced, while preserving the original backscatter data by only smoothing a narrow buffer zone around the seams (Fig. 2).



a) b)

Fig. 1- a) Mosaic of 27 acquisition lines Little Bay, NH. . The sonar used was a Simrad EM3000 Multibeam, 300kHz, at a water depth of 20m. b) The same image showing the navigation of the acquisition lines in blue, and the coverage of one selected line in red. Notice the common radiometric scale, the reduced seams and reduced nadir artifacts among overlapping lines.

CONCLUSION

An efficient backscatter map constructor was developed to process acoustic backscatter data acquired by multibeam and sidescan sonars. Raw backscatter samples were radiometrically corrected to remove variable acquisition gains, power levels, pulse widths, insonification areas and incidence angles. Geometric corrections were applied to compensate for the slant-range distortion, navigation and transducer attitude. A homography transformation was used to map backscatter samples into a projection coordinate systems, using an interpolation scheme that resembles the acquisition geometry. Anti-aliasing and speckle removal algorithms were applied during the mosaicking, which allowed the assemblage of smaller mosaics while preserving general features. A feathering algorithm was used to reduce the seam artifact between overlapping lines. With all the corrections applied, the final acoustic backscatter mosaic offers more reliable auxiliary information not only for marine geological and environmental studies but also for hydrographic surveys.

BIBLIOGRAPHY

Beaudoin, J, Hughes Clarke, J.E. , Van Den Ameele, E.J. and Gardner,J.V., 2002, "Geometric and radiometric correction of multibeam backscatter derived from Reson 8101 systems", Canadian Hydrographic Conference Proceedings, p. 1-22.

Cobra, D., 1992, "Geometric Distortions in Side-Scan Sonar Images: A Procedure for their Estimation and Correction", IEEE Journal of Oceanic Engineering, v. 17 (3).

Crow, F., 1981, "A Comparison of Antialiasing Techniques", IEEE Computer Graphics and Applications, Vol. 1 (1).

Fonseca, L, 1996, "Correções Radiométricas dos Dados Sonográficos da Bacia de Campos", Proceedings of the 8th Brazilian Congress of Remote Sensing.

Hughes-Clark, J., Mayer, L and Wells, D, 1996, "Shallow-Water Imaging Multibeam Sonars: A New Tool for Investigating Seafloor Processes in the Coastal Zone and on the Continental Shelf", Marine Geophysical Researches 18.

Malinverno, M., Edwards, M and Ryan, Bill, 1990, "Processing of SeaMARC Swath Sonar Data", IEEE Journal of Oceanic Engineering, Vol. 15 (1).

Miller, L. Richard, Dwan, S. F and Cheng C., 1991, "Digital Preprocessing Techniques for GLORIA II Sonar Images", Geo-Marine Letter, Vol. 11.

Rzhanov, Y., Huff, L., and Cutter, G.R, 2002, "Seafloor video mapping: modeling, algorithms, apparatus", Proceedings IEEE International Conference on Image Processing (ICIP'02), Rochester, NY.

Tyce, R., 1986, "Deep Seafloor Mapping Systems – A Review", Marine Technology Society Journal, Vol. 20 (4).