Topics In Acoustic Seabed Segmentation – Current Practice, Open Software, and Data Fusion

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ABSTRACT

The primary topic of this presentation is the inference of seabed characteristics from multibeam sonar backscatter data. This process may be carried out using one or more of four different approaches. These are feature analysis, image processing, inverse modelling, and use of part or all of the backscatter curve as a geometric entity. Acoustic seabed segmentation from single beam systems (echosounders) is also briefly discussed as a prelude to two other topics. These are (1) fusion of seabed acoustic data obtained from different types of acoustic systems (single beam, sidescan sonar, and multibeam sonar), and (2) the growing call for open software for acoustic seabed segmentation. Fusion of acoustic seabed segmentation data has received little attention, whether for data from the same types of acoustic instruments, or for different types. Sufficient detail has been published on method and theory of acoustic seabed segmentation for open software to be a reality, although the benefits of commercial software may prove more useful to many users.

INTRODUCTION

It is possible to infer seabed type (e.g. mud, sand, gravel, rock) from the shapes and energies of echoes stimulated by conventional echosounders (Hughes-Clark (1994)). It is assumed that seabeds with similar acoustic responses have similar physical properties such as grainsize distribution, although this is not always true, since some responses may be ambiguous (Hamilton et al (1999)). Maps of seabed areas with similar acoustic responses are constructed, a process known as acoustic seabed segmentation. If actual seabed types can be attributed to the segmentations, then segmentation becomes acoustic seabed classification.

Acoustic backscatter received by multibeam sonars may also be used for this purpose. Multibeam sonars are a type of downwards directed active sonar which form hundreds of narrow beams in a fan configuration to ensonify a thin strip or swathe of seabed perpendicular to direction of travel of a vessel (Figure 1). Data are built up strip by strip as a vessel moves along a survey track.

Both time of flight and seabed acoustic backscatter are typically recorded for each beam. The backscatter data for each beam are recorded as a single value (e.g. an average or a peak value estimate), or as a time series. Time of flight provides detailed bathymetry, and backscatter potentially provides an indicator of seabed type.

This presentation outlines methods used for acoustic segmentation.

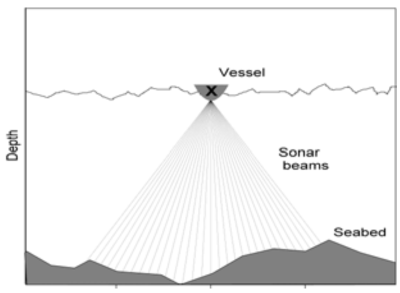

Figure 1. Configuration of multibeam sonar beams for vessel travelling into or out of the page.

BACKSCATTER PROCESSING

Single beam (echosounder) pre-processing

Electrical hardware separate of the sounder may be used to receive, store, and process the transmitted and received acoustic signals. Sounders are usually required to run on constant settings so that output ping duration and power and system gain are unchanged over a survey. Systems then need not be calibrated, beam patterns need not be known, and only the ping duration needs to be known for processing.

Echoes are corrected for acoustic attenuation (spreading and absorption) and for dilation/contraction effects. If a constant sampling rate f_s is used, more/fewer samples will be taken between any two particular angles as depth increases/decreases, causing signal dilation/contraction (an apparent lengthening/shortening of the echo in time), even for seabeds with similar sediment properties. In order for two returns at different depths d and d_0 to maintain the same time/angle relationship the data are resampled. When the relative contribution of ping duration to echo duration is small (Hamilton (2011) suggests 20% or less), a so called deepwater correction is applied as $f_{resamp}=(d_0/d)f_s$, where d_0 is a reference depth near the mean survey depth, and f_s is the original sampling rate (Caughey and Kirlin, 1996). When the relative contribution of ping duration to echo duration is large, a so called approximate shallow water correction must be made which is more complex than the deepwater correction (Preston, 2006).

The effect of the shallow- and deep-water corrections is to transform received echoes to the shape they would have if all were received from the same depth, typically chosen as average survey depth. Sequences of shape and energy corrected echoes must be averaged to obtain signal stability.

The properties of seabed echoes are affected by seabed slope, vessel self noise, and vessel motion. Self noise is allowed for by using constant vessel survey speed. Vessel motion is allowed for by averaging sets of echoes to obtain signal stability. However, echosounder based acoustic segmentation is suitable only for flatter seabeds, perhaps less than 4°.

Multibeam sonar pre-processing

Allowance is made for system gain, pulse duration, power, acoustic attenuation (spreading and absorption), and beam pattern. First, for each swathe, the position of the centre point of ensonification on the seabed for each of the beams is calculated using motion sensor data to find the 3-D beam geometry. Individual beam values are spatially gridded and averaged, and a bathymetry model is constructed. The bathymetry model is used to correct the backscatter for incident angle and for the area insonified by each beam, but is not otherwise discussed in the present paper.

RESON 8125 backscatter data used in this paper were obtained for each beam from envelopes of the backscatter amplitudes distributed around the bottom pick for each beam. RESON refer to this as "Snippets" data. Methods developed by Gavrilov et al (2005) to process Snippets data were used to calculate a Surface Backscattering Coefficient for each beam.

Backscattered energy was obtained for each beam as the integral of the square of the Snippet amplitudes times the sampling interval. These energies were normalised by the width of the transmitted pulse to give an average Snippet intensity. This average intensity is then independent of the system pulse width, which may be changed by the system operator during a survey to allow for changes in depth or other factors.

In normal operation the multibeam system applies time variable gain (TVG) to the received signals from each beam to compensate for spreading and absorption losses. This TVG was removed as it is not always adequate to correct for the actual acoustic propagation conditions, and corrections for the actual spreading and absorption loss for each beam were applied. The backscatter estimates were then adjusted for transmit power, which can also be changed by the operator during a survey, to give a backscatter ratio for each beam which is independent of system settings.

Next, the backscatter intensity ratios were normalised by the insonification area or footprint size of their respective beams (Figure 2), and the surface backscattering coefficient for each beam was calculated as a decibel value.

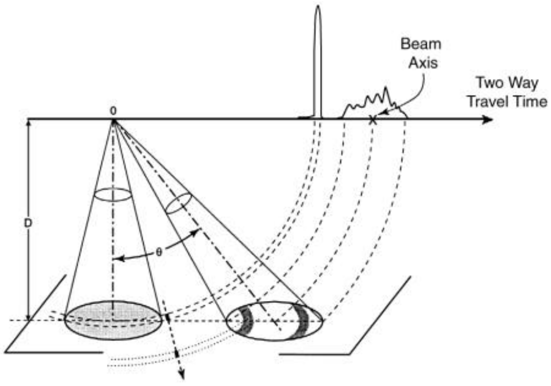

Figure 2. Nadir and oblique return echoes ensonify different areas (after de Moustier, 1998).

The resulting multibeam backscatter curves are typically noisy, and along track averaging is used to obtain reliable backscatter estimates (Figure 3). The backscatter responses are now ready for analysis.

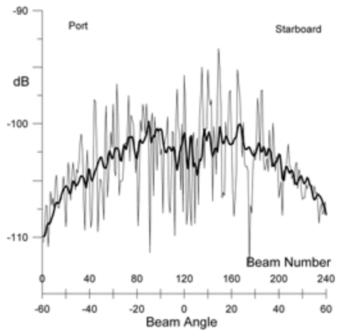

Figure 3. A multibeam backscatter curve (thick line) formed from the average of 32 successive scans, only one of which is shown (thin line).

Methods of acoustic segmentation

Single beam, sidescan sonar, and multibeam sonar typically provide tens to hundreds of thousands of acoustic responses for a survey. Each response is a curve (an echo or a scanline) with tens to hundreds of data points. This data volume has traditionally been handled by data reduction methods such as a combination of feature extraction, Principal Components Analysis (PCA), and statistical clustering, an approach pioneered by the Quester Tangent Corporation (Preston (2006)). Alternatively, inverse modelling based on the features may be used to infer seabed type (Fonseca and Mayer (2007)).

Feature analysis for single beam data

Many features have been used to characterise single beam echoes, e.g. means, peak values and positions, widths of peaks, slopes, percentiles, cumulative sums, Fourier transform coefficients, spectral parameters, wavelet transform coefficients, fractal dimension, and any number of others.

Some parameters may have a known physical relation to the backscattering process, but many are just thrown into the mix with the hope they may contribute something useful. PCA is then used to suppress noise and to provide data reduction. This means that a classification for one geographical area cannot be directly compared to classifications for other geographical areas.

Feature analysis for multibeam sonar data

Feature analysis characterises multibeam backscatter curves by properties such as slopes and means for the near-field, far-field, and outer-field scattering regimes (Hughes Clarke, 1994).

Single beam echo responses are treated as point data, although they are typically received from a circular or elliptical area of seabed which varies with depth according to the beamwidth. Multibeam response curves may be treated as characterising a single point on the seabed, port and starboard segments, multiple segments, or the whole scanline. Whichever is chosen, allowance must be made for the variation of backscatter with angle.

Multibeam sonar backscatter angular dependence

The angular backscatter information provided by multibeam sonar is an intrinsic property of the seafloor (Fonseca and Mayer, 2007). However, the variation of backscatter with angle has often been treated as a problem to be removed, rather than being made use of. Average compensation curves are established for seabed areas judged to be homogeneous in properties, and used to transform backscatter values for all beams to the value received at a particular angle for individual scans. The angle is selected in a range where backscatter curves are linear, e.g. 20-60° (or the average for this angular range is used). Applying the average compensation curve to backscatter curves preserves variations in backscatter across the swath. In this "one angle fits all approach", the compensated backscatter values are spatially binned and averaged, and treated as a grey scale image, which is subject to textural analysis, often by Grey Level Co-occurrence Matrix (GLCM) analysis methods. GLCM methods are used because they are not overly dependent on absolute amplitude. This method is useful for automatic classification of seabeds with sandwaves and other distinctive seabeds, e.g. seagrass, which can have distinctive statistical properties.

Fonseca and Calder (2007) clustered on five multibeam backscatter features, then formed average backscatter curves for the clusters. The average curves were used to remove angular dependence to enable image processing. Fonseca et al (2009) first constructed a backscatter mosaic normalised to an angular range, then formed average backscatter curves for areas in the mosaic judged visually homogeneous. Inverse modelling was used to infer average sediment properties for the visual themes.

Parnum et al (2007) formed a sparse 3-D matrix (X, Y, θ) to hold survey backscatter data, where X and Y are geographical co-ordinates of pixels or grid cells, and θ is the angle of ensonification. Empty matrix elements were populated by kriging interpolation, to infer a full backscatter curve for each pixel. This requires the majority of cells to be ensonified at a range of angles. A backscatter mosaic was then formed as the average for an angular range.

Rzhanov et al (2012) construct a backscatter mosaic normalised to some particular angle. They then construct a catalogue of a predefined number of backscatter curves based on the denser parts of an overplot of all backscatter data for the survey. Each of these curves is assigned an average grain size. Contiguous gridded survey backscatter data (pixels) are joined into small segments. A user specifies the number of pixels that segments may have, e.g. tens to hundreds. It is stated that segments must honour all boundaries found in the backscatter mosaic, but it is not stated how a boundary is defined, or how segments are formed. The composited backscatter properties for all pixels in a segment (the original angular data, not the normalised mosaic values) are matched to curves in the catalogue, and segments with similar assigned average grain size according to the catalogue are joined to form the predefined themes. Various parameters assessing matching of segments are changed by the user until the user obtains a picture (a mosaic) they are happy with.

Canepa and Pace (2000) formed average backscatter curves for training areas judged to have homogeneous seabed properties, then used supervised classification for other data. Problems in classification occurred for slopes, heterogeneous areas, and habitat or grain size boundaries.

With the exception of Canepa and Pace (2000) multibeam sonar backscatter processing is reliant on feature analysis and/or the construction of backscatter mosaics for one angular range which are analysed by image processing techniques. The full angular information is not used. Numerous other papers follow these approaches. It is also the case that training areas are visually determined, typically from normalised mosaics or groundtruth, rather than from the angular backscatter data itself. None of these approaches are particularly satisfactory. The potential of the angular backscatter data is not being realised.

Direct clustering of curves

A relatively simple processing technique is now introduced which makes full use of both single beam echoes and multibeam sonar backscatter curves. This is statistical clustering of single valued curves (see Hamilton (2007, 2010, 2011), Hamilton & Parnum, 2011). The CLARA clustering algorithm of Kaufman & Rousseeuw (1990) has been found suitable to execute this concept. CLARA (Clustering LARge Applications) is a fast algorithm through employment of divide and conquer techniques. Statistical clustering of curves does not require feature extraction, curve fitting, or dimensional reduction. Curves are treated as geometrical entities, and are grouped by their shapes and positions. Each cluster contains echoes of similar shape and and each group has a different basic shape than other groups. Examples for single beam echoes (adjusted for sampling artefacts) and the resulting geographic segmentation are shown in Figure 4.

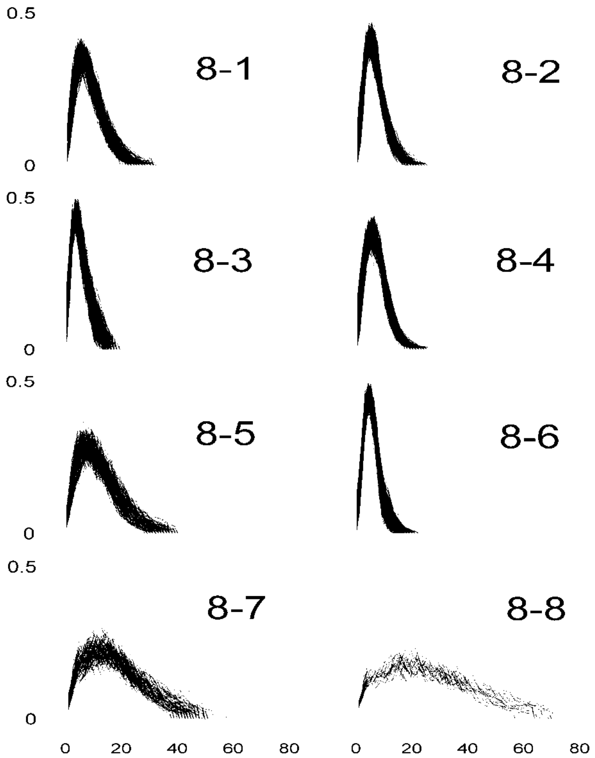

Figure 4(a). Direct statistical clustering of seabed acoustic echoes into eight classes (Hamilton 2011).

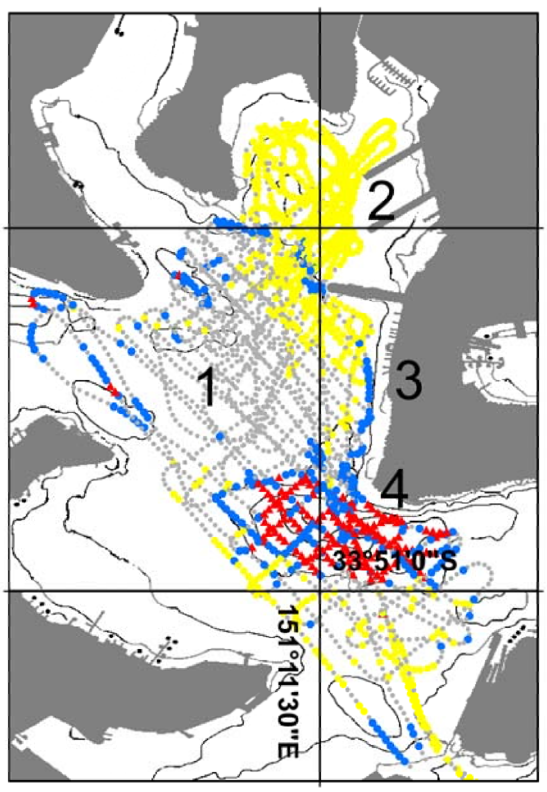

Figure 4(b). A four class segmentation for Balls Head Bay, Sydney Harbour (Hamilton, 2011).

Examples for radiometrically and geometrically corrected multibeam sonar backscatter curves and the resulting geographic segmentation are shown in Figure 5.

Because the actual echoes and backscatter curves are processed, in principle the segmentation returned by this technique for a particular system does not require groundtruthing, unlike feature extraction and image processing techniques. The technique returns only a single classification for a multibeam swathe (or two classifications if port and starboard are treated separately), and does not explicitly process small scale features such as sand ripples. Consequently image processing forms a more suitable processing technique for some data. Even so, in principle the direct clustering technique is suitable for a first pass examination of all multibeam backscatter data. It does not require overlapping swathes. It forms an improved method of finding average backscatter curves for the acoustic themes of Rzhanov et al (2012), because results are shape dependent, and are not dependent on numerical dominance of a particular shape. Here we note that if there are real differences in properties within a set of curves, then the clustering approach will find those differences, providing a sufficient number of clusters are formed. Direct clustering can also be used to find errors and anomalies based on the properties of the whole curve. The CLARA algorithm can be configured to provide a quicklook examination of large numbers of curves (about 50,000), aiding in estimations of the number of clusters in a data set and the viability of particular analyses.

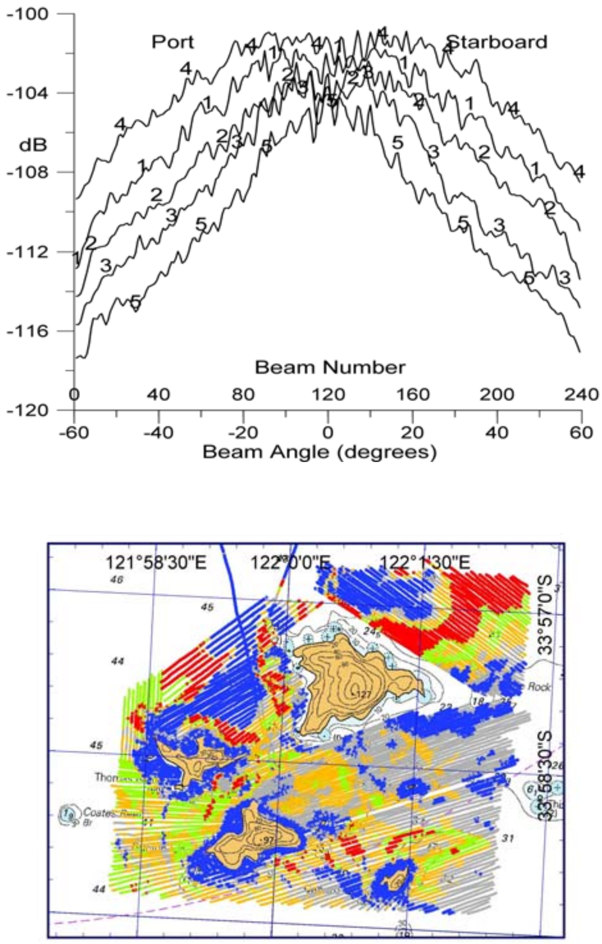

Figure 5. Segmentation of RESON 8125 backscatter data for a 7 km x 6 km area by direct clustering of backscatter curves (Hamilton and Parnum, 2011). The top panel shows the representative central tendency for each of the five clusters.

DATA FUSION

This topic is raised as one likely to become increasingly important as the use of acoustic seabed classification systems becomes more widespread. A similar question is whether or not data gathered by the same particular system over a period of time is self consistent. Transducers may degrade with time or become fouled on occasions, and ambient noise levels may change. Note that many papers compare classifications from different systems, rather than trying to actually fuse different data types.

Single beam sonar

Different sounders may have different frequency, output power, ping shape, ping duration, beam width, and beam pattern. Some systems use first echo parameters, and some use parameters derived from the first and second echoes. Use of different frequencies and output power means some systems may penetrate more deeply into the seabed than others. This may cause systems to see different properties of the seabed, and data fusion may not be possible in some cases.

Greenstreet et al (1998) attempted to compare RoxAnn data gathered in an area by the same system at different times using image processing techniques and clustering. RoxAnn is a two parameter system. Parameter E1 is the backscatter energy in the tail of echoes, beginning one output ping duration after the echo start. E2 is the energy of the whole of the first multiple echo (with path emitter/seabed/vessel and sea surface/seabed/receiver). E1-E2 values were higher in the second survey. This caused problems for Greenstreet et al (1998), because the clustering for one survey was not aligned with the clustering results for the second. If the corresponding ranges of E1 (and E2) for the two surveys had been found from co-located data points for the two surveys, then the methods may have yielded better results.

Hamilton et al (1999) used collocated points to successfully map acoustic classes obtained with a 38 kHz Quester Tangent Corporation (QTC) View system to a 50 kHz RoxAnn data space, providing a limited fusion of the two data types. The single echo shape approach of QTC-View and the double-echo energy approach of RoxAnn could provide equivalent classifications, although RoxAnn variability was difficult to overcome.

Single beam and sidescan sonar

Several workers have interpolated single beam point data from line surveys to large spatial pixels for comparison with the complete area coverage of sidescan sonar. It is increaseingly being realised that a better approach is to use the classified single beam point data to assist in interpretation of the sidescan sonar data.

OPEN SOURCE SOFTWARE

If digitally recorded echosounder data are available, then in principle it is not difficult to implement processing for acoustic seabed classification. The deepwater form of correction for echo shapes obtained from conventional sounders appears in Caughey & Kirlin (1996). The shallow water form of correction requires more careful treatment, and may be patented in some countries (Preston (2006)). Other details appear in Clarke & Hamilton (1999), Hamilton (2001), Brouwer (2008).

Durand and Legendre (2006) and Sanchez-Carnero et al (2007) have provided open source software packages for echo processing which use the deepwater form of correction. The status, correctness of method, and effectiveness of these systems is unknown. Several commercial software packages for seabed classification are available, e.g. see Hydro International (2009). The benefits of commercial software may prove more useful to many users than open source software, depending on their level of expertise in physics and acoustics.

In general the same remarks apply to processing of multibeam sonar backscatter data. A method of preparing multibeam backscatter curves for analysis is outlined in Gavrilov et al (2005). Direct clustering of the backscatter curves (Hamilton and Parnum (2011)) then provides a first pass unsupervised method of processing available to all which is not dependent on a particular angular range, swathe overlap, selection of training areas, or groundtruth. Again, direct clustering of corrected backscatter curves may not always be the best method for classifying multibeam sonar backscatter data, but it does provide a unifying method of processing. Data are not distorted and mathematical complexity and abstraction are removed.

STANDARDISED METHODOLOGY

It is also noted that a unified and standardised methodology for classification of seabed backscatter data has not been developed. The concept of direct clustering of curves used by Hamilton (2011) can be used to accomplish this. Direct clustering of corrected echo shapes and multibeam sonar backscatter curves may not always be the best method for segmentation, but by eliminating feature extraction it does provide a unifying method of processing. Unlike other processing methods, the seabed segmentations returned by direct clustering of curves are known to be directly related to seabed properties, because they use the actual backscatter response curves, not proxies. In themselves the segmentations provided by direct clustering of single-valued curves do not require ground-truthing (in the absence of ambiguities).

DISCUSSION

The concept of direct clustering of curves provides a simplifying and unifying method of classification for single beam and swathe backscatter data which is easily understood and interpreted.

By directly using echoes and backscatter curves as geometrical objects, feature extraction is eliminated. The problem of different users employing different features is removed. Since the actual backscatter response curve is used, there is also no doubt that segmentations do relate to seabed properties as captured by particular acoustic systems.

By using divide and conquer strategies such as those of the CLARA clustering algorithm of Kaufman & Rousseeuw (1990), the immediate need for data reduction through feature extraction and/or PCA are removed. Analyses need not be made in mathematical spaces with unknown relation to the backscatter response curves.

For some backscatter data sets, analysis by direct clustering of curves may be all that is required to obtain a satisfactory seabed segmentation. In other cases other techniques such as image processing may be needed to utilise all the available information. By providing a first pass classification of backscatter data largely independent of user influences, direct clustering should in principle enable more informed subsequent processsing by the feature extraction and image processing methods currently in use.

Direct clustering of curves is useful for analysis in many branches of the geosciences for which data relations can be described as single valued curves. Multi-valued curves can also be classified by direct clustering techniques.

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