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Edited by Jon Davies (senior editor), John Baxter, Martin Bradley, David Connor, Janet Khan, Eleanor Murray, William Sanderson, Caroline Turnbull and Malcolm Vincent

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Procedural Guideline No. 1–5 Mosaicing of sidescan sonar images to map seabed features

James D. Bennell, School of Ocean Sciences,
University of Wales, Bangor

Background

The aim of this guideline is to describe those aspects of sidescan sonar data acquisition and processing that enable the production of good quality sonar maps of the seabed which can be used for habitat mapping and monitoring. The process of producing these acoustic maps of the seabed is known as mosaicing since individual sidescan traces from different traverses are pieced together in adjacent positions to form a complete image (Green and Cunningham 1998, Fish and Carr 1990). Originally this was literally achieved by cutting up analogue paper records and sticking them together to get the overall view of a sonar survey (Figure 1). When using this guideline reference should be made to Procedural Guidelines 1-4 (Kenny et al. 2000) and 6-1 (Ince et al. 2000).

With the advent of digital technology this process has been computerised and there are now several software packages that can take digital sonar data and produce composite images of multiple present traverses of a study area to produce an acoustic map of the seabed. Kenny et al. (2000), give an excellent overview of the procedures to follow in order to ensure that good quality sidescan data are obtained during field operations. This guide will reiterate and expand those aspects that are of particular importance in producing good quality mosaics from sidescan sonar images. This guideline therefore assumes that the reader has knowledge of sidescan sonar and its application for mapping seabed habitats.

Figure 1. Cut and paste mosaic production. (Ocean Imaging Consultants Inc.)

Traditionally sidescan images were printed out on long sheets of paper. Most modern systems digitise the sonar data and process it on a dedicated PC system to produce a 'waterfall' type of display, on a monitor, where the most recent data appears at the top of the screen and the older data falls of the bottom

Figure 2. A typical 'waterfall' display of uncorrected sidescan sonar data. Navigational data are shown down the right of the display.

of the screen (Figure 2). The data are stored to some form of magnetic media and can be replayed for subsequent display and interpretation. When the sonar data are combined with navigation data[1], various corrections can be automatically applied to the image to allow it to be displayed as a true scale picture of the seabed without any of the distortions present in the original image. For example it is possible to correct for slant range. This effectively removes the blank water column zone above the first seabed return (Figure 3). Notice that the region closest to the seabed below the sidescan sonar tow-fish has been severely distorted and stretched. This process requires the accurate 'picking' of the first seabed return so that the height of the tow-fish above the seabed has to be continually monitored. It is also possible to produce equally scaled images where the cross-track scale is the same as the along-track scale. This enables the true size of sonar targets to be measured and located, further aiding the interpretation of the sonar data. In many instances these interpretations are then manually plotted with respect to the ships track in order to produce a map or chart of the seabed features shown by the sidescan sonar.

The basis of sidescan sonar mosaicing is to automatically plot each 'pixel' of sonar data, on a display, with respect to the track of the sidescan sonar tow-fish. The track is very rarely the straight line that it appears to be in a typical waterfall display. This process effectively geo-references each pixel of sonar data so that it is correctly positioned within an appropriate coordinate system. In other words the sonar data are displayed on a screen or printout in their correct geographical location with respect to the track of the tow-fish behind the survey vessel (Figure 4).

Adjacent survey lines can also be plotted on the same display to form a 'mosaic' of sonar data which serves as an 'acoustic' map of the survey area on which common features can be traced across the survey lines (Figure 5). The acoustic data are often superimposed on a coordinate grid system or even an Admiralty/hydrographic chart of the area to facilitate the sonar interpretation, allowing digitisation of seabed sediment boundaries and seafloor classification. A number of mosaicing systems provide this sort of processing and allow the resulting data (along with bathymetry etc.) to be output in a GIS (Geographical Information System) compatible format. This ensures effective management and archiving of the data from a particular survey area.

Previously, the final sidescan sonar mosaic was only available after post-processing the data. More recently, however, there are more and more systems that offer the option of Real-Time sidescan sonar Mosaicing (RTM). In this mode corrections and computations are applied to each ping of the sonar data to form a sidescan map on-screen as the survey proceeds. With this option sonar operators gain more

[1] This shows the location of the vessel and its speed.

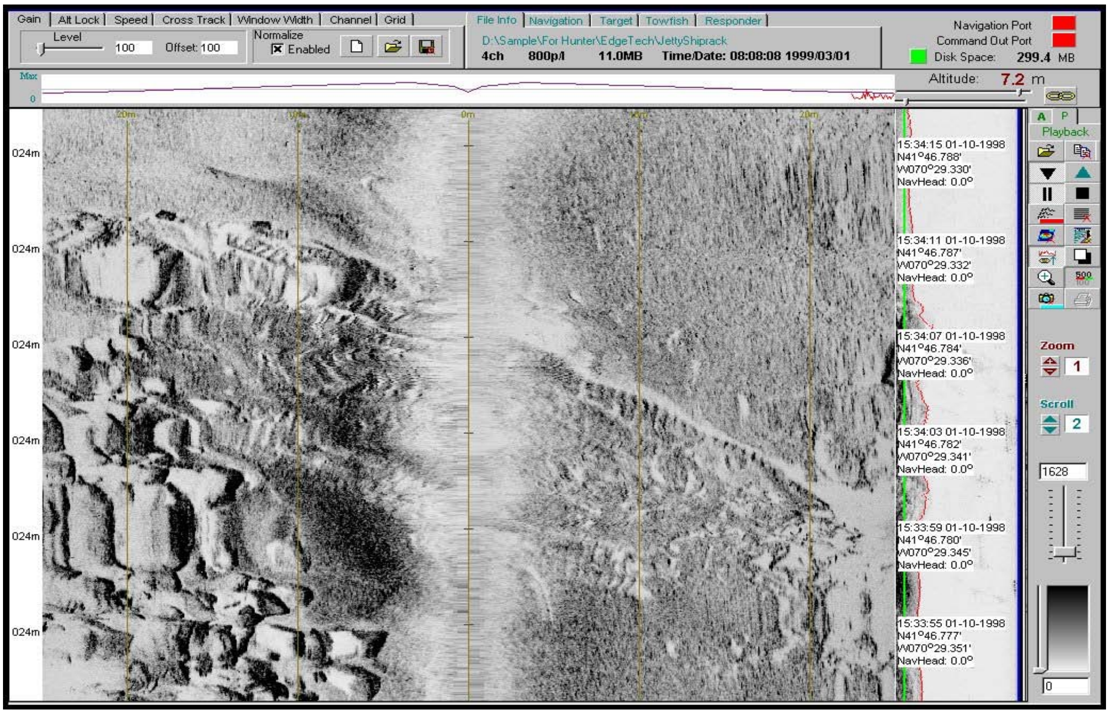

Figure 3. A slant range corrected image of the data shown in figure 2.

control over the survey execution. The survey can be altered without waiting for post-processing. This extra flexibility usually translates into greater survey quality and reduced survey costs. The sonar operator can check immediately for 100% coverage of the area and any gaps can immediately be filled without the need to wait for post processing to reveal these problems. In fact the Real-Time sidescan sonar Mosaic can be used as a guide for the helmsman to adjust the vessel's heading to maintain the optimum overlap of the sonar data and so prevent gaps or excessive overlap in the sonar coverage. Sonar

Figure 4. The sonar data from figures 2 and 3 plotted in their correct geographical location. (Note that the data coverage shown here is much more extensive than that shown in figures 2 & 3)

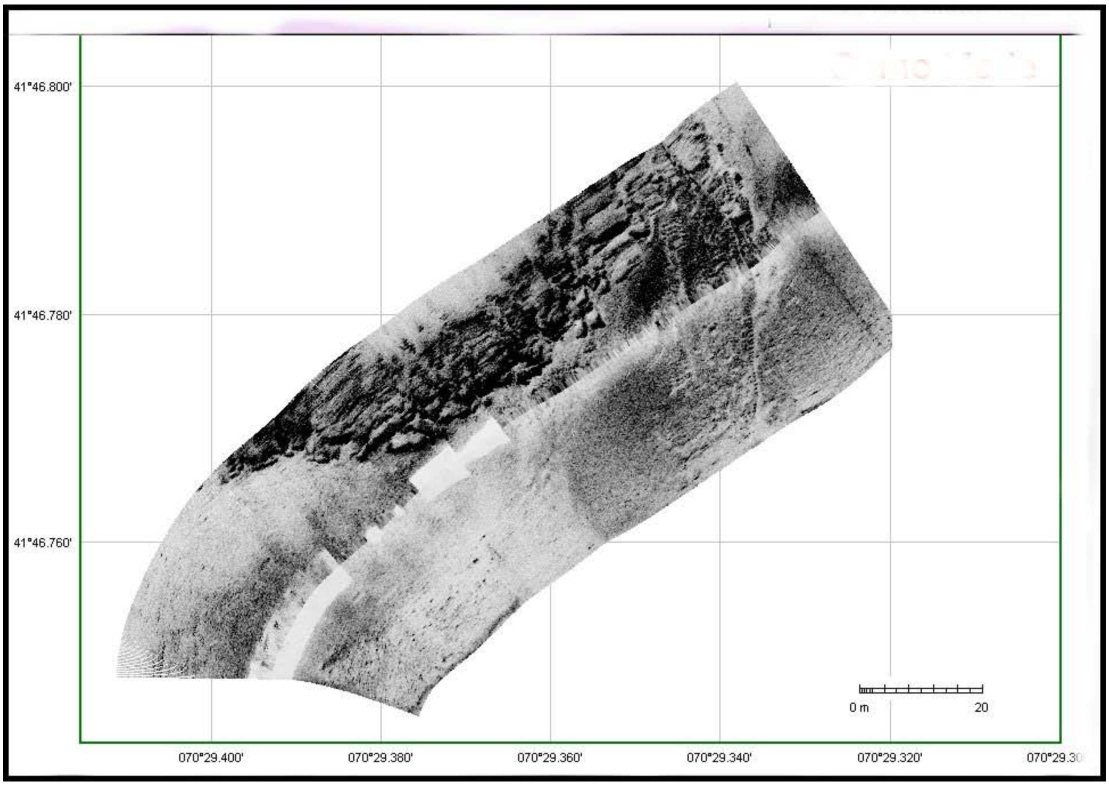

Figure 5. Sidescan sonar mosaic showing the occurrence of a coral reef (areas in black) occurring across several traces.

settings can be fine tuned to improve the quality of the data, processing parameters can be modified and the entire mosaic reprocessed and redrawn whilst the data acquisition proceeds.

The need to include a large area of sidescan mosaic on-screen inevitably reduces the overall resolution of the sonar data compared to the raw data observed in the waterfall type of displays (figures 2 and 3). The larger the area covered by the mosaic then the larger the features have to be, to be resolved.

So in theory it should be relatively simple to produce good quality sidescan sonar mosaics. All you have to do is acquire ‘perfect’ sonar data and position the sonar fish to within 1m. In practice, however, there are many problems, which can lead to less than perfect sonar mosaics. For example

- the quality of the sonar data might be poor due for example to the prevailing weather conditions;
- the navigation data may be poor;
- the tow-fish may not be accurately positioned with respect to the survey vessel;
- the survey lines might be erratic with too many course corrections made by the helmsman;
- or there may be too much or too little swath overlap between adjacent survey lines.

The quality of the final mosaic will therefore depend on careful planning of the survey, careful data acquisition during the execution of the survey and appropriate processing of the data either during (for RTM) or after the survey has been completed.

Pre-survey planning

A number of factors need to be considered and planned before the actual survey takes place. These include

- The size and the geometry of the area to be covered;
- The water depths to be found in the area under investigation;
- The tidal conditions in the area;
- The exposure of the site to wind and wave action;
- The resolution required of the survey in terms of the scale/dimensions of the seabed features of interest, and;
- The size and stability of the survey vessel.

These factors will dictate the way the survey should be undertaken in terms of the orientation and spacing of the planned survey tracks, the timing of surveying any inshore lines to coincide with high tide and utilising a favourable weather window.

Survey tracks should be planned if possible to be parallel to the prevailing currents so that the tow-fish follows directly behind the vessel instead of being swept down tide of the ship track Towing the tow-fish across a current can also cause the fish to yaw, resulting in poor data quality and a skewed sonar image. Vessel steerage will also be maintained, and it will be easier to follow the planned survey track when following or stemming the tide.

To ensure 100% coverage of the area, the survey lines should be spaced at less than twice the sonar range. The consequent overlap, however, should not be too great, as the quality of the final mosaic will be degraded. For example, when using the high frequency sonar option (500 kHz equivalent) a maximum sonar range of 100m is recommended and in this case a planned line spacing of 150m should be adequate.

The survey lines should not form a grid pattern as might be employed for a bathymetric survey but should consist of a number of parallel lines for optimal mosaicing. The reason for this is that the same seabed feature when ensonified from different orientations will often give different sonar images. If these were then combined on the sonar mosaic the final image would be highly distorted. For the same reason, it is recommended that the images recorded during the turn from one line to another are not included in the final mosaic. These images are highly distorted anyway since the data is stretched on the outside of the turn and compressed on the inside of the turn resulting in different data densities. Where detailed resolution of small features is required, it may be necessary to ensure all tracks are recorded by the vessel travelling in the same direction.

Sidescan sonar data acquisition

Every effort should be made to acquire the highest possible quality of sonar data as the quality of the final mosaic image will inevitably depend on this.

The prevailing weather conditions and sea state together with the size of the survey vessel are of primary importance. Sidescan sonar needs a stable platform from which to operate, otherwise the motion of the vessel will be transferred to the tow-fish via the cable, resulting in ‘noisy’ data.

The quality of the navigation is also of paramount importance. Although the Global Positioning System (GPS) now provides a more accurate position fixing since the cessation of Selective Availability (SA) in May 2000, the use of differential GPS (dGPS) is still highly recommended. With all navigation systems there will be navigation spikes that need to be removed during data processing (see later). Whilst acquiring navigation data, some thought should be given to the co-ordinate system for the presentation of final mosaic data. Mosaicing packages do not always have a facility for transforming between different datums (e.g. WGS84 and OSGB36) as described in Ince et al. (2000), so are dependent on the datum used in the dGPS receiver. Mosaiced data are also normally presented in some form of grid co-ordinates (Universal Transverse Mercator: UTM or Ordnance Survey: OS grid). It is recommended that if the final mosaic is to be presented in OS grid co-ordinates then the dGPS navigation data (latitude and longitude) should be collected using the OSGB36 datum. However, for displaying sidescan mosaics in Irish Grid co-ordinates, dGPS data should be saved in the Ireland 65 datum.

It is vitally important to know the location of the sonar tow-fish behind the survey vessel, or GPS antenna for accurate mosaicing (often termed ‘layback’). This is dependent on a number of factors, including the speed of the vessel through the water, the water depth, the length of tow cable deployed and the influence of any currents deflecting the tow-fish off the course of the vessel. An approximation can be made by estimating the length of cable paid out from the stern of the survey vessel and adding to it the offset distance from the GPS aerial to the vessel stern to give the ‘layback’. However, the most accurate way of recording the tow-fish position is by using an ultra short baseline underwater acoustic tracking system (e.g. ORE LXT Tracker system). A transducer is attached to the tow cable immediately in front of the tow-fish and responds to a hydrophone mounted via a bracket to the vessel.

The speed of the survey vessel is critical for optimum sonar resolution along track and accurate control of the tow-fish above the seabed. A speed of between 3 and 4 knots through the water has been found to be a good compromise between a speed slow enough to get the tow-fish to tow close to the seabed and fast enough for the survey to proceed at an economical pace with an optimum data density. With some vessels it might be difficult to survey at this relatively slow speed. A more controlled speed over the ground may, however, be maintained by steaming into the tide than when the vessel is travelling in the same direction as the current flow. Where tidal flows influence the speed of the vessel, data should be acquired in one direction to overcome speed-related bias.

The quality of the sidescan sonar images and hence the final mosaic depends to a large extent on the skill of the helmsman or the efficiency of the autopilot. This is because the sidescan tow-fish can only collect good images if its heading changes as little as possible. A turning tow-fish stretches the image on one side and compresses it on the other. It also upsets the matching between the gain profile and the beam shape, causing alternate light and dark patches in the inner areas of the image that will have an impact on the final mosaic. If the heading of the vessel is being continually adjusted to remain on a pre-planned course the sidescan beam will oscillate or swing back and forth resulting in a mosaic image with overlapping data. As the tow-fish is towed off the stern of the vessel, rudder movements as well as course deviations will affect it. The helmsman should thus minimize the amount and rate of rudder movement, even if this means that the vessel deviates temporarily from the planned survey line. If an autopilot is available it should be used, since under most conditions it will steer a better sidescan course than a human helmsman, even though the heading may still need to be trimmed occasionally.

Care must also be taken to avoid contact between the tow-fish and the seabed or any obstruction in the water column. In particular when the survey vessel turns to approach a new survey line, the tow-fish is prone to sink towards the seabed as its speed through the water temporarily reduces. It is good practice to raise the tow-fish slightly before commencing a turn, which should be in as wide an arc as possible and not abrupt. It goes without saying that all obstacles such as moorings, shot lines and fishing 'pots' should be avoided at all costs as entanglement can often result in the loss of the tow-fish.

A common fault is to 'fly' the tow-fish too far above the seabed for fear of damaging the tow-fish by it striking the seabed. An optimum height above the seabed is between 10% and 20% of the range setting. For example, a range setting of 100m would have an ideal 'tow-fish' height of 10m off the bottom. However, there is a fine balance between 'flying' the tow-fish at a high enough distance off the bottom to prevent collisions yet low enough to gather high quality sidescan data. In areas of variable seabed topography it is recommended to maintain the tow-fish at a greater height off the bottom in order to avoid having to continuously alter the tow-fish height. This minimizes having to reel the tow cable in and out which can distort the sonar data and disturb any automatic gain settings.

The tow-fish should not be towed so high in the water column that it is in the wake of the survey vessel. In this situation the signal may be lost altogether and there is a danger of inadvertently raising the tow-fish up into the pulley through which the tow cable passes. This is to be avoided at all costs as damage to the tow cable termination will occur and in the worst case the cable will break resulting in the loss of the tow-fish.

It is suggested that each survey line of sidescan sonar data should be recorded as a separate data file. This will facilitate the mosaicing process in that some mosaicing packages cannot deal with survey lines that have excessive curvature or that double back on themselves. It is highly recommended to record the survey date and survey line number somewhere in the file name, as this is useful when selecting files for further analysis.

Sidescan processing to produce the optimum mosaic image

The basis of all mosaicing systems is to perform a slant range correction and remove the water column from the sonar data. The resulting data are then plotted with respect to the position and heading of the tow-fish on a scaled chart of the seabed. Each mosaicing system, however, handles the imaging of the data in different ways in order to create the optimum geometric proportionality of the image. Most mosaicing systems allow for some form of data processing or manipulation in order to create the optimum mosaic image. Consequently less than perfect sidescan sonar and navigation data can still be used to produce an acceptable sidescan sonar mosaic if a number of enhancement processes are applied to the data. This section describes the application of these processes in order to optimize the final mosaic image.

As a guide to the post-processing that can be applied to the sidescan sonar data, the Octopus 461 Sidescan Sonar Toolkit (from CodaOctopus Ltd.) will be used as an example. This toolkit incorporates a cost effective mosaicing package (£4995 at time of writing in 2002) which can be used to process sidescan sonar data recorded in many different data formats, including QMIPS, XFT, Coda and Muse.

The first step is to preview the raw data in the 461 Viewer, where features such as reefs can be measured. General data quality can also be assessed at this time. It is also possible to save features of interest as Geo-Tiff images[2].

The second step is to extract navigation data from each survey track using the 461 Utilities and then save it as a unique *.QPX file. In practice it is best to extract positions every 10 to 30 seconds rather than saving every navigation position, since the track of the tow-fish is likely to be less erratic than the track of the survey vessel. This enables fast, efficient mosaicing and allows for easier editing of the navigation data without compromising the original navigation data. Navigation files can also be exported and imported in ASCII file format to other software to facilitate editing. Spikes and jitters in the track lines can be edited in the 461 Utilities, by removal or adjustment of points, to give a 'smooth' track line. Survey lines can be cropped to cover the area of interest i.e. turns and line overruns can be edited out. The navigation can also be corrected for layback and offset between the vessel and the tow-fish, (either by using values recorded during the survey or by measurements made on the mosaic preview), by observing the offset between the same features recorded on overlapping survey runs. Another option is to import the corrected and smoothed navigation data from an external source as an ASCII file. Over editing or smoothing will however compromise the geographical spatial accuracy of the final image and must be avoided where such accuracy is required.

The third step is to 'clean-up' the raw sonar data. Corrections can be made to fix any gain problems with the data so that the overall signal levels are uniform across the sonar's range. Port and Starboard channels should be balanced. Amplitudes at maximum range should be normalized by applying TVG (Time Varying Gain). Anomalies in the first or seabed return should be minimized by using auxiliary TVG functions. Bottom tracking should be added if absent or checked for accuracy and re-tracked as necessary. SRC (Slant Range Correction) should also be applied at this time. All these adjustments should then be saved as a processed file in the Octopus QMIPS format.

The fourth and final step is to fine-tune the data to create the final mosaic tiles. To achieve this it is necessary to specify the scales, resolution and the tile position co-ordinates. Adjustments can be made to the final contrasts and in-fill densities of the sonar images. A choice can be made on which kind of overlap mode to use and whether to use feathering to 'soften' the hard edges of any overlapping data. Finally it is necessary to select the survey line order, as this will determine which line will overlay any of the others.

A number of mosaicing systems are available from different companies. Some only allow mosaicing offline after the completion of the survey. Other systems allow Real-Time online Mosaicing (RTM). Although this has the advantage of being able to view the sonar coverage as the survey progresses, so that any gaps can be filled in before survey completion, it is likely that some post processing will be required to edit the navigation and sonar data to optimize the final mosaic image. A list of mosaicing systems currently available in 2002 is given in Table 1.

Table 1 Sidescan sonar mosaicing packages

Company	Product	Real time	Web Address
CodaOctopus Ltd	461 Sidescan Processing Toolkit	No	www.octopusmarine.com
CodaOctopus Ltd	Geosurvey Software Suite, Mosaic module	No	www.coda-technologies.com
Ocean Imaging Consultants Inc	OICToolkit	No	www.oceanicimaging.com
GeoAcoustics	GeoPro	Yes	www.geoacoustics.com
Triton Elics	DelphMap	No	www.tritonelics.com
OceaStar Systems Inc	Hunter, Mapper	Yes	www.marine-group.com
Chesapeake Technology Inc	Sonar Web	No	www.chesapeakeTech.com

Data Products

The final product will normally be a series of image files, of adjoining tiles, which can be used to put together the final mosaic image by importing them into a mapping system either a CAD or G.I.S. package. These files can be either bitmap *.BMP image files with associated geo-reference data in separate files or Geo-TIFF files which can be imported directly into G.I.S. packages without the need for defining

[2] A Geo-Tiff image has geographic co-ordinates incorporated to facilitate accurate plotting in GIS.

positions of four reference points on the image. The user should consider the size (in pixels) and hence the resolution of the final images. The user should ensure the images are sufficiently detailed to display the features of interest, but avoiding overly detailed images that may require significant computing power to display the final map. For example as a general rule using the 2000 × 2000 pixel images, a resolution of 50cm per pixel (1km × 1km per image) would be considered fairly coarse, whilst 25cm per pixel (500m × 500m) is classed as high resolution. A mapping project of Flamborough Head SAC, comprising 60km^2 used 25cm resolution (Hydrosurveys 2002). The image files required 1.2 GB of disc space and the full mosaic could be displayed by a P4 1.7 GHz computer in approximately 3.5 minutes. In the standard version of the toolkit the resolution of each tile is 540 × 540 pixels. The automated version of the package (AutoMosaic) allows the creation of individual tiles of up to 2000 × 2000 pixels.

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