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CLASSIFICATION	SYSTEM NUMBER 504202
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TITLE

CREATING A SEABED MOSAIC FROM GEOCODED SIDESCAN SONAR IMAGES

System Number:

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TECHNICAL MEMORANDUM 97/215
March 1997

CREATING A SEABED MOSAIC FROM GEOCODED SIDESCAN SONAR IMAGES

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CREATING A SEABED MOSAIC

FROM

GEOCODED SIDESCAN SONAR IMAGES

R.H.Poeckert

March 1997

Approved by R.E. Erickson *Signiture on File*
Head/Electromagnetics Section

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ABSTRACT

The use of high frequency sidescan sonars mounted on a towfish to accurately map the seabed with sufficient resolution to detect mine-sized objects (~2 m) is well established. Typically such sonars have swath widths between 150 to 300 m and there is usually a region directly beneath the towfish which is poorly imaged. Multiple overlapping swaths are used to map an area wider than an individual swath and to provide useful data directly along a towfish path. The data collected on such a survey can be geocoded and mosaiced into a large seabed map. The mosaicing process involves registering overlapping images and combining them. The absolute navigational accuracy achievable at present is ~10 m RMS. Thus images will not register exactly, and, if left un-corrected the resultant mosaic will have unacceptable discontinuities across cut-lines where the images are joined. Several solutions exist to minimize these discontinuities and this paper describes a process in which images are warped and mosaiced in such a way as to almost eliminate cut-line discontinuities and at the same time preserve positional accuracy.

RÉSUMÉ

L'emploi de sonars à haute fréquence à balayage latéral montés sur un poisson remorqué afin de tracer précisément le fond de la mer avec suffisamment de discrimination pour permettre la détection d'objets de la grandeur de mines (~2m) est bien établi. Typiquement de tels sonars ont des largeurs de passe entre 150 et 300m et il se manifeste généralement une région directement au-dessous du poisson remorqué dont l'image n'est pas bonne. De multiples passes chevauchantes servent à tracer une superficie plus large qu'une passe individuelle et à fournir des données utiles directement le long de la traversée d'un poisson remorqué. Il est possible de géocoder et de mosaïquer les données collectionnées au cours d'un tel relevé pour en créer une grande carte du fond de la mer. La création de la mosaïque comprend l'enregistrement, suivi de la synthèse, des images chevauchantes. La précision absolue de navigation actuellement possible est ~10m d'erreur quadratique moyenne. Alors les images ne s'enregistrent pas avec précision ; donc, sans correction, la mosaïque qui en résulte sera caractérisée de discontinuités inacceptables à travers les lignes de coupe où les images se joignent. Plusieurs solutions existent pour minimiser ces discontinuités. Cet article décrit un processus par lequel les images sont tordues et mosaïquées d'une manière qui réussit à presque éliminer les discontinuités de ligne de coupe tout en préservant la précision de position.

CREATING A SEABED MOSAIC FROM GEOCODED SIDESCAN SONAR IMAGES

by R.H. Poeckert

EXECUTIVE SUMMARY

INTRODUCTION The Canadian Navy is developing a route survey/mine hunting capability based on a towed sidescan sonar. The sonar provides route survey data, which is essentially a detailed map of the seabed. A single swath of data may be up to 300 m wide, but more typically 200 m wide. In order to cover wider lanes, multiple swaths will have to be obtained and assembled into one map. Also, sidescan sonar does not provide good data along a path, ~20 m wide, directly beneath the towfish. This poorly imaged area must be covered, either by having overlapping swaths, or by use of a gap-filling sonar (fore or aft looking sector scan sonar). In either case image data will have to be fused in order to make one seamless map of the seabed. The navigational requirements of the route survey/mine hunting system are such that the absolute position error is two orders of magnitude greater than the resolution of the sonar. To assemble multiple swaths, and/or gap data, will require the seabed image data to be co-registered, to adjust for navigation error, and mosaiced. In this report a process is described wherein multiple images may be mosaiced into one seamless map while at the same time minimizing the absolute position error in the resultant seabed map.

PRINCIPAL RESULTS A process is described wherein multiple overlapping sidescan sonar images are co-registered using seabed objects as registration points. The offsets between multiple images are combined and considered simultaneously, with the result that an optimum set of offsets for each image is determined. These offsets, because they arise from a global optimization, actually can reduce the position error for the sonar data, compared to the error for a single sonar image. The multiple images can then be warped using the offsets, such that all images register exactly. A mosaic can then be constructed from the warped images.

SIGNIFICANCE OF THE RESULTS The use of a global optimization has two benefits. First, constructing a mosaic is simpler since all the images that will make up the mosaic are co-registered. Second, the overall position error of the data is reduced.

FUTURE PLANS The process described in this report has been used to construct several seabed mosaics. However, much of the process is still very labour intensive and rather ad hoc. A set of tools, computer aided image analysis, will be implemented to make the process more efficient and database support for the process will be provided, formalizing the process.

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INTRODUCTION

The Mine Countermeasures (MCM) Group of the Defence Research Establishment Atlantic (DREA, located at the Esquimalt Defence Research Detachment (EDRD), formerly the Defence Research Establishment Pacific), has conducted numerous sidescan sonar surveys. These surveys provided high resolution (~0.3 m) seabed images over relatively large areas and are intended for use in route survey and mine hunting. High resolution is necessary in order to identify and locate mine-sized objects on the seabed. A typical swath width along a single survey track is 200 m. A typical sea lane or Q-route is much wider, at least 500 m and perhaps up to 2 km. Thus a single survey track does not provide sufficient breadth to cover an entire sea lane. Wide areas have been surveyed using overlapping swaths. The problem of accurately assembling these individual survey lines into one seabed mosaic is the subject of this report.

The use of mosaics for route survey is only necessary where the seabed is textured, for example sand ripples, and/or cluttered with mine-sized objects. The intent of a mosaic is to provide a map of the seabed such that objects on the seabed can be identified in subsequent surveys. It is likely that an area of interest will be surveyed more than once and a mosaic should incorporate the best data from such surveys, but still present a unique map of the seabed. If the seabed is dynamic, for example sand ripples that migrate, a mosaic will only be valid as a snapshot of the seabed. However, boulder fields, which present a high false alarm rate problem during mine hunting, are unlikely to change.

The process of creating a mosaic begins by collecting the data. In addition to the sonar data, navigational data, which allow the sonar's geographic location and orientation to be determined, are also required. With these data it is possible to geocode the sonar information to produce a geographically correct seabed map for each track of a survey.

In principle, geocoded data from adjacent survey tracks can be mosaiced directly without the need for registering the images. Mosaics are constructed by defining "cut-lines" where one image ends and another begins or by summing and averaging the image data where there is overlap. However, with current technology, the quality of the navigation data is poor compared to the sonar resolution. Typically, high resolution sidescan sonars have resolution better than 0.5 m, while the navigational accuracy is on the order of 10 m. A mosaic constructed directly from the geocoded images would have large discontinuities along the cut-lines. Such discontinuities result in large local relative position errors across the cut-lines. In addition, some seabed areas will appear twice in the mosaic while other seabed areas, although surveyed, will not appear at all.

Adjacent overlapping geocoded images can be co-registered before mosaicing. Registration is accomplished by identifying common points, typically a boulder or other feature, appearing in adjacent survey tracks, and shifting one or both images such that the feature appears at the same geographic position in both images. Obviously such an alignment only registers the images at one point and the problem of discontinuities will still be present away from the registered point. The solution to this problem is to identify multiple registration points, define a spatial transformation and then "warp" one or both images such that the common points lie at the same location.

The spatial transformation function should be suited to the kind of distortion present in the images. For example, optical cameras often have "pin cushion" distortion. In such a case it is possible to use a relatively simple global function such as a polynomial. In the case of sonar data there are local quasi-random distortions, but no large global distortions. What is needed in this case is a transformation function that accommodates local distortions, but which is globally flat.

There are a number of functions that meet these requirements and a thin-plate-spline (TPS; Barrodale et al, 1992) has been used successfully on sonar data. A mosaic constructed from registered and warped geocoded images will have minimal discontinuities along cut-lines. However, absolute positional accuracy tends to suffer if many tracks are involved in making the mosaic. This occurs because as images are added to the mosaic it is usual to warp the image to be added to register with the mosaic. Positional error will grow as images are added, similar to a random walk.

This report describes a procedure in which multiple survey tracks are globally registered, and absolute navigational accuracy is preserved.

SURVEY EQUIPMENT

The surveys discussed in this report were carried out using a dual-beam Mesotech 972 sidescan sonar. The sonar frequency was 330 kHz and the one-sided range was 100 m, providing a 200 m swath width. The resolution of the system is 0.1 m across track and ~0.35 m along track. The nominal towing speed was ~2 meters per second. The geographic position of the towfish was estimated by first determining the position of the tow vessel using DGPS. The position of the towfish relative to the tow ship was measured using a Trackpoint II acoustic positioning system. Towfish tracks were estimated using a dead reckoning algorithm (Poeckert, 1993). Typical navigational accuracy achieved using this equipment is ±10 m (RMS) absolute and 2% relative (RMS).

SURVEY AREA

The MCM Group has conducted several area surveys, but this report will concentrate on one survey, off Halifax, NS, as a typical example (figure 1). The survey covers a 1 km X 6.2 km area. Survey tracks run the full 6.2 km length of the area and 11 tracks at a spacing of 75 m were needed to cover the area. Ideally the tracks are straight lines, but as can be seen in figure 1 the tracks deviate from straight lines by ±20 m (note the 1:10 exaggeration in figure 1). This deviation is a combination of navigation error and the track keeping ability of the tow ship.

GEOCODING AND REGISTRATION

The EDRD Sonar Image Processing System (SIPS; Desandoli and Taylor, 1989) was used to process the sidescan sonar image data. The image data were first geocoded using the estimated position of the towfish as given by the dead reckoning algorithm (Poeckert, 1993). The images from overlapping survey tracks were then compared and common registration points selected. The number and selection of registration points is discussed below. Image comparison was carried out using a "blink" technique (Poeckert, 1991). The blink technique not only determines offsets between images, but is also useful in estimating local distortions. Local distortions between images are readily apparent when the images are displayed in this way.

There are several sources of error which contribute to the misalignment of the geocoded image data. As discussed by Preston (1988), the major contributors are tow ship position, towfish range and bearing, and towfish heading. Ship position and towfish range and bearing errors combine to produce a towfish position error. This results in a common position error for both port and starboard beams, and the geocoded image at any given point has a single translation error. Heading errors, on the other hand, introduce skew in a geocoded image. That is, the positional error increases with distance from the towfish and has opposite sign on either side of the towfish. Very little skew is evident in the geocoded images collected so far and it appears to contribute less than ~2 m to the overall position error. As will be seen, this is an important factor as it simplifies the warping process.

The selection of registration points is based on the availability of objects on the seabed, typically boulders. Scour marks or other linear features on the seabed are useful in assessing the relative error between images, but are generally not useful in defining registration points as they only provide information on one coordinate. There are methods in which such linear features may be employed (Smith and Barrodale, 1992), but these were not used in this study. Misalignment cannot be determined where there are no objects or features on the seabed to use as registration points. However, since the seabeds in such areas are featureless, misalignment is not a problem. Given that the relative navigational accuracy is on average a few percent, registration points were selected at a minimum every 200 m along a track. Where significant distortion was apparent, i.e. the relative navigational error was >10%, registration points have a closer spacing to fully characterize the distortion.

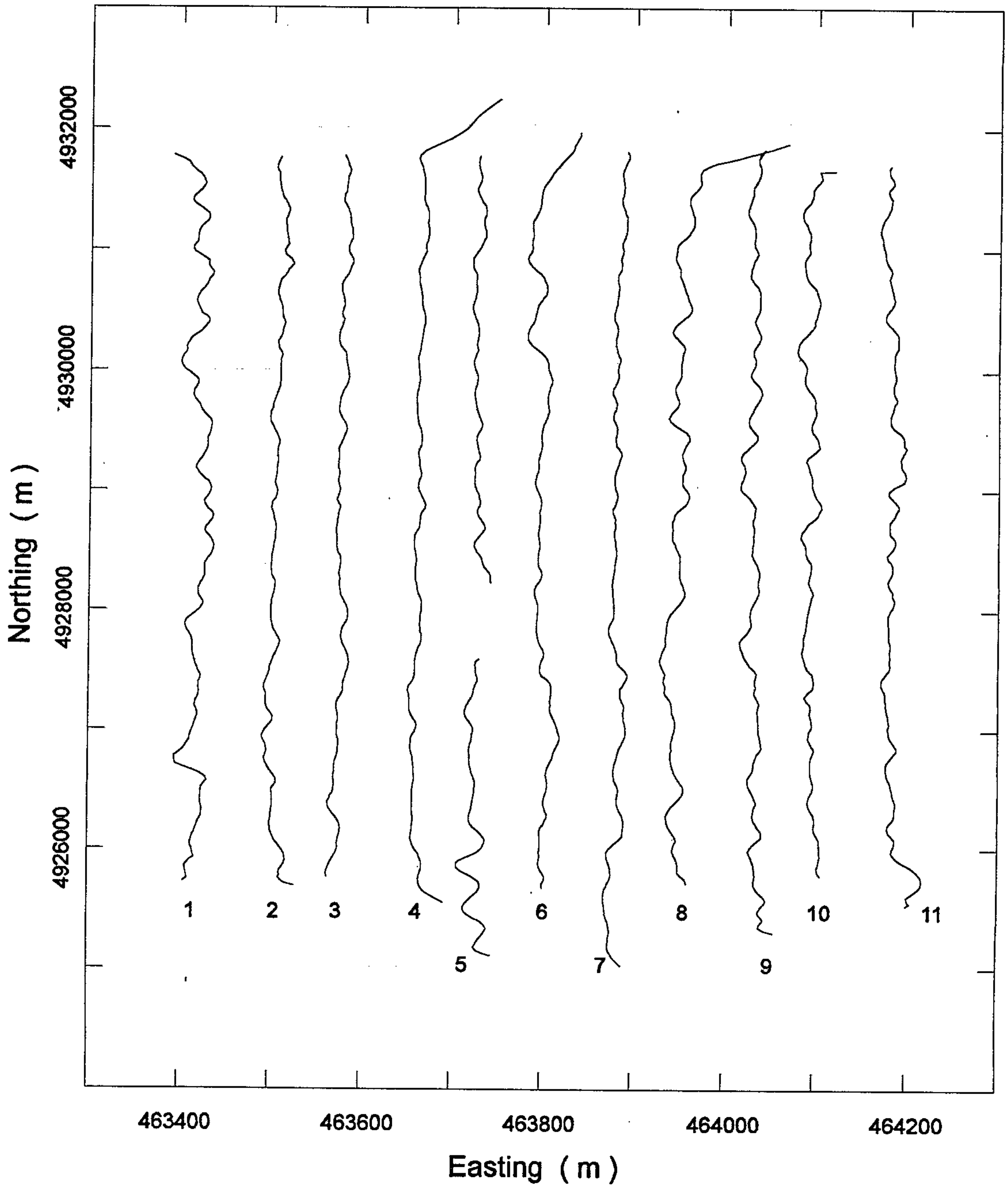


Figure 1. Halifax survey lines. The gap in line 5 is due to a temporary equipment malfunction. Note the 1:10 exaggeration in scale.

Table 1 gives a list of registration points arising from a comparison of lines 7 and 8 of the survey. This list illustrates one of the poorer survey line pairs, poorer in the sense of relative position error. The offsets are measured to the nearest metre. Figure 2 shows the offsets as a function of along track distance.

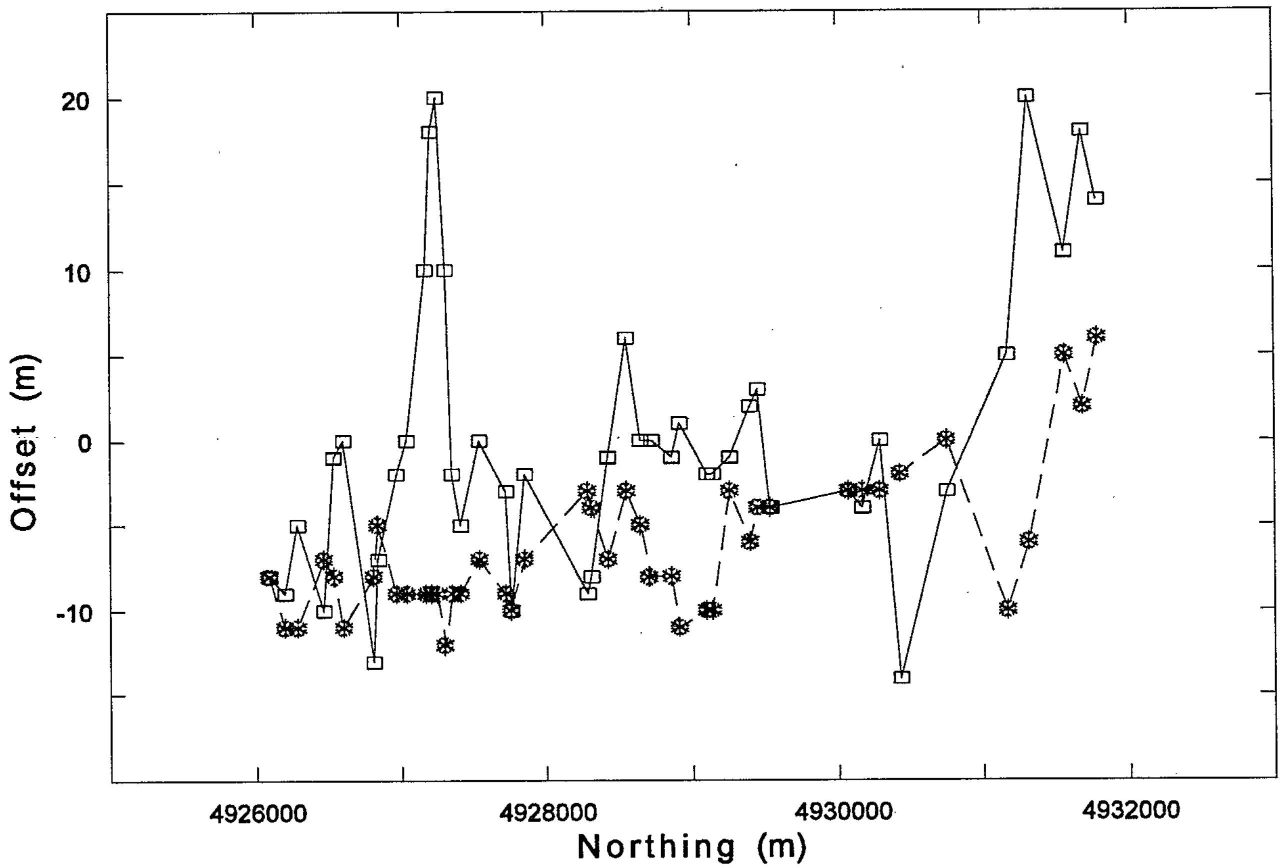


Figure 2. Offsets between adjacent lines (7/8); ✱ - Easting offset, ☐ - Northing offset.

Some statistics for this pair of survey lines follow. The average along-track distance between registration points is 132 m. The mean offset between the survey lines is 5.6 m in easting and 0.6 m in northing, with maximum offsets of 12 m in easting and 20 m in northing . The mean relative distortion between the survey lines is 1.8% in easting and 4.0% in northing, with maximum relative distortion of 8.3% in easting and 11.4% in northing.

Having determined the offsets between adjacent lines it is possible to warp the geocoded image from one survey line using TPS and to register it with its neighbour. However, this involves two re-samplings of the original data, the first through geocoding and the second by TPS warping. Resampling inevitably degrades the data quality.

Table 1. Registration Points for Lines 7/8

Line 7		Line 8			
Easting	Northing	Easting	Northing	D Easting(m)	D Northing(m)
463965	4926091	463973	4926099	-8	-8
463869	4926196	463880	4926205	-11	-9
463960	4926283	463971	4926288	-11	-5
463909	4926464	463916	4926474	-7	-10
463904	4926535	463912	4926536	-8	-1
463892	4926600	463903	4926600	-11	0
463846	4926807	463854	4926820	-8	-13
463847	4926835	463852	4926842	-5	-7
463907	4926965	463916	4926967	-9	-2
463907	4927037	463916	4927037	-9	0
463976	4927169	463985	4927159	-9	10
463969	4927208	463978	4927190	-9	18
463958	4927248	463967	4927228	-9	20
463947	4927309	463959	4927299	-12	10
463841	4927350	463850	4927352	-9	-2
463850	4927409	463859	4927414	-9	-5
463914	4927540	463921	4927540	-7	0
463901	4927725	463910	4927728	-9	-3
463851	4927760	463861	4927770	-10	-10
463839	4927853	463846	4927855	-7	-2
463851	4928283	463854	4928292	-3	-9
463869	4928309	463873	4928317	-4	-8
463907	4928422	463914	4928423	-7	-1
463932	4928548	463935	4928542	-3	6
463917	4928644	463922	4928644	-5	0
463909	4928719	463917	4928719	-8	0
463914	4928856	463922	4928857	-8	-1
463895	4928912	463906	4928911	-11	1
463915	4929097	463925	4929099	-10	-2
463899	4929137	463909	4929139	-10	-2
463915	4929255	463918	4929256	-3	-1
463934	4929395	463940	4929393	-6	2
463923	4929449	463927	4929446	-4	3
463893	4929532	463897	4929536	-4	-4
463890	4930069	463893	4930072	-3	-3
463888	4930164	463891	4930168	-3	-4
463953	4930284	463956	4930284	-3	0
463853	4930425	463855	4930439	-2	-14
463913	4930747	463913	4930750	0	-3
463977	4931168	463987	4931163	-10	5
463925	4931316	463931	4931296	-6	20
463916	4931562	463911	4931551	5	11
463927	4931684	463925	4931666	2	18
463941	4931787	463935	4931773	6	14

Another approach is to apply offsets to the towfish position and heading data and to re-geocode the sonar data using the modified data. This approach involves only a single resampling of the original image data and it is somewhat more efficient computationally than TPS. A drawback to this approach is that in addition to the registration points it is also necessary to determine the towfish location associated with the registration point, since it is the towfish position and heading that one is altering. This presents an extra burden during the registration point identification process.

However, the process can be greatly simplified if it can be assumed that skew distortion is not significant and that the towfish heading is equivalent to the track heading, or course made good. The first assumption removes heading corrections from the problem. The second assumption allows for a simple determination of measured towfish position for each registration point.

Once the sonar data from an adjacent survey track has been warped it is possible to build a mosaic from two survey tracks. Successive tracks can be added to build up the mosaic to cover the entire survey area. Each track is registered with the mosaic, offsets are determined, the image data are warped and are added to the mosaic. Unfortunately this process can degrade the overall navigational accuracy as offsets accumulate. The process is akin to a random walk and the navigational accuracy can deteriorate as the mosaic is built up. The cumulative error can be minimized by starting at the middle of the survey area and working out to the edges in both directions. However, a better solution is to use a global warping strategy.

GLOBAL WARPING

A global approach is needed to avoid the effects of accumulating offsets. In such a process all offsets between images are considered simultaneously and navigational accuracy is consistent across an entire mosaic.

The process that was developed to do this consists of measuring all the offsets between adjacent survey lines using registration points common to two or more geocoded images. As noted above, skew distortions are not significant and will be ignored in the discussion that follows. All of the offsets are combined in a set of simultaneous linear equations. The solution to these equations provides offsets for each towfish track. The offsets are added to the original towfish position for each track. The sonar data are re-geocoded and the resultant images can be mosaiced without further alignment.

The process of identifying and measuring offsets at registration points, and associating a registration point with a towfish position has already been discussed. The next step is to interpolate offsets along each towfish track such that for each pair of tracks we have an offset at the same along-track position. Offsets

Table 2 - Mean Offsets Between Survey Lines

Line Pairs		Δ Easting	Δ Northing
1	2	-3.1 ± 4.9	-17.8 ± 5.4
2	3	9.5 ± 3.0	22.1 ± 7.1
3	4	-4.4 ± 3.6	-22.1 ± 7.6
4	5	3.0 ± 3.4	-16.0 ± 5.6
5	6	-1.9 ± 3.9	-0.6 ± 5.6
6	7	7.0 ± 4.5	1.6 ± 6.2
7	8	-5.4 ± 4.2	-1.7 ± 7.5
8	9	5.7 ± 4.7	1.5 ± 5.8
9	10	-1.6 ± 3.5	2.4 ± 6.4
10	11	5.8 ± 5.1	5.8 ± 7.6

Figure 3 shows an example of the calculated northing position corrections, the N_7 and N_8 along two survey lines. By comparing figures 2 and 4 one can see that the sharp 20 m offset between lines 7 and 8 at a northing of 4927250 was corrected primarily in survey line 8 and not in line 7. One can conclude from this that the line 8 position data had a substantial error at this location.

The corrections are now added to the original navigation data and the sonar images are re-geocoded. The geocoded images of the individual survey tracks will now be in perfect alignment at each of the registration points. The images can now be mosaiced.

Figure 4 shows samples of the mosaic image data. The figure shows identical geographic areas from two mosaics. The upper image consists of only west looking sonar beams, shadows are cast to the left, while the lower image shows the east looking sonar beams, shadows are cast to the right. The geographic area shown encompasses the region where the 20 m northing offset between lines 7 and 8 occurred. Cut lines, where adjacent images abut, are apparent in both mosaics. These cut lines are most prominent where there is insufficient overlap between survey lines to cover the poorly imaged area directly beneath the towfish path.

The mosaics show an area of bedrock outcrops (dark gray) protruding through a gravely seabed (light gray). Shadows are black, and can be seen most prominently along the right edge of the rock outcrop in the lower image. Areas where the bedrock emerges from the seabed, facing the sonar, are more normal to the sonar beam than the tops of the outcrops and this results in a higher (brighter) backscatter strength along these boundaries.

Figure 5 illustrates schematically the contributions made by various survey lines to the mosaics shown in figure 4. The cut lines were defined interactively and chosen to retain the best data of a particular area.

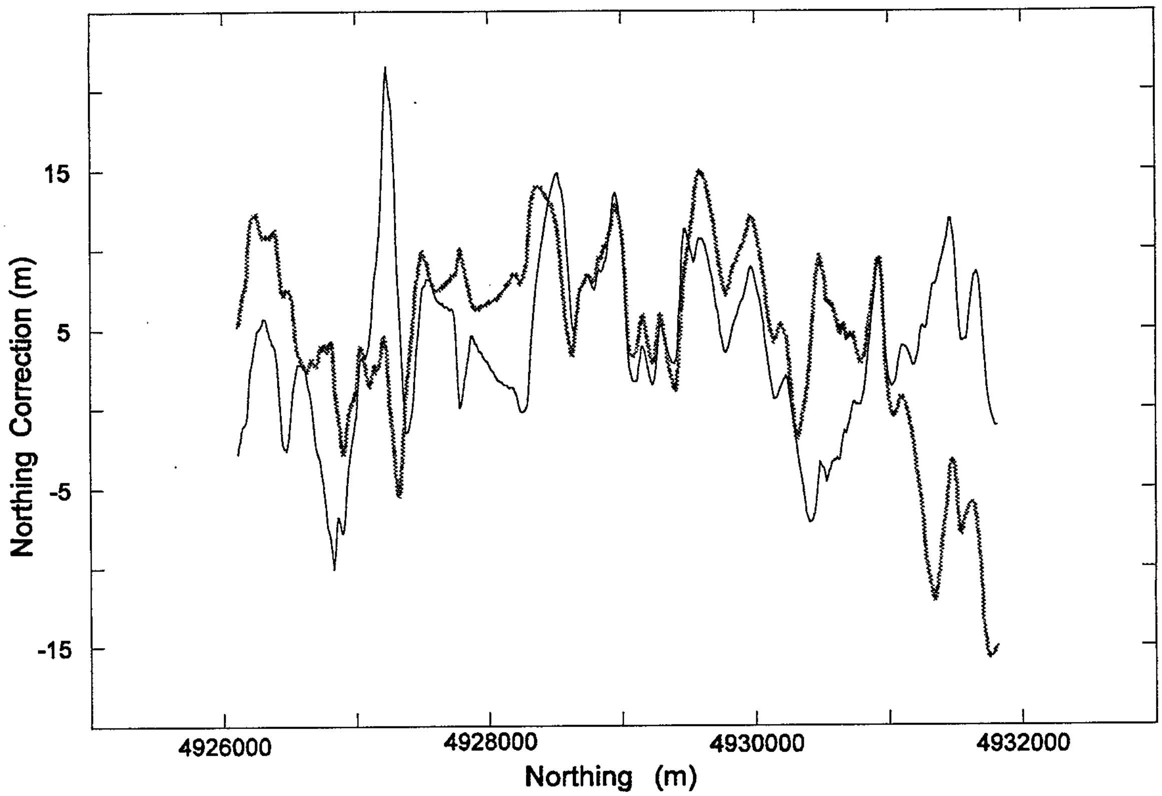


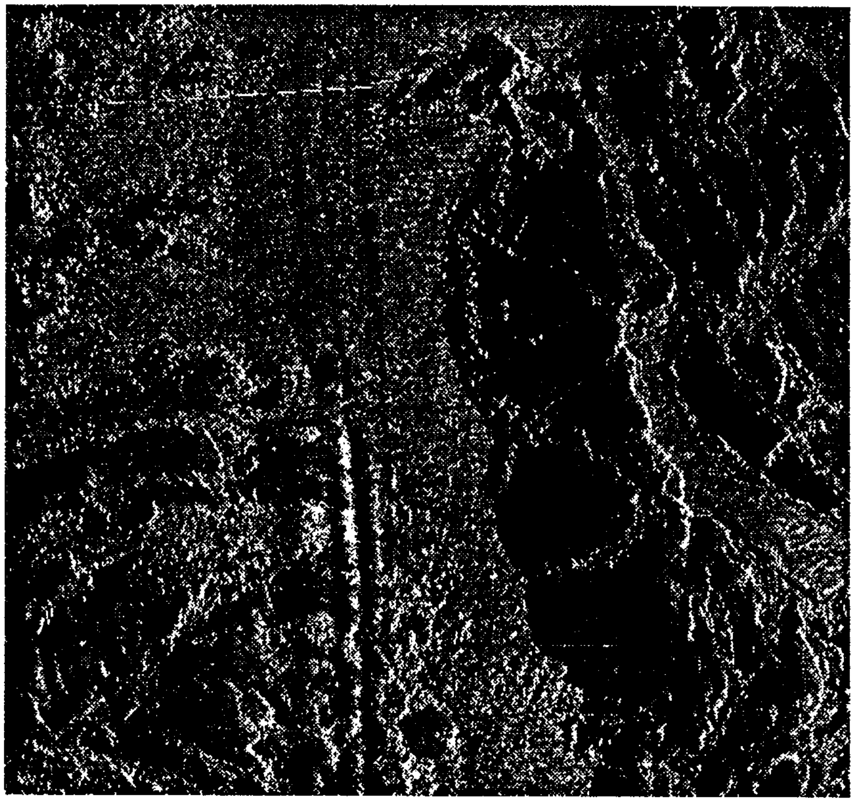
Figure 3. Northing position corrections for lines 7 (gray) and 8 (black)

There were six registration points within the area covered by the images in figure 4, four to register lines 7 and 8 and two to register lines 8 and 9. None of the registration points for lines 6 or 10 are within the area. The relatively close spacing of registration points for lines 7 and 8 reflect the fact that there was a large local distortion in this area due to navigation errors in line 8.

The two mosaics have been compared and the maximum residual offset (mis-registration) between the two mosaics in this area is 4 m. For the bulk of the area the offset is <2 m. While this may not appear to be particularly good over a 40000 m^2 area, it should be remembered that this level of alignment was achieved over a 6 km^2 area involving 11 tracks.

In summary, the proposed mosaicing process consists of the following steps:

1) geocode all survey data,
2) compare overlapping areas and select registration points,
3) calculate the track offsets necessary to eliminate the mis-registration,
4) re-geocode the data using the corrected navigation data (equivalent to warping),
5) construct the mosaic image.



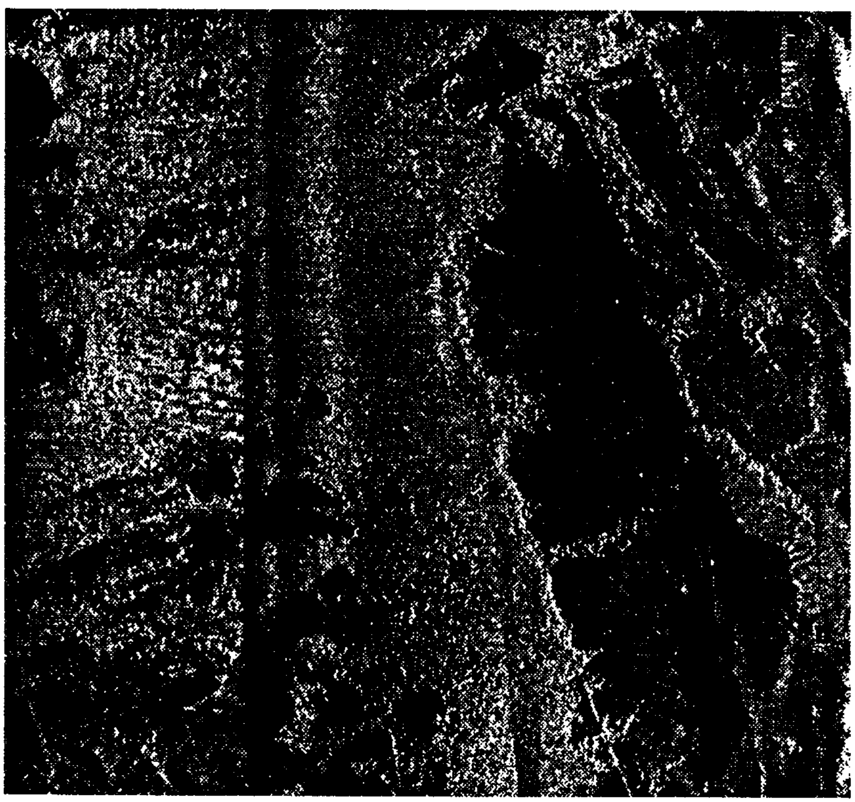


Figure 4. Mosaics of a 200 X 200 m area centered on 4927250N, 463950E. The upper mosaic consists of west looking sonar beams. The lower mosaic shows east looking beams.

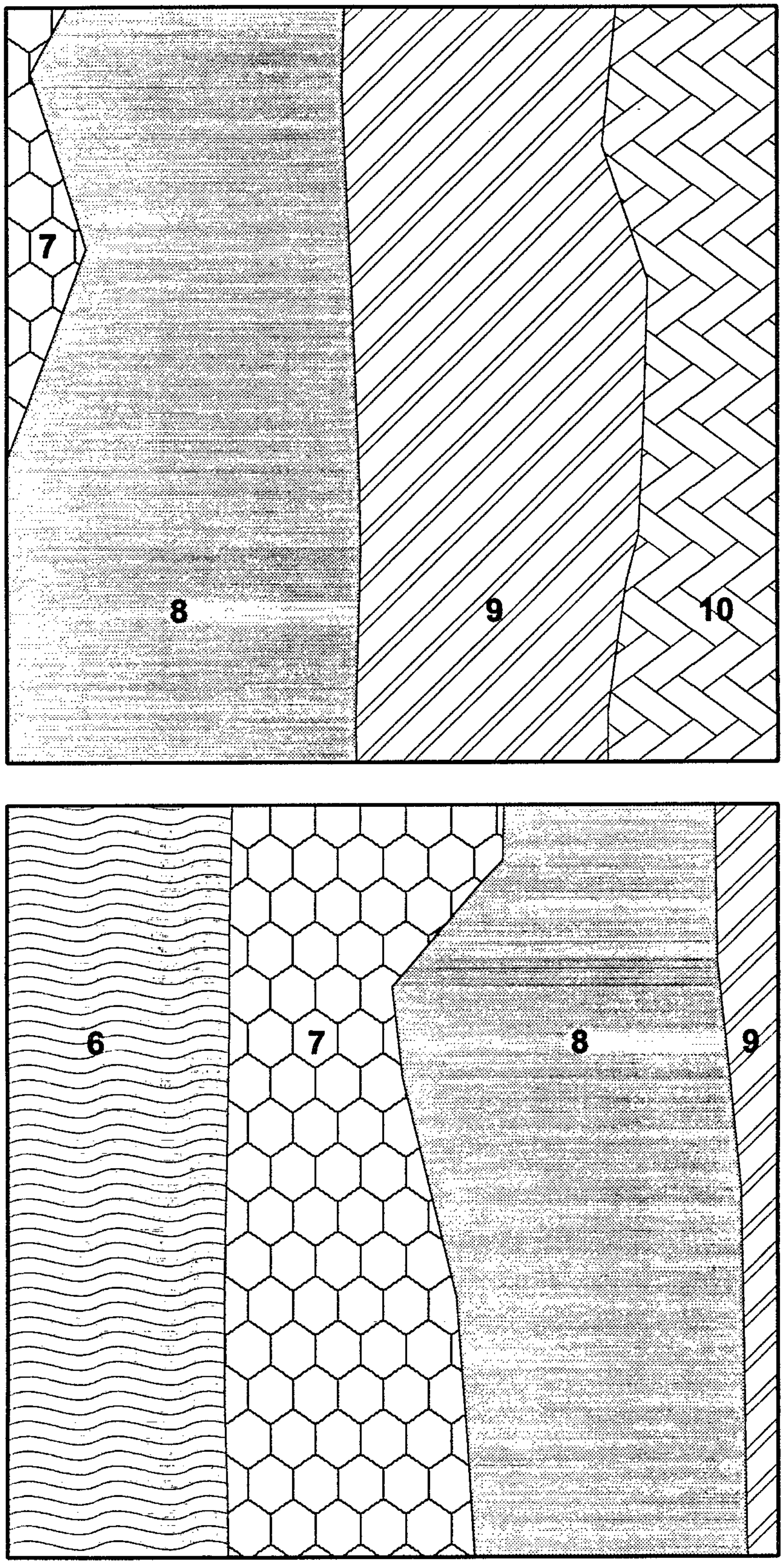


Figure 5. Schematic of the mosaics shown in figure 4. Contributions from survey lines are indicated.

CONCLUSIONS

The global mosaicing process described above has been used in constructing mosaics of four different areas, covering a total of 23 km^2. Two mosaics were assembled for each area, giving a total imaged area of 46 km^2. All mosaics were constructed of image data that had 0.2 X 0.2 m pixels. The results reported above for the Halifax data were typical. For the most part, alignment errors between mosaics were <2 m, with a few areas in each mosaic showing residual offsets of ~4 m.

Because the mosaicing process averages navigation errors over a number of survey lines, the overall navigation accuracy of the mosaic is actually improved over that of an individual line. A verification of this occurred when Halifax mosaics were used as part of a trial in which seabed objects were inspected by ROV. Seabed objects visited in 10 dives were all within 10 m of the location indicated in the mosaic. Typical ROV positioning error was on the order of 5 m.

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UNCLASSIFIED

SECURITY CLASSIFICATION OF FORM
(highest classification of Title, Abstract, Keywords)

DOCUMENT CONTROL DATA

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATOR (The name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g. Establishment sponsoring a contractor's report, or tasking agency, are entered in section 8.) Defence Research Establishment Atlantic P.O. Box 1012, Dartmouth, N.S. B2Y 3Z7	2. SECURITY CLASSIFICATION (Overall security of the document including special warning terms if applicable.) Unclassified

3. TITLE (The complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S,C,R or U) in parentheses after the title.)

Creating a Seabed Mosaic from Geocoded Sidescan Sonar Images

4. AUTHORS (Last name, first name, middle initial. If military, show rank, e.g. Doe, Maj. John E.)

POECKERT Roland H.

5. DATE OF PUBLICATION (Month and year of publication of document.) March 1997	6a. NO. OF PAGES (Total containing information. Include Annexes, Appendices, etc.) 19	6b. NO. OF REFS. (Total cited in document.) 6

6. DESCRIPTIVE NOTES (The category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

DREA Technical Memorandum

8. SPONSORING ACTIVITY (The name of the department project office or laboratory sponsoring the reseach and development. Include the address.)

Mine Countermeasures Group,EDRD, FMO,Victoria, Victoria, B.C.

9a. PROJECT OR GRANT NUMBER (If appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant.) 1da	9b. CONTRACT NUMBER (If appropriate, the applicable number under which the document was written.)
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The use of high frequency sidescan sonar mounted on a towfish to accurately map the seabed with sufficient resolution to detect mine-sized objects (~2 m) is well established. Typically such sonars have swath widths between 150 to 300 m and there is usually a region directly beneath the towfish which is poorly imaged. Multiple overlapping swaths are used to map an area wider than an individual swath and to provide useful data directly along a towfish path. The data collected on such a survey can be geocoded and mosaiced into a large seabed map. The mosaicing process involves registering overlapping images and combining them. The navigational accuracy achievable at present is ~10 m RMS. Thus images will not register exactly, and, if left uncorrected the resultant mosaic will have unacceptable discontinuities across cut-lines where images are joined. Several solutions exist to minimize these discontinuities and this paper describes a process in which images are warped and mosaiced in such a way as to almost eliminate cut-line discontinuities and at the same time preserve overall positional accuracy.

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Sidescan Sonar, Mosaics, Geocoding, Seabed Images

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