

## Use of Swath Data in Realtime Navigation by Pattern Recognition

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**Abstract** *A new method is proposed with the aim of reducing dead reckoning error (DRE) during multibeam echosounding survey in deep ocean. Bathymetric data is used in this method to estimate DRE in position fixing. This method can be activated at any desired interval to check the DRE accumulation in addition to available external navigation systems. A pattern recognition algorithm is developed to quantify the shift in position of a selected bathymetric feature that has been observed already once. This difference is used to correct the position fixing and navigation data.*

**Keywords** Navigation, dead reckoning, bathymetry, pattern recognition, swath data.

### Introduction

Swath survey or multibeam echosounding is a more efficient and faster technique than conventional bathymetric survey. In a short time a detailed bathymetric chart can be produced using the data collected over an area whereas in a conventional sounding operation, data must be collected along a single profile. But when positional quality is compared, there is hardly any improvement of swath over conventional sounding. The position data collection remains the same in both the operations, i.e., shore-based electronic positioning in near-shore and satellite position fixing with dead reckoning in deep ocean.

The problems of dead reckoning error (DRE) and fix error are common to both systems in deep ocean. This results in mismatch of contours at places where data are available from more than one observation, as in the case of track crossings and overlaps. This necessitates smoothing of contour lines at misfit patches during post processing, which may lead to incorrect representation of surveyed terrain in the end.

There are several methods available for smoothing of swath survey data during post processing. In one such method, the ship's track, which is straight and long, is assumed to be correct, and other tracks are adjusted with respect to that. In another method, the lines which have good positioning (like GPS) are fixed, and other tracks are adjusted accordingly (Milliken and Zoller 1978). In yet another method, track error is computed by comparing distinct bathymetric features available at the crossing of tracks, and a new navigation solution is evaluated giving due weightage to crossings and position fixes. Using the new solution, tracks are recomputed and bathymetric data are presented (Nishimura and Forsyth 1988).

All these methods are restricted to post processing; hence, the growth of DRE during data collection is unaffected. A new method that aims at reducing error growth during data collection as well as post processing is discussed here. In this method, bathymetric is used in combination with position data to minimize DRE, thereby reducing contour mismatch during processing. The method will soon be tried out on ORV *Sagarkanya* with data collected from a HYDROSWEEP multibeam echosounding system.

## Description

The following analogy roughly outlines the logic of the proposed method.

Assume that a ship is traveling along a survey line, collecting multibeam echosounding (MBES) data. Let there be a seamount identified at time  $T_1$ , when the ship's position is  $X_{s1}$ ,  $Y_{s1}$ , and the seamount's position as computed from MBES data is  $X_1, Y_1$ .

Let the ship, after traversing some distance, return in a parallel track and observe the seamount once again. Let the coordinates of ship be  $X_{s2}, Y_{s2}$ , and  $T_2$  and that of the seamount be  $X_2, Y_2$ .

If the positioning and soundings were error free, then the seamount's position  $X_1, Y_1$  and  $X_2, Y_2$  would be the same. but in a practical situation this cannot be expected, because there are many factors which affect positioning and sounding accuracy. As a result, there will be two different positions  $X_1, Y_1$  and  $X_2, Y_2$  for the same seamount.

The cause of difference is attributed only to positioning, assuming that sounding inaccuracy is of negligible magnitude. By quantifying the difference, it is possible to correct that and also the ship's positioning thereafter. In other words, if the ship's position can affect the seamount position, then the converse should also be possible—i.e., the ship's position being affected through adjustment of the observed seamount position.

In this method, the two observed positions are merged. The resulting shifts in the ship's position are distributed among two observing locations at times  $T_1$ , and  $T_2$ . In a real situation, a profile is taken in place of the seamount.

To work with the method, the data should be collected with an overlap on the adjacent track. In the lap area, a part of the bathymetric feature is selected and retained (in computer memory). This piece of information is recalled and checked for its recurrence while the ship is traveling for the second time in the same vicinity. Because of the reasons mentioned earlier, the recognized location of the feature will vary slightly from that of the first observation. Generally the variation or the difference in position is directly proportional to dead reckoning time. This difference in position is found out and nullified so that both positions are merged to represent the feature. The corrections thus obtained are valid between two observations and are also used to reset the ship's position in realtime near the second observation. This reset prevents DRE accumulation, and the ship can be maneuvered more effectively to align with the preplanned track. Because the position comparison can be done at any desired interval, the deviation from the planned track can be checked periodically, avoiding the long absence of reset, and the jumps in track can be minimized.

The method proceeds through four steps:

- (1) Selection of the feature in the first sweep of the survey
- (2) Identification of the search area during the second sweep and modeling it with a polynomial trend surface
- (3) Location of the feature in the modeled surface
- (4) Discovery of the most probable position of the feature and correction of the navigation of the vessel accordingly

The replica of the feature that is stored is a set of  $x, y, z$  coordinates—eastings, northing, and depth. This is taken from the observation of one side transducer array of the ship (the side where a second sweep is planned for overlap). Because the computation of positions within this profile is based on MBES data, it is free from velocity errors of the vessel. Among these points, an origin is selected arbitrarily, and the positions of the remaining points are reduced to relative positions from that origin. The stored data now contains a location with an absolute position and a group of relative  $x, y$  coordinates along with depth coordinates. To check the occurrence of this feature during the second sweep, the absolute position is kept aside, and only the size and shape of the feature are searched on the modeled surface.

Due to overlapping in data collection, the sounding operation covers the feature for the second time. From this second set of data, an area is demarcated that contains the feature. This forms the search area. Using available  $x, y, z$  coordinates collected during the second observation in the search area, a trend surface is created with polynomial coefficients. To minimize the errors introduced due to modeling, the computed values of  $z$  within the search area must be matched exactly with the observed values by using the required degree of polynomial model.

The search for the feature is carried out on this modeled surface. Here the replica of the retained feature is superimposed on a test location, and its mismatch with the model surface is quantified. By optimization techniques, the search is directed to a better place, until it gets superimposed at a place where the mismatch is minimal. Once the feature is located in the modeled surface, the search is terminated. This is the second position of the feature as per the second sweep, the replica of which was stored in memory during the first observation. The difference of these first and second positions of the feature indicates the error that crept into the positioning during the time of the two observations.

The last stage of the operation is the correction of navigation using the above result. Weightages are given to the two positions of the feature, and a common position is worked out. The ship's position is reset so as to satisfy the most probable position of the feature. The shift in position of ship navigation may be laid back proportionally on the track connecting the first and second observations of the feature.

There are some assumptions that are yet to be validated through field trial. First, it is assumed that positional mismatch of the feature in the two observations is due only to navigational error of the ship. The effect of error due to MBES inaccuracy is negligible. Second, it is assumed that positions within the profile that are retained from the first observation are free from error, especially navigational errors. Hence, the feasibility of the method can be confirmed only after trials with real data (de Moustier and Kleinrock 1986).

Although the field trials of the proposed method are awaited, the core of the problem—search operations for feature recognition—was simulated on a hypothetical surface. The modeling was done by adopting a surface fitting program developed by Balch and Thompson (1989). The search algorithm developed using optimization tech-

niques (Beightler et al. 1979) is discussed in the appendix. The simulation was done using an IBM PC with a polynomial surface of degree 11. Profile points were selected from the trend surface itself. There were 11 points at one meter separation in both  $x$  and  $y$  directions. The search area was  $100 \times 120$  m. Time required to recognize the profile from the surface was found to vary from a minimum of 2 min to a maximum of 35 min, from different locations supplied as initial estimates.

## Conclusion

An attempt is made to derive a method to use bathymetric data to reduce DRE in swath survey. The possibility is explored from a theoretical point of view. This method cannot be a stand-alone technique, but it may substantially reduce DRE and track deviations. It is expected that the accuracy of GPS civilian sets will be limited to about 100 m (Stansell 1986). In such a situation, the study presents a new approach to further improve navigation on the high seas.

## References

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## Appendix

Notations used:

- $px, py$  Raw coordinates of the bathymetric feature (profile) in  $xy$  plane.
- $n$  Number of selected and stored  $px, py$ .
- $pdx, pdy$  Feature coordinates reduced to relative positions.
- $Zp$  Recorded depth as per first observation at the profile location  $(px, py)$ .
- $Zs$  Depth coordinate as computed from the modeled surface at any point  $(x, y)$  in the search area.
- $A$  Polynomial coefficients in the form of diagonal matrix of order  $(j, k)$ .  $j = k = N + 1$ , where  $N$  is the degree of polynomial surface used for modeling the search area.
- $R_i$  Difference between computed depth on the modeled surface and superimposed profile depth.
- $RI$   $\sum R_i$  the mismatch at test location  $x, y$ .
- $F(x, y)$  Function to quantify surface mismatch at any location  $x, y$ .

$G_x, G_y$  Gradient on response surface along  $x$  and  $y$  axes, respectively.

$p$  Optimum distance on response surface in the direction  $G_x:G_y$ .

$d1, d2$  First and second differential coefficient of  $F(x,y)$  with respect to  $p$ .

Profile points are selected during the first sweep.

$$(Px_i, Py_i, Zp_i)_i = 0, n$$

where  $n$  is the number of points selected.

The first data point is selected as the origin, and other points are reduced to relative positions with respect to the origin.

$$Pdx_i = Px_i - Px_o$$

$$Pdy_i = Py_i - Py_o$$

The search area is demarcated and modeled with required degree of polynomial trend surface.

Then the depth coordinate on the modeled surface at any location defined by  $x, y$  is

$$Z_s = \sum_{k=0}^N \sum_{j=0}^{N-k} A_{jk} x^j y^k$$

To calculate the mismatch at a given place  $x, y$  on the modeled surface, a group of points is selected (Fig. 1A) resembling the profile (of the first sweep) layout taking  $x, y$  as the origin.  $z$  value is calculated from the modeled surface for such points. Then, sequentially, the differences between each point  $z$  value on the profile ( $Zp$ ) and  $z$  value on the surface ( $Zs$ ) are computed; these residuals are squared and summed up to avoid negative values and attributed to the test point  $x, y$ .

Thus, the residual  $R$  for one point of profile at  $x, y$  is

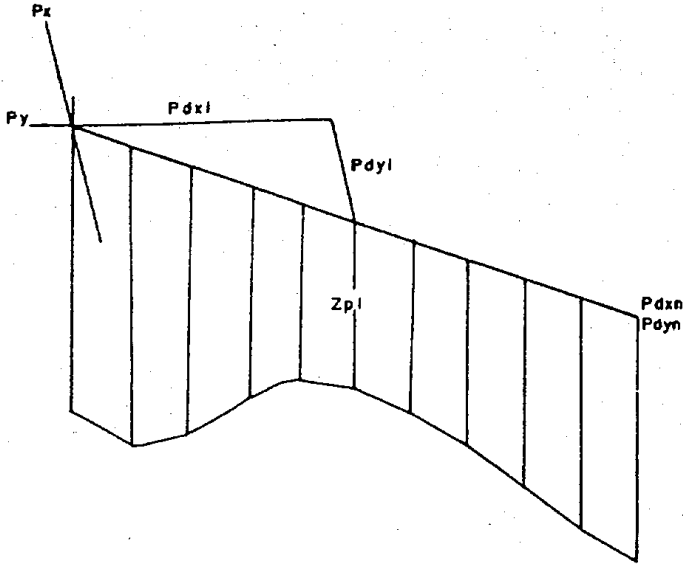
$$Z_s - Z_p = \sum_{k=0}^N \sum_{j=0}^{N-k} A_{jk} x_i^j y_i^k - Z_{pi}$$

and the mismatch for the whole profile is

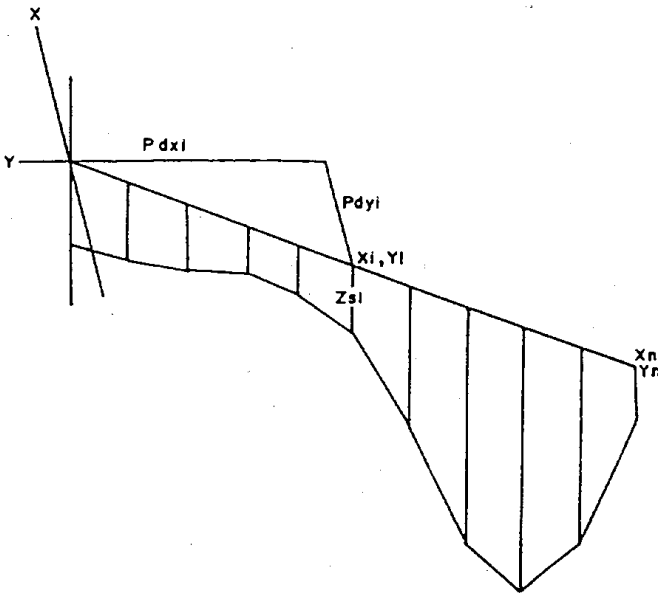
$$RI = \sum_{i=0}^n R_i^2 = \sum_{i=0}^n \left[ \sum_{k=0}^N \sum_{j=0}^{N-k} A_{jk} x_i^j y_i^k - Z_{pi} \right]^2 = F(x, y)$$

If this computation is carried out on a location where the slice of the modeled surface and the profile from the previous sweep are identical in shape and size, the outcome  $RI$  would be theoretically equal to zero. This in turn would indicate that the feature is identified from the modeled surface that was stored in the previous sweep as a group of points.

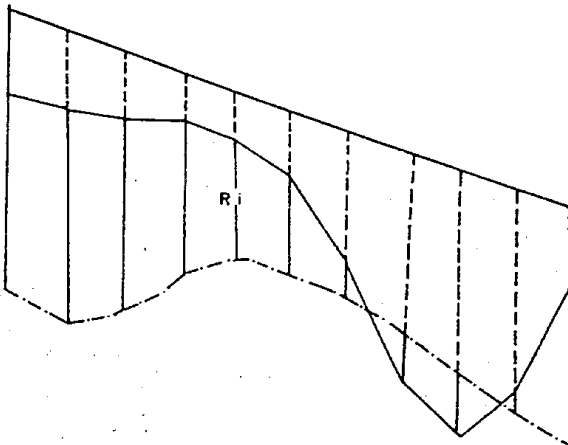
If a response surface indicating all the  $RI$  over the search area is constructed, then there will be a point (theoretically only one) where the surface has a zero value along its



RETAINED PROFILE OF FIRST SWEEP AT  $P_x, P_y$  WITH TAILING POINTS  $P_{dx1}, P_{dy1}$ .  $Z_{pi}$  ARE OBSERVED DEPTH VALUES.



PROFILE AT TEST LOCATION  $X, Y$  ON SEARCH AREA WITH TAILING POINTS EXACTLY RESEMBLING RETAINED PROFILE.  $Z_{si}$  ARE COMPUTED FROM POLYNOMIAL SURFACE MODEL.



BOTH PROFILES SUPERIMPOSED. DIFFERENCE IN ORDINATES (FIRM LINES) ARE SQUARED AND SUMMED UP TO GIVE  $R_i$  FOR THE LOCATION  $X, Y$ .

Figure 1A. Quantifying the mismatch by superimposing profiles at a test location.

$z$  coordinate. Our problem is to find out this absolute minimum mathematically, without really computing all  $RI$  over the search area. This operation is divided into two portions, the first one being a search guided with the gradient of the response surface—called *gradient search*, and the second without any guidance on the  $xy$  plane—called *blind search*.

Gradient search is carried out as long as the slope on the response surface in  $x$  and  $y$  directions is perceivable and expected to lead to a better position (where  $RI$  is lower than the present test location) within the search area. Blind search is carried out in a systematic pattern of radiating lines to find a better position from a location where the gradient search has failed. This failure of the gradient search will occur if the slopes of the surface along  $x$  and  $y$  axes are insignificant, indicating a stationary point. These stationary points may be numerous, depending on the terrain. This is the low point where differential coefficients are very close to zero along both  $x$  and  $y$  axes, but may not be the lowest, which we intend to find out. Blind search is resorted to if a local low as described above is encountered, by assuming this point as the origin, and the surrounding area is tested for a more favorable point.

The gradient search is carried out as follows.

Let  $G_x, G_y$  be the slopes of response surface.

$$G_x = \frac{\partial}{\partial x} F(x,y) = \sum_{i=0}^n 2R_i \sum_{k=0}^N \sum_{j=0}^{N-k} A_{jk} \cdot x_i^{j-1} \cdot y_i^k$$

Similarly,

$$G_y = \frac{\partial}{\partial y} F(x,y) = \sum_{i=0}^n \sum_{k=0}^N \sum_{j=0}^{N-k} A_{jk} \cdot j \cdot x_i^j \cdot k \cdot y_i^{k-1}$$

In the direction  $G_x : G_y$  the test location should be shifted for a distance  $p$  from the present location  $(x,y)$ , because  $G_x : G_y$  indicates the steepest slope on the response surface at  $x,y$ .

The value of  $p$ , being univariable, is found using the Newton-Raphson method with successive iterations as follows.

Let  $pp$  be the present estimate of  $p$ ; then:

$$d_1 = \frac{d}{dp} F(x + G_x \cdot p, y + G_y \cdot p)$$

$$d_2 = \frac{d^2}{dp^2} F(x + G_x \cdot p, y + G_y \cdot p)$$

$pn$  (the next better value of  $p$ ) =  $pp - d_1/d_2$ .

Now  $pn$  is renamed as  $pp$  and again  $d_1, d_2$  are evaluated to find the next better  $p$ . This sequence is repeated until the  $p$  value converges. Then the corrections needed to improve (i.e., to minimize) the  $RI$  value by shifting the test location in  $x$  and  $y$  directions are given by the equations

$$X_{step} = G_x \cdot (-p)$$

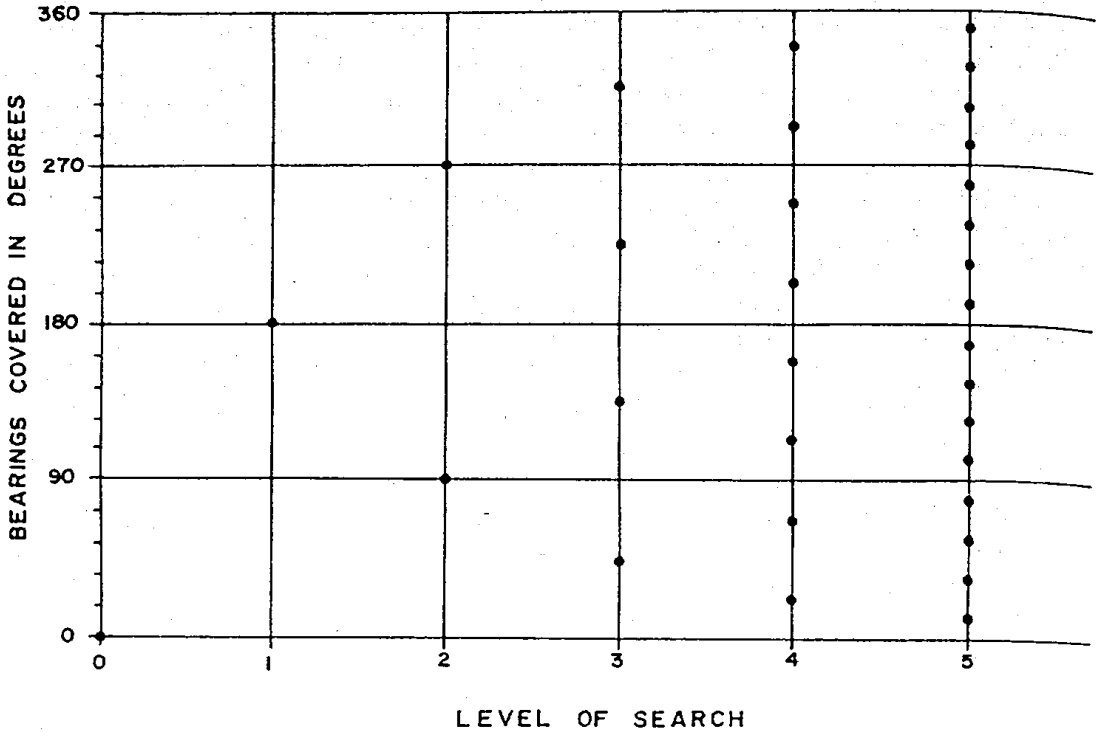


Figure 2A. Progression of search scheme at various levels.

$$Y_{\text{step}} = G_y \cdot (-p)$$

Then the new location

$$x_n = x + X_{\text{step}}$$

$$y_n = y + Y_{\text{step}}$$

At this new location  $G_x$ ,  $G_y$  and  $p$  are again evaluated, and the sequence is repeated until the improvement becomes negligible. This location is tested to see whether its  $RI$  value is lower than the preset tolerance value. (This preset tolerance can be zero in a theoretical response surface, but for practical conditions it has to have some value a little higher than zero to accommodate the errors in observations and loss of precision in computer arithmetic). If  $RI$  is less, then it indicates that this location is the required position of the feature, and the search operation is terminated. If  $RI$  is higher, then a blind search is started. Assuming that the present location is a local low, radial lines are extended in all directions in such a way that no line is repeated in a particular angle, and the area is covered as widely as possible in subsequent searches.

For this, the search is made to progress in levels. In the first level, the search circle (surrounding) is segmented into one and the search is carried out along  $0^\circ$  bearing. In the second level the segments will be two, and the search should be along  $0^\circ$  and  $180^\circ$ . As  $0^\circ$  has already been searched during the previous level, now it is skipped. Similarly, at any given level of search  $n$ , the number of segments will be  $2^{n-1}$ , and the actual search will be on alternate bearings with an angular difference of  $\pi/2^n$ . This way, the entire surrounding will be swept with progressively closer angular intervals (Fig. 2A).



In a direction thus selected, the search is carried out to find a better point with a lower *RI* value. This is done in two steps. First *RI* and slope are computed at an arbitrarily selected distance. If the slope is tending upward at that point, the distance is increased. Once the slope is found to be negative, then a Newton-Raphson search is carried out to find the exact location of the low point. This low is compared with the present low, and if it is lower, then the blind search is terminated and a gradient search is started. Otherwise, computing of the slope is carried out up to the boundary of the search area, and the next segment is taken for testing. Thus, after finishing all directions, the level is incremented by one, and the search is continued until the conditions are met and the gradient search takes place.