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Gridding Digitized Bathymetry in the Straits of Malacca

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Abstract

Maritime charts in the form of bathymetry from the Straits of Malacca were digitised to form the data set that was operated on by the Kriging algorithm to provide gridded digital data sets. There were two forms of algorithms tested, the Kriging and the Minimum Curvature, of these two Kriging was found to be the most suitable. Along with these two algorithms different grid sizes were also experimented with, these were 1 minute and 5 minutes (1` & 5`). The 1` grid size and the Kriging were found to be the best combination for the gridding of the digitised bathymetry.

The bathymetry was digitised 'on screen' using Golden Software's Didger3. The maps were of mixed scales 1:200000 and 1:300000, scanned at a resolution of 150 dpi, this was done in order to decrease the size of the digital file, namely the TIF format. Affine polynomial calibrations were performed on all charts and were within acceptable limits. A total of 18357 points were digitised including soundings and coastlines, the minimum height being -358.86 m the maximum being 0 m. All soundings were transformed to Mean Sea Level (MSL) using the tidal information published by the Department of Surveying and Mapping Malaysia (JUPEM) Tide Tables for the year 1998.

A comparison of the gridded (Kriging) digitised points is accomplished through comparing an independent set of digitised points (approximately 10%) with the gridded digitised data. Also a comparison with ETOPO5 is made, the results are as follows: a mean of the differences of -0.332 m and the standard deviation of the mean of ±7.784m, for the digitised data set and a mean of the differences of -0.281 m and the standard deviation of the mean of ±15.812m for ETOPO5. This tends to show that ETOPO5 is not as representative of the bathymetry of the Straits of Malacca and that the gridding process followed by the authors is suitable enough for the data to be used in other applications, such as tidal studies or current analysis for offshore and coastal engineering processes.

Key words: Digitising, Kriging, Minimum Curvature.

1. Introduction

Most branches of science and engineering require some form of way to derive an ordered data set from randomly distributed data. In this instance it is the need to acquire an ordered data set from randomly distributed soundings on maritime charts of the Straits of Malacca. The subject area ranges from Latitude south 1^0 to Latitude north 6.5^0 and Longitude east 98^0 to Longitude east 103.5^0. On screen digitising is used as a way of capturing the soundings, this is more efficient and convenient than the usual form of tablet digitising, but nevertheless does have its drawbacks.

Before any type of gridding is carried out or for that matter digitising, it is essential to fully understand the use of the data set once completed. In this case it is to be used to derive accurate tide models of the Straits of Malacca. This procedure requires at least a 1` evenly gridded data set, globally there is a 5` data set ETOPO5. This data set ETOPO5 could easily have been used and saved a lot of time and effort, however it has been shown that ETOPO5 is not necessarily that reliable in the subject area. After deciding on a suitable grid size for the results, it is necessary to find suitable data sources that can provide such results. The maritime charts were chosen, as they are the most easily accessible data source for soundings. It was not possible to attain the raw soundings from the Navy as they are regarded as sensitive data not meant for public domain. In all, five charts of the Straits of Malacca were purchased and from these charts it was possible to determine that the soundings were all approximately spaced at least 1` to 2` apart. Therefore this data source is suitable for on screen digitising.

The data were all digitised on screen, after scanning the charts. Once the scanning had been accomplished, the charts were then calibrated and the digitising carried out. This process was lengthy but much quicker than had conventional table digitising methods been used. The data were gridded at several different combinations in order to determine which combination was the most suitable. Comparisons were made to ETOPO5 and an independent data set not included in the gridding process.

2. Digitizing

The five charts used for digitising were, starting from the most southern MAL 521, MAL 532, MAL 540, MAL 553 and MAL 565, all these charts overlapped each other by at least 5% in the south eastern corner. Positions are based on the Revised Kertau Datum and the soundings are based on the Lowest Astronomical Tide (LAT). The datum for the soundings to be used in the tidal modelling process is Mean Sea Level (MSL), the soundings were converted to MSL by applying a constant offset to each different chart, and this offset was attained from the nearest tide gauge benchmark to the particular chart in question. The positions after being digitised were converted to WGS84, these positions are used in the gridding procedures. Figure 1, shows the distribution of the digitised soundings and the respective charts. A total of 18357 points were digitised including soundings and coastlines, the minimum height being -358.86 m the maximum being 0 m.

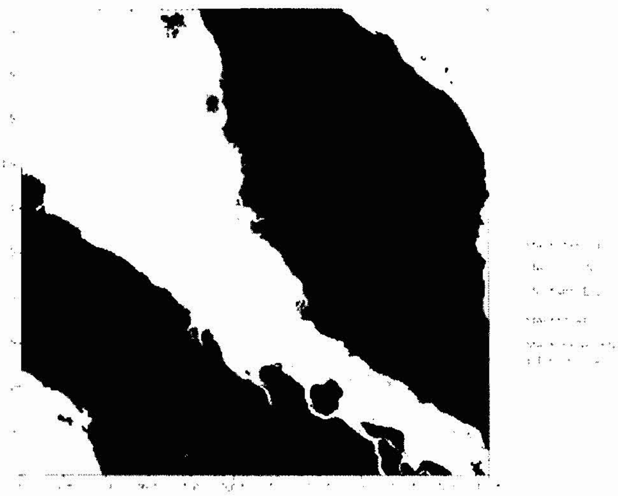

Figure 1: The digitised data used in the gridding process.

Before on screen digitising occurs the charts must be converted to digital form, this is done using the Scan Plus III 813SC digital scanner. For this purpose the charts were scanned in black and white only and at a low resolution so as to save memory, this helps when using the on screen digitising software. Once this is completed the charts are ready to be calibrated by the software, via transformation. The most common transformation is Affine Polynomial. Affine transformations are a subset of bilinear transformations. Bilinear transformations account for rotation, shift, and differential scaling in X and Y. The X and Y axis orthogonality may change, but parallel lines remain parallel. Affine polynomial transformations of a plane change squares into parallelograms and change circles into ellipses of the same shape and orientation. For a discussion of this and other techniques refer to Wolberg (1990). The affine polynomial transformation results may not be as good as when using a higher order polynomial.

3. Gridding

Once the data have been digitised it is possible to proceed with the gridding. This is done in order to attain homogenous evenly spaced data (X,Y,Z) triplets. Gridding methods produce a regularly spaced, rectangular array of Z values from irregularly spaced XYZ data. The term "irregularly spaced" means that the points follow no particular pattern over the extent of the map, so there are many "holes" where data are missing. Gridding fills in these holes by interpolating Z values at those locations where no data exists.

A grid is a rectangular region comprised of evenly spaced rows and columns. The intersection of a row and column is called a grid node. Rows contain grid nodes with the same Y coordinate, and columns contain grid nodes with the same X coordinate. Gridding generates a Z value at each grid node by interpolating or extrapolating the data values.

Grid file columns and rows are sometimes referred to as X grid lines and Y grid lines, respectively. There are many gridding techniques to choose from, as to which one is used can depend on the type of data and spacing of the irregular data (if indeed it is irregular). All gridding methods require at least three non-collinear data points. Some methods require more data points. For example, a higher-order polynomial fit needs more than three data points; there must be at least as many data as there are degrees of freedom. However, the number of data points in this case is irrelevant as there are thousands of data points.

The set of digitised bathymetry data is combined with the GTOPO30 base for the region. The GTOPO30 Z value is set to 0 m, this is done in order to control the gridding in close to the coast and to prevent the gridding algorithm from gridding land areas as ocean areas. This is masking and although it is not a very sophisticated way, it is quick and easy to implement. The draw back is that the gridding algorithm must now process an exceptional amount of extra data.

Two gridding methods are used; these are Kriging and Minimum Curvature.

Kriging: is a geostatistical gridding method that has proven useful and popular in many fields. This method produces visually appealing maps from irregularly spaced data. Kriging attempts to express trends suggested in your data, so that, for example, high points might be connected along a ridge rather than isolated by bull's-eye type contours. Kriging is a very flexible gridding method. You can accept the Kriging defaults to produce an accurate grid of your data, or Kriging can be custom-fit to a data set by specifying the appropriate variogram model. The variogram is a measure of how quickly things change on the average. The underlying principle is that, on the average, two observations closer together are more similar than two observations farther apart. Because the underlying processes of the data often have preferred orientations, values may change more quickly in one direction than another. As such, the variogram is a function of direction.

The variogram is a three-dimensional function. There are two independent variables (the direction θ, the separation distance h) and one dependent variable (the variogram value $\gamma(\theta,h)$). The variogram model mathematically specifies the spatial variability of the data set and the resulting grid file. The interpolation weights, which are applied to data points during the grid node calculations, are direct functions of the variogram model. The variogram (XY plot) is a radial slice (like a piece of pie) from the variogram grid, which can be thought of as a "funnel shaped" surface. This is necessary because it is difficult to draw the three-dimensional surface, let alone try to fit a three dimensional function (model) to it. By taking slices, it is possible to draw and work with the directional experimental variogram in a familiar form (- an XY plot).

Minimum Curvature: is widely used in the earth sciences. The interpolated surface generated by Minimum Curvature is analogous to a thin, linearly elastic plate passing through each of the data values with a minimum amount of bending. Minimum Curvature generates the smoothest possible surface while attempting to honour your data as closely as possible. Minimum Curvature is not an exact interpolator, however. This means that your data are not always honoured exactly. Minimum Curvature produces a grid by repeatedly applying an equation over the grid in an attempt to smooth the grid. Each pass over the grid is counted as one iteration. The grid node values are recalculated until successive changes in the values are less than the Maximum Residuals value, or the maximum number of iterations is reached (Maximum Iteration field). The code used by Surfer 7, fully implements the concepts of tension as described and detailed in Smith and Wessel (1990). This routine first fits a simple planar model using least squares regression:

$$AX+BY+C=Z(X,Y)$$

[1]GTOPO30 is a 30`` global digital elevation model produced by the USGS.

Thus, there are four steps to generate the final grid using the Minimum Curvature method. First, the least squares regression model is fit to the data. Second, the values of the planar regression model at the data locations are subtracted from the data values; this yields a set of residual data values. Third, the Minimum Curvature algorithm is used to interpolate the residuals at the grid nodes. Fourth, the values of the planar regression model at the grid nodes are added to the interpolated residuals, yielding a final interpolated surface.

Unlike Smith and Wessel (1990), the fixed nodes are defined as the average of the neighbouring observed values. That is, consider a rectangle the size and shape of a grid cell. The neighbourhood of a grid node is defined by this rectangle centred on the grid node. If there are any observed data within the neighbourhood of a grid node, the value of that grid node is fixed equal to the arithmetic average of contained data.

The Minimum Curvature algorithm generates the surface that interpolates the available data and solves the modified biharmonic differential equation with tension:

$$(1-T_i)\nabla^2(\nabla^2 Z)-(T_i)\nabla^2 Z = 0$$

There are three sets of associated boundary conditions:

$$(1-T_b)\frac{\partial^2 Z}{\partial n^2}+(T_b)\frac{\partial Z}{\partial n} = 0$$

On the edges: $$\frac{\partial(\nabla^2 Z)}{\partial n} = 0$$

At the corners: $$\frac{\partial^2 Z}{\partial x \partial y} = 0$$

where:

∇^2 is the Laplacian operator
n is the boundary normal
T^i is the internal tension
T^b is the boundary tension

The surface using Kriging is shown in Figure 2, this surface is gridded at 1` intervals in X and Y with contour intervals at 10 m. Figure 2 shows a much more smoother surface than compared to that of the surface produced by Minimum Curvature in Figure 3. Both figures also show the 10% of data retained from the original set to do the comparisons with.

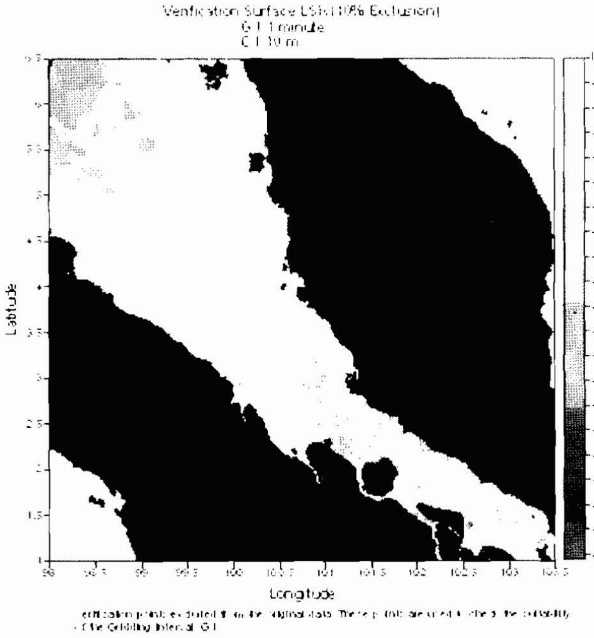

Figure 2 : Verification surface using Kriging

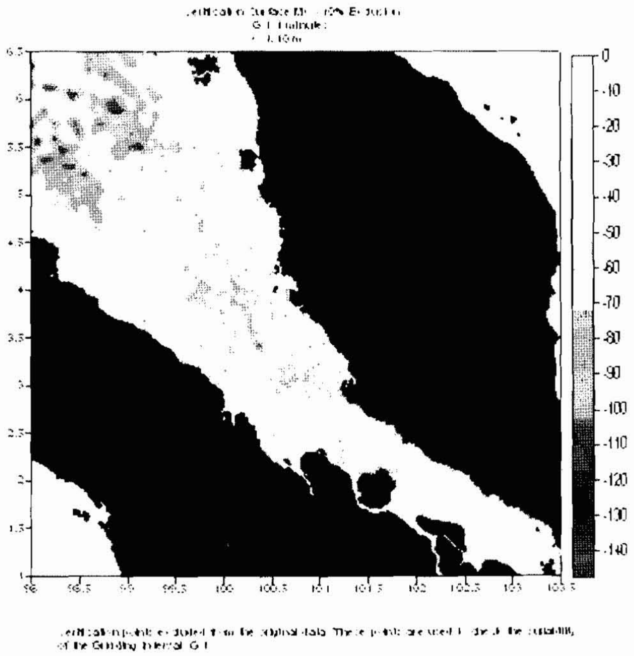

Figure 3 : Verification surface using Minimum Curvature

Figure 3 represents the digitised bathymetry gridded at 1`using Minimum Curvature and shows a slightly less smooth result than Kriging. This is to be expected as kriging when computing the interpolation weights considers the inherent trustworthiness of the data. If the data measurements are exceedingly precise and accurate, the interpolated surface goes through each and every observed value. If the data measurements are suspect, the interpolated surface may not go through an observed value, especially if a particular value is in stark disagreement with the neighbouring observed values. This is an issue of data repeatability.

4. Comparisons

In order to gauge some kind of quality measurement for the final gridded surface and of which gridding method is the most suitable, two tests are carried out. These are: 1. Comparison with ETOPO5 grid, and 2. Comparison with a retained data set, which excludes 10% of the digitised data from the gridding process.

The later is the more important test as it gives a direct check on how well the gridding algorithms handle the data, whereas the former test is to provide a comparison with the global bathymetry model, ETOPO5. Table 1 represents the comparisons undertaken as mentioned previously.

	KRIG	MC	ETOPO 5
1′	•	•	
$\bar{x}$	0.332	-1.244	*nil*
σ ±	7.784	10.674	*nil*
Num	824	824	*nil*
5′	•	•	•
$\bar{x}$	-0.503	-1.757	-0.281
σ ±	9.720	9.403	15.812
Num	824	824	824

Table 1 : Results of comparisons (all necessary units in metres)

It is seen how gridding the data using Kriging and a gridding interval of 1`gives the better results, other grid sizes were not tried so it is inconclusive as to the most suitable gridding interval for this data set, what is shown is the most suitable according to the authors needs.

The Kriging method although slower in computing the surface, better fits the control data than that of the surface computed using Minimum Curvature. ETOPO5 is a 5`global model therefore it is not expected to compare as well with the control data as the digitised sets. Also it is to be kept in mind that the control data itself comes from the same digitised set, so what these comparisons really are checking is the digitising process and the algorithm's ability to map the surface appropriately. In order to perform a thorough and conclusive check, it would be better to compare with in-situ reduced bathymetry soundings. However due to the obvious financial constraints of doing this, the control data as is, is considered acceptable.

5. Results

Of the digitised data there are some 8000 points excluding the coastlines that are digitised and of this 10% are excluded for comparisons. Kriging was found to be the better algorithm to use for gridding with the other choice of Minimum Curvature. 1`for this study was shown to be the most suitable gridding interval, however this is not shown conclusively, as other grid sizes apart from 5`were not used. Comparisons are made to ETOPO5 and were found to be not as good when compared to the other methods.

ETOPO5 is better suited to the open oceans, where in this study it has been constrained to coastal shallow waters. It is recommended that ETOPO5 not be used in any further studies where bathymetry is needed in a shallow water context, until further studies with in-situ data can be used for the comparisons.

It is recommended that for this study a gridding interval of 1`be used and that Kriging be chosen as the method of gridding, as the comparisons show this is the better of the two methods tested.

References

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