Processing And Filtering Of Multibeam Data

Grid Modelling Versus Tin Based Modelling

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Multibeam echosounder measurements serve to make a digital terrain model (DTM) of the seafloor. The Delaunay triangulation is a widely appreciated and investigated mathematical model to represent the relief of such a terrain and is highly efficient for building triangular irregular networks out of non-homogeneous data such as raw multibeam data. However, most multibeam systems deliver equidistant interpolated data, allowing faster processing to be achieved by using equidistant grid modelling. Both approaches yield their own advantages and drawbacks. More specifically, the filtering options of TIN and grid models are quite different. An analysis of both workflows will be worked out.

Introduction

Obtaining an accurate model of the seafloor is a major concern in dredging works. Nowadays' hydrographic surveying tools, especially the multibeam echosounder, yield a very dense sampling of the seafloor and this immense amount of data needs to be processed, according to some constraints imposed by the client, to form an accurate terrain model. Modelling can be performed in post-processing or in real-time, performing a real-time accountability which keeps track of the haul realised at some moment.

DTM software for hydrographic purposes must meet the following four requirements:

1. Fast model creation. The purpose is to create the model as fast as the data is gathered, so that real-time control and verification are possible;
2. Allow manual editing of the model: adding as well as deleting data points (vertices) in the model are both considered. When examining the theoretical model of a site, intervening directly in the model as it is displayed on the computer monitor by relocating, deleting or adding vertices is a prerequisite. It should also be possible to replace resurveyed areas with the new data and to update the existing model with this new information;
3. Reduce the large amounts of multibeam data to acceptable levels, keeping the seafloor model as accurate as possible;
4. The final result in the form of volume calculations should be as close to the truth as possible and certainly not farther away than acceptable, assuming that the acceptable quality level is realisable.

Grid models and triangulation models are the most frequently used models, offering different kinds of advantages and drawbacks. Both will be discussed with their advantages and drawbacks, with special attention to the filter-capabilities of each approach.

Grid Modelling

Principle

Nowadays, most multibeam systems offer equidistant grid data as default output of the on-line/on-board processing chain. The plane coordinate system used is generally a square grid with the axis parallel to the Easting- and Northing axis of the grid coordinate system used. Since the use of GPS equipment, the universal transverse Mercator system (UTM) in relation to the ETRS89 datum (referencing the global ellipsoid GRS80) has established itself as the standard grid system in Europe. This leaves the grid interval distance as the unique and most important user-defined parameter.

The use of equidistant points allows to store in computer memory only the depth values and not the Easting and Northing values, as these values can be computed out of the row and column number of each point, assuming (for instance) that the point storage is performed in a rowwise manner in the computer memory, using arrays of integer values that only need 2 byte for each depth or point.

Filtering

As the amount of data generated by a multibeam echosounder depends on the ping rate, which goes up to 30Hz, and the number of beams in the swath, typically between 100 and 300, incoming data flows can reach up to more than 30 million points per hour. It will be clear that reducing the data gathered by multibeam echosounding is indispensable because of the huge amount and because most of it does not contribute to a more detailed seafloor approximation anyway. Indeed, descriptions in literature are given of dataset reductions of scanned surfaces down to 5 or 10% of the original dataset size without significant loss of accuracy. An ongoing concern is therefore dataset reduction.

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Dataset reduction can be performed by increasing the grid interval distance, either in the software of the multibeam manufacturer, or in the software used for the post-processing. While the first one often works as a black box without much control on the filtering parameters used, the second often offers a number of intelligent filter-processing options.

One obvious type of filtering is obtained by increasing the grid interval distance, e.g. an initial 1m by 1m grid is reduced to a 5 by 5m grid, yielding a reduction factor that is the square of the linear proportions, yielding a factor of 25 in this example. There is no need to use a multiple of the initial grid interval distance, though it may speed up the computation. For the filtering algorithm, different approaches are possible to compute the depth in the resulting bigger grid cell:
- The depth is the average depth of all depths of the initial grid points lying inside the resulting bigger grid cell.
- The depth is a weighted average of all depths of the initial grid points lying inside the resulting bigger grid cell, The weighting factor is usually the inverse of the distance between both, raised to the power n. Often, n = 2 is chosen, yielding an inverse quadratic distance as weighting factor.
- The depth can be taken to be the minimum of all depths of the initial grid points lying inside the resulting bigger grid cell. This can be motivated if the purpose is to determine the minimal sea bottom depth rather then computing an accurate volume, as can occur in dredging projects. Analogously, in reclamation projects, the maximum depth can be the most important characteristic of each resulting grid cell.

Advantages and drawbacks

The principal advantages are the simplicity of a basic grid model and the low memory requirements for the processing of the depth data, as planimetric coordinates are computed and not stored in memory. Hence, computations are fast and quite straightforward. In the case of homogeneous sea bottom coverage by a multibeam sensor, grid models are often the preferred data model for the bathymetric modelling of the sea bottom. Due to the less complex algorithms involved in the computational geometry modelling operations, real-time modelling is easier to implement using grid modelling than using TIN modelling.

An obvious drawback of grid systems is the loss of the initial measured bathymetric survey points. Their information is used to interpolate the depths of the grid points, yielding a planimetric shift of the data with depth information and resulting in a global smoothing of the digital sea bottom model. This can be particularly frustrating if a relatively small object with important depth variation was measured, for example a sleeve for pipe-laying projects. Typically the sleeve width has to be realised within decimetre range accuracy. If a high density grid model with an interval distance of 1m is used, the sleeve design will be highly distorted. This can be counteracted by the use of a heterogeneous model with different grid intervals depending on the area. Quadtree structures can be used for the modelling. However, heterogeneous models are complex, involving data manipulation routines that are difficult to implement and require significant higher amounts of computer memory and processing time.

Tin Based Modelling

Principle

It is common practice to use the Delaunay triangulation [1] to construct a TIN rather than other, less restrictive triangulations. In a Delaunay triangulation, the circumscribing circle of any triangle contains no other vertices [2].

Triangles whose circumcircle does contain another vertex are invalid and need to be replaced by another triangle by a process called *edge flipping*; this is shown in figure 1a and 1b. The triangles *abc* and *acd* are not Delaunay triangles as they contain *d* and *b* respectively in their circumscribing circles. After flipping the edge *ac* to *bd*, the triangles *abd* and *bcd* are created, which do not contain other vertices in their circumscribing circle. They therefore meet the Delaunay requirement.

Figure 1c represents what is called *edge completion*: when four points are cocircular, the resulting quadrilateral is (arbitrarily) split in two separate triangles. This constitutes a degenerate case as either of the two diagonals can be constructed.

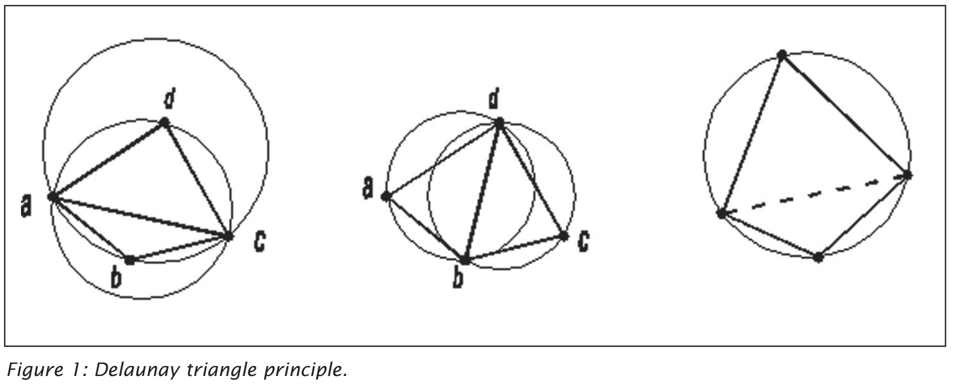

Figure 1: Delaunay triangle principle.

It can be proved that the Delaunay triangulation of a set of vertices is unique; this is an important quality asset towards the client as it allows him to repeat the calculations to verify the results independently.

Filtering

A necessary feature for a survey program is editing in order to optimize the digital terrain model. Two operations are comprised in editing an existing triangulation: it should be possible to add vertices and it should be possible to delete them. The latter is particularly important for filtering purposes, to reduce the multibeam data set to the most significant points.

Deleting points yields a retriangulation of the star shaped polygon that results when the vertex and its edges are eliminated. When deleting a vertex, the triangles containing this vertex become invalid and a hole is created around the removed point. The edges of this hole define a polygon. It has been shown by the authors [4] that it suffices to insert the conforming Delaunay triangulation of this polygon into the hole to obtain the updated Delaunay triangulation of the reduced dataset. The conforming Delaunay triangulation of the hole is in fact filling the hole with triangles that are Delaunay triangles for the updated triangulation also.

By extension, when deleting a group of vertices, a big hole is created, that can be filled with Delaunay triangles and reinserted to form the complete Delaunay triangulation of the reduced dataset.

Adding vertices one by one is easily done by the incremental algorithm as it is the basic operation of this construction method.

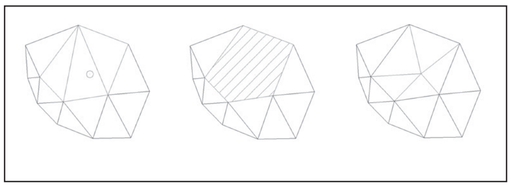

Figure 5: Vertex addition.

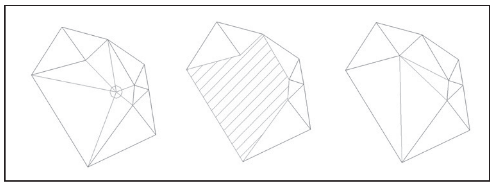

Figure 6: Vertex deletion.

A particular need for surveying at sea is replacing a part of an existing triangulation by newly available data. This means freeing the area of vertices of the original dataset where the new data are measured, in order to create a hole large enough to receive the new triangulation. Both triangulations need to be connected to each other.

An algorithm, based on the merge-step of the divide-and-conquer method for constructing a Delaunay triangulation, has been devised to join seamlessly both triangulated areas. The merging of overlapping triangulations requires determination of the overlapped area, deleting the influenced vertices and stitching together both disjoint triangulations.

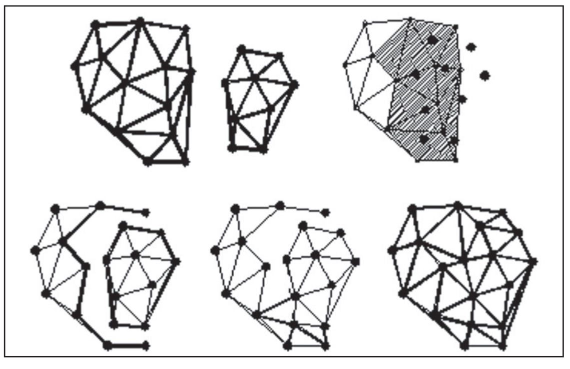

Figure 7: Merging two overlapping triangulations.

Advantages and drawbacks

It can be a requirement that the original survey points be in the digital terrain model from which the volumes are derived. This allows the client to check the results. Triangulated irregular networks (TINs) are a favourite scheme to construct a digital terrain model (DTM) from a seafloor measured at discrete spots. Overlaying the sampled points with a regular grid has three important drawbacks, compared to TINs.

1. It is generally impossible to have each sampled point in a separate regular grid position as the measurements are not on a regular grid but depend on the survey ship's survey system (equally spaced measurements or not) and attitude (roll, pitch, yaw).
2. Grid values do not reflect the actual measurements as gridding means either assigning interpolated values where the measurement density is inferior to the grid size, or resampling and loss of information where the measurement density is superior to the grid size; it introduces errors in the DTM.
3. The grid model is not adaptive. Whereas TINs will naturally represent areas with detailed relief information with a denser triangle pattern than areas with a smoother relief, grids will be far less flexible to cope with varied levels of detail.

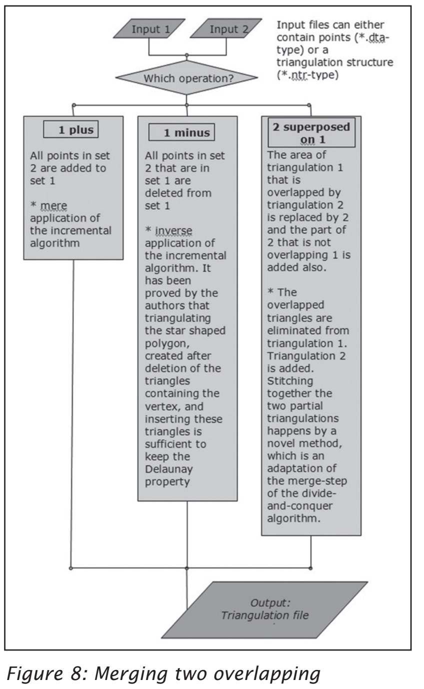

Figure 8: Merging two overlapping triangulations.

TINs do not have these drawbacks, but are more demanding towards computer memory and processing time, and the algorithms needed for geometric computations are more sophisticated.

Conclusions

Multibeam echosounder data impose some specific requirements to the processing. These requirements have been identified and the different aspects of DTM construction by grid modelling and by Delaunay triangulation have been treated in this context and opposed to each other as two alternatives, of which the advantages and drawbacks have been discussed.

The editing of the model is significantly more complex when TINs are used. As an example, the merging of two overlapping triangulation sets was demonstrated. The authors use an adapted merge-step in the divide-and-conquer algorithm to replace old data in an existing triangulation by newly available data. TINs are to be preferred when the surveyed area has a non-homogeneous coverage.

Equidistant grid models are less flexible, but offer higher speed, lower memory and easier implementation algorithms as most important assets, making them to be preferred when the surveyed area is homogeneously covered by a high-density multibeam survey. For heterogeneous covered areas, typical for singlebeam surveys, TINs are a priori the preferred option.

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