TIN-Based Digital Terrain Modelling Using Multibeam Data

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The latest bathymetric sounding equipment that is available nowadays, especially the multibeam echosounder, yield a very dense bottom sampling. When compared to the common singlebeam echosounder, an enormous amount of data is produced that needs to be processed in a correct and fast way. Grid-overlay (by local linear or more sophisticated interpolation and attributing values to individual grid cells) is not an option here as this method uses an interpolation of the measured values and hence will either cause accuracy loss or generate a still larger amount of data. A triangular irregular network (TIN for short), especially the Delaunay triangulation (Dt), does respect the actual measurements and will not generate new data. In literature, a number of algorithms have been developed that determine the Dt of a set of points (vertices) given in the plane.

Introduction

Many marine scientists and users of the sea take knowledge of the sea bottom's topography for granted; the consider is as a mere context to carry out research or deploy activities. Some disciplines do need more accurate bathymetric data than others, depending on depth values being background information or crucial information for their research or activities. In bathymetry, the representation of the sea bottom surface is the main objective and hence, this discipline will try to render the sea bottom relief as accurate as possible.

Multibeam Echosounder Calibration

A proper calibration of the geometrical setup of the echosounding equipment before taking off for a survey is indispensable [1]. The purpose of this calibration is to determine accurately the position of the hydrographical equipment, in casu the multibeam echosounder, with respect to the geometry of the vessel and especially with respect to the positioning antennae. This geometry is realised by means of a number of fixed reference points on the vessel for subsequent calibration measurements.

The calibration allows to refer accurately each echosounder measurement to the corresponding position and therefore to a plotted chart.

Rigorous processing of the calibration data by means of least squares adjustment [2] is necessary to obtain reliable calibration results and thus accurately georeferenced measurements.

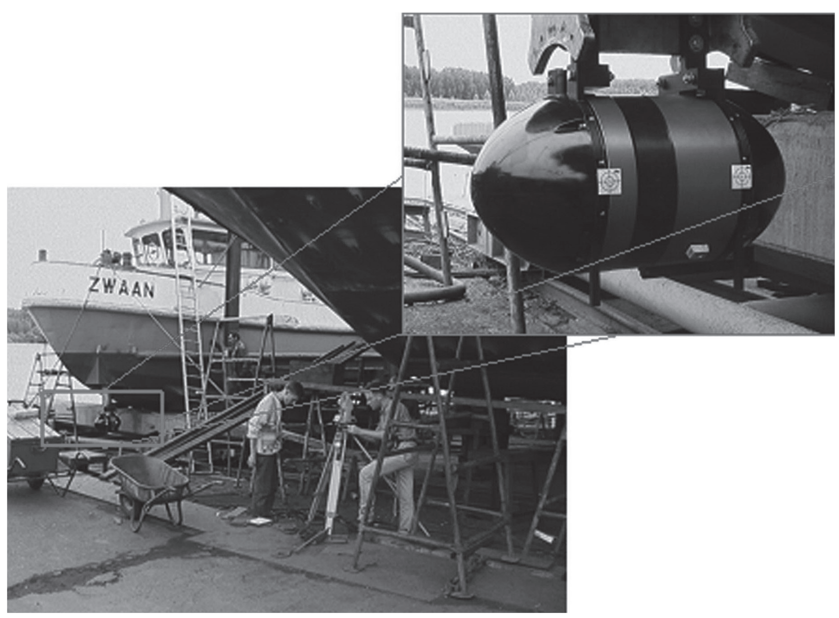

Figure 1: Pictures of the survey vessel 'Zwaan' during installation and calibration of the multibeam echosounder (magnified) in the docks in Rupelmonde, Belgium.

Creation of a TIN (Triangulated Irregular Network) Using The Delaunay Algoritm

Principle

It is common practice to use the Delaunay triangulation [3] to construct a TIN rather than other, less restrictive triangulations. In a Delaunay triangulation, the circumscribing circle of any triangles contains no other vertices of the triangulation [4]. 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 2a and 2b. 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 2c 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.

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.

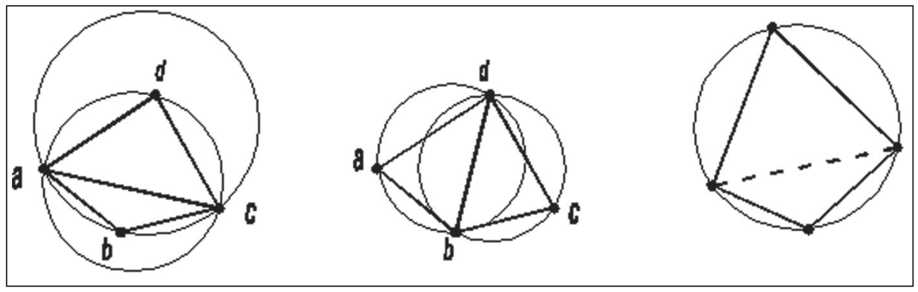

Figure 2: Delaunay triangle principle.

Exploitable Delaunay triangulation algorithms

Five algorithmic approaches exist to construct a Delaunay triangulation [5]. When looking closely at their conception and properties, two of them can be used advantageously for DTM construction in dredging works:

The divide-and-conquer algorithm is very apt for triangulating large datasets because of its calculation speed. The incremental algorithm on the contrary can be exploited to edit an existing triangulation. Both algorithms are briefly depicted.

Divide-and-conquer algorithm

The divide-and-conquer method [6] starts with the entire dataset, repeatedly cuts it in half until only subsets of two or three neighbouring vertices are left and recursively stitches together these partial triangulations. Some triangles near the edges are deleted in this process and new triangles gluing together both triangulations are created. Figure 3 clarifies this. Implementing this algorithm is rather difficult when compared to the incremental method, but it is well worth the effort as its calculation speed is far better than the latter's.

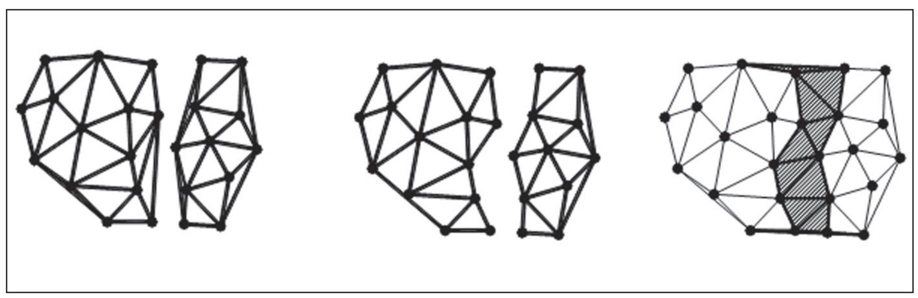
Figure 3: divide-and-conquer principle – merge step.

Incremental algorithm

The incremental algorithm is the most widely used because of its straightforward construction and implementation [7]. The principle is represented in figure 3:

- The triangle that contains the vertex is located.
- The triangles influenced by the new vertex are identified (these triangles contain the new vertex in their circumscribing circle)
- The triangulation is updated with the new triangles so that the Delaunay property remains valid for all triangles.

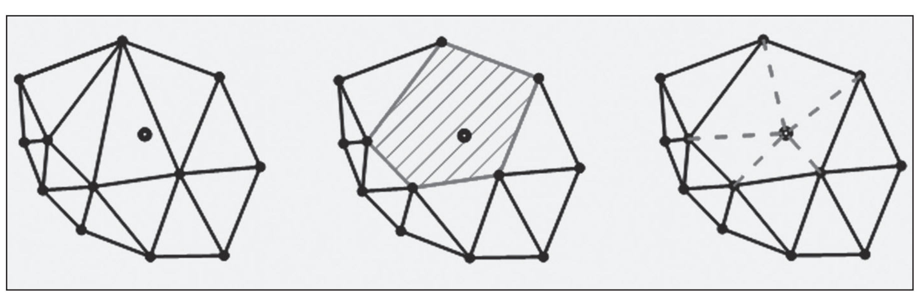
Figure 4: incremental algorithm principle.

Because of its lower speed and its inherent decreasing speed for increasing dataset size (see Figure 5 and Table 1), it is not an adequate method to construct the Delaunay triangulation for the large datasets envisaged. It is, however, the ideal method to add vertices to an existing triangulation [8]. Where its application domain was previously 'constructing a TIN', it now shifts to 'editing a TIN'.

Runtime comparison

A comparison has been carried out between the speed of the divide-and-conquer method and that of the incremental method. The following graph and table make clear that for increasing dataset size, the divide-and-conquer algorithm is increasingly faster when compared to the incremental algorithm.

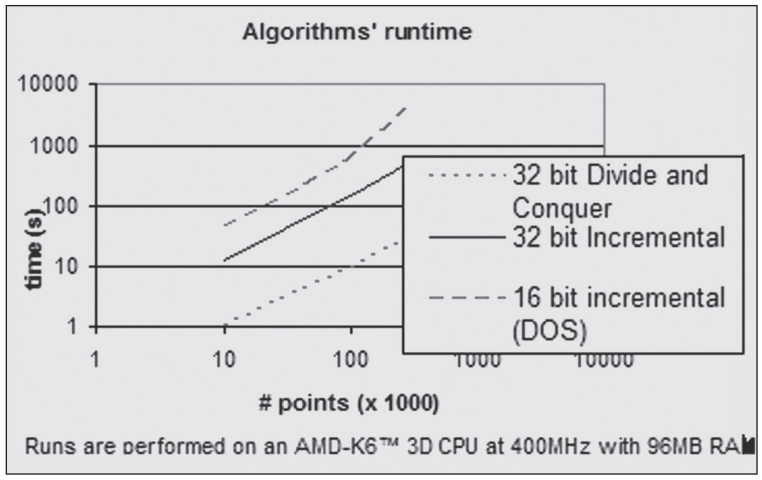

Figure 5: Performance of the different algorithms for different dataset sizes.

Multibeam Dataset Reduction

The amount of data generated by a multibeam echosounder is dependent on the ping rate, which goes up to 30Hz, and the number of beams in the swath, typically between 100 and 300, incoming dataflows 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 [9]. 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, either by *vertex decimation* (eliminating redundant data from an existing Delaunay triangulation) or by *greedy insertion or refinement* (gradually constructing the Delaunay triangulation by adding only those points that really contribute to the precision of the seafloor model).

Algorithm used / Number of points (x 1000)	A) D&C 32 bits	B) Inc 32 bits	C) Inc 16 bits	Ratio B/A	Ratio C/B	Ratio C/A
10	1	12	45	12,0	3,8	45,0
30	3	42	136	14,0	3,2	45,3
100	9	148	602	16,4	4,1	66,9
300	30	510	4235	16,8	8,3	139,9
1000	150					

Table 1: Performance of the different algorithms for different dataset sizes. Values are runtimes in seconds. Points are randomly distributed in a square.

Refinement (coarse to detailed) adds only those points to the triangulation that are, according to some selection criterion, necessary to obtain the required accuracy.

Decimation (detailed to coarse) requires a triangulation of all the input points and then eliminates redundant height points from it. The decimation method is the most promising for the application at hand, as it seems to keep the highest accuracy. It can be subdivided into:
- *vertex decimation*
- *edge contraction*
- *triangle decimation*
- *patch decimation*

The hole that results after deletion of a point, a triangle or a patch is subsequently retriangulated.

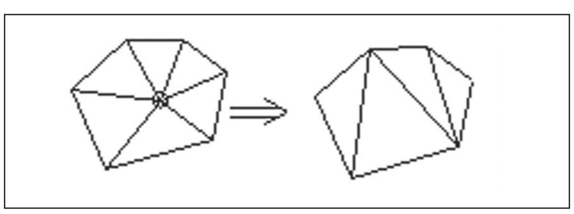

Figure 6 : Vertex decimation

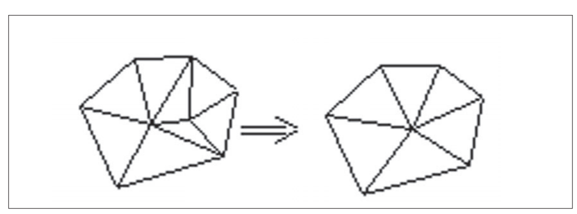

Figure 7 : Edge contraction

Almost all filtering algorithms described in literature use a height difference to determine whether or not to add a vertex or to delete one from the model. In case volume calculations are the final aim of survey, it is more useful to determine the generated volume difference between the two models. Hybrid models could combine the advantages of both.

Conclusion

In this paper, several aspects of terrain modelling by TIN modelling have been discussed. Starting with the proper calibration of a multibeam echosounder, the next step introduces triangulation.

Two interesting Delaunay triangulation algorithms have been indicated: the incremental method and the divide-and-conquer

method. A comparison test between the speed of both algorithms has been presented, showing the better performances of the latter. Because of its runtime performance, the divide-and-conquer method can be exploited for the initial triangulation of the large datasets gathered by multibeam echosounding. However, the incremental algorithm is very adapted to editing an existing triangulation.

After this step or, as an alternative, prior to the triangulation, data set reduction can be performed, in order to reduce redundant information in the data file. The last step is the editing of the TIN, including operations as vertex addition, vertex deletion and merging of triangulated areas. Each of these aspects has to be executed with care and precision in order to obtain a valid digital sea bottom model.

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