Data reduction for seafloor 3D mapping from multibeam sonar scans

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Application of seabed mapping and imaging is very attractive in many applications including marine navigation, hydrography and GIS systems. The problem is especially important when mapping of the seabed is performed using data obtained from multibeam sonar systems. Even after preprocessing by internal signal processor units these systems deliver large amount of data. Typically they contain bathymetry data along with navigation information, which allows for further visualisation and mapping. To address the problem of storing huge amount of data, the paper presents application of data reduction algorithms derived from image processing theory and computer graphics technology. As the raw data from multibeam system represents discrete points in 3D coordinate system, which may be treated as irregular mesh, the decimation or polygon reduction algorithms may be applied. The aim of these techniques is to reduce the number of polygons in a mesh while maintaining a good approximation of original data. The adopted algorithms use modified Delaunay triangulation and decimation algorithms for achieving high reduction of amount of data. The results in the form of 3D images of bottom relief are also presented.

Introduction

Echosounding as a technique for measuring water depths by transmitting acoustic pulses from the ocean surface and listening for their reflection from the seafloor, has been used since the early twentieth century to provide the vital depth input to charts that now map most of the world's water-covered areas. Until the early 1960s most depth sounding used single-beam echo sounders. The wide-beam unstabilized systems lack the necessary spatial resolution, while the narrow-beam stabilized systems map too little area with each ping. The first multiple narrow-beam systems employed two separate sonar arrays oriented orthogonal to one another in an arrangement called a Mills Cross Array. This system allowed survey vessels to produce high-resolution coverage of wide swaths of the ocean bottom in far less ship time than would have been required for a single-beam echo sounder, greatly reducing the costs of such mapping endeavors.

Nowadays, as faster computers and integrated digital chips have become available, most of the signal processing, including beam forming, moved from analog signal processing into the digital signal processing domain. The availability of fast signal processors has also permitted the implementation of sophisticated bottom detection algorithms based on amplitude and phase information. As a result, survey vessels equipped today with multibeam system and additional sensors (GPS, HPR) can do onboard real-time multibeam processing and display of bathymetry data. It may deliver geographically referenced data, which represents detailed surface model of the seabed.

Surface simplification algorithms

Multibeam systems can easily generate seabed model with high spatial resolution. But, as a result it produces huge amount of data. A variety of methods for simplifying curves and surfaces have been explored over the years. Work on this topic is spread among a number of fields including cartography, geographic information systems (GIS), virtual reality, computer vision, computer graphics, scientific visualization, computer-aided geometric design, finite element methods, approximation theory, and computational geometry [1].

Generally, polygon reduction algorithms can be classified in two ways [2]: whether they modify the geometry of a mesh, and whether they modify the topology of the mesh. Algorithms that modify the geometry of a mesh create new vertices, or possibly move existing vertices to new positions. The advantage of modifying geometry is that vertices can be repositioned to give a better approximation of the original mesh. The disadvantage is that if attribute information like texture coordinates or color is associated with the vertices, it must be mapped to new values when the vertex location changes. Unfortunately, both the calculation of new vertex positions and attribute mapping tend to be expensive operation. Algorithms that modify topology may close holes, add holes or split the mesh, or even introduce nonmanifold attachments. Most polygon reduction algorithms preserve the topology of the mesh, but it is common to modify the mesh geometry.

The detailed classification of all polygon reduction methods presented in [1], categorize algorithms according to the class of surfaces on which they operate: height fields and parametric surfaces, manifold surfaces, and non-manifold surfaces. The data from multibeam system represents a height fields and they are the simplest class of surfaces. Within this class of surfaces, the methods may be divided into the following six sub-classes: regular grid methods, hierarchical subdivision methods, feature methods, refinement methods, decimation methods, and optimal methods. Most of the methods employ more general subdivision and triangulation methods, most commonly Delaunay triangulation. For many height field simplification tasks, the input is a height field and the output is a general triangulation, called a triangulated irregular network (TIN).

The decimation approach to surface simplification starts with the entire input model and iteratively simplifies it, deleting certain geometric features on each pass. One of the first method of this kind was proposed by Lee in 1989. His "drop heuristic" method for simplifying terrains is called vertex decimation approach because on each pass it deletes a vertex. The algorithm takes the height field grid as input and creates an initial triangulation in which each square between neighboring input points is split into two triangles. On each pass, the error at each vertex is computed and the vertex with lowest error is deleted. The error at a vertex is found by temporarily deleting the vertex from the triangulation, doing a local Delaunay retriangulation, and measuring the vertical distance from the vertex to its containing triangle. The process continues until the error exceeds the desired level, or the desired number of vertices is reached. Deletion in a Delaunay triangulation can be done incrementally to avoid excessive cost. The drop heuristic method yields high quality approximations, but its computational cost and memory cost appear very high. The newer decimation algorithms performs a series of local operations on a mesh to gradually reduce the number of vertices, edges, triangles, and patches, performing appropriate local geometry classification [2].

Results

Sample data acquired on Baltic Sea were stored in the file as X,Y,Z coordinates expressed in UTM standard. As an example, around 333 scans each having 60 sounding points were triangulated, obtaining 40358 triangles. Then (see Fig. 1), they were decimated using the GNU Triangulated Surface Library (GTS), which provides a set of useful functions to deal with 3D surfaces. 95% decimated image of the seabed model are presented in Fig. 2 along with original one.

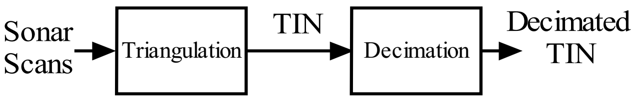

Fig. 1. Decimation processing of sonar scans

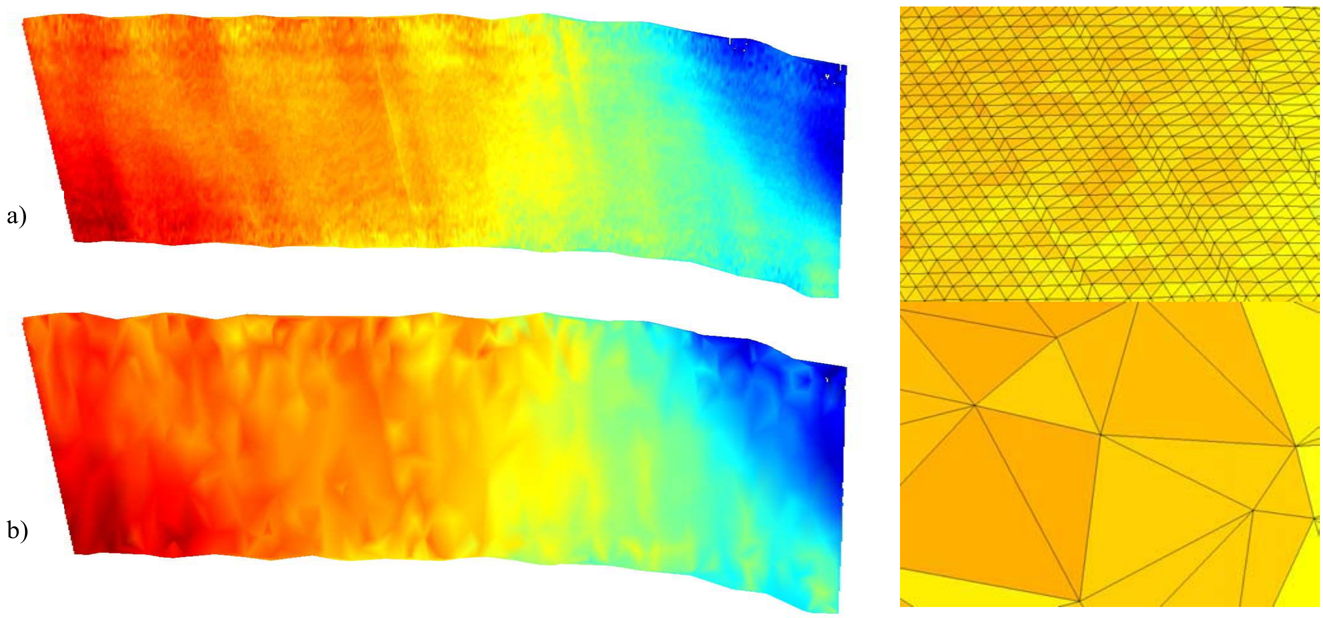

Fig. 2. Original image representing seabed model (a) and 95% decimated image (b) along with enlarged TINs.

Conclusion

Surface simplification is useful in order to make storage, transmission, computation, and display more efficient. A compact approximation of a shape can reduce disk and memory requirements and can speed network transmission. It can also accelerate a number of computations involving shape information, such as finite element analysis, collision detection, visibility testing, shape recognition, and display. Reducing the number of polygons in a model can make the difference between slow display and real time display.

Triangle decimation algorithms play an important role in maintaining the responsiveness of 3-D graphics systems. By compressing 3-D graphics data using triangle decimation, you can often squeeze out the last ounce of performance, which can make the difference between an engaging interactive system or one that annoys users. It is needed for several reasons: to remove unnecessary detail for aesthetic reasons, to save memory/disk space, and to reduce plotting/display time.

Acknowledgements

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References

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