HYDROGRAPHIC DATA REDUCTION - A PRECONDITION FOR EFFICIENT CARTOGRAPHIC VISUALISATION OF THE MARINE RELIEF

Dr.-Ing. Gerd Buziek
Institute of Cartography
University of Hannover
Appelstr. 9 a
D-30167 Hannover (FRG)

Abstract

Modern bathymetric surveying systems capture primary hydrographic data sets (PHDS) of depths with high density. These data sets serve as basis for modelling the underwater relief. Digital primary terrain models (DPM) are the result.

The outcome of the huge amount of data is an increased reliability of surveyed relief forms, but most of the data needed for modelling become redundant. This fact implies the necessity of reducing primary data sets. The result is so-called secondary hydrographic data set (SHDS), which is optimal from a geometrical and economical point of view. It is the base for a wide range of different applications like the compiling of a bathymetric chart for geomorphologic purposes. The compilation of a bathymetric chart discussed in this paper was done by use of an optimisation method.

The optimisation strategy comprises the sub-processes of modelling, modifying, analysing and classifying the digital terrain model. The selection of depths achieves the reduction of data. Statistical analysis conducts the assessment of the resulting secondary hydrographic data set (SHDS).

The importance of data reduction is emphasised by a recent resolution of FIG commission 4, in which is recommended to investigate what criteria should be used to determine the quantity of data to be retained and managed [1].

1. Problems of modelling and strategy for solution

The digital terrain model (DTM) is the base for various applications in hydrography, ocean cartography, geo sciences and other disciplines. Some examples for bathymetric application are the derivation of contour lines (isobaths), computation of volumes and perspective views.

The quality of digital terrain modelling in hydrography depends on the accuracy of positioning and depth measurement as well as the distribution of depths and the structure of the data set. Another impact is the result of the chosen modelling method.

In comparison to bathymetric surveying, the topographic measurement of the terrestrial surface makes it possible to capture directly the relevant structures of the relief. This is necessary for the plausible morphologic processing of the digital model. The use of bathymetric (hydro acoustic) methods prohibit the capture of important structure lines. Thus, a high density of depth measurements is required to compensate this disadvantage. This comes together with a geometric distribution of depths, that is not adapted to the relief forms. Investigations had shown, that the data set can be improved by description of structure lines in combination with data reduction.

Until now, the automatic topographical structuring of hydrographic data sets is not completely solved. Instead, semi automatic or manual methods must be used [21].

After structuring the data set, its reduction follows. This can be done with different intention:

1. Generalisation: The number of depths is reduced. Intention is to create a simplified DTM that is scale dependent. Changes in morphologic quality are possible.

2. Optimisation: The number of depths is reduced, but still without any changes in morphologic quality of the model.

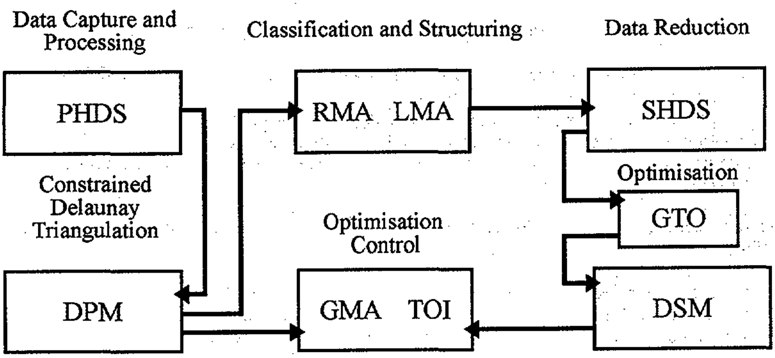

Figure 1: Strategy for optimisation of hydrographic data sets [2]

With regard to store only those data in digital data bases that are necessary for modelling, the optimisation of hydrographic data sets is very important. Results are decreased storage capacity (linear to the number of eliminated points) and computing time for the DTM (logarithmic to the number of eliminated points when using triangular irregular networks). Additionally, the morphologic quality of the data set is obtained by structuring the data.

For the processing of an optimal DTM of the underwater relief with high quality, processing steps as shown in figure 1 are useful. They are components of the herein proposed optimisation strategy. This strategy comprises the following main components:

1. Classification of measured depths from a morphological point of view (DTM analysis),
2. geometric and topologic optimisation of hydrographic data (DTM modelling and modification),
3. reduction of the number of measured depths and
4. assessment of model quality.

The geometric basis for the optimisation is the primary hydrographic data set (PHDS). This is the result of the processed hydrographic raw data (e. g. tide correction is considered, gross errors are eliminated). Furthermore the data set is referred to a geodetic coordinate and height system.

In the example of this paper, the captured data set covers an area of the German Bay with the size of 5 X 6 km^2. It comprises more than 3.5 millions of measured depths. The hydrographic surveying was carried out by the research vessel „Wega" of the German „Bundesamt für Seeschiffahrt and Hydrographie", Hamburg. The depths measurements were done by the fan sweeping system

„Hydrosweep MD". The processing of raw data to gain the PHDS were achieved by the software package Hydromap 300 [3].

2. Modelling of a primary hydrographic data set

The optimisation of the PHDS first leads to the digital primary model (DPM). For the computing, a constrained delaunay triangulation (CDT) is used [4]. The use of a triangulated irregular network (TIN) delivers certain advantages for the implementation of the optimisation methodics:

1. Depths are directly contained within the DPM. This is of great importance for the morphologic classification;
2. edges of triangles define topological relationships between nodes, which can be used for analysis and classification;
3. local procedures can be applied to the TIN, to integrate line structures additionally;
4. furthermore, it is possible to integrate nodes into or to eliminate nodes out of the DPM;
5. cartographic depiction is possible and usable for visual assessment of optimisation results (see chapter 6).

Before modelling data, the creation of a logical data structure is necessary. The demands for efficient optimisation are:

1. fast access to the PHDS,
2. triangulation within subcells to achieve a high processing speed and
3. incorporated relationships of geometric elements for TIN modification later on.

These demands are accomplished by use of a hash-table or grid-file [5]. Further examples are given by [4, 6, 7]. The optimisation of the size of grid-cells for fast TIN computing is discussed in [8]. Investigations of [8] had shown, that the TIN computing speed depends mainly on the number of depths within the cells of the hash-table. For the herein discussed example, an average number of 10 depths within each cell was determined.

The implemented triangulation procedure belongs to the iterative triangulation algorithms [9]. For each computed triangle the delaunay-criteria is valid, if a circumscribing circle can be defined through the triangle nodes. The circle may not include other nodes of the data set. All processes for creation of triangles can be solved efficient by hash-function and grid-file.

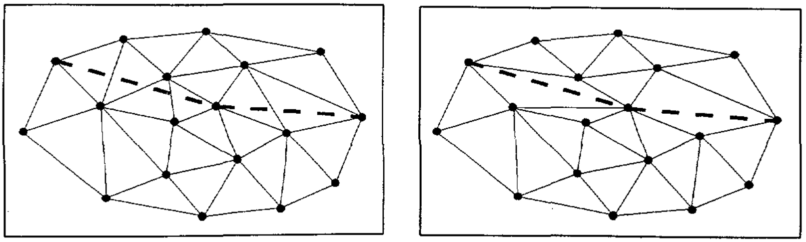

Figure 2: Constrained delaunay triangulation that improves the morphologic quality. The dashed line indicates a structure line within the digital model.

The Delaunay-Triangulation is optimal in a mathematical sense. From a topographical point of view, it is necessary to modify this TIN, because structure lines, break lines and form lines are represented by triangle edges only in those cases, in which the triangle fits the delaunay-criteria.

For further improvement of the TIN, an approach was developed, to modify the delaunay-mesh to consider manually or semi-automatically defined line structures within the data set. The modification of the TIN is achieved by an iterative application of an edge swapping procedure [4]. This procedure achieves the geometric and topologic optimisation (GTO) of the DPM. The result is a constrained delaunay triangulation (CDT) with increased morphologic quality.

Due to the huge amount of data, the PHDS of the research area was tessellated into subcells for optimisation processing. Each cell contains an averaged number of 100.000 depths. This method achieves some advantages:

1. Only the space on the hard disc limits the number of depths to be processed.
2. The software modules can be adapted to different types of computers.
3. For each subcell a set of optimisation parameters is adapted to consider locally different types of terrain.
4. The optimisation process can be stopped after each processed cell and continued later on.

The avoidance of problems occurring at the borders requires an overlapping of the subcells. The combination of the resulting partial SHDS leads to the optimised secondary hydrographic data set.

3. Analysis of the digital primary model (DPM)

3.1 Global model analysis (GMA)

The Global Model Analysis (GMA) delivers parameters that can be used for classification of each subcell in a geomorphologic and geometric-statistic sense. For PHDS of one class one can make use of the already determined control parameters that were chosen for the optimisation of previously optimised data sets.

The GMA can be separated into profile oriented and area oriented methods. These methods should be of high sensitivity for any changes of the model. For profile oriented analysis, the time series analysis was applied. Therefore, it is necessary to extract terrain profiles out of the DPM and uses them as time series. A filter function is applied to the profile (fig. 3 a) to eliminate the trend of the process. This is necessary to meet the demands of stationarity and ergodicity [10]. The resulting signal and noise are analysed for periodicity (fig. 3 b). The result is an auto covariance or auto correlation function that contains information about the accuracy and correlation of the samples. The empirical variance delivers information that is comparable with the standard deviation of a mean value. Furthermore, assertions can be made for high or low correlated data along the profile.

The herein given example shows a section of a rippled underwater relief (fig. 3 a). The empirical variance was delineated to $s = 0.26$ m (fig. 3 b). The theoretic accuracy of the multi beam sonar system is $\sigma = 0.10$ m. One can suppose that outer influences, which were not considered within the raw data processing are a possible reason for the difference.

This example shows further a high correlation of data at a distance between samples of 9 m, 25 m and 36 m. The spectral description *(Fig. 3 d)* or power spectrum shows a peak at a wavelength of 25 m. This means, that most of the morphologic features are of this size. This hypothesis is confirmed by the morphological structure of the vertical section shown in figure 3 a. Methods and parameters for an area oriented analysis is discussed in detail in [8, 10].

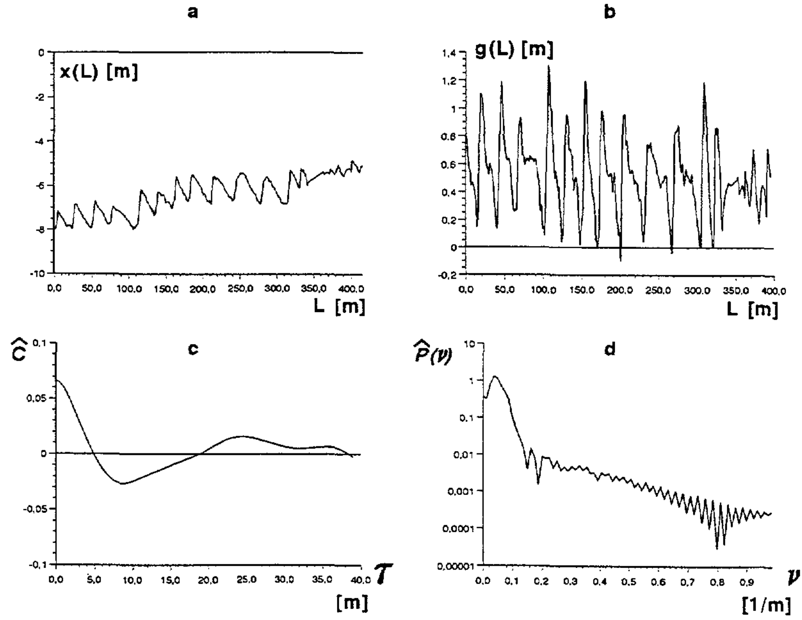

Figure 3: Results of time series analysis of terrain profile (a: vertical section of an underwater relief; b: function of signal and noise; c: auto covariance function; d: power spectrum)

3.2 Regional model analysis (RMA)

The Regional Model Analysis (RMA) uses the geometric and topologic information of the DPM to convert a combination of certain triangles into relief element models (REM) [8]. Those elements consist of triangles that are unified in slope and orientation within the DPM. The digital combination of triangles into REM is done by an algorithm proposed by [11]. Every triangle is classified whether it is convex, concave or plane in its neighbourhood. The derived REM are also of this behavior. The further analysis is concentrated to the common triangle edges of neighbored REM. This obtains the classification of the spatial boundary of those objects. According to [8], possible classes are shown in figure 4.

An alternative method is the analysis of slope of the DPM. The DPM is separated into relief elements with certain slope information. The width of classes of slope controls the consideration of surface roughness. Triangle edges can be extracted, which lay on significant changes of slope.

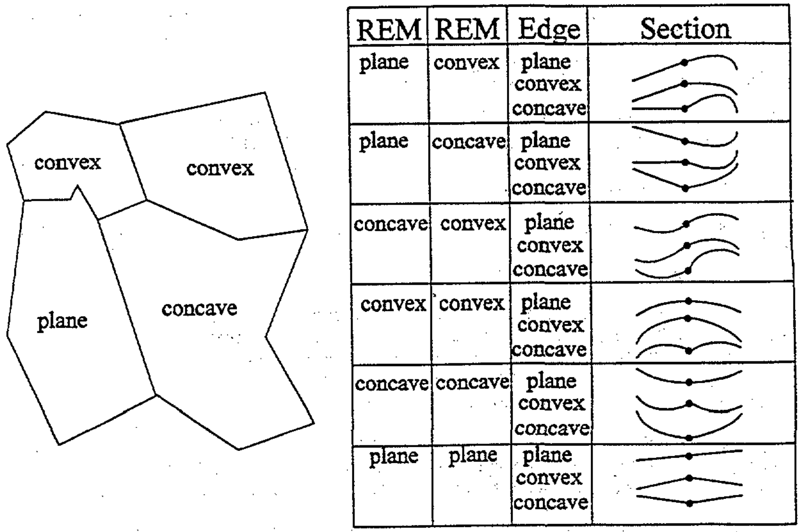

Figure 4: Relief elements of a DPM (a) and classification of their boundaries (b)

3.3 Local Model Analysis (LMA)

A third method of analysis is the Local Model Analysis (LMA). The nodes of the DPM are classified. The determination of their morphological impact for modelling is the result.

The basic idea of the implemented algorithm was given by [12], who developed a method to extract ridge and valley lines out of square gridded DTM. This method fits to a TIN as well. All nodes of the DPM that lay on almost horizontal ridges and valleys are recognised. A disadvantage of this method is, that ridges and valleys that run with a certain slope through the terrain are not recognised [8].

In addition, a further procedure was developed to analyse the height of nodes within a local set of triangles within the TIN. This allows to detect isolated maximum and minimum values. These geometric procedures where applied to a data set which was topographical measured to assess the performance. Rates of recognition between 85% and 100% were the result (Table 1).

ridge nodes	valley nodes	change of slope	local minima	local maxima	terrain nodes
87%	100%	95%	100%	100%	85%

Table 1: Recognition rates of morphologic differentiation by local model analysis

The investigations of model analysis had shown, that it is possible to distinguish the morphologic meaning of nodes within a digital primary model. This is an important process, before methods for the reduction of the number of points are applied to the PHDS to gather the optimised secondary hydrographic data set (SHDS). The following chapter will show, that this information is needed to achieve a reduction of the number of points without minimal lost of morphologic quality.

4. Data reduction and quality assessment

The necessity for data reduction is a logical consequence of the application of modern hydrographic sonar systems (multi beam and swath sounding systems) for bathymetric mapping. Those systems are capable of collecting more data than is required to precisely model the underwater relief. This leads to the demand, that the retention of all data may not be useful.

The hannover approach for data filtering and determination which quantity of data should be used for modelling the underwater relief bases on the previously described methods of analysis and uses the determined topographical meaning of depths as well.

For the assessment of data filtering mathematical statistics was applied to geometric parameters derived out of DPM and DSM. This makes it possible to compare the resulting digital secondary model (DSM) with the DPM (reference model). This procedure is called test of identity (TOI).

4.1 Parameters for quality assessment and statistical proof

Parameters for TOI can be derived directly out of DPM and DSM. Suitable are geomorphometric parameters that serve as geometric description for the surface of the model. The investigations have shown, that it is possible, to describe the digital model by a set of various geometric parameters.

The local relief H, acronyms are relief energy or maximum amplitude, is calculated by (1), where z_{min} and z_{max} are the extreme values of depth in the DTM under investigation. This value describes the range of depth within the data base. H should be unchanged after reduction of the PHDS.

$$H = z_{max} - z_{min} \tag{1}$$

Another important parameter is the elevation-relief ratio E (2). E is identically to the hypsometric integral. Geometrically, this value is equal to the ratio of the volume between model surface and a plane through z_{min} to the volume of a solid within the boundary of the model and planes through z_{min} and z_{max}. $\overline{z}$ is the mean value of all depths.

$$E = (\overline{z} - z_{min})/(z_{max} - z_{min}) \tag{2}$$

Parametrical or non parametrical statistics like mean value and standard deviation or median and median deviation do not solve the problem of an appropriate statistic proof. They can be interpreted like result of low pass filtering. E. g. small changes in morphology may not be recognised by the statistical comparison of those parameters. This is the reason that investigations for automated quality assessment should be concentrated rather to distributions than to single values.

Surface roughness can be described by unit vector normals of the triangles, where $\underline{e}_i(e_x, e_y, e_z)$ is the unit vector of triangle i. Using formula (3) and (4) slope α_i and exposition φ_i of triangles can be computed.

$$\alpha_i = \mathrm{asin}(e_{xi}^2 + e_{yi}^2)^{-2} \tag{3}$$

$$\varphi_i = \mathrm{atan}(e_{xi}/e_{yi}) \tag{4}$$

Characteristic for the digital models is the distribution of slope (5) and exposition (6).

$$\alpha \sim D\{\overline{\alpha},\sigma\} \quad (5)$$
$$\varphi \sim D\{\overline{\varphi},\sigma\} \quad (6)$$

The hypothesis is, that an optimal reduction of data leads to a DSM that has the same morphological quality as the DPM from which it was derived. If this is true, the distributions of D_{DSM} and D_{DPM} of exposition or slope should be nearly identical.

For an automated statistical comparison a test method is needed which is able to proof whether D_{DSM} is identical with D_{DPM} or not. Suitable is a method that was developed by Wilcoxon [13]. The advantage is, that this method can be applied to distributions with unknown probability functions and different number of samples. If the hypothesis (H_0: $D_{DPM} = D_{DSM}$) can be accepted, one can suggest, that the major relief forms of the DSM are almost identical with those of the DPM. Examples of the application of the Wilcoxon test are given in [8].

Finally, one can say, that it makes no sense to look for a single or "magic" value, which describes whether a DSM is of high or low morphological quality. It is much better to use a set of geomorphometric parameters to describe the surface. For examples see [14, 15, 16]. For detailed discussion of geomorphometric parameters and their suitability within application for hydrographic data reduction please see [8].

4.2 Determination of optimal data quality

For the reduction of the number of data within a PHDS a selection method was applied. Useful methods are discussed in [18, 19, 20].

Selection rules must previously defined for data reduction. To meet the demands for the optimisation of the DPM, it is important to consider the morphologic attributes derived by RMA and LMA. A possible prescription would be to retain all depths with a certain meaning in a topographic sense (e. g. depths on ridges and valleys). To support an optimal modelling in areas without any specific topographic information an arbitrarily choice of data can be recommended. This method was applied to a DSM consisting of 3.5 million depths of a part of the underwater relief in the German Bay.

The selection rule was to select all depths with the meaning of minima, maxima, ridge and valley points to assure a good support for modelling of the whole model. 350.000 depths were selected for processing of the DSM. For the visual assessment of the DSM contour lines were drawn in a scale of 1:10.000. They are depicted for a 1400 m by 600 m window in figure 5.

5. Conclusion

The investigations had shown, that the morphologic quality of reduced hydrographic data sets depends highly on their analysis. Methods of regional and local analysis of the digital primary model lead to additional attributive information, to describe the morphologic meaning of measured depths. This knowledge can be used for structuring the data base by adding formlines and break lines that are considered later on within the modelling process. For data reduction a selection technique is recommended which makes use of the attributive topographic information of depths. The elimination can be concentrated to those data that are simply defined as "terrain points". A rate of reduction with maintained morphologic quality of 90% was gained for a map scale of 1:10000 of a research area in the German Bay.

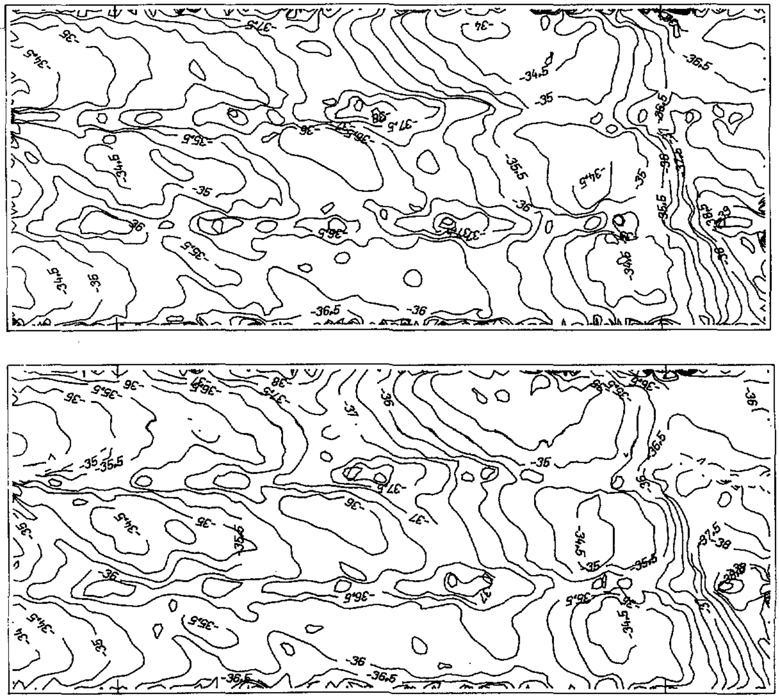

Figure 5: Contour lines of the test area (above: isobaths of DPM, window contains 85.000 depths; below: isobaths of DSM, window contains 10.000 depths)

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Finally, experiments are to be made with the breaking down of the complex cartographic depiction into single layers, as encouraged by Vogler (1985) and tested by Mohr (1993).

In the further future, the combination of media and audio-tactile information systems should receive their due attention.

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