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# Proposal of new data structures for the management of the multilayer seabed DTM

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**Abstract**
The paper contains a proposal of developing new data structures, which would describe a digital terrain model (DTM). The essential characteristic of of the proposed design is the fact, that they consist of multiple layers, where each layer describes the same, but with different accuracy (density point), and the whole structure describes a selected seabed area. Using such a novel data structure will allow for creating seabed models incorporating data of varying accuracy, and the particular layers might be used for specific purposes (e.g. low density data for quick visualisation, medium density data for general calculations, high density data for analysis small objects on the seabed). The author describes the assumptions underlying the development of such a structure, its functionality, possible applications and properties, as well as the outline of planned research regarding the structure.

## Introduction

Many water basins in Poland are being regularly surveyed, which is related mainly to the maintenance of routes and controlling of the sailing safety. However, there are no unified standards of conveying the surveys, only maximal values of errors on the depth maps are regulated. The recording and further processing of data relies mainly on the expertise of people performing these tasks. The immense amount of obtained data and the high precision of created models make it impossible in practice to process larger areas or even whole basins or sea routes. The operators face the dilemma, whether to preserve a high model accuracy (for a small area), or to cover a larger area while giving up high accuracy. In practice, usually a third option is chosen, to divide the area under examination into many smaller subareas, and then to manage each of them separately. Such a solution makes it impossible to manage the whole processed area comprehensively.

The specialised hydrographic software utilised across the world deals quite well with processing of large data sets coming from sea surveys, allowing for creating models of high resolution. However, unsolved in this software (also in GIS software) remains the problem of managing and processing such precise models covering larger areas. For example, the visualisation of the bay area, of the whole water route, of all the port basins, of whole lake or of the fragment of sea requires processing a huge amount of data (precise models must be recalculated into the models of lower resolution and then visualised or analysed). Commonly used in worldwide solutions (such as Caris, Qinsy Survey, Surfer, etd.) single layer models (based on grid or TIN) function in such a way. The author in his previous research have not came across any solution allowing for creating flexible multilayer models with varying accuracy levels (concerning both existing software and research activities) [1].

In the literature one can find numerous papers concerning creating DTM based on TIN structures [2, 3, 4, 5, 6, 7] and GRID structures DTM [8, 9, 10, 11, 12, 13]. They contain descriptions of methods for interpolation, filtering and smoothing of creating surfaces. One, can also find some sparse works on examining the accuracy of created DTM [14, 15, 16, 17, 18]. However, no solutions have been found in the literature, that would allow for describing a fragment of the seabed with varying accuracy at the same time, or that would solve the problem of huge data amount when creating precise models of significantly large areas. No paper has been found, which would describe creating multi-layered structures for describing spatial data. The research results in this area might in the future increase the functionality of hydrographic and GIS software in the scope of modelling and managing data describing DTM.

## Essence of accuracy in DTM

One of the most important and most difficult tasks involved in the complex process of constructing spatial information systems is the creation of a digital terrain model (DTM). In order to build a DTM of the seabed, it is necessary to acquire and subsequently to process the hydrographic measurements data. The created models must conform to the standards specified in the Special Publication No. 44, issued by the International Hydrographic Organization (IHO). The main goal of the mentioned document is to specify the minimal standards of hydrographic measurements, so that the data being gathered according to those standards is sufficiently accurate. The standards also allow to determine the spatial uncertainty of the measurements, in order to facilitate a safe utilisation of the measurements results by the users.

The formula below, supplied by IHO, is used to compute, at a 95% confidence level, the maximum allowable TVU (total vertical uncertainty):

$$TVU = \pm\sqrt{a^2 + (b \times d)^2} \qquad (1)$$

where: $a$ represents the portion of the uncertainty that does not vary with depth, $b$ is a coefficient which represents the portion of the uncertainty that varies with depth, $d$ is the depth, and $b \times d$ represents the portion of the uncertainty that varies with depth.

In the contemporary measurement systems increasingly often the multibeam echosounders are utilised, which allow for gathering in a relatively short time the immense amount of data, comprised of the set of measurement points with an irregular spatial distribution [19]. On the basis of acquired measurement data the DTMs are created, usually in the form of a regular square depth grid, using adequately selected processing algorithms [20].

In the case, when larger water areas are covered by hydrographic measurements (from several square kilometres upwards), we are faced by an immense number of measurement points (billions of points and more). Further processing of the data is therefore cumbersome, due to the long computation time and the size of the model (and as the result, the size of the data structures). For example, the area 10×10 kilometres in size, amounts in approximately 10 billion of measurement points, which after processing give a grid containing 100 million nodes (for the resolution of GRID = 1 meter). Given the currently available measurement equipment, the amount of measurement data and the size of the structures describing the spatial data are a common problem in GIS systems and put a challenge in front of the designers of specialised software.

Commonly used contemporary hydrographic software is not capable of comprehensive processing of such huge datasets, hence the operators of such systems divide the areas into the smaller ones. In practice, it is usually assumed, that routes under measurements can be divided into segments 1 km long, and larger water areas into smaller ones of approximately 1 square km. Each of those subareas is then processed separately. In such case the analysis of larger areas involves the manual analysis of many segments or subareas, which is a cumbersome and time consuming process.

A second significant problem is the fact, that usually the measurement data is used to create only one model of the selected area (characterised by the operator selected parameters, especially by the resolution of a grid, which determines the accuracy of created model). The following stages of analysis, computations and visualisation (also in the further future) are based only on that model [21]. One could easily imagine such a situation, where a model with lower resolution (which significantly reduces computation time) is more suitable for analysis (e.g. for fast visualisation of large areas), but also a situation, where the required model's accuracy is much higher (e.g. for seeking small objects on the bottom). Creating the models with a predefined the complexity is in such a case a certain compromise between the amount of data describing the surface and the accuracy [22].

The operators of hydrographic systems basing on the measurement data usually create one precise DTM model (assuming a GRID size of e.g. one meter). Describing larger areas of the seabed with such a high accuracy generates huge amount of data. Its visualisation, processing or analysis becomes significantly time consuming and troublesome. The same problems cause significant difficulties in creating the systems aimed at managing global hydrographic information for large areas (hydrographic data banks), and practically there are no good solutions of such kind.

## The main proposal

The author of this article state a hypothesis, that it is possible to develop new data structures describing the DTM of the seabed, allowing to simultaneously obtain the models of different accuracy and resolution. It will enable the simultaneous and automated management of large amount of data covering larger areas.

The main goal is to create new data structures and the mechanism for managing them and the algorithms facilitating entering, processing, analysis and storing of data describing the DTM with multilevel accuracy structure (the author propose the term "multilayer DTM") (Fig. 1).

The base assumption of the multilayer DTM structure is the description of the same seabed area using several GRIDs of varying resolution (dimensions) and model's accuracy. For example, the area of 10×10 square km can be described using the following GRIDs:

- grid = 100 metres (the grid of 100×100 points) – suitable for fast visualisation of large areas;
- grid = 10 metres (the grid of 1000×1000 points) – suitable for detailed visualisation of the described area;
- grid = 1 meter (the grid of 10,000×10,000 points) – the main layer for calculations and analyses or creation of detailed maps;
- grid = 0.1 meter (the grid of 100,000×100,000 points) – suitable e.g. for analysis of small elements within the subareas, of untypical objects on the bottom, like shipwrecks or underwater constructions.

The number and the resolution of layers in the multilayer DTM structure would be variable, and it would be a one-time task of system's operator to define those parameters (according to the type and the purpose of performed tasks).

The flexibility of developed solutions will allow for storing within one data structure the data coming from different measurements, performed in a different period. Such an approach facilitates the overview and analysis of the changes occurring within the area under examination. This property can also enable the forecasting of further changes in the seabed surface shape.

In order to diminish the amount of data being saved in the mass storage, the author's plan to develop completely new algorithm for lossy compression of multilayer DTM data. The KLT transform will be utilised for this job. It is worth noting that this is original approach to the lossy compression, where the data will be compressed with the highest possible compression factor, while maintaining the required accuracy of data reconstruction. This should guarantee a high accuracy of created and processed DTM models. It will be possible to set

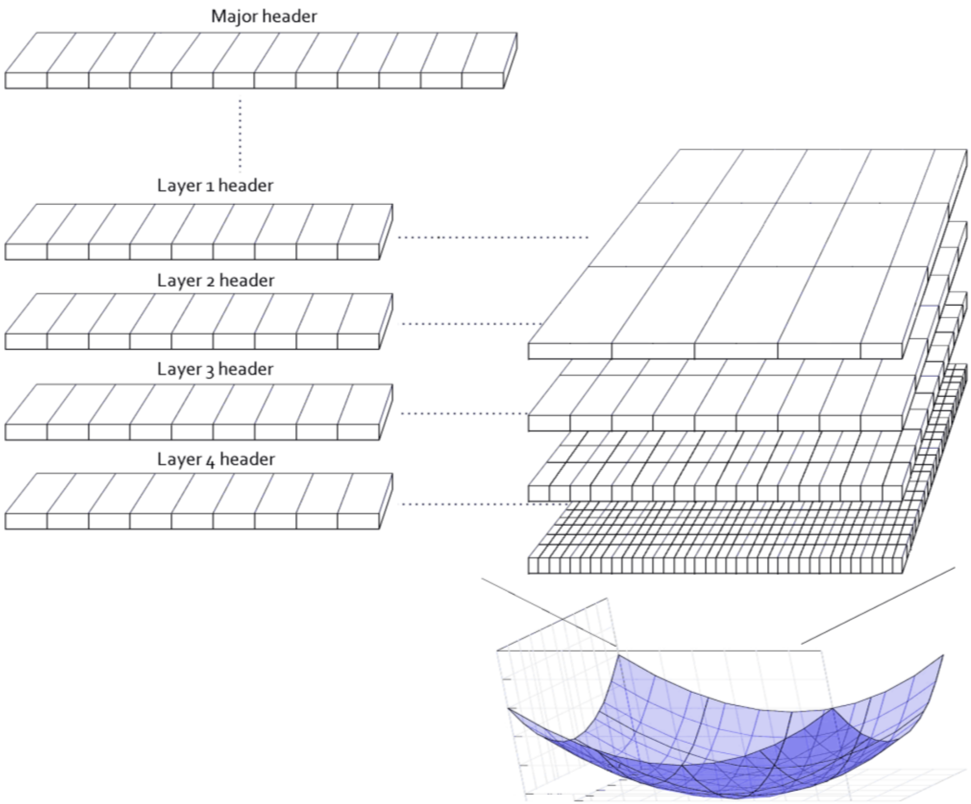


Fig. 1. Multilayer DTM scheme

a different compression factor for each layer of multilayer DTM (including no compression at all).

The most important properties of the multilayer structure are:

- storing of information about the seabed shape in several layers varying in accuracy (defined by the user);
- the possibility to define any number of layers with different parameters;
- the possibility to select the levels of mapping accuracy, for which the data are automatically generated;
- full flexibility of the model, tailored to the users' expectations;
- fast reading of data of a given accuracy;
- automated management of high resolution data;
- lossy compression of data stored within particular layers, resulting in significant reduction of data volume while preserving required model's accuracy;
- the possibility of defining compression ratio for each layer separately;
- the possibility of storing within a single structure the data coming from different measurements – storing historical data can facilitate the overview and the analysis of changes occurring within a given area.

In the course of the planned research the algorithms and data structures within the following domains should be developed:

- measurement data standardisation (into UTM ASCII);
- source data compression (of UTM ASCII files);
- measurement data filtration – removing coarse errors (within UTM files);
- measurement profiles smoothing as a method of increasing the accuracy of DTM creation;
- development of multilayer dynamic structure describing DTM – multilayer DTM;
- optimisation and modification of interpolation methods forming multilayer DTM;
- development of algorithms and structures of multilayer DTM files;
- development of a lossy compression method for multilayer DTM data (stored within a multilayer grid);
- development of fast DTM smoothing algorithms;
- development of fast multilayer grid visualisation.

The results of the above research will significantly extend the knowledge within the domain of geodata processing and may in the further future form the basis for the design and implementation of hydrographic data bank software, that could be used for storing and processing of all the data coming from sea surveys. The inception of such software would solve the problem of immense data volume gathered and stored by institutions having been performing the sea surveys for years.

## Research plan

The first stage should consist in acquiring and preparation measurement data required for the subsequent research and tests. Several sea surveys are planned to be performed, using the multibeam echosounder. These surveys will be performed in cooperation with Maritime Office in Szczecin or with the measurement vessel of the Maritime University of Szczecin (those are the institutions having the proper equipment at their disposal). The gathered data will be subject to pre-processing and recalculated into the proper data formats (ASCII UTM and GRID) using the Surfer and Matlab software.

In the second stage of research the author will propose a standard for survey data description (XYZ). Next, the measurement data will be analysed using algorithms for measurement data filtering. The filtering algorithms aim at removing the faulty measurements (while maintaining possibly lowest percentage of proper measurements removal). During these tests the optimal algorithms and solutions will be sought for. During this stage of research it is planned to develop a dedicated method for lossless compression of such kind of files (in order to reduce their size, which is important for systems storing huge numbers of them). The results of this work stage will contain the proposed standard of measurement data (XYZ) file in the UTM system, the conclusions regarding filtering algorithms effectiveness and the developed original compression system for such files. The research will be based on the data acquired in the first stage of work.

The third stage of research is of great significance. Based on the available knowledge, both contained in software and acquired from experts (hydrographs), the functional requirements will be developed for the data structures describing DTM of the seabed. Based on these requirements and available knowledge the scheme for multilayer DTM structures will be developed. The proper recognition of requirements and constraints will allow for creating useful data structures, which are the most important element of the proposed research.

The next stage of research is aimed at verification of the developed multilayer DTM structures. In order to do so, the structure along with a set of fundamental functions, procedures and methods will be implemented in a chosen programming language. The complete demonstration software solution will allow for performing many tests verifying the correctness of the design and implementation. The main result of this stage of research will be the demonstration software and the tests outcomes.

The fifth stage of research will consist in developing an original method for multilayer DTM structure data. The basic feature of this compression method will be locally adaptive compression factor, in order to achieve a highest possible compression ratio with the predetermined reconstruction accuracy (which is important due to the IHO regulations). The result of this research should be a full ready compression and reconstruction algorithm.

The last stage will comprise in searching for algorithms allowing for fast visualisation of the described kind of data, as well as in the additional tests (using real measurement data) aimed at checking the correctness of the developed solutions.

The research is interdisciplinary in nature, and it covers the issues within the areas of hydrography, geodesy and cartography, GIS and computer science.

## Methodology

For the tasks aimed at examining the accuracy of created DTM models (new methods of fast interpolation, methods of surface smoothing, increasing the precision of DTM models), the virtual sea survey simulator will be used, which was developed in 2010 at the Faculty of Computer Science and Information Technology [17]. The simulator allows for examination of the created seabed DTMs accuracy at the stage of measurement data acquisition (simulated sea survey with the multibeam echosounder device), as well as at its further processing (interpolation, smoothing, DTM compression).

Searching for faster interpolation methods will consist in modification of existing solutions (such as the moving average, invert distance to a power, kriging) and in optimal selection of input parameters for these methods (e.g. search radius, minimal number and distribution of node points, surface smoothing factor, and others). All the results obtained will also be checked for emerging errors, so that a given accuracy of models is preserved.

In the course of DTM structure development the knowledge and experience stemming from other similar solutions will be utilised (e.g. multilayerdness in vector maps, multilayerdness in 2D and 3D graphics, etc.). The presented structure and algorithms are completely novel in this domain, hence they will be tested empirically for fulfilment of requirements stated during development.

In the area of data compression new algorithms will be developed, suited for compression of data described by multilayer DTM structure. The algorithms will be verified using multiple models created from the actual measurement data, describing surfaces with varying shapes, and for varying assumed compression ratios. First of all, the main assumption of preserving the model reconstruction accuracy predefined by the user will be verified (after compression/decompression).

All the developed and optimised methods and structures will be tested by “practical activities”, i.e. by creating various seabed models based on actual measurement data and by verification of their operative correctness, especially regarding the accuracy of created models.

## Conclusions

The algorithms for lossy hydrographic data compression under development may bring a completely new approach (different than for example in computer graphics) to the reduction of information describing a given phenomenon. The main element of novelty in data compression is maintaining a predefined reconstruction accuracy (of the model). One might say, that the compression ratio is adapted in such a way, that the highest possible data reduction is achieved, while still allowing for model reconstruction at the predefined level. Such a solution will allow to guarantee a high precision for DTM models. The author has not come across such a solution to hydrographic data compression in the literature.

The proposed solutions allow for a different approach to solving the problem of the amount of data describing a given phenomenon and to the precision of created models. In the further future, they can also form the basis to modify hydrographic software and GIS systems. Implementing the developed structures and methods in that scope will allow for more effective management of huge amount of data describing larger sea areas. It will be possible to manage much larger areas, while maintaining a high precision of created models. The authors' plan for the further future include implementing demonstration software, presenting the possible applications of multilayer DTM structures.

The lossy data compression method under development (maintaining a predefined reconstruction accuracy) will allow for a significant reduction of data stored, which is highly desirable given the current huge amount of processed and stored data. This method can be also used in GIS systems in every case, where one must deal with big data matrices describing a given phenomenon.

The algorithms for speeding up the processing of measurement data in the process of DTM creation, as well as the algorithms for increasing the precision of created models, are the next step in improving the methods of creating seabed models and sea maps. Since in the sea navigation, and especially in inland navigation, the depth of a basin is one of the most important parameters influencing the safety, one can say, that the results of conducted research can improve the sailing safety significantly.

The research results can be significant for the domains, where the precision of seabed models is important, for example in oceanographic research, geology, hydrotechnics, military or tourism.

It should be noted and clearly stated, that in spite of the fact, that the proposed research deals with hydrographic data and methods for seabed surface modelling, the developed data structures and algorithms could be probably utilised (after proper verification) also to other kinds of data (e.g. land data). Looking at the issue from a broad perspective, the research outcome might be useful in processing and archiving of various kinds of geodata describing phenomena in the form of surface data in GIS systems.

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