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Comparison of Selected Reduction Methods of Bathymetric Data Obtained by Multibeam Echosounder

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***Abstract*—The publication presents a comparison of various methods to reduce datasets obtained by multibeam echo sounder. Data reduction is the process of minimizing the amount of data that needs to be stored in a data storage environment. Data reduction makes data easier and more effective for the purposes of the analysis. The authors decided to compare selected reduction method used in hydrography: GeoSwath Plus software and BathyDataBASE software. As the scale of the final product was applied 1: 2000. Selected parameters for each of the test methods have been adopted. After reduction of the points surfaces were created. In the next step these surfaces were compared and detailed analysis was conducted.**

***Keywords*— sonar measurements, reduction, data processing**

I. Introduction

Measurements of depth is a main task for a hydrographer, and should meet the standards recommended by IHO for accuracy and coverage as described in special publication S-44 5th Edition [1]. The most rigorous conditions for accuracy and coverage are on critical areas like berthing areas, harbors and critical areas of shipping channels [2].

Single beam echo sounders (SBES) are used in hydrographic surveying since the mid-1900s. During the last several years, the technology applied in SBES has progressively improved and SBES are still remain like common used system around the word.

Another modern systems - multibeam echo sounders (MBES) and airborne laser sounding systems (ALS) now provide almost full seafloor coverage and depth measurement. The very high density of data and large acquisition rates effected large bathymetric data volumes [1].

Interferometric sonar systems are the new way for bathymetric data collection with full seabed coverage. The principles of working interferometric sonar system are differs from MBES which forms a set of receive beams and performs seabed detection for each beam, either by amplitude or phase, to detect the returning signal across the swath [1].

An example of an interferometric systems is GeoSwath Plus which was used to data collection on hydrographic boat HYDROGRAF XXI.

According to producer's info [3] GeoSwath Plus offers broad swath bathymetry (up to 12 times the water depth) and additionally side scan seabed scanning with accuracies exceeded IHO S-44 Standard which is especially useful in shallow water environments.

Multibeam technologies have become a valuable tool for depth measurements when full seabed covering is required. Many National Hydrographic Offices (NHO) used MBES as a tools for the bathymetric data collection for new navigation chart production [1]. Aspects of MBES bathymetric data processing and Electronic Navigational Chart (ENC) production was discussed by several authors [4-15].

The general scheme of processing of bathymetric data is presented in Fig. 1.

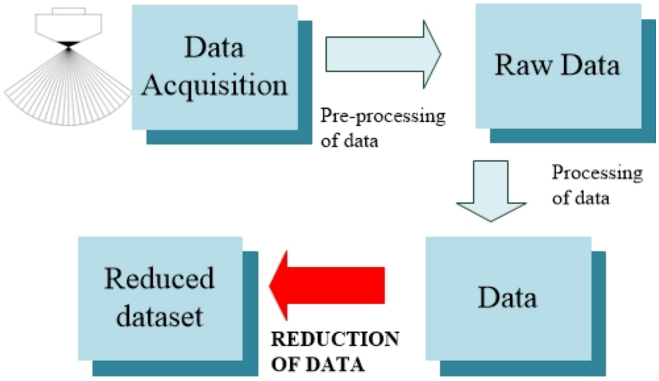

Fig. 1. General scheme of processing of bathymetric data.

II. Reduction of Data

Reduction of data is the process of data sets minimization that needs to be stored. Reduction makes data easier and more effective for the purposes of the analysis. The result of the reduction are selected from the set of initial points that meet certain criteria. A collection of original can be summarized as follows:

$$\{\boldsymbol{\Omega_j}\} = \bigcup_{i=1}^{n} \{\boldsymbol{P_i}(\boldsymbol{X_i}, \boldsymbol{Y_i}, \boldsymbol{Z_i}) : \boldsymbol{i} = \boldsymbol{1}, \boldsymbol{2}, \dots, \boldsymbol{n}\} \quad (1)$$

Reduced result dataset can take the form:

$$\{\boldsymbol{\Omega_j}\}_{\boldsymbol{R}} = \bigcup_{i=1}^{m} \{\boldsymbol{P_i}(\boldsymbol{X_i}, \boldsymbol{Y_i}, \boldsymbol{Z_i}) : \boldsymbol{i} = \boldsymbol{1_r}, \boldsymbol{2_r}, \dots, \boldsymbol{m}\} \quad (2)$$

provided that m <n, where:

n - number of collected points in the original dataset;

m - number of points in the reduced dataset;

$\{\Omega_j\}$- the original dataset;

$\{\Omega_j\}_R$- the reduced dataset; j = 1,2,…,N; N – number of datasets; P_i (X_i, Y_i, Z_i) - points of the dataset with their coordinates XYZ;

1_r,2_r - points of the reduced dataset.

One of reduction methods is to convert a big amount of samples into a single, common value.

From statistics, it can be found that single value are [16]:

- mode – the point that appears most often in a set of data;
- mean – the average: sum of the values divided by the number of values;
- median – the number separating the higher half of a data population from the lower half;
- nearest to mean – the point closest to the mean.

Next manner to data reduction is to use advanced statistical methods that make it possible to decrease the size of a dataset by breaking it down into basic factors, dimensions or concentrations, specifying the basic relations between the analyzed events and variables.

Another method is to remove a given quantity of instances from a large set, while maintaining its overall suitability for the analyzed population.

Frequently, hydrographic systems generate a GRID (based on "square" cells) by using means, weighted means or minimum value.

III. Selected method of reduction

The authors decided to compare selected reduction method used in hydrography. GeoSwath Plus software (further referred to as GS+) and BathyDataBASE (BDB) software (further referred to as BDB) were used. GS+ software is developed by GeoAcoustics and it is a part of hydrographic system. BDB software is produced by Caris and it use 3D Double Buffering method to reduce bathymetric data.

A. GS+

During data reduction the GS+ software uses GRID and it adapts the following methods to generate the grid [3]:

- minimum – the shallowest value of depth;
- maximum – the deepest value of depth;
- mean – the mean value of depth;
- weighted mean – uses amplitude values to give higher weighting to data points which are higher in amplitude when calculating the mean depth value;
- virtual – allows information on all data points in the swath files to be retained in each bin.

Subsequently, the resulting GRID can be subjected to filtration. One can resort to interpolation of the grid's empty spaces, define the depth value limits, set the X and Y components, and so forth. There is also the possibility to eliminate the spike from the grid.

The article focused on the reduction method, which is determined in the matrix size and center weight fields. It is based on the correlation procedure. The calculated grid value is computed based on adjoining values. Each adjoining value takes part in establishing the value of the grid after reduction as a percentage of its value – weight. The weights of particular values are registered in the form of a relevant matrix [17].

B. BathyDataBASE sofware

Reduction of data in BathyDataBASE (BDB) software is more complicated process. At the beginning the GRID is formed. During XYZ data import, BDB has the ability to choose which method you want to use when creating a GRID: basic weighted mean, TPU weighted mean, shallowest depth, shallowest depth true with position and point cloud. The next step is creating a TIN (Triangular Irregular Network). It is necessary to get the desired surface, which will then be subject of reduction. In subsequent step desired surface is created and it is subject to smoothing with using 3D Double Buffering method. In the course of its creation, the resolution and interpolation method (linear or natural neighbor) have to be selected.

3D Double buffering is similar to rolling a ball over the given surface at an interval determined by the surface's node resolution. Usually the radius of the ball is determined from the map scale (radius = 1/100 of map scale). As the ball is rolled over the surface, the surface is smoothed. The received surface is buffered again, this time in the opposite direction. The final surface is the surface after reduction [18].

IV. Testing of Selected Methods

Data used in the course of research was collected near the Babina canal within the Szczecin Harbor. The measurement points from this area were also used by the authors in the study related to processing of bathymetric data [19-21]. Because of its large volume XYZ data preparation for tests have been "clipped" to a smaller area. This area is visible on Fig. 2. The data is a collection of irregular and includes 1638170 samples with a specific geographic position and depth.

All data was collected and processed in Universal Transverse Mercator coordinate system. The tested values of depth are within the range from 4.00 meters to 9.11 meters. The mean value of depth in the tested area is 7.14 meters. The dimensions of the test area are 91 m x 146 m, giving 13286 m2.

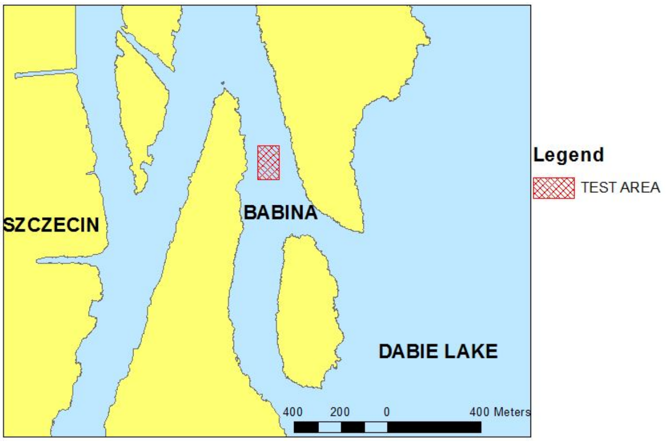

Fig. 2. Test area [21].

For research purposes, as the scale of the final product was adopted 1:2000. Having processed the measurement data during reduction using GS+ GRID file was created and submitted to further study. As a methods of generating a grid, the mean was used. The bin size value was set at 1 meter and additionally, the spike filter was set to 1 meter (default system setting). The GS+ system's main parameters associated with the process of reduction are matrix size and center weight. The default values are respectively 3 and 8 and these values have been adopted for tests. The filter matrix size is 3x3 and its central value is suitably weighted.

During reduction of data using BDB, in first step point cloud was imported to Caris software. The theme of the publication is to explore methods of reduction, so the authors wanted to avoid unnecessary data interpolation. Then TIN was built and with it the final surface has been created. In the middle of it the method of linear interpolation and resolution equal to 1m were implemented. The next stage of research was reduction process of resultant surface using 3D Double Buffering method. At this stage, the scale of final hydrographic product has been determined and – according to the operation method – radius of the circle and the resolution. The authors have adopted the following parameters: radius of the circle equal 20 meters and the resolution equals 1 meter. Authors assumed to use the precision of two decimal places.

V. Results

After reduction in selected systems two different GRIDs were obtained and each is consisted of miscellaneous dataset. It should be noted that in these GRIDs, geographical positions X and Y are shifted by half a meter to each other. Tab. 1 shows a summary of statistics for received sets of samples.

TABLE I. COMPARISON OF STATISTICS FOR GS+ AND BDB

	GS+	BDB
Number if points	13506	13761
Minimum depth [m]	4.27	4.29
Maximum depth [m]	8.71	8.66
Range [m]	4.44	4.37
Mean depth [m]	7.121819	7.023564
Standard Deviation	0.780642	0.78488
Volume [m3]	94714.27	95073.40

Using the BDB method received 255 samples more than using GS+ method. The distances between individual points is 1 meter, so difference in the amount of samples is connected with points located close to the boundary of test area. The minimum values of depth differ from each other only about 2 centimeters. While the difference in the maximum depths is 5 centimeters and for GS+ it is greater than for BDB. The mean depth for GS+ is greater than for BDB. Standard deviation is at a similar level. The last position in the table is volume. It is calculated for the level of water (taken 0). For GS+ volume is smaller than for BDB and the difference is about 360 cubic meters. Fig. 3 presents frequency distribution for received datasets.

The horizontal axis shows the value of frequency distribution and the vertical axis represents the number of samples. The diagrams differ from each other. The frequency distribution for GS+ is more regular, while for BDB it can be seen, that a large number of points has a depth of 7 meters.

The next step was the visualization of the results in the form of TIN. ArcGIS software with ArcMap application was used. Fig. 4 presents visualization of obtained surfaces. If the color is brighter the received depth in this area is greater. It should be noted that surface received using BDB method is smoother

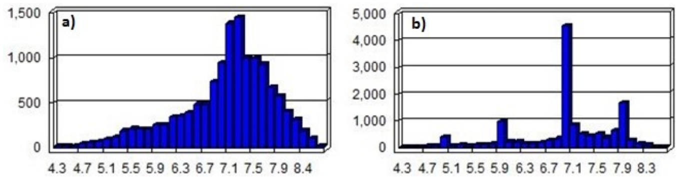

Fig. 3. Frequency distribution for a) GS+ and b) BDB.

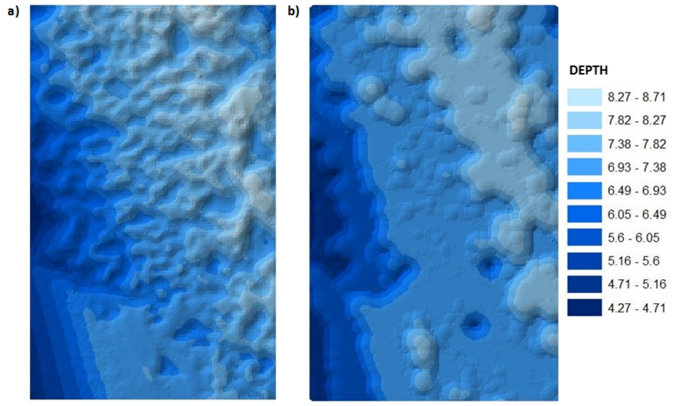

Fig. 4. Visualization of surfaces for a) GS+ and b) BDB.

Subsequently received surfaces were compared to give surface difference as TIN. Its values represent the difference between the input and reference surface. The input is surface whose relative displacement is being evaluated from the reference surface and as it adopted surfaces from GS+. The reference surface is surface that is used as the baseline for determining the relative displacement of the input surface. As it applied surfaces from BDB. Fig. 5 shows surface difference as TIN. The differences comprise in the range from +0.82 meter to -0.77 meter.

Additionally, displacement between two surfaces was calculated. The output feature class is shown in Fig. 6. It is polygon features that separate regions of the input surface by whether they are above, below or the same as the reference plane.

The received feature has the following attributes:

- code – value that describes the spatial relationship of the input surface to the reference surface; 1 characterizes the surface is above the reference surface (blue color in the Fig.6), -1 characterizes the surface is below the reference surface (green color in the Fig.6) and 0 characterizes the surface is the same as the reference surface (red color in the Fig.6);
- area – surface area that is bounded by the polygon; for the above regions it equal 8951.60 m2, for the below regions it equal 4433.25 m2 and for the same regions it equal 0.13 m2 .
- volume – volume of space between the input and reference surface that is bounded by the polygon; for the above regions it equal 1998.57 m3, for the below regions it equal 790.26 m3.

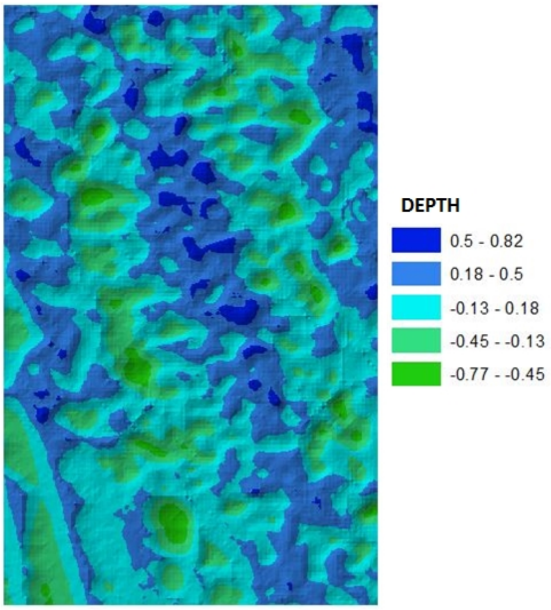

Fig. 5. Surface difference as TIN.

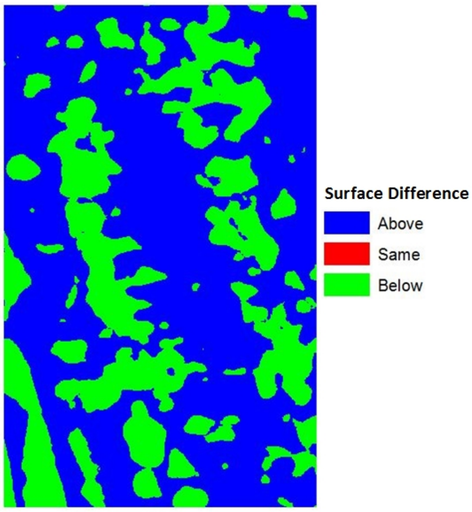

Fig. 6. Surface difference.

VI. Conclusions

Based on the observations it can be concluded that the results of reduction methods are varied. The geographical positions X and Y of obtained GRIDS are shifted by half a meter to each other. The minimum values of depth differ from each other only about 2 centimeters. While the difference in the maximum depths is 5 centimeters. However, given the visualization of surfaces a significant difference can be noticed. The difference in volume is about 360 cubic meters. After comparing the obtained surface the differences comprise in the range from +0.82 meter to -0.77 meter. All results meet the requirements of international standards but it should be noted, that minimum depth of raw data is about 30 centimeters less than data after reduction of selected methods.

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