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**TEST RESULTS OF BATHYMETRIC DATA  
PROCESSING OBTAINED  
BY SWATH SOUNDER GS+**

**ABSTRACT**

A navigational chart is the primary source of information for the navigator. The main component that contributes significantly to the safety of navigation is the information on the depth of the area. A sonar, which uses acoustic waves is a device for bathymetric measurements and it measures the vertical distance between the head and the bottom or an object located at the bottom. For the purposes of the article, data was used from an interferometric sonar, which is a modification of a multi-beam sonar. Due to the very wide operating angle, it allows for simultaneous vertical data collection, similar to a typical multi-beam sonar, as well as horizontal data collection, much like a sidescan sonar. Bathymetric data is obtained not only on the basis of measurement of time, in which the acoustic wave reflected from the object returns to the receiving transducer, but also by measuring the difference between phases of the wave reaching the piezoelectric elements within a head. The paper presents the test result of bathymetric data processing obtained by the swath sonar GeoSwath+, which is trademark of GeoAcoustics. Data collected during the acquisition was subjected to filtration. For the purpose of the article, the authors used pre-filtered measurement data collected in the area of the Port of Szczecin. However, the filtered samples are large sets of data. Data reduction is a procedure meant to reduce the size of a data set to make it easier and more effective to analyze. This paper examines the capabilities of the GS+ software in the scope of reduced bathymetric data after filtration. The results of different settings are presented in the form of grids, which were then exported to the Surfer 10 software and subjected to detailed analysis.

Keywords:

hydrography, multibeam sonar, data processing.

## INTRODUCTION

The sonar is a device used to measure the vertical distance between the head of the sonar and the sea bed, or an object located on the sea bed, using an acoustic wave. Speaking in broader terms, establishing the depth of water is achieved by measuring the time in which the acoustic wave needs to reach the bottom or an object, as well as to return to the receiving transducer as a reflected wave. In order to obtain a full measurement, one also needs to know the speed at which sound travels through water, as well as the direction in which the impulse was sent, and from which it returns. The angle measurement is carried out in various manners, depending on the type of the sonar.

The simplest example of a sonar is the single beam sonar, also known as the echosounder. It operates by sending a narrow acoustic signal beam from the antenna vertically downwards. In order to increase the efficiency and effectiveness of the measurement, one should use a multi-beam sonar, in which a single antenna emits several signal beams in multiple directions, monitoring in all these directions. This solution allows for a much wider area of measurement, when compared to a single beam sonar, by increasing the width of the scanning zone.

A specific modification of the multi-beam sonar is the interferometric sonar. Due to the extremely wide angle of measurement, it allows to simultaneously collect vertical data (much like a standard multi-beam sonar), as well as horizontal data (like a lateral sonar). The depth data is received not only based on the measurement of time in which the acoustic wave reflected off the object returns to the receiving transducer, but also based on measuring the difference between phases of the wave reaching the piezoelectric sensors installed within the head. Knowing the location and orientation of the head, as well as the time it takes for the signal to travel and the phase difference, it is possible to pinpoint the locations of multiple points in a wide angle spectrum. The head of the interferometric sonar is comprised of two elements, aimed at opposite directions, equipped with an emitter located in the bottom part, as well as several piezoelectric receiving sensors located above. Both elements of the head are fixed at a  $30^\circ$  angle to the horizontal surface, in the shape of the letter V. The device is set with the transducers aimed at the opposite sides of the research vessel. The impulse emitted from the transmitting antenna has a very wide angle profile across and along the very narrow (about  $1^\circ$ ). The measurement of phase difference of the reflected signal for that impulse allows to precisely determine the direction of the incoming echo, while the measurement of time allows to establish depth. Additionally, the amplitude of the returning signal is also measured, giving us a sonar image [1].

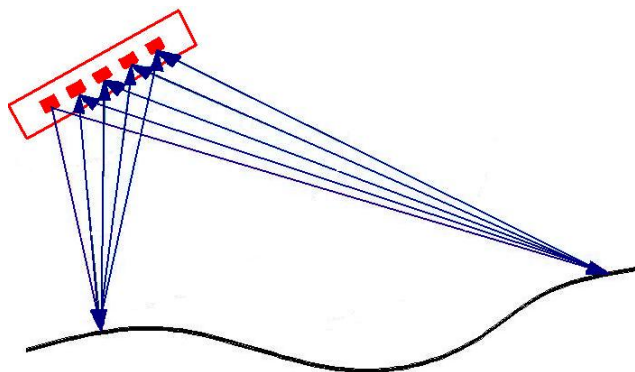


Fig. 1. The concept of interferometric sonar functionality

Source: own study.

The solution allows to simultaneously monitor a wide spectrum of a 240° angle and a length of 390 m (depending on the depth of water).

The basic instrument for the measurement system for the Hydrograf XXI research unit used at the Maritime University of Szczecin is the GeoSwath+ interferometric sonar, including the accompanying research and navigational software. It allows to simultaneously carry out bathymetric measurements and lateral scans of the bottom with the precision meeting the requirements of the IHO (International Hydrographic Organization). For bathymetric measurements, the device uses the signal phase measuring technique and provides a monitoring width up to 12 times bigger than the depth of water. The sonar is perfect for shallow water measurement.



Fig. 2. The head of the GeoSwatch+ sonar

Source: GeoAcoustics.

The S-44 (Standards for Hydrographic Survey) standard, issued by the IHO, is a global standard, encompassing the requirements regarding hydrographical operations. The precision of the collected data depends on the category of the navigational area. For the purposes of the article, requirements for the special category have been adopted. It is worth noting that the precision of positioning and depth measurement must meet the confidence level of 0.95 [3].

### **PROCESSING OF BATHYMETRIC DATA**

When performing operations connected to establishing the geological layout of the sea bed and the locations of underwater objects, one needs to take numerous factors into consideration, mostly related to the measurement unit properties, as well as hydrology and meteorology. These are crucial factors when it comes to the quality and precision of the gathered data, which is only useful when properly processed. All registered information are stored as raw data, registered in limited storage mode. This means that any corrections made to the data are saved as supplementary files. Changing the parameters only influences the supplementary files, while the source data is not modified [2].

One of the issues connected to bathymetric measurements is registering an abundant amount of data, as well as various types of interference. Bathymetric data processing is realized in several stages. First off, all values of corrections influencing the accuracy of the measurement are taken into consideration, such as: water properties, head submersion, errors in the average speed of sound in water and erroneous offset inputs in the measurement devices. Subsequently, the system operator performs the initial rough filtration, using predefined data processing filters. Applying filters is a process dependant on the given measurement session. Values assigned to filters must be applied each time with caution, having previously analyzed the measurement conditions and the expected results. The filters are applied to large portions of the material and their automatic appliance must be double-checked by the user subjectively, in regards to the true measurement quality.

Contemporary measurement systems offer a wide range of semi-automatic tools for the initial data filtration. The solution is based on a range of algorithms, for which one needs to define the proper attributes, so as to use them for the entire data package. In concordance with the S-44 standard, having processed the data automatically, an experienced hydrographer should review and approve the results, resolving any occurring ambiguities. One needs to remember that utilizing this solution requires caution and considerable amount of practice [3].

Imprecise processing of the collected data or invalid filter settings can result in the rod (the long, thin element) being ejected from the bottom, among other possible complications. This may result in creating a threat to the safety of navigation. Bathymetric data processing can also be a secondary source of generating further errors, lowering the quality of the results. The proper filtration of data is a process demanding care and attention, as the hydrographer needs to be aware of the potential hazards.

As was previously mentioned, before the acquired data is registered as raw data, it undergoes initial filtration. The data acquired through peripheral devices can be filtered as well, in order to assure its validity. In order to use them to create a three-dimensional grid model of the bottom, they need to be processed. The first stage of processing is to convert the raw data into files serving as a framework for the grid ('swath' files). There are four basic types of filters used to process data: the amplitude filter, the limit filter, the across track filter and the along track filter. The first filter sets amplitude below and above which all points are rejected. The second filter sets limits of data. The across track filter allows the determination of the area running across the profile — all data outside are rejected. This is a learning filter uses a percentage of the previous ping to guide the filtering of the new ping. The along track filter finds a mean of the data within each specified step and defines a depth box either side of this mean as set up in the controls. If properly applied, the combination of these filters guarantees the optimal size and content of the files serving as a base for the grid.

Having properly processed the data, one can use it to create grids. It is worth noting that the filtered samples are large sets of data. Data reduction is a procedure meant to reduce the size of the data set, in order to make them easier and more effective for the purposes of the analysis. There are several ways to perform data reduction. One can use advanced statistical methods, that will make it possible to decrease the size of a data pack by breaking it down into basic factors, dimensions or concentrations, pinpointing the basic relations between the analyzed instances and variables. Another way to reduce data is to transform a large quantity of variables into a single, common value. Yet another method is to deduct a given number of instances from a large array, while maintaining its overall suitability for the analyzed population. The GS+ system uses the following methods to generate the grid: mean (select a mean depth value), weighted mean (uses amplitude values to give higher weighting to data points which are higher in amplitude when calculating the mean depth value), minimum (select the shallowest value), maximum (select the deepest value) and virtual (allows information on all data points in the swath files to be retained in each bin). It is important for the precision of the results to properly determine the processing criteria, as well as to properly choose the construction parameters of a given structure.

### GRID FILTRATION IN GS+

Having processed the measurement data, a 'grid' file was created and submitted to further study. The GS+ system encompasses several methods of generating a grid: mean, weighted mean, minimum, maximum and virtual. For research purposes, the mean and virtual methods were used, which allow to retain all information concerning each depth value in the bin. At the same time, one can input the bin size value, set at 1 meter for the purposes of the article.

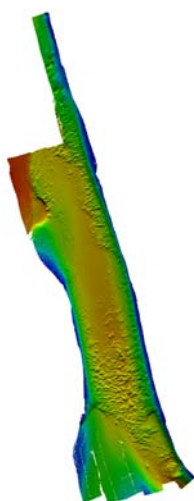


Fig. 3. The grid used for the study

Source: own study.

The resulting grid can subsequently be submitted 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 remove the spike from the grid. All possible filtration options for the grid has been displayed on the image below.

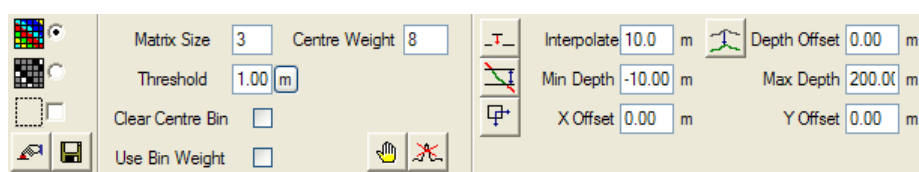


Fig. 4. Grid filtration options in GS+

Source: own study.

The article focused on the grid smoothing option, determined in the matrix size and centre weight fields. Additionally, for all analyzed grids, the spike filter was set to 1 meter (default system setting). The GS+ system's default values are: matrix size 3 and centre weight 8. The values used for the study are shown in table 1.

Table 1. Smoothing values used for the study

GRID	1	2	3	4	5	6	7	8	9	10
MATRIX SIZE	3	1	5	5	5	9	9	9	21	21
CENTRE WEIGHT	8	8	1	5	10	1	5	10	5	10

Source: own study.

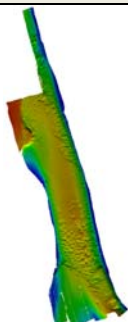
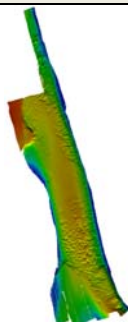
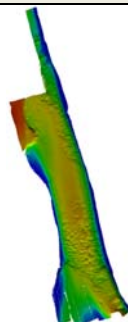
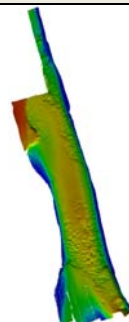
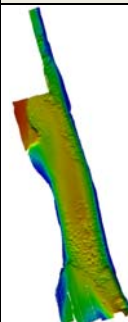
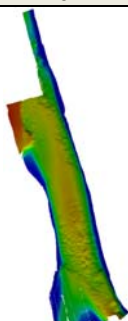
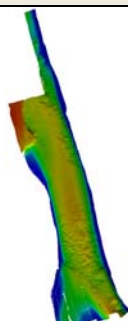
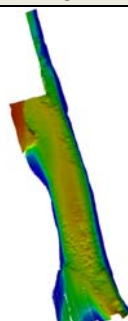
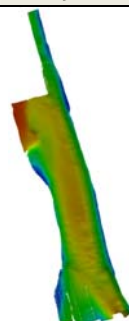
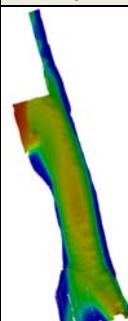
As was previously mentioned, when generating the grid, the virtual method was used, which, upon exporting the grid into ASCII format, yielded the following values:

- mean — bin values set to mean depth;
- weighted mean — bin values set to the weighted mean of each bin;
- minimum — bin values set to minimum depth;
- maximum — bin values set to maximum depth;
- mode — bin values set to mode values of each bin;
- range — bin values set to the depth range in each bin;
- standard deviation — bin values set to standard deviation of each bin;
- standard error — bin values set to standard error of each bin;
- population — bin values set to population of each bin.

#### **ANALYSIS OF GRID FILTRATION PARAMETERS BASED ON TANGIBLE DATA**

The analysis of grid filtration parameters was performed on the basis of samples collected within the Szczecin Harbor, near the Babina canal, on May 23, 2010. The grid model was generated based on the values given in table 1. The resulting differences between the grid area yielded the statistics presented in the table below. The study was carried out for the mean values (bin values set to mean depth). The article focused solely on the smoothing option.

Table 2. Comparison results for the grid generated using the set filter smoothening settings

<b>GRID</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>
Graphical representation of grid					
Minimum	-0.986 m	-3.051 m	-2.100 m	-2.118 m	1.806 m
Maximum	0.911 m	1.348 m	5.068 m	4.371 m	3.790 m
Range	1.897 m	4.399 m	7.168 m	6.489 m	5.596 m
Mean	-0.000 m	-0.000 m	-0.000 m	-0.000 m	-0.000 m
Mode (value occurs most frequently)	0.000 m	0.000 m	0.000 m	0.000 m	0.000 m
Standard Deviation	0.027 m	0.000 m	0.086 m	0.072 m	0.059 m
Standard Error	0.000 m	0.000 m	0.000 m	0.000 m	0.000 m
<b>GRID</b>	<b>6</b>	<b>7</b>	<b>8</b>	<b>9</b>	<b>10</b>
Graphical representation of grid					
Minimum	-2.269 m	-2.122 m	-1.989 m	-3.375 m	-4.159 m
Maximum	4.982 m	4.914 m	4.745 m	4.144 m	4.299 m
Range	7.252 m	7.036 m	6.735 m	7.519 m	8.457 m
Mean	-0.003 m	-0.002 m	-0.002 m	-0.014 m	-0.024 m
Mode (value occurs most frequently)	0.000 m	0.000 m	0.000 m	0.020 m	0.020 m
Standard Deviation	0.144 m	0.134 m	0.123 m	0.336 m	0.359 m
Standard Error	0.000 m	0.000 m	0.000 m	0.001 m	0.001 m

Source: own study.

Having analyzed the resulting statistics, one can conclude that with the matrix size set to 1, no changes in the grid were observed. This leads to an assumption that



using this filter results in the original grid. Intuitively, one could assume that, should the matrix size value be increased, the resulting grid will be more smoothed. The standard deviation increases with the increased matrix size values. At the same time, one can note that for larger values of centre weight (while retaining the same matrix size) standard deviation decreases. It is worth remembering that the standard deviation informs us how widely the depth values are distributed around the average.

After the initial analysis, the grid generated on the basis of the given filter settings was exported into ASCII format and opened with the Surfer10 software. There, the grid was compared with the grid model, arriving at a detailed analysis of the smoothing method used in the GS+ software. Having extensively studied the working principle of the filter, the authors reached the conclusions, presented in the latter part of the article.

First of all, it's worth noting that, during the GS+ smoothing, the following filter path direction was used to calculate the new grid value: from the upper left corner to the right. This was shown on the image below.

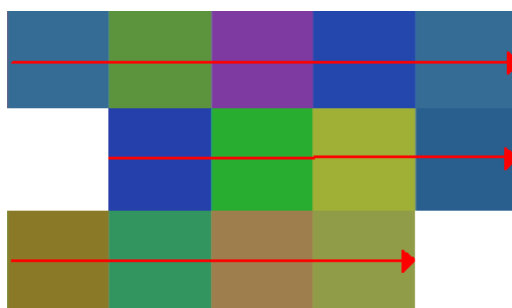


Fig. 5. The direction of the smoothing filter path

Source: own study.

Another important conclusion is that, when determining a new grid value, both pre-calculated values ('rear' values) and original values ('forward' values) are used. The above is pictured on Image 6.

The smoothing option within the GS+ software is based on the correlation procedure. The new grid value is calculated based on adjacent values. Each adjacent value takes part in establishing the value of the smoothed grid as a percentage of its value — weight [4]. The weights of individual values are registered in the form of an appropriate matrix. For the purpose of the article, each element of the filter matrix was named a filter factor. All in all, one could say that the filter is defined as a matrix comprised of factors  $F(i, j)$ .

The application of the smoothening option will be discussed in detail on the example of default settings, namely: matrix size 3 and centre weight 8.

The filter matrix size is 3 x 3 and is set centrally to the analyzed grid value. As was previously mentioned, it uses both pre-calculated and original values, according to the path direction.

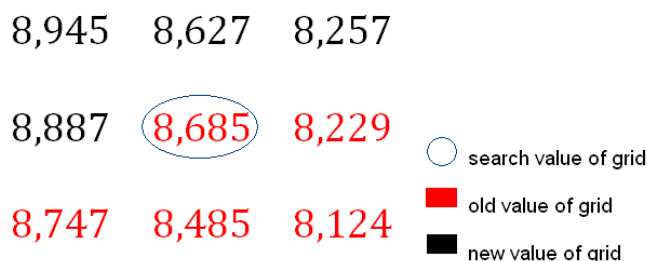


Fig. 6. Examples of values adopted for calculations on a 3 x 3 matrix

Source: own study.

The central value is suitably weighted, according to the operator’s presumptions. It is worth noting that with the centre weight larger than 1, the central value of the old grid value has a more profound impact on the processed value. Additionally, each adjacent value affects the desired final value, which can be expressed as the following formula:

$$\text{New\_Value\_G} = \left[ \frac{\sum G(x, y) * F(i, j)}{\sum F(i, j)} \right]$$

where:

New\_Value\_G — the desired final value of the grid post-filtration;

G — subsequent value of the grid;

F — subsequent value of the grid factor.

This operation is repeated separately for each grid value. In the discussed instance, the matrix size is 3, while the centre weight is 8. In general, the smoothening filter in the GS+ software is defined as a matrix comprised of specific factors  $F(i, j)$ .

$$F = \begin{matrix} F_{i-1,j+1} & F_{i,j+1} & F_{i+1,j+1} & 1 & 1 & 1 \\ F_{i-1,j} & F_{i,j} & F_{i+1,j} & 1 & 8 & 1 \\ F_{i-1,j-1} & F_{i,j-1} & F_{i+1,j-1} & 1 & 1 & 1 \end{matrix}$$

$$\sum F(i, j) = 16$$

The new value of the grid will depend on the old (central) one, as well as the eight adjacent values. With the centre weight equal to 8, the role of the central point becomes more important.

$$\text{New\_Value\_}G = [(G_{x-1,y+1} * 1) + (G_{x,y+1} * 1) + (G_{x+1,y+1} * 1) + (G_{x-1,y} * 1) + (G_{x,y} * 8) + (G_{x+1,y} * 1) + (G_{x-1,y-1} * 1) + (G_{x,y-1} * 1) + (G_{x+1,y-1} * 1)]/16$$

$$\begin{bmatrix} 8,945 & 8,629 & 8,257 \\ 8,887 & 8,685 & 8,229 \\ 8,747 & 8,485 & 8,124 \end{bmatrix} * \begin{bmatrix} 1 & 1 & 1 \\ 1 & 8 & 1 \\ 1 & 1 & 1 \end{bmatrix} = \textcircled{8,618}$$

Fig. 7. Example of filter use for matrix size 3 and centre weight 8

Source: own study.

It has been assumed that when the sum of filter factor values equals 0, the value used for the calculations is always 1.

One can intuitively observe that, should the matrix size be increased, thus enhancing the matrix, the grid will be smoothed to a larger extent than when using a 3 x 3 grid. If we assume the matrix size of 1, we will arrive at the initial grid. Only the central value of the old grid will be taken into consideration for the purposes of the calculations.

In cases when the centre weight will be set to 0, the central point will not be taken into account — only the environment will be considered.

A filter of the matrix size equal to 21 (a 21 x 21 matrix) was used for research purposes only. Enlarging the matrix to such an extent results in substantial smoothing of the studied area. Using such a filter is only feasible with large-scale charts.

Depending on the used matrix size, the GS+ software provides slightly rounded smoothing results. These approximations are measured in centimeters. The interferometric sonar has the accuracy of 8 cm, so this has little impact on the results.

## SUMMARY

The grid smoothing filter in the GS+ software operates on the principle of correlation. The new grid value is calculated based on the adjacent values. Each

adjacent value affects the calculations of the smoothed grid as a percentage of its value — the inputted centre weight value. It is worth noting that the centre weighting value indicates how much the new value is weighted towards the centre value in the window. What is more, a centre weight value smaller than 1, the central value of the old grid affects the processed value to a more significant extent. Should the matrix size value be increased, thus enlarging the matrix, then the grid will be smoothed to a larger extent than when using a smaller matrix. It is pointless to use a matrix size value of 1, as it will yield the initial grid as a result. Only the central value of the old grid will contribute to the filtration results.

The smoothing filter removes slight variations of depth and smoothens the grid. However, the filter also has a certain disadvantage. Namely, it blurs the contours of objects and lowers the sharpness of shapes. There is also the potential risk of smoothing a navigational obstacle, which might prove a potential threat to navigation. That is why the selection of filter parameters depends on the function of the generated grid. The target use and location of the grid is a crucial factor. Setting up the filter properly, in concordance with established regulations and the developer's guidelines, guarantees the validity of the grid generated from the collected geodata.

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## **WYNIKI TESTÓW PRZETWARZANIA DANYCH BATYMETRYCZNYCH UZYSKANYCH Z SONDY GS+**

### **STRESZCZENIE**

Mapa nawigacyjna jest głównym źródłem informacji dla nawigatora. Zasadniczym elementem, który wpływa na bezpieczeństwo nawigacji, jest informacja odnosząca się do głębokości morza. Urządzeniem do pomiarów batymetrycznych jest sonar. Mierzy pionową odległość pomiędzy przetwornikiem a dnem lub obiektem umieszczonym na dnie. Dla celów tego artykułu wykorzystano dane z sonaru interferometrycznego, który jest modyfikacją sonaru wielowiązkowego. Dzięki szerokiemu kątowemu operacyjnemu pozwala on na symultaniczne zbieranie danych pionowych, podobnie jak typowy wielowiązkowy sonar, oraz danych poziomych, podobnie jak sonar boczny. Dane batymetryczne są uzyskiwane nie tylko na podstawie pomiaru czasu, lecz także poprzez mierzenie różnic fazowych pomiędzy elementami piezoelektrycznymi w przetworniku. Artykuł prezentuje przetwarzanie testowych danych batymetrycznych uzyskanych przez sonar GeoSwath+. Autorzy wykorzystali uprzednio przefiltrowane dane pomiarowe zebrane w rejonie Portu Szczecin. Ponieważ przefiltrowane próbki są dużymi zbiorami danych, poddano je redukcji, czyli procedurze zmniejszenia wielkości zbioru danych, aby łatwiej i efektywniej je analizować. Niniejszy artykuł bada

możliwości sondy GS+ w zakresie zredukowanych danych batymetrycznych po filtracji. Wyniki różnych zestawień zostały zaprezentowane w formie siatek, które następnie eksportowano do programu Surfer 10 i poddawano szczegółowej analizie.

Słowa kluczowe:

hydrografia, sonar, przetwarzanie danych.