Wojciech MALEIKA

West Pomeranian University of Technology, Szczecin

Development of a Method for the Estimation of Multibeam Echosounder Measurement Accuracy

Abstract. *This article presents a method developed for the estimation of measurement error values (and their distribution) that occur in the process of marine sounding by a multibeam echosounder. The method, based on real data obtained in a specific marine environment, yields much more precise information on measuring instrument accuracy. The author also describes research done on a test set of more than 280 million measurement points covering an area of 20 km^2. The obtained results are presented and interpreted.*

Streszczenie. *W artykule przedstawiono opracowaną metodę szacowania wartości błędów pomiaru (oraz ich rozkładu) powstających w procesie sondażu morskiego z wykorzystaniem echosondy wielowiązkowej. Metoda ta bazując na rzeczywistych danych uzyskanych w określonym środowisku morskim i daje dużo precyzyjniejsze informacje o dokładności pomiarowej urządzenia. W artykule opisano także badania jakie wykonano na zbiorze testowym ponad 280 mln punktów pomiarowych z obszaru 20 km^2. Otrzymane wyniki zaprezentowano i zinterpretowano.*
(Opracowanie metody umożliwiającej szacowanie dokładności pomiarowej echosondy wielowiązkowej.)

Keywords: digital terrain model, multibeam echosounder, measurement error, hydrographic survey.
Słowa kluczowe: cyfrowy model terenu, echosonda wielowiązkowa, błąd pomiarowy, sondaż morski.

Introduction

Operations in water areas connected with seaborne transport and those aimed at the exploration of the seabed and resources underneath create a demand for detailed spatial information, particularly bathymetric data. This information is often visualized and processed by geoinformatic tools, which enables a variety of comprehensive analyses. Contrary to land areas, where survey methods or global positioning systems can be used to determine the elevation of any point with high accuracy, depth measurement still remains less accurate and more expensive. Besides, in many areas depth figures quickly get outdated due to constant changes in the seabed relief [3].

At present, one of the most effective and accurate methods of depth measurement is the sounding with a multibeam echosounder, which is capable of obtaining a set of sounding points covering a strip of bottom along the so called profile or survey vessel's route. The mapping of a seabed area by a multibeam echosounder generally requires a very large dataset of points that are characterized by irregular spatial distribution. On this basis, spatial models are created, described in ordered data structures such as TIN (triangulated irregular network) and GRID (regular square net), known as digital terrain models (DTM) [8,9].

The importance of accuracy in seabed modelling

The most important parameter in the process of creating seabed models is its accuracy expressed as an error, i.e. depth difference between each point in the created model and the real depth at each point. All sounding work and the subsequent creation of a DTM should by done in such a way so as to get the maximum accuracy of the error estimation, thus the accuracy of the created model [10].

The total modelling error is affected by individual errors made in each stage of data collection and processing, i.e.:

- depth readout error made by a measuring device (depending on depth, type of seabed, device model – essential but difficult to estimate) [1],
- errors due to assumed sounding parameters (vessel speed, arrangement of profiles, multibeam echosounder parameters (difficult to estimate and usually neglected) [2, 4],
- position determination error (depends on the positioning system),
- errors occurring in the DTM process [5].

The necessity to estimate the total error of the created model results from the requirement of assuring high reliability of maps, and the maxiumum allowable error values are specified by regulations of the International Hydrographic Organization (IHO) in the S-44 publication "IHO standards for hydrographic surveys" [6].

The use of advanced numerical algorithms enables both effective data processing (essential due to a large quantity of data) and high quality of DTM modelling and analysis. The main problem encountered in this work is that accuracy cannot be precisely estimated. This refers to the measurement data and the further stage of modelling and results from the fact that we do not know the actual relief of the surveyed seabed surface, consequently we cannot compare the created model with the original terrain surface. In practice accuracy estimation comes down to approximate estimation, then the errors from each stage are summed up. It is generally assumed that the depth error corresponds to the accuracy of the measuring device, indicated by its manufacturer. Unfortunately, manufacturers only provide an averaged value, mainly as the root mean square error (RMS). This value does not reveal the actual distribution of errors that, as can be expected, depend on a number of factors, such as the depth at the measurement location, value of the beam angle (angle between the beam ray and the vertical line), type of seabed, measurement frequency, type of device etc. Practical measurements show that the error of the measuring device accounts for the greater part of total error in the whole process of digital terrain modelling.

The ability to estimate the measurement error of a multibeam echosounder for specific soundings will allow to more precisely estimate overall accuracy of DTM created on the basis of these soundings. The proposed method, therefore, can be used in the future by institutions and companies involved in sea soundings using a multibeam echosounder. Higher accuracy of sea charts and digital models will contribute to navigational safety.

Introduction to the method

The method consists of a few main stages:

- entering measurement data, and separating successive measurement lines,
- assessment of a measurement line – correct / incorrect,
- for correct measurement lines – determination of a theoretical seabed profile in that place,

- for all points in a measurement line – calculation of errors understood as a difference between measured depth and corresponding value in the theoretical profile; additionally, calculation of beam (ray) angle,
- grouping of the error depending on beam angle and depth value,
- after measurement data processing, calculation of average values and standard deviations for each group.

Figure 1 presents schematically the proposed method.

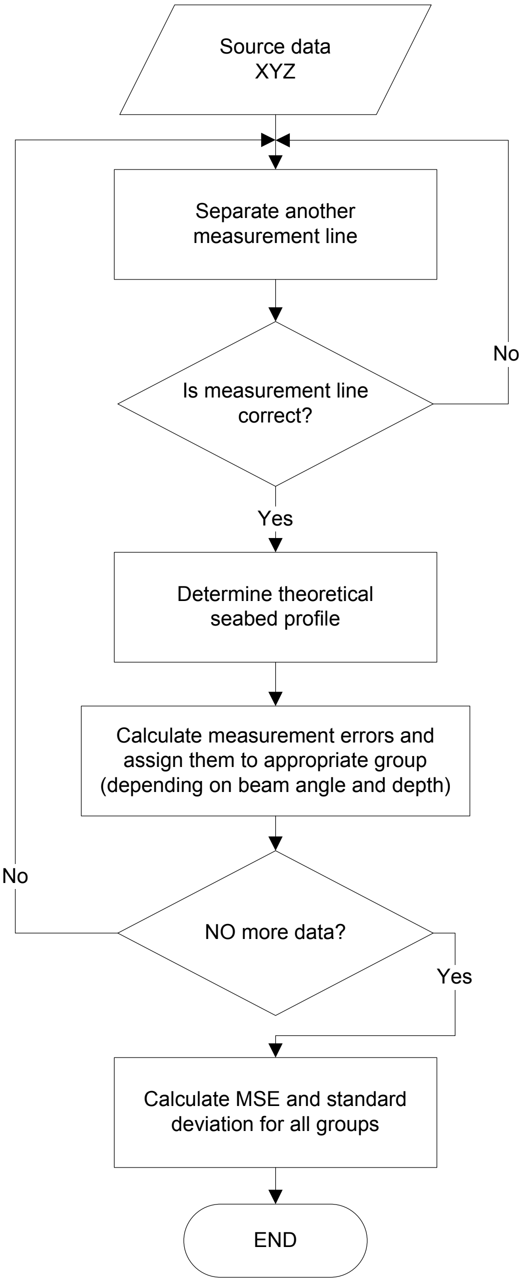

Fig. 1. Schematic diagram of the proposed method

Description of source data

In the first phase of the process of creating a seabed model sea soundings are performed. The result is a set of measurement points (mostly in the XYZ format - longitude, latitude and depth). These points are not uniformly distributed in space and consist of the so called profiles (measurement strips overlapping with vessel route), and each profile is composed of successive measurement lines (during one measurement the echosounder reads out 80 to 130 measurement points lying on a straight line perpendicular to vessel's track). The angle between a straight line connecting a measurement point with the echosounder head and a vertical line is referred to as the beam angle. The larger maximum allowable beam angle is, the broader measurement strip is, and so is the distance between measurement points on both ends of a measurement line. By increasing the maximum beam angle we can accelerate the process of measurement data collection (we record data of a wider strip making fewer profiles). Such approach negatively affects the accuracy of the created model, as points for which the beam angle is large are burdened with a larger measurement error (in reference to depth and position). An example distribution of a measurement data portion is presented in Figure 3.

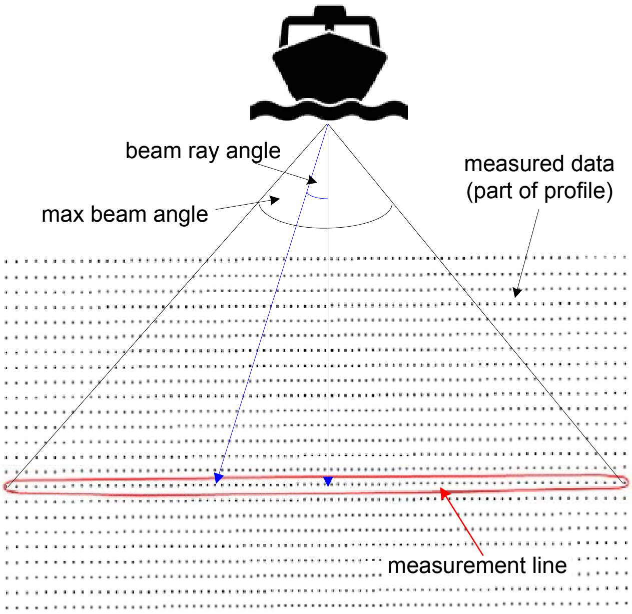

Fig. 2. Measurement data distribution and beam angles

Separation of measurement lines

Data in a source file are written down as single points making up successive measurement lines, and points lying on that line are written down one by one from left to right. The number of these points (resulting from the number of beams in a multibeam echosounder) depends on the echosounder model used for measurements. In presently used echosounders there are usually 127 beams [7].

The process of separating a single measurement line from a data file is based on calculation, then verification of a distance between adjacent points in that file. The distances for one measurement line should not exceed approx. 20 cm at 5 m depth or 50 cm at 10 m depth. The boundary value depends on the maximum beam angle and depth. On the other hand, the distance between the last point in a current measurement line and the first point of the next line is at least a few meters, often a two-digit figure. Based on this regularity, we can set a boundary value for which the system will recognize that the separation of measurement line data is completed.

Assessment of measurement line correctness

In the course of sounding hydrographic software performs a preliminary filtration of data rejecting those that differ significantly from the adjacent ones (blunders). Also, in further processing of source data some points may be removed, e.g. in cropping data. For these reasons a file with data may contain many incomplete measurement lines that should be rejected. A principle has been assumed in the method that for a measurement line to be regarded as complete, it has to contain a specific minimum number of points, in practice the figure oscillates around 100. All measurement lines including more than a specified number of points are further processed, the others are rejected.

Determination of a theoretical seabed profile

At this stage for each correct measurement line a theoretical profile of seabed was determined using an approximating polynomial of degree 10. The degree of the polynomial was defined from two criteria:

1. Approximation accuracy – during the research mean errors were calculated (understood as a difference between measurement values and corresponding values of the theoretical profile) for polynomials of degree 1 to 20. It is obvious that the higher degree polynomial, the lower the error, although at some point the changes are slight while computing time gets much longer. In the case considered the difference in mean error calculated by using polynomials of degree 10 and 20 was only 0.08 cm.
2. Visual assessment – the obtained theoretical seabed profile was visually examined to see if it reflected probable seabed shape (by comparison with the distribution of measurement points lying on one measurement line). It was observed that for polynomials of higher degree (on average above degree 13) the determined profile is often disturbed between measurement points at the ends of the examined measurement line. Such profile, although runs closer to measurement points, looks unnatural, as shown in Figure 3 (lower chart).

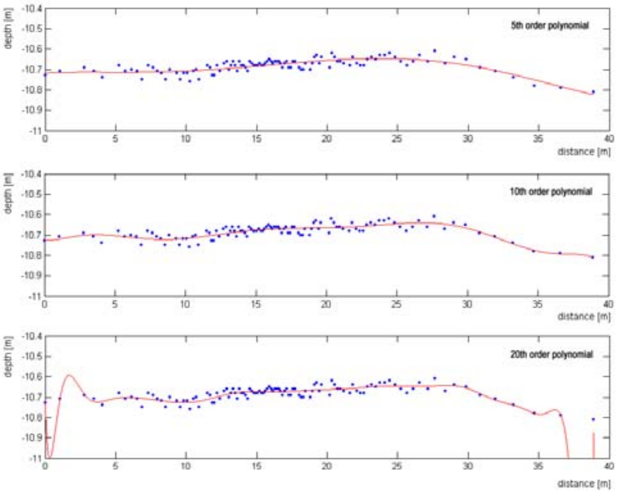

Fig. 3. Measurement lines and a theoretical seabed profile determined using polynomials n = 5, 10 and 20 degree

One weak point of this part of the method is that the theoretical profile is mathematically computed from measurements, so it is only an approximation of the real seabed profile. However, if we assume that the device readout error is to a large extent random, while constant errors are compensated by appropriate calibration of the device before measurements, then theoretical profiles determined in the manner adopted in the method should be very close to the real ones. At present no other existing method is capable of solving this problem.

Calculation and grouping of measurement errors

At the next stage for each measurement line point an error is calculated, understood as the difference between the depth measured and its corresponding value of the theoretical profile. The obtained error values are grouped in separate intervals by the values of beam angle and depth. The number and breadth of these intervals can be set by the operator.

Calculation of mean error distribution for the measuring device

After an analysis of all points from a source file the last phase consists in calculating mean values of errors and standard deviation in each of previously defined intervals. As a result, we obtain a distribution of mean error and standard deviation values. The distribution depends on depth and beam angle. The obtained results allow to more precisely estimate the measurement error of the tested device, which in turn enables more precise estimation of created DTM fidelity.

Example tests

The operation of the developed method was tested by an analysis of measurement accuracy of a multibeam echosounder Simrad EM3000 [7] based on a data file collected from measurements in the region of Zalew Szczeciński and Pomorska Bay.

The analyzed files had a total capacity of over 8GB and contained about 280 million measurement points. The system had the following settings:

- minimum distance between points indicating the next measurement line - 2 meters,
- minimum number of measurement points qualifying a measurement line as correct - 100,
- number of intervals for various beam angles - 16 (-85° to 85° every 10°),
- number of intervals depending on depth - 20 (2 to 20 meters every 1 meter).

More than 3.5 million measurement lines were distinguished during calculations. Of these, nearly 2 million were qualified as correct. On that basis, calculations of over 200 million single measurement errors were made. The errors were divided into 320 groups. The results, the distributions of mean errors depending on beam angle and depth, are shown in Figure 4.

The results

The Simrad EM3000 echosounder manufacturer declares a depth accuracy of 5 cm (RMS). The developed method allows to more precisely estimate errors occurring in measurements. The value of these errors mainly depends on depth. In the described case it is, respectively: approx. 3 cm at 2-8 m depth, approx. 4 cm at 8-16 metres, 5-6 cm at 16-20 metres and approx. 7-8 cm at a depth of 22 metres. In the examined depth range the relationship is approximately linear.

For beams above 55□ (on both sides) the measurement error increases rapidly. For example, for 5 meter depth mean errors are equal to: 3.3 cm (45°-55°), 4.2 cm (55°-65°), 6.3 cm (65°-75°) up to 9.5 cm (75°-85°). It clearly follows from the results that to maintain high accuracy of measurements the maximum beam angle should not exceed 110 degrees (in total - covering both sides).

In general, for the examined case the measurement accuracy is at a 5 cm level (MSE), and 99% of measurements had an accuracy to 8.2 cm.

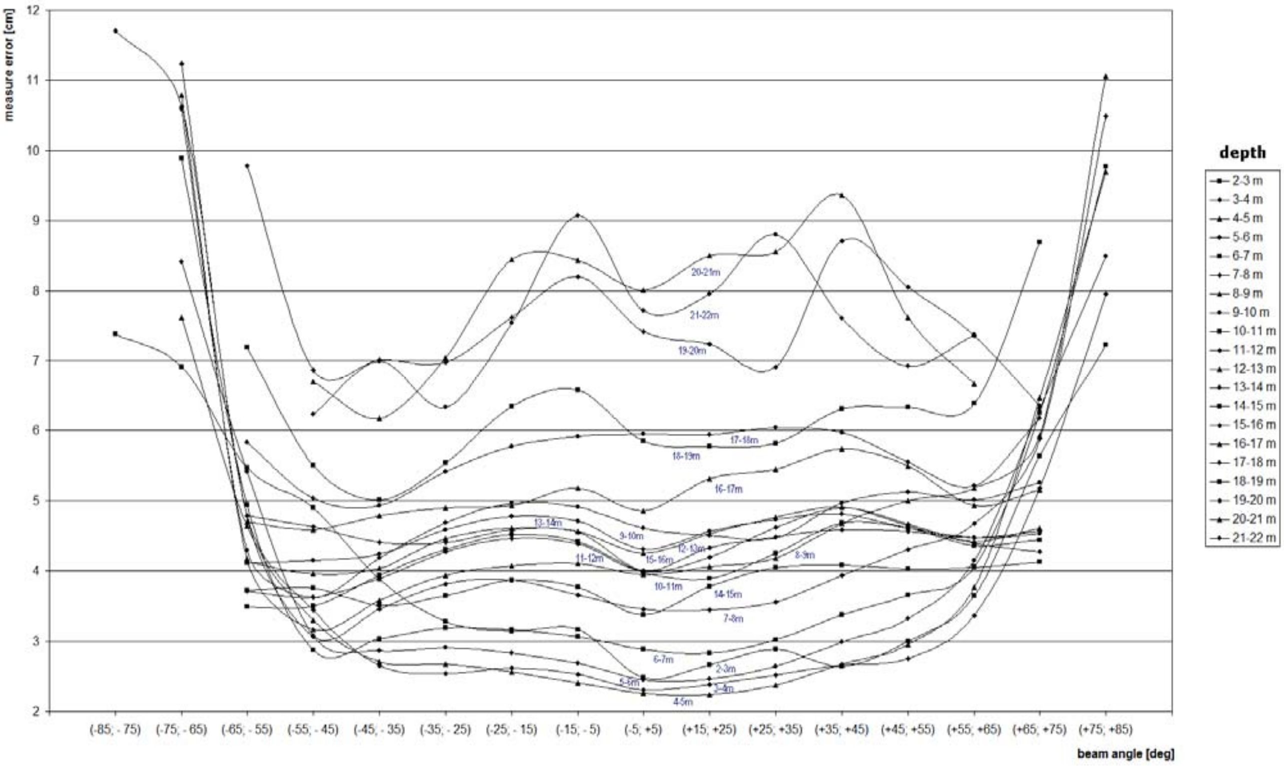

Fig. 4. Distributions of mean errors depending on beam angle and depth

Summary

The herein proposed method for estimation of measurement accuracy of a multibeam echosounder allows to more precisely estimate measurement errors occurring during soundings, which means higher accuracy of new digital terrain models.

One essential advantage of the method is that error distribution of a measuring device can be determined for any device, water area and for various parameters related to sounding work done.

The method, when used by institutions and companies engaged in hydrographic survey, will allow to far more precisely estimate the accuracy of newly created models and maps.

Wydanie publikacji zrealizowano przy udziale środków finansowych otrzymanych z budżetu Województwa Zachodniopomorskiego.

REFERENCES

[1] Maleika W., Pałczyński M., Frejlichowski D., Multibeam Echosounder Simulator Applying Noise Generator for the Purpose of Sea Bottom Visualisation, *In: G. Maino and G. L. Foresti (Eds.): ICIAP 2011, Part II, Lecture Notes in Computer Science,* vol.6979, 285-293, 2011

[2] Maleika W., Pałczyński M., Wpływ prędkości jednostki hydrograficznej na dokładność uzyskanych modeli dna (The impast of the hydrogaphic ship's velocity on the accuracy of seabed models), *Roczniki Geomatyki 2011*, Tom IX, Zeszyt 2 (46), s. 67-77, PTI Warszawa 2011

[3] Stateczny A. (red.): The methods of the comparative navigation (In Polish). In: *Gdanskie Towarzystwo Naukowe*, Gdansk (2004)

[4] Maleika W., Pałczyński M., Frejlichowski D., Effect of Density of Measurement Points Collected from a Multibeam Echosounder on the Accuracy of a Digital Terrain Model, *In: Jeng-Shyang Pan, Shyi-Ming Chen, Ngoc Thanh Nguyen (Eds.): Intelligent Information and Database System,* Part III, Lecture Notes in Artificial Intelligence, vol.7198, 456-465 (2012)

[5] Maleika W., Pałczyński M., Frejlichowski D., Interpolation Methods and the Accuracy of Bathymetric Seabed Models Based on Multibeam Echosounder Data, *In: Jeng-Shyang Pan, Shyi-Ming Chen, Ngoc Thanh Nguyen (Eds.): Intelligent Information and Database System,* Part III, Lecture Notes in Artificial Intelligence, vol.7198, 466-475 (2012)

[6] International Hydrographic Organization, IHO standards for hydrographic surveys, *Publication No. 44, 4th Edition*, 1998.

[7] EM3000 - Multibeam echo sounder, *Kongsberg Maritime GmbH*, [online] http://www.kongsberg-simrad.de, November 2011

[8] Calder B. R., Mayer, L. A.: Automatic processing of high-rate, high-density multibeam echosounder data. In: *Geochemistry Geophysics Geosystems*, VOL. 4(6), 1048-1069 (2003)

[9] Hamilton E.L.: Geoacoustic modeling of the sea floor. In: *Journal of the Acoustical Society of America*, vol. 68, issue 5, 1313-1340 (1980)

[10] Gao J.: Resolution and accuracy of terrain representation by grid DEMs at a micro-scale. In: *International Journal of Geographical Information Science*, vol. 11, issue 2, 199 – 212 (2001)

***Author**: dr inż. Wojciech Maleika, West Pomeranian University of Technology Szczecin, Faculty of Computer Science and Information Systems, ul. Żołnierska 52, 71-719 Szczecin, E-mail: wmaleika@wi.zut.edu.pl.*