VERIFICATION OF THE DIGITAL SEA BOTTOM MODEL BUILT BY BATHYMETRIC DATA – DEEP WATER STUDY

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ABSTRACT

Data that come from multi- and singlebeam echosounders make a basic source for reliable and complex displaying of the seabed profile. Their quality and reliability have significant impact on safe shipping and navigation. These are main targets and purposes of the measurements. Thanks to detection and description of many underwater objects, shallows or other dangerous places, the hydrographical measurements do guarantee improvement of safe human activities at sea.

The measurement dynamics and variation of factors disturbing in time mean that the bathymetric measurements are especially difficult and they require experience in the process of planning, performing and elaborating the measurements. The geospatial data obtained for the need of creating a numerical model of the seabed must be reliable because it is not possible to compare them with any standard.

There is a method of verification of the geospatial data obtained by means of an MBES multibeam echosounder used in bathymetric deep-water maritime measurements presented in the article. Dynamic calibration, being a preliminary stage of the echosounding works, has been applied in the process of the model verification. Reference to DTM (Digital Terrain Model) verification in photogrammetry has been done – where ground points obtained in land survey make references.

Keywords: *Digital Terrain Model, Digital Sea Bottom Model, multibeam echosounder, calibration, verification*

INTRODUCTION

Hydrographical survey is of great significance in securing underwater works among which the following ones may be underlined: routing submarine cables, construction of pipelines or dredging of waterways. The seabed relief may change due to inflow of sediments. It is necessary to make systematic surveys on sea routes, fairways and other sea areas.

Numerical Terrain Models (NTMs) make one of the most important subject matters of Geographical Information Systems these days. They are applicable in rendering two or three dimensions of the seabed and in checking its shape. Methods of creating the NMTs are greatly various hence they differ in accuracy. This is to note that the seabed is an environment changing dynamically, so it is recommended to elaborate methods allowing verification of the models already existing.

Character of performance of bathymetric survey (dynamic measurements, waving, variability of conditions for acoustic wave propagation in water) makes execution of many measurements or a long-term measurement in the same place, in order to strengthen accuracy or to verify the model, impossible [8], [9], [10]. As far as the method is concerned, the measurements are similar to photogrammetric estimations (dynamics, spatial orientation of an airplane) but they differ in respect to verification, due to lack of reference. In photogrammetry, it is possible to refer to characteristic terrain points determined with geodesic methods applied.

METHODS OF DATA ACQUISITION AND SOURCES OF ERRORS

Aerial photogrammetry and low bank UAV (unmanned aerial vehicles) are the main data sources for building DTM (digital terrain model) of terrestrial areas. The photogrammetric works mainly consist in measuring homologous points on two or more pictures (photos). In digital photogrammetry, algorithms of automatic measurements on digital images are mostly based on methods of correlation. Correlation coefficient is a basic benchmark of similarity (goal function) [11], [13]. Having the homologous points of pixel coordinates been determined, it is possible to translate them into photogrammetric coordinate system and then, based on the known elements of reciprocal and absolute orientations, to determine terrestrial coordinates of the DTM's points [7].

The following factors, among the others, have impact on accuracy of the DTM's photogrammetric elaboration [1], [11], [13]:

- proper calibration of photogrammetric cameras,
- atmospheric refraction,
- contraction of film in the period between exposition and scanning,
- mechanical and optical errors of photogrammetric scanners,
- precision in identification of photo-points and accuracy in measuring them on pictures and in the field,
- pure correlation of the pictures' certain areas having impact on the process of automatic measurement of the points.

In the hydrographical survey, where bathymetric measurements make primary part, focused on determination of the seabed relief for the need of navigation maps' elaboration, the main factors that influence accuracy of the determination are as follow:

- positioning of the echosounding ship,
- considering vertical distribution of sound velocity in water,
- sonar calibration, mainly dynamic calibration of multibeam echosounder,

- disruptions of movement of the echosounding ship compensated by measurements of her roll, heave and pitch motions by means of instruments serving determination of spatial orientation,
- considering variations in water level.

With a use of the multibeam echosounder, the least distortions resulting from the acoustic wave propagation in water – from occurrence of refraction phenomenon, appear under converter for beams the least tilted from the vertical [8, 9, 10]. The distortions arise for the beams having larger and larger output angle and they are the most significant on an edge of the stream [4], [5], [12]what has an impact on accuracy of the DTM's determination.

VERIFICATION OF THE DIGITAL TERRAIN MODEL

Surface described by the DTM is only an approximate of the Earth real surface. Difference between these two surfaces is defined as [11], [13]:

$$r(x, y) = f(x, y) - f('x, y) \tag{1}$$

and the mean error of the difference as [11], [13]:

$$\sigma^2 = \frac{1}{lxly} \int_0^{ly} \int_0^{lx} r(x, y)^2 dxdy \tag{2}$$

In practice, the "real" terrain surface is unknown, so it is not possible to determine difference between the generated DTM (approximate surface of the terrain) and the real area of the surface. Different, more accurate (by an order of magnitude) model of surface of the same area must be used in order to verify quality of the given DTM.

The proposed [11], [13] examination of the DTM's correctness consists in performance of statistical hypothesis' verification. It has been assumed that there is a model we want to test there and a difference of elevation between the two models, defined for enough number of points.

The first step is to check whether the random variable (difference between the models on the selected area of the elaboration) for this sample represents normal distribution.

Then, elements of the statistical test are being defined [11], [13]:

- We hypothesize that the parameter m amounts to the value of m_0. Thereby, we shall verify the hypothesis H_0 in the form $m = m_0$.
- We also define an alternative hypothesis $m>m_0$ (or H_A: $m<m_0$)
- We perform the statistical test – determination of the statistics' value which allows assessing whether we may reject a null hypothesis.

The real surface on ground may be determined based on land measurements, with an accuracy of 1 cm, executed by means of satellite measuring systems. They are also used in securing measurements being taken by UAVs [2], [14] to determine georeferenced points.

In hydrography, determination of the sea-bed's DTM, as a reference surface in respect to the measuring system's calibration or the DTM's verification, is very difficult and even not possible. Therefore, there are geodesic positioning systems and methods of echo-sounders' calibration used there – to obtain the best possible accuracy of the seabed DTM's determination.

MBES CALIBRATION AS A TOOL INCREASING RELIABILITY OF DTM DETERMINATION

Control of multibeam echosounder's indications should be performed each time before and after execution of the bathymetric survey – in order to check correctness of operation of the system and devises. The cross check consists in performing two measurements on profiles perpendicular to one another. Measurements on extreme outer beams, burdened with the greatest error (red points), with vertical indications (green points) vitiated by the smallest error (Fig. 1). Difference in the indications' values should not be greater than 10 cm.

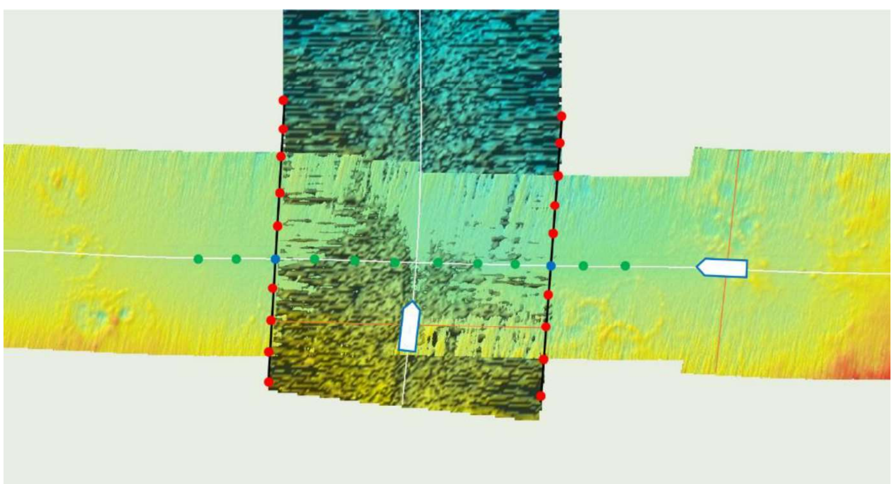

Fig. 1. Calibration of multibeam echosounder

Phenomenon of refraction of diagonal beams' acoustic rays is a basic source of uncertainty of measurement taken by means of MBES. This is a result of sound velocity changes in water. Field of acoustic wave emitted in water environment by the echo-sounder's transducer and its changes in time-domain may be described mathematically with solving wave equation [3], [6], which in hydroacoustics is a basis for descriptions of small amplitude waves. This solution does exist, however – only for simple or idealized cases. In general, a point source of the acoustic wave and horizontal stratification of water – in which the sound speed $c(x,y,h) = c(h)$ – are assumed.

In short, determination of the acoustic ray's trajectory is based on the Snell's law which defines relationship between the acoustic ray's direction and velocity of the sound wave propagation [4], [5]. The sound radius shall deflect towards lower velocity of sound. The acoustic ray deflection phenomenon is the most visible for diagonal beams, therefore the extreme outer beams of the multibeam echosounder's radiation characteristics implement the greatest errors in depth measurement.

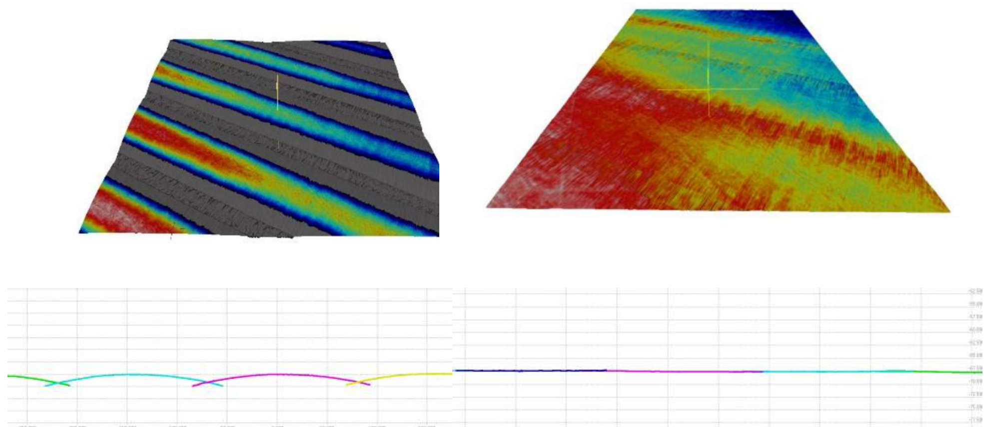

Fig. 2. Influence of the refraction phenomena (sound speed in water) on determination the seabed.

RESEARCH

Geospatial data recorded during calibration of the multibeam echosounder for rolling correction on waters of Gdansk Bay (Fig. 3)were used to verify the Digital Sea Bottom Model. The calibration preceded hydrographical soundings executed by hydrographic ship by means of R2Sonic 2022 multibeam echosounder, operating at the 300 kHz frequency. The hydrographic system was also constituted by: two-antenna Applanix POS MV precise positioning system, Applanix detector of roll and heave motions, Valeport Mini sound velocity profiler, DESO-30 singlebeam echosounder. They all were integrated by QPS QINSy hydrographic system.

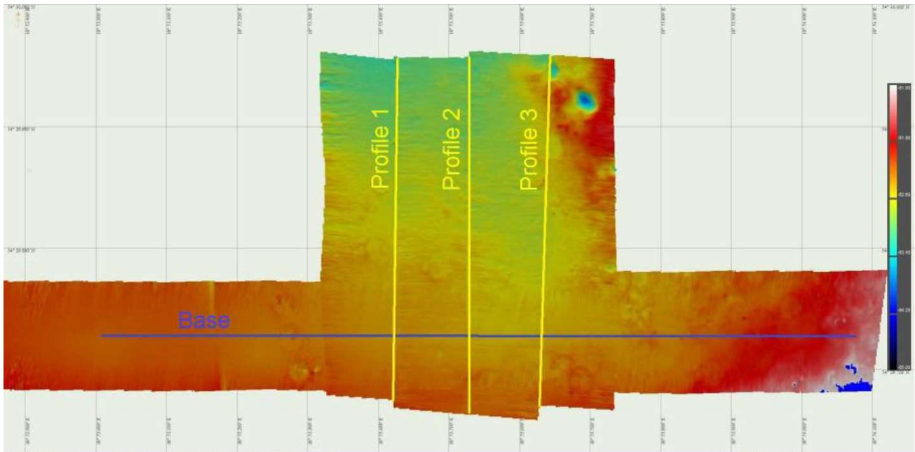

Fig. 3. Area of the research

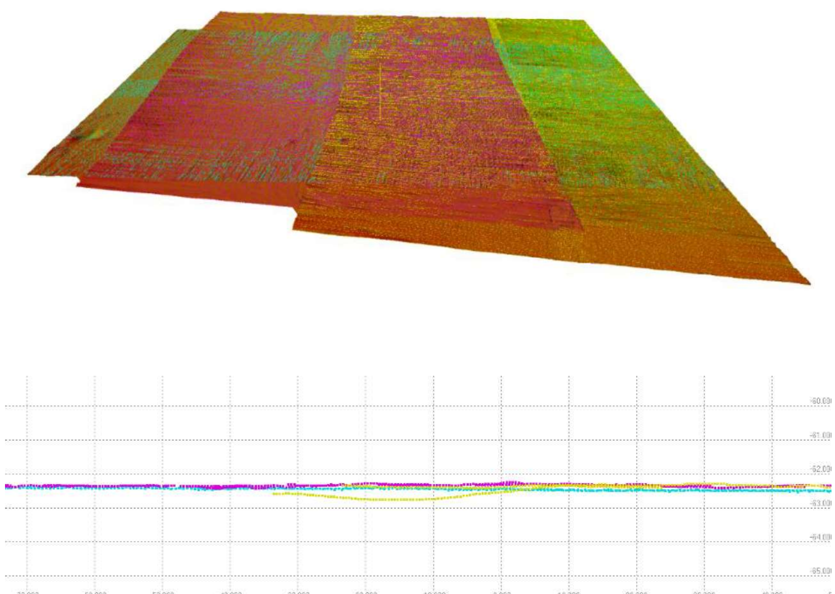

Fig. 4. 3D and cross-section visualizations of crossed profile and the base

In the process of the seabed model verification, the depths were compared at the stage of raw data for the same narrow area of the seabed. The depths obtained from the survey on the entire width of the swatch with a sector searching one head in sector 87° were analysed with depths obtained by means of the echo-sounder's vertical beam during passage of the vessel perpendicular to the given profiles. Values of the depths were acquired in VALIDATOR application, with a 2m interval, what as a consequence provided over 100 measurement points for each profile.

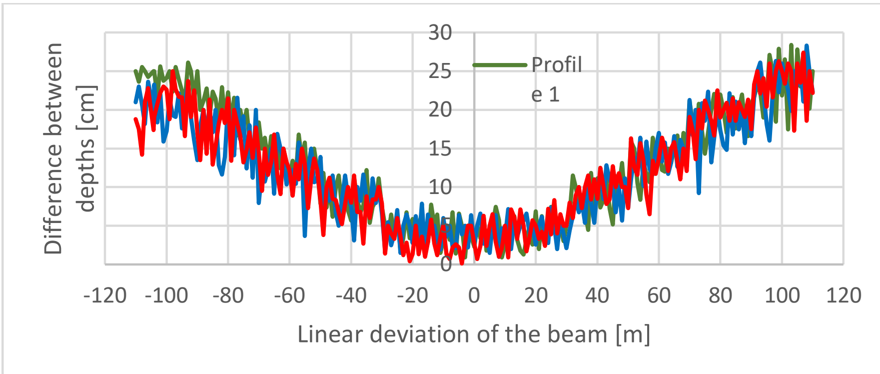

Fig. 5. Errors' determination of the depths with relations to linear deviation od the acoustic beam

Tab. 1. Differences between depths in crossed profiles

Number of profile	Differences between depths		
	min [cm]	max [cm]	average [cm]
Profile 1	1	28	13
Profile 2	1	28	12
Profile 3	1	27	12

CONCLUSIONS

These days, systems of multibeam echosounder pay a serious role in the field of hydrographical survey and creation of Digital Terrain Models of sea areas' beds. The presented results regarding evaluation of the model quality have been obtained based on data collected from deepwater survey – this reduces, in significant way, the requirements concerning accuracy imposed by IHO, as well as the requirements resulting from principles for charting depths onto marine navigational maps. This criterion has been met in all measurement points of the test – on the entire width of the swatch. This has been possible thanks to the method of executing the measurements, adjustment of the ship speed to the conditions, skills of the helmsman, consideration of the sound velocity in water, as well as calibration of the shipboard hydrographical system, including: the positioning system, detector of the roll and heave motions and others used in the test.

Findings obtained as a result of the performed analysis show that the topic regarding verification of DTM, built as a result of charting bathymetric data coming from multi-beam sonar, is broad. Accuracy of those measurements greatly depends on accuracy of additional sensors and Motion Reference Units. The test results do show that the angular coverage sector is limited due to serious errors being generated by extreme outer beams – even with a use of two heads to map the seabed. When assessing the measurements' accuracy, a user should be aware of the maximal and effective width of the seabed coverage sector.

ACKNOWLEDGEMENTS

The author would like to thank the headquarter and officers of Hydrographic Support Squadron of the Polish Navy for permitting participation in soundings and using hydrographic equipment and recorded data.

REFERENCES

[1] Ackermann F., Technique and strategies for DEM generation. Digital photogrammetry: an addendum to the manual photogrammetry. American Society for Photogrammetry and Remote Sensing, USA, s. 135-141, 1996.

[2] Banaszek A., Zarnowski A., Cellmer A., Banaszek S., Application of New Technology Data Acquisition Using Aerial (UAV) Digital Images for the Needs of Urban Revitalization. "Environmental Engineering" 10th International Conference, Vilnius Gediminas Technical University, Lithuania, 2017.

[3] Brekhovskikh L.M., Lysanov Yu.P., Fundamentals of Ocean Acoustics. Springer-Verlag, New York Berlin Heidelberg, 2014.

[4] Grządziel A., Felski A., Depth measurement accuracy for outer part of the multibeam echosounder swath width, Logistics, pp. 2246-2251, 2014.

[5] Grządziel A., Wąż M., Estimation of effective swath width for dual-head multibeam echosounder, Annual of Navigation, vol. 23, pp. 173-183, 2016.

[6] Klusek Z., Propagation Conditions of the Sound Speed in the Southern Baltic. Polish Academy of Science, 1990.

[7] Krzystek P., Generation of Digital Elevation Models. In Second Course in Digital Photogrammetry, Bonn, Germany. Institute for Photogrammetry at Bonn University and Landesvermessungsamt Nordrhein-Westfalen, 1995.

[8] Makar A. Sea bottom surface described by Coons pieces, Scientific Journals of the Maritime University of Szczecin, Poland, 45 (117), 2016, pp. 187-190

[9] Makar A. Cleaning of hydrographic data for determination the seabed of waterways. 7th International Conference on Maritime Transport Technological, Innovation and Research Barcelona, Spain, pp. 213-219, 2016.

[10] Makar A. Cleaning of MBES Data Using CUBE Algorithm. 17th International Multidisciplinary Scientific GeoConference SGEM2017 Albena, Bulgaria, Volume: 17 (21), pp. 841-847, 2017.

[11] Paszotta Z., Szumiło M.: Verification of the Digital Terrain Model, Archives of Photogrammetry, Cartography and Remote Sensing, vol.16, 2006, pp. 457-466.

[12] Snellen M., Siemes K., Simons D., An efficient method for reducing the sound speed induced errors in multibeam echosounder bathymetric measurements, Delf University of Technology, The Netherlands, 2009.

[13] Szumiło M., Fotogrametryczne metody budowy i badania dokładności numerycznego modelu terenu, Wydawnictwo Polskiego Internetowego Informatora Geodezyjnego, seria GEOMATYKA, 2016.

[14] Zarnowski A., Banaszek A., Banaszek S., Application of Technical Measures and Software in Constructing Photorealistic 3D Models of Historical Building Using Ground-Based and Aerial (UAV) Digital Images. Reports on Geodesy and Geoinformatics vol. 99 /2015; pages 54-63, 2015.