Reliability of the Digital Sea Bottom Model Sourced by Multibeam Echosounder in Shallow Water

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Abstract. Reliability of Digital Terrain Model created with geospatial data is a parameter in evaluation of its quality that takes into consideration both the method as well as the quality of data. Bathymetric surveys – dynamic measurements of a moving transducer of a singlebeam or multibeam echosounder used for depth measurements in water are a string of interrelated phenomena that determine the quality (accuracy) of geospatial coordinates. Inclusion of all factors influencing the accuracy of measurements, such as echosounder’s calibration, is a prerequisite for minimisation of systematic measurement errors. Random and gross errors are inevitable, and are eliminated during the cleaning process of geospatial data. High reliability, preliminarily filtered cloud of data is the initial source of the data for the creation of the Digital Sea Bottom Model. Comparison of two models using interpolation methods on the basis of discrete data carries the risk of the outcome being blurry. Cell size optimization on the basis of echosounder beams geometry is one of the essential parameters in quality assessment – two surface models comparison. Dynamic calibration of multibeam echosounder, based on the comparison of depths of outer edges of the bathymetric swath, is carried out utilizing raw data. Correct spatial orientation of echosounder’s head(s), due to the angular regulation of the echosounder’s head, minimizes discrepancies and increases the reliability of the data that is to be used to create the Digital Sea Bottom Model. This article presents the results of the analysis of accuracy of DSBM created with geospatial data acquired by multibeam echosounder, based on the calibration soundings that are the enabling stage for hydrographic surveys using MBES. The data used was recorded by R2Sonic multibeam echosounder in shallow waters (up to 30m depth), deriving from general rules of depths cartography on nautical charts.

1. Introduction

Digital Terrain Model created based on geospatial data gathered by a multibeam echosounder is a cloud of a large amount of data homogenously distributed over the bottom surface. Their distribution depends on: along the direction of the echosounding vessel’s course – its speed which is dependent on the water area type and its size, and – when along the traverse of the hydrographic vessel – depth of the water area, along with the constant angular separation of particular beams. There are spikes amongst points under registration, being coarse errors, and they are removed by cleaning in the postprocessing stage [1-3].

It is difficult to assess reliability [4-6] of that model built by the data registered during dynamic measurements [7, 8]. One should assume that it is sufficient if all the factors having a significant impact on the determination of coordinates of points of the acoustic waves reflection from the bed have been met [9]. The main factors are as the following: positioning, measurement of depth and
spatial orientation of the hydrographic vessel being under way. The accuracy requirements are given in specifications of international hydrographic organisations [10, 11]. Dynamic [7, 8, 12] geodetic systems [13-15] ensuring high accuracy of positioning, in conditions different for geodesy, are applied more and more often. The spatial orientation and, at the same time, compensation of motion disruptions are executed with the use of MRU – Motion Reference Unit sensors, making – apart from meters of the sound speed in water – obligatory equipment of the hydrographic system based on depth measurement performed using the multibeam echosounder.

The highest distortions of the sea bottom model are observed on an edge of the swath [16, 17] – as a result of refraction phenomenon [9, 18, 19]. It is reduced during the calibration process of the multibeam echosounder – by hand or automatically [20-22]. The geospatial data is cleaned and filtered [1-3] as this is essential for creating the Digital Sea Bottom Model [23-25].

2. Soundings
Charted soundings must represent the depth measured from Chart Datum (Figure 1) to the sea floor placed in such a way that the centre of gravity (geometric centre) of the set of numerals coincides with the position referred to [26]. Rounding of depths, including drying heights, must always be on the safe (shoaler) side (that is: soundings must be rounded down and drying heights rounded up, if necessary). For depths the rounding should be [26]:

- to the nearest decimetre between 0,1 and 21m: 0,001 to 0,099 rounds down to nearest decimetre for example: a recorded depth of 4,38m rounds down to 4,3m.

- to the nearest half metre from 21 to 31m: 0,001 to 0,499 rounds down to 0,0 for example: a recorded depth of 23,49 rounds down to 23m;0,500 to 0,999 rounds down to 0,5 for example: a recorded depth of 23,51 rounds down to 23,5m.

- thereafter, to the nearest metre:0,001 to 0,999 rounds down to 0,0 for example: a recorded depth of 31,85m rounds down to 31m.

For drying heights [26]: to the nearest decimetre: 0,001 to 0,099 rounds up to the nearest decimetre for example: a recorded drying height of -2,32m rounds up to -2,4m

However, these soundings must be adjusted as a function of the degree of accuracy with which the depths were actually measured so that the precision with which the soundings are recorded on charts can never be misleading as to the accuracy of such soundings.

3. Methodology
The measurements have been executed in water areas of two depths, resulting from principles for depth charting [26] described above. For the deep area, of the depths higher than 31 m, verification of the Digital Sea Bottom Model is presented in [3]. Results of bathymetric surveys on perpendicular profiles were used to assess DSBM’s reliability (shallow water up to 21m – Figure 2) and diagonal one (mean water with the depths from 21m to 31m – Figure 3).
Figure 2. Sounding area in shallow water with depths up to 21m

Figure 3. Sounding area in mean water with depths between 21m and 31m

Method analogical to [6] was applied on perpendicular profiles. At the first contact of the beams radiated through the echosounder, the geospatial data were obtained by means of bias beams. Then, the depth is to be measured in the place where it was controlled by means of the beams of a smaller and smaller angle of inclination, as far as to a place the profiles intersect. Here, all the beams on one profile correspond with the data obtained using the vertical beam. As the distance from the place was bigger, the data on the perpendicular profile was gathered by means of the beams becoming increasingly deviated from vertical. Results of the measurements executed on edge (maximum deviation) and along the axis (vertical beam) of one profile can be subject to analysis.

As far as average depths are concerned, profiles intersecting at small angles were used. As a result, the geospatial data obtained by means of the extreme edge beams are corresponsive. Then, the overlapping becomes higher and higher when the extreme edge beams of one profile overlap vertical beams of the second profile. The coverage is 50%. In the place the beams cover the same area in 100%, the extreme edge beams of both profiles deflect in the same positions. As the sounding vessel moves, overlapping of mutual measurements is smaller and smaller. Analysis can be done for the data gathered using extreme edge beams (Figure 4 – yellow line) or extreme edge beams in the place they were obtained by means of the vertical beam (Figure 4 – red line).
4. Measurements

4.1. Soundings in the area with depths up to 21m
Geospatial data recorded during calibration of the multibeam echosounder on waters of Gdansk Bay (Figure 4) were used to verify the Digital Sea Bottom Model. The calibration preceded hydrographic soundings executed by hydrographic motorboat by means of EM2040 multibeam echosounder, operating at 200 kHz frequency. The hydrographic system also consisted of: two-antenna Trimble SPS461 precise positioning system, SMC IMU-108 detector of roll and heave motions, Valeport MiniSVP sound velocity profiler, EA400 singlebeam echosounder operating at the 38kHz and 200kHz frequencies. They all were integrated by QPS QINSy hydrographic system. Calibration (mainly HPR) parameters are shown in Table 1.

Table 1. Calibration parameters of EM2040 MBES

|        | Pitch [°] | Roll [°] | Heading [°] | Starboard [m] | Forward [m] | Up [m] |
|--------|-----------|----------|-------------|---------------|-------------|--------|
| EM2040 Tx | -1.380    | 0.130    | -0.920      | -0.032        | 0.101       | -0.153 |
| EM2040 Rx | 0.580     | -0.310   | 179.080     | -0.337        | 0.205       | -0.139 |

Figure 4. Sounding area in shallow water with depths up to 21m

4.2. Soundings in the area with depths between 21m and 31m
To verify the Digital Sea Bottom Model, geospatial data recorded during calibration of the multibeam echosounder for rolling correction (Figure 5) were used. 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 also consisted of: 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. Calibration (mainly HPR) parameters are shown in Table 2.

Table 2. Calibration parameters of R2Sonic 2022 MBES

|        | Pitch [°] | Roll [°] | Heading [°] | Starboard [m] | Forward [m] | Up [m] |
|--------|-----------|----------|-------------|---------------|-------------|--------|
| Sonic2022 Port | -0.930     | 10.200   | 1.910       | -1.040        | 0.681       | 0.024  |
| Sonic2022 Starboard | 0.250      | -10.170  | 1.510       | 1.051         | 0.686       | 0.028  |
5. Results

5.1. Soundings in the area with depths up to 21m
When it comes to low depths, examined on perpendicular profiles, measured MBES and SBES depths were compared. It was assumed that the smallest error occurs at the measurement performed with a vertical beam (Figure 4 – red colour points). The most significant error should be encountered on the extreme edge of both profiles marked with yellow colour. Sections on the extreme edge (maximal deflection of the beams) and in the centre (vertical beam) of the profile were presented (Figures 6 and 7) to assess accuracy in adjusting the depths measured twice. Differences in the measured distances were – respectively – 10 cm and 5 cm at the depths of approx. 9 m.

Figure 5. Sounding area in mean water with depths between 21m and 31m

Figure 6. Slice across the track in the area with depths up to 21m – an outer swath
5.2. Soundings in the area with depths between 21m and 31m
As far as medium depths are concerned, examined on intersecting profiles, both the vertical beam and the marginal beams of one profile correspond, at the beginning, with the marginal beam of the second profile. Then, they start matching the beams less and less deviated, the vertical beam and the more and more deflected ones on the opposite side. Analysis of the depths’ variations was performed along the profile axis (the vertical beam) and on the edge (the most deviated beams). Differences in the measured distances were – respectively - 20 cm and 5 cm at the depths of approx. 30 m (Figure 8, 9).

**Figure 7.** Slice across the track in the area with depths up to 21m – vertical beams

**Figure 8.** Slice across the track in the area with depths from 21 to 31m – an outer swath

**Figure 9.** Slice across the track in the area with depths from 21 to 31m – vertical beams
6. Conclusions
Assessment of accuracy of the Digital Sea Bottom Model is difficult due to the lack of reference model. In photogrammetry, for instance, geospatial data - obtained from aerial pictures or UAV - Unmanned Aerial Vehicle – may be compared with coordinates from the field measurements, but not in hydrography – here, it is presumed that one dynamic measurement is of the best accuracy. Minimisation of errors in the depth measurement is obtained thanks to MBES calibration, mostly the dynamic one, consideration of environmental factors: sound velocity in water and water level, and spatial orientation of the hydrographical vessel. The highest diligence of the operator is to ensure the reliability of the measurements taken to benefit maritime safety – especially the ones performed at low depths. The depths given on charts, with resolution meeting INT requirements, should be measured with accuracy higher than the one required by IHO. For the depths lower than or equal to 31 m, presented on the chart with the resolution of 10 cm, total vertical uncertainty in special order is: for the depth of 10 m – 26 cm and for the depth of 30 m – 36 cm. TVU – Total Vertical Uncertainty is, respectively, 52 cm and 63 cm for the measurements in the 1a category.

Based on the presented results of the research, it may be concluded that the TVU measurement vertical uncertainty is close to the resolution of the presented depths and it clearly exceeds IHO requirements. It is possible to obtain so good accuracy of the DTM thanks to, despite of the human factor – diligence of the operator, the high accuracy of the hydro-acoustic equipment, positioning systems, MRU sensors and hydrological observations.

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