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DETECTION OF SMALL BOTTOM OBJECTS FROM MULTIBEAM ECHOSOUNDER DATA

ABSTRACT

Multibeam Echo Sounder Systems (MBES) shallow water surveys provide capability not only acquiring bathymetric data useful for determining isobaths and mapping features on the seafloor which may be a hazard to navigation. They also allow detection of objects smaller or deeper than those required for the safety of seafaring and International Hydrography Organization (IHO) standards. In this article some of issues related to of efficient MBES shallow water surveys are stressed. Additionally a draft of post-processing techniques and result data format together with tools allowing extraction of bottom object from bathymetric data are presented.

Keywords: Multibeam Echo sounder, bathymetric survey, bottom object, detection.

1. INTRODUCTION

Technical development in multibeam Echo sounders in recent years resulted in a centimeter accuracy and single beam resolution below one degree. It gives surveyors an ability to perform bottom clearance sweeps of shallow water areas without the need of using Side Scan Sonars (SSS). There is no aim to neglect the usefulness of these systems which are still the best underwater detecting tools but showing that MBES, with some restriction, can present comparable detection capabilities but less time and attention consuming during online operations. Additionally, the positioning uncertainty is never degraded due the fact that the measuring unit is not fix, but in many cases towed on some depth behind the surveying vessel. Another advantage is that

MBES result data consist of geography referenced points (X, Y, Z) in contrast of two-dimensional raster type sonar mosaics.

2. ACQUISITION OF BATHYMETRIC DATA WITH MBES

Multibeam survey systems represent an effective mechanism for detection of shoals, rocks, wrecks, debris, or other navigation hazards lying above grade in a navigation channel. IHO Standards requires the surveyor to use equipment that is capable of detecting all targets of the specified size dependent of the IHO Order. It does however go further and obliges the surveyor to operate the equipment in such a way that there is a high probability of all such targets being located. The list of factors that needs to be taken into consideration can be divided in to two groups. The first one concerns a description of an area that is to be surveyed. It consists of the current state of the sea, physical properties of water, area dimensions, overall depth,. The second one is a set of hydrographic capabilities of ship – the working platform, like geometrical details, seaworthiness, maneuverability and technical specification of measuring equipment. It is up to a surveyor to analyze all the aforementioned aspects and to plan parameters of the bathymetric survey like: swath coverage and line spacing, the vessel speed, frequency and impulse length of the acoustic signal.

2.1. Swath coverage and line spacing

The coverage of multibeam systems is a function of swath width and water depth. The number of individual beams (and footprint size) within the swath array varies with the manufacturer and operating principle. There are two commonly used MBES configurations used in bathymetric survey: single head and dual head. For example Kongsberg Maritime the producer of EM 2040C echo sounder states that the angular coverage for 200 to 300 kHz is 130º with one Sonar Head, allowing coverage of 4.3 times water depth. With two Sonar Heads, tilted 35-40º to each side, 200º can be covered. This allows surveying to the water surface or up to 10 times water depth on flat bottoms. As presented in Fig.1., the outer beams on each side of the swath are subject to more corrections and may not be useful for most navigation applications. Depending on various factors, primarily speed of the sound profile and bottom reflectivity variations, it may be necessary to restrict beam widths to less than the measured limits.

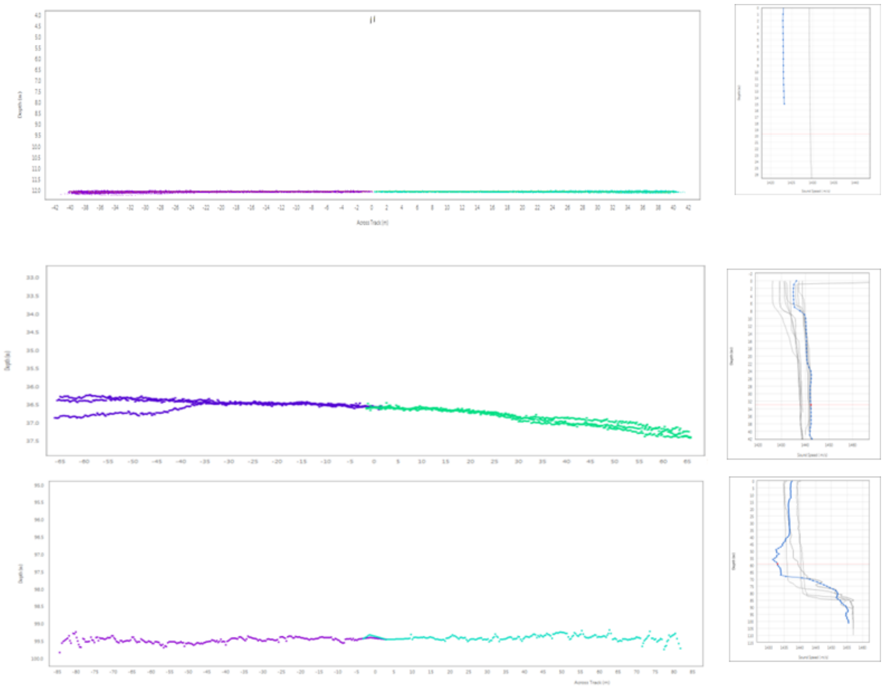

Figure1. Maximum Swath coverage in 3 different survey areas depending of speed of sound profile and depth. Source: Authors.

Most multibeam surveys are designed to obtain 100% bottom coverage. Based simply on the project depth and beam array limit, a rough line spacing can be estimated. A survey line spacing may be computed to provide for a specified overlap between lines. This may help reduce gaps due to off track steering alignment. Alternatively, in order to enhance the probability of detection, and depending on the documented system performance characteristics, 200% bottom coverage may be specified in order to ensure objects are insonified from two aspects. However, gathering bathymetric data from multiples survey lines over objects requires the use of precise positioning systems with centimeter horizontal accuracy in order to achieve repetitiveness and reliability of information [Iwen, 2017].

2.2. Speed of the vessel

When utilizing MBES for bottom features searches, the ping density is such that the chance of a danger escaping detection is remote. This may necessitate performing sounding at slower speeds and greater swath overlaps than for standard survey lines. To achieve this, a vessel is run on typically slow speeds (e.g. 5 to 10 knots) in order to ensure 100% along-track insonification and enable multiple hits on potential hazards or shoals. At a nominal update rate of 30 profiles per sec in shallow water (depth 15 m), and a 512 beam array (Dual Head System), over 15,000 depths per second are generated; resulting in a large but densely detailed point cloud for the processing. In contrast, the same system in depth of around 100 m acquire only less than 3000 measurements. According to New Zealand Hydrographic Authority, the insonification sufficient to delineate small wavelength features on the seabed requires a minimum of three along track and three across track strikes on a target of a specified size. To attain the above, the centre-to-centre distance of each ping should be no more than half the required target dimension apart. This analysis is, to some extent, consistent with the USACE recommended use of a "3-hit rule" detection method. The maximum vessel speed limit may, alternatively, be specified by the survey requirement, where it is typical to specify a minimum "number of hits" on a target to ensure suitable probability of detection.

$$v = L * \frac{C}{2} * \frac{\frac{3600}{1852}}{D*H} \tag{1}$$

where:
c = speed of sound in meters per second,
L = Target size in meters,
H = hits on target,
d = range from the transducer in meters.

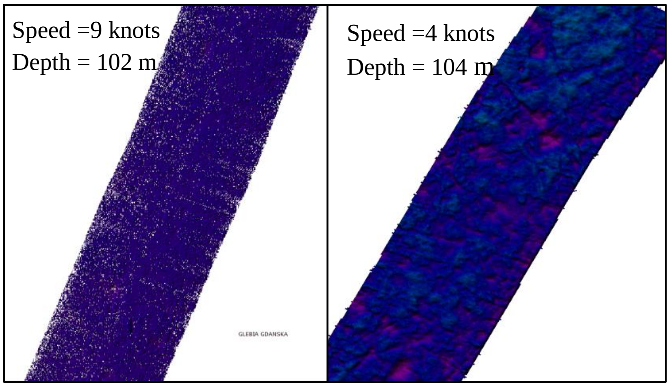

Figure 2. Two MBES swath with different survey speed. (GRID 1 x 1m). Source: Authors

For this condition, v = 4.8 knots for a 1 meter target at 100m range scale for 3 hits on target, which is a common National Oceanic and Atmospheric Administration (NOAA) survey requirement. Additionally the multiple "hits" may be obtained not only on a single sweep pass but from multiple sweep passes over an area with suspected bottom features.

2.3. Frequency and impulse length

The echo sounder's acoustic frequency is the parameter which determines the range and the sound penetration of sediments. Aside the major influence of the water column sound velocity, which affects the speed of transmission (and return) and in result determines the swath coverage, there are other influences that will affect acoustic energy in water and these are transmission losses. Absorption refers to the conversion of acoustic energy to heat when it strikes chemically distinct molecules in the water column. It is one of the key factors in the attenuation of the acoustic energy based on frequency. The higher the frequency, the greater the absorption and consequently, the lower the range. There is also bottom absorption based on the sea floor terrain and composition. This parameter is also dependent on the operating frequency of the sonar and the angle of incidence. Bottom absorption will be greater for a higher frequency and large angle of incidence. For example mud bottom will absorb more of the acoustic energy than a rocky bottom.

Taking into account only the attenuation issues, the higher frequency used during survey the better. Nevertheless, there is another frequency dependent parameter characterizing the transducer of an echo sounder - the beam width. It is commonly defined by the angle at the -3dB level and it is the angular aperture corresponding to half power referred to the beam axis. The depth measurement is performed in any direction within the cone defined by the beam width. The transmitted beam is wide across-track and narrow along-track. Conversely, the beams formed during reception are narrow across-track and wide along-track. The intersections of those beams in the seafloor are the footprints for which the depths are measured. They characterize the angular resolution of the bathymetric system (Table 1).

Table 1.Angular performance specifications of EM2040C. Source: [8].

Beam width (TX x RX)	**Beam angle** (in degrees)
200 kHz	2 x 2
300 kHz	1.3 x 1.3
400 kHz	1 x 1

The pulse length determines the energy transmitted into the water; for the same power, the longer the pulse length, the higher the energy put into the water will be and the greater the range that can be achieved with the echo sounder. The general guideline is to maintain as short a pulse length as possible to optimize the vertical resolution, which is the ability of a system to distinguish between two or more targets on the same bearing but at different ranges.

$$R = c * \frac{\tau}{2} \tag{2}$$

where:
c = speed of sound in meters per second,
τ = pulse length in seconds,
R = Range resolution in meters.

For example EM2040C shortest pulse length is 25 µs which gives a raw range resolution of 18.8 mm. The drawback of longer pulses is the decrease in vertical resolution of two adjacent features (Fig. 3.).

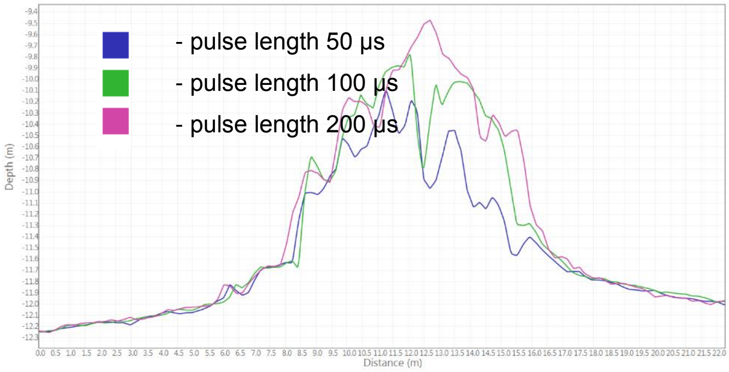

Figure 3. Profiles from MBES sweeps over a derelict wreck (S/S „Stuttgart”) with different pulse lengths. EM 3002D – 300 kHz. Source: Authors, 2015.

Most of the MBES operating software’s can automatically adjust various parameters like pulse length, ping rate, swath to change of depth or bottom absorption but in the end it is up to surveyor to tail the system for specific survey project and conditions.

2.4. Data processing

Collected multibeam data is processed and edited on a variety of commercial platforms and software packages. One of the most common platform used in Polish Navy is QPS “QINSy” Multibeam depths are time-synchronizes with the positioning and motion sensors, corrected for water velocity, refraction and draft. The acquired data typically contains noise that must be edited out. Filtering and editing can be done in real-time, in post-processing, or in combination. Manual spike editing can be performed by viewing each ping's cross-section and editing out spikes from individual beams. More commonly, a block dataset is viewed as a 3D point cloud or meshed surface form and data spikes are edited out manually. This however constitutes a time consuming labor-intensive process.

QINSy offers some faster means of processing data like automated spike or data anomaly filtering. This process is usually based on statistical methods. For example QINSy's: Surface Spline Filter calculates a 3D surface using a weighted least squares method through the available data. When sounding's depth is too remote to statistical surface and meets the criteria set by the operator it will be flagged as rejected. Given the increasing densities of collected multibeam data, use of automated filtering and editing has become a practical way to process these large datasets. Both manual or automated filtering and editing routines must be used with caution based on operator's experience so that valid sounding may not be erroneously eliminated.

The volume of post processed information is in most of the cases still unmanageable for most GIS software. In current practice, multibeam datasets are thinned into a uniformed grid cell. The matrix cell size is selected based on purpose of the project and depth and bottom feature detection IHO Standards. The commonly utilized grid resolution for creation and update of navigational charts published by Hydrographic Office of the Polish Navy is 4 m. Combined with additional data characterizing bottom features it fulfils the IHO-S44 order 1a specification. According to studies on examining the influence of grid resolution on the accuracy of created DTM, only 1 or 2m grid assures a high model accuracy (respectively 3 and 5 cm). Additionally, when creating DTM no objects bigger than 1 m^3 are missed [Maleika, 2015]. Still there exist situations where the data collected includes a large number of untypical small objects found on the seabed. In such cases grid resolution is required to be much higher, so that we are able to describe the bottom more precisely. Thinning the survey data in such scenario to commonly used bin size of 4 x 4 m will result in rejection of most of the depth measurements including the details of bottom morphology as well as small bottom objects, the detection of which is not required by current hydrographic standards (Fig.4).

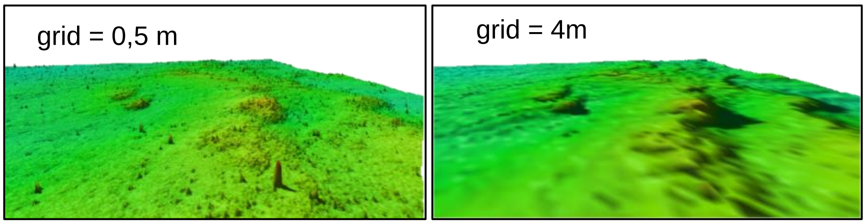

Figure 4. DTM surface described by means of grid with different size. Source: Authors.

To author's best knowledge common hydrographic processing software packages do not include any dedicated tool and it is in surveyors competence: firstly not to filter them out and then to manually add an information in Survey Documentation describing the object or areas, where features appear. It seems reasonable to develop a method that allows an automatic extraction of data characterizing, among others, small bottom objects (SBO) lying on the bottom from bathymetric measurements and make the information useful for a particular recipient (for example S-57 Additional Military Layers - Small Bottom Objects).

Bathymetric data stored in a raster grid format allows use of different terrain analyses techniques. These methods can be grouped into four types of information:

- Slope,
- Orientation (aspect),
- Curvature and relative position of features,
- Terrain variability.

Having reviewed the results of analyzing methods on bathymetric grids, the variability or complexity of the terrain proved to be effective in distinguishing bottom feature for the surrounding. There are many different algorithms to calculate parameters that reflect variations related to seabed morphology. The author presents two of them used during terrain analysis with QGIS software.

The Terrain Ruggedness Index (TRI) was adapted [Valentine, 2004] for bathymetry data from the method designed for terrestrial ruggedness [Riley, 1999]. The TRI is calculated by comparing a central pixel with its neighbors, taking the absolute values of the differences, and averaging the result.

$$TRI = \big(\left|z_{(-1,1)} - z_{(0,0)}\right| + \left|z_{(0,1)} - z_{(0,0)}\right| + \left|z_{(1,1)} - z_{(0,0)}\right| + \left|z_{(-1,0)} - z_{(0,0)}\right| + \left|z_{(1,0)} - z_{(0,0)}\right| + \left|z_{(1,1)} - z_{(0,0)}\right| + \left|z_{(0,-1)} - z_{(0,0)}\right| + \left|z_{(1,-1)} - z_{(0,0)}\right|\big) \quad (3)$$

The rugosity [Jenness,2002] has been used by a number of marine habitat studies [Lundblad, 2006]. This is the ratio of the surface area to the planar area across the neighborhood of our central pixel. By this method flat areas will have a rugosity value near to 1, while high relief areas will exhibit higher values of rugosity.

$$rugosity = \frac{surface\ area\ of\ 3*3\ neighbourhood}{planar\ area\ of\ 3*3\ neighbourhood} \quad (4)$$

Both of above analysis are limited to a single scale and are therefore sensitive to the initial raster resolution (Fig.5).

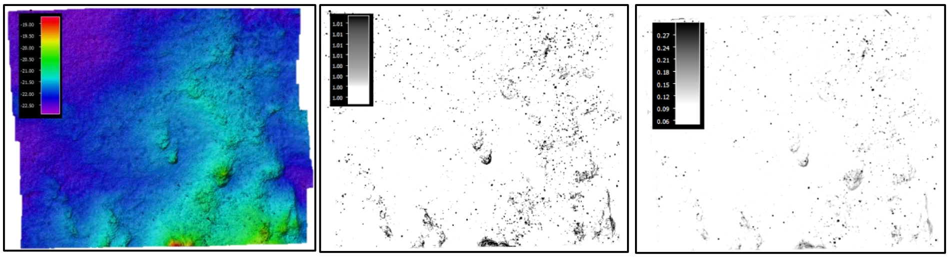

Figure 5. Terrain Ruggedness Index (centre), rugosity (right) and bathymetric source grid at 0,5 m resolution (left). Source: Authors.

An alternative to GIS-based terrain analysis are methods based on the wavelet transform [Csillag, Kabos 2002;] to perform multiscale analysis of seafloor bathymetry. A small-scale wavelet is able to detect rapidly changing details, whereas a large-scale wavelet is able to detect slowly changing coarse features [Mallat 1999]. Multiscale terrain analysis using wavelets exploits this multi-resolution property central to wavelet theory. During wavelet decomposition, the original signal (bathymetry) is broken down into many lower resolution components forming a wavelet decomposition tree This process is called the Discrete Wavelet Transform (DWT). Bathymetric data can be decomposed to whatever scales are required above the smallest scale present in the DTM [Guinan, Grehan, 2008]

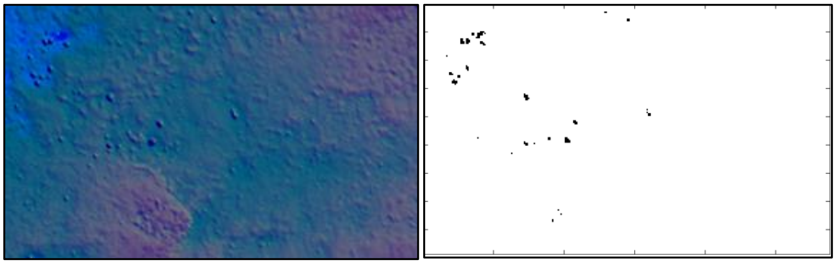

Figure 6. DTM Grid and Residuals after DWT (Biorthogonal Bior1.5 wavelet), MATLAB Wavelet Analyzer 2D. Source: Authors.

While certain terrain analyses and feature detection may be performed on the basis of the raster grid and algebraic interactions between pixels or multiscale wavelet decomposition, they present many drawback mainly associated with principles of an uniform grid creation. According to the author’s experience they may be applied in cases when the raw survey density is comparable with grid resolution.

In very shallow water areas (less than 20 m), a nominal update rate of 30 measurement, and a 512 beam array (Dual Head System), over 45,000 depth points per second are acquired; resulting in a large but densely detailed bathymetric data that is becoming similar to Terrestrial Laser Scanning (TLS) results. Terrestrial LIDAR data are mostly 3D and traditional terrain analysis based on raster grids cannot be applied in general [Sithole and Vosselman, 2004]. Although sea bottom is mostly a flat 2D surface, and can be gridded, the shallow, coastal water and inland areas (berthing places, harbors) are 3D. The gridding process would have led to the rejection of large number of measurements (Fig. 7.)

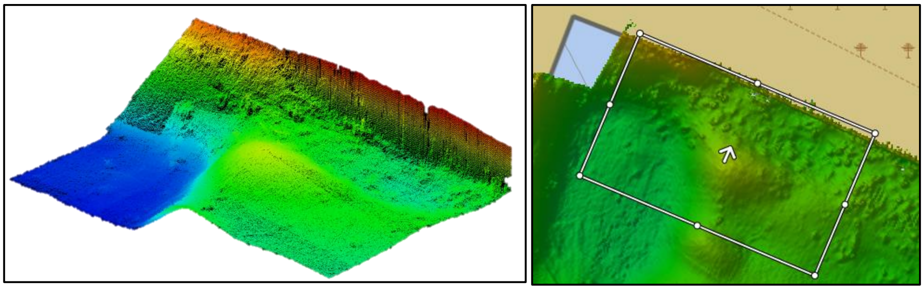

Figure 7. A 3D point cloud and a raster grid (0,25 m) of harbor basin, QPS QIMERA software. Source: Authors.

As technology evolves, data sets are denser and larger. Manual, operator dependent techniques for detection of bottom features are extremely time consuming. For this reason automatic processing is thus urgently needed, together with fast and precise methods allowing extraction of particular data from large 3D points clouds.

As an example of implementation of a classification method for 3D point cloud - the CANAPO (CAractérisation de NUages de POints) is presented. The multi-scale dimensionality analysis was designed to characterize features according to their geometry in complex natural 3D scenes obtained by terrestrial laser scanning methods. Firstly, it analyses local dimensionality properties of the scene at each point, at different scales and calculates if the point cloud in given location is more similar to a line, plane or if the points are distributed in the whole neighborhood ball. Then the method combines information from different scales and builds signatures to identify some features of objects in the scene. [Brodu, Lague, 2012]. This designation can then be used, for example, to discriminate object from bottom (Fig. 8).

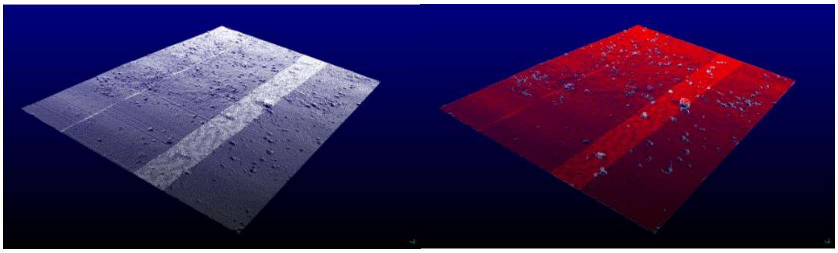

Figure 8. Result of the classification process using CANAPO method (right) on an area of bottom with large number of rocks. Source: Authors by means of CloudCompare software.

Another advantage of this method is that it lets you create your own classifiers (by training them on small samples) and apply one classifier at a time on a point cloud so as to separate it into two subsets. It could be used as automatic tool with the availability to distinguish valid sounding from noise during post processing and editing operations (Fig. 9).

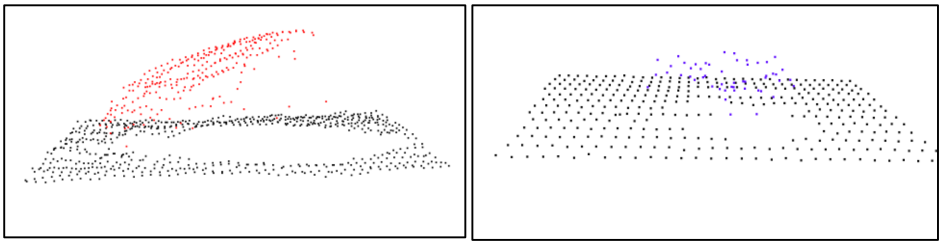

Figure 9. Raw Point cloud data of rock (left) and a blunder detections that should be filtered out (right). Source: Authors.

CONCLUSIONS

Hydrography includes detection and characterization of the bottom features for a number of purposes not restricted to navigation. MBES has proven to be an effective tool with capabilities allowing it to provide a full insonification of the seafloor whilst meeting IHO specifications for bathymetry. Even though, MBES detection of objects of the size that meet IHO Special Order or other even smaller features, cannot be certain unless precautions are taken. Surveyors must verify the performance of a MBES before it is employed for feature detection. It may require limiting the useable swath width, conducting multiple passes over an area and calculating an appropriate speed for a desired ping rate. It is also necessary to configure multibeam acoustic frequencies and pulse length to match the environmental conditions and survey requirements. Additional studies should be taken to calculate values of uncertainty of depth measurement conducted at different acoustic signal parameters. Though different pulse length or bandwidth do not affect the ability to detect features, the surveyor needs to know that they may provide unreliable data describing bottom object geometry.

The acquisition of bathymetric data is undoubtedly an essential part of creating a Digital Terrain Model that will serve a source of information for a wide range of recipients related to maritime economy. Most of the wrong decisions taken during that phase cannot be altered, and sometimes there may occur a need to conduct a re-survey of a previously scanned area. Nevertheless, the postprocessor and editing operation are as well labor consuming as a survey itself. The volume of data increases along with the development of tools to process it but the results are still dependent on the operator's hydrographical knowledge and experience.

The article discuss examples of tools that can help in detecting bottom objects. Both terrain analysis based on a regular grid of points and a method using machine learning to discriminate 3D point clouds depending on their relative position are presented. There are also popular methods for both, image analysis and data from LIDAR measurements, using semantic segmentation techniques that also may prove to be a very useful tool in discussed manner.

Future study will be carried out in order to use the presented algorithms for the automatic detection process, possible classification or filtration of bathymetric data acquired by MBES from areas of varied depth and morphology.

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STRESZCZENIE

Pomiary na płytkich wodach z użyciem systemu echosondy wielowiązkowej dają możliwości pozyskiwania danych batymetrycznych przydatnych do aproksymacji izobat, ale również mapowania cech dna morskiego mogących stanowić niebezpieczeństwo dla nawigacji. Ponadto pozwalają wykryć obiekty mniejsze lub położone głębiej niż wymaga tego standard Międzynarodowej Organizacji Hydrograficznej dla zapewnienia bezpiecznej żeglugi.

W tym artykule zwrócono uwagę na pewne zagadnienia odnoszące się do wydajności pomiarów z użyciem echosondy wielowiązkowej na płytkich wodach. Ponadto przedstawiono sugestie odnośnie technik opracowania danych w trybie post-processingu wraz z dyskusją przydatności konkretnych formatów danych w przypadku posługiwania się wybranymi narzędziami dla wydzielenia obiektów dennych spośród danych batymetrycznych.