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DEVELOPMENT OF UNDERWATER SURFACE MEASUREMENT – MULTIBEAM SONAR

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Abstract: This study was written in the title theme as a result of the cooperation between the staff of the departments of the two scientific institutions mentioned above. Its first author is also a PhD student of the IGGIS. This year the Bay Zoltán Applied Research Public Benefit Nonprofit Ltd. has purchased a Norbit-iWBMSe multibeam ultrasonic system. The primary purpose of this paper is to describe a multibeam ultrasonic system (Norbit-iWBMSe) and to examine its useful application for mine surveying purposes, particularly for measurements used in underwater mining situations, such as the official determination of the amount of the extracted mineral resources, which also serves as the basis for determining the payable annual mining rent. In our study, first, we will briefly review the new surveying technologies which have appeared in Hungarian mine surveying recently and are likely to be used more and more in the future. Then we will deal with the history of underwater topographic mapping. Afterwards the multibeam sonar survey device and its advantages will be discussed, and two waterbed surveying examples from our own practice will be shown. Finally, the legal background of mining volume computation will be briefly described. Furthermore, it is important to highlight the role of multibeam sonar in mining exploitation process.

Keywords: *new surveying technologies, mine surveying, volume computation, history of bathymetry, single-beam sonar, multibeam sonar, mining volume computation, relevant legislation*

1. CHANGES IN MINE SURVEYING TECHNOLOGY

It is known that the extraction of mineral raw materials, and even mining planning, must be based on reliable and accurate spatial data. These are provided by mine surveyors for each mining company and mining entrepreneur. Their most important tasks include but are not limited to the accurate survey of the excavated areas, the precise determination of the quantity (stocks) of various materials, the representation of the surface and underground spatial position on the various mine maps, mining plans, etc.

Today, new opportunities and challenges are arising in mine surveying, as several new survey methods are being applied and systematized [1]. What are these? Ground-based laser scanning; UAV (drone)-based aerial laser scanning and aerial photogrammetry; ultrasonic measurements; and USV (Unmanned Surface Vehicle) sonar systems, that is to say, “vehicles” for unmanned aerial or waterborne transport to which sensors or devices using various surveying technologies can be installed. Terrestrial Laser Scanning (TLS) is an alternative which automatically produces a large amount of spatial information (a dense 3D point cloud) relative to the location of the scanner. Consequently, the method is suitable for determining the spatial changes characterizing the progress of mining activity over time, thus for calculating volumes, as well as for studying movements and deformations in a mine, and for documenting unfortunate accidents. Although the investment price of TLS is steadily decreasing, it is still quite high. Recently, more and more mining companies have also started to use UAV-based aerial photogrammetry. These aircraft (drones) have state-of-the-art digital cameras which allow high-resolution aerial photography. By processing these digital images, several valuable survey products (e.g. orthophoto map, point clouds, 3D models, etc.) can be produced. Thus, this measuring procedure can also facilitate the performance of mining and mine surveying tasks, such as exploration; surveying stockpiles, or tracking time-varying processes. Combining UAV with LIDAR (Light Detection and Ranging) can also support the implementation of several mining monitoring activities (e.g., environmental, mining, etc.). In connection with technologies based on unmanned aerial vehicles, however, it is necessary to mention the dependence on weather, the relatively high cost of LIDAR equipment, the environmental and other constraints associated with the application, and the required expertise. Portable laser scanners are much more affordable and can be a solution mainly to facilitate certain tasks of underground mine surveying (e.g. surveying inaccessible areas).

2. DEVELOPMENTAL HISTORY OF WATER DEPTH MEASUREMENT AND SINGLE-BEAM SONAR

Water depth measurement, known also by the Greek word bathymetry, means the measurement and mapping of the surface under different waters (e.g., the seabeds, lakes, and riverbeds). Products from this survey include, for example, depth lines connecting points of the same depth, a depth-coloured bed map, or a bottom-bed Digital Terrain Model. These can then be used for a number of purposes, including safer water, underwater transport, or underwater mining, which is the most interesting to us now, and the computation of mineral raw material stocks using time-varying bed surfaces associated with it.

Mapping of the Hungarian surface waters dates back to the 18th century. In the second half of it, regulation of our larger rivers (the Danube and the Tisza) began, and this was accompanied by remarkable mapping results. Studying the change in our water network was formerly – and still is today – an important research theme. As for the technological development of riverbed survey and water depth measurement concretely, it is important to examine the method of determining the spatial location of the survey points related to the route of a watercraft moving above the surface to be mapped (e.g. surveying with a total station, RTK GPS technique) and the depth surveying procedure adapted to these points. Let us focus now on the latter. In the past, a rope/wire loaded with plummets/weights was used for this purpose. In this method, the accuracy of the measurement was significantly affected by currents and vessel movement. This was later replaced by the fish radar. Today, either a sonar device is used for this task, which is mounted under/next to a boat, or a LIDAR sensor may be installed on a device flying above the water (mostly on a drone). The sonar records the created sound wave(s), while LIDAR records the reflection of light from the bed. Here we only deal with the sonar approach.

The depth measured with a sonar can be calculated by the following formula:

$$\mathbf{D} = \frac{1}{2}\mathbf{v} \cdot \mathbf{t}$$

where *v* is the propagation velocity and *t* is the travel time.

The use of single-beam sonar (SONAR Mite SPX in this example) for bed surveying is described in [2]. In this we gain a detailed insight into the riverbed survey of Lake Bánki, which is 60 km from Budapest and has an average depth of almost 4 m. The measuring system used here consisted of 3 main units. These were a single-beam sonar (transmitter and main unit), a RTK GPS receiver and a data acquisition unit (portable PC), to which the former two were connected. Among the technical data of the sonar measuring instrument, it is worth mentioning its small size and weight, easy handling, the measuring limit up to 75 m, and the approximately 20 cm depth measurement accuracy.

Before starting the measurement, the instrument was fixed to the side of a boat, making sure that its probe was a few centimeters below the water level (taking into account any tilting of the water craft). Considering the progress of the measurement and the nearly regular survey grid, parallel lines at intervals of 4 m on a land office map were designated to measure the depth of the inner part of the lake, and this was supplemented by a survey of parts close to the shore. As the nature of the water of the lake to be measured (in this case it was fresh water) and its temperature affect the velocity of the sound waves, this was taken into account by the surveyors with a correction factor.

When processing the survey data, the y, x and z coordinates of each survey point measured by RTK; the water depth obtained with the sonar; the depth offset value (RTK-GPS-sonar distance) and the average water level correction were taken into account. Further evaluation was then performed in a GIS environment (Quantum GIS), providing visualizations such as a Triangulated Irregular Network (TIN) model (treating the lake shore as 0 depth), a depth-line diagram, or a layer-colored bed map.

The brief description of measuring the mining lake bed with a modern single-beam sonar [2] is relevant further highlight the new possibilities and benefits associated with the multi-beam sonar, which is the backbone of our study.

3. Introduction of Norbit-iWBMSe multibeam sonar, practical application examples

In the field concerned (in this case: mining), the multibeam sonar surveying tool is suitable for the efficient solution of a wide range of problems that arise, coupled with significant measuring capacity and flexibility. Bay Zoltán Applied Research Public Benefit Nonprofit Ltd. is one of the first Hungarian service providers to have this modern sonar system. Accordingly, we consider it important to provide convincing information about the surveying instrument, as well as to describe the essential characteristics of surveys carried out with it. In the present study, comparing this multi-beam ultrasonic measuring device with the sonar ones already common in practice, its most important features will be highlighted. These are the following [3], [4]:

1. guaranteed high surveying accuracy;
2. efficiency;
   a. high measurement resolution, huge amount of data (point cloud) (15,000 points/sec is possible), fast surveying, shorter measuring time, less vehicle revolutions than with single-beam sonar, with significantly higher measuring accuracy,
   b. a significant number of parameters which can be adjusted according to the purpose of the measurement,
3. mobility.

More detailed information on these features is provided below.

1. Units of the multibeam survey system which ensure guaranteed measuring accuracy:

- the sonar system also includes two GPS antennas capable of receiving RTK corrections and an integrated GPS receiver;
- the inertial unit (acceleration sensors, angular velocity meters) for elimination of factors influencing surveying accuracy on water (rotation about the spatial axis X, Y, Z, namely rocking of the boat “rotation in place” back and forth, right and left, and the change in height due to waves;
- the unit for determining the speed of sound propagation (sound speed meter) for determination and correction of different physical parameters (temperature, water pressure, speed of sound) necessarily resulting from the depth of the water column above the riverbed (water depth) in the water medium to be measured, as an external unit, and an additional one integrated in the sonar body so that the shape of the emitted measuring signal corresponds to the surveying parameters;
- the Sonar Interface Unit (SIU) collects sonar, inertial unit, sonic speed meter data, calculates depth surveying data, and automatically performs corrections;
- special software to control the measurement and perform data processing, to define the surveying parameters appropriate to the purpose of the planned measurement (simple bed survey; detailed, high-density bed survey or inves-

tigation of a pipeline, possibly sunken objects such as hull search for a vessel), and to edit and convert surveying data (point cloud, up to a few cm^2 resolution).

2. Efficiency
- In contrast to the single-beam devices accepted and used in practice in Hungary (which only work with one test signal at a time), this measuring system works simultaneously with up to 512 test signals/separate radii in a fan-like arrangement;
- With the help of a large number of emitted test signals, it has a very wide measuring zone, even in the lateral direction, so that the coastal strip of surface waters can be surveyed, which is often an areas that a boat can only reach with great difficulty or not at all. Thus, no other (terrestrial) surveying method is required to determine the coastal strip;
- After starting the parameterized measurement, no operator intervention is required, as the measurement and correction are taken into account automatically;
- The survey speed is high. It is capable of emitting the test signal at a maximum frequency of 60 Hz for all 512 signal sources. This frequency may even change automatically depending on the water depth; therefore the sonar system is able to provide the highest expected measuring resolution without intervention. The frequency of the emitted signal can be adjusted between 200 kHz and 700 kHz, and the practical depth measuring range is from 1 m to 250 m;
- By changing the surveying parameters on the sonar units, it is possible to improve the device according to the purpose of the measurement, so the required time for surveying, the measured amount of data and, in this connection, the amount of post-work in the office can be optimized.

3. Mobility
- Despite the multiple units which ensure the required surveying accuracy, the device is characterized by compact size and weight;
- The measuring device can be mounted on the vast majority of boats and smaller vessels used in practice, so it is not necessary to transport it fixed to a boat, since it can be mounted on a watercraft available at the survey location.

The excellent signal processing sonar and the state-of-the-art GNSS which form the basis of the depth surveying and navigation systems, and the inertial system complementary to the RTK, result in reliable depth measurement and driving stability. With a multibeam sonar, a large number of bed points are measured in a short time, so that a much more accurate model of the river/lake bed topography can be produced.

The survey diagram which can be associated with the measuring device and its parameters can be seen in *Figure 1*.

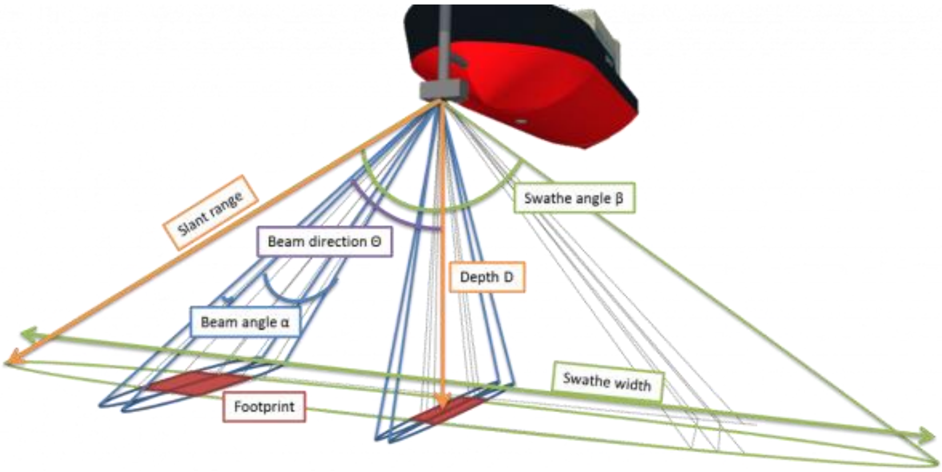

Figure 1
The multibeam sonar (survey diagram + parameters)
https://www.hydro-international.com

Here the above parameters supplemented with some explanations are briefly overviewed:

Depth – <u>*the measured data*</u>,
Slant range – the maximum of line-of-sight distance along a slant direction between the vessel and the area to be measured,
Swathe angle – the width of the measuring band, the angular range of the receiving angles of the sensors (hydrophones),
Swathe width – section of the receiving angle range of the sensors formed with the bed bottom (sensing band of the sonar),
Beam direction – the orientation and location of the signal sources (usually at the same distance or with equal angular deviation, but there are other options as well),
Beam angle – the angle of narrowing of the emitted signals (it can be 512 at the same time), the extent of this largely determines the horizontal resolution of the sonar,
Footprint – the common part of the cross-section of the measuring signals with the river or lakebed (blue ellipses) and the cross-section of the sensor receiving angle with the just-mentioned bed (larger green ellipse): the red rectangles. This is the horizontal resolution of the sonar. As a result, we get just one depth data from an area of a red rectangle.

The width of the described sonar measuring band/adjustable angle range of the receiving angles of the sensors: 5° to 210°; depth measuring range: 0.2 m to 275 m and the angle range of the resolution for the standard operating frequency (400 kHz) is 0.9° to 1.9°. The specified operating temperature range is –4 °C to +40 °C. In the following, we briefly describe the main units of the multi-beam sonar system, which is the subject of our study, and the preparation of the measuring device mounted on the boat *(Figure 2)* for the bed survey, which we illustrate with several photos *(Figures 2–11)* thereby making it even more understandable.

Figure 2

The multibeam ultrasonic measuring installed for bed survey

The survey equipment includes the following:

- 2 GPS antennas, which are placed on the support frame during the measurement,
- a sonar head *(Figure 4)*, which is also mounted on the frame (this frame must be attached to the boat),
- an interface unit (with interface, a GPS unit for receiving RTK correction, and an integrated inertial unit),
- a mobile hotspot, a telephone for internet connection,
- a sound speed meter,
- a control laptop with the necessary software,
- the powered battery and an inverter.

Several of the system components listed above can be seen in *Figure 3*.

Figure 3

The sonar instrument and its accessories in the carrying case

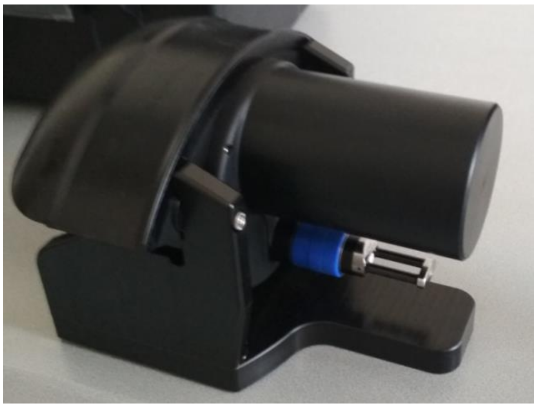

Figure 4
The Norbit-iWBMSe sonar head unit

A very important instrumental unit of this ultrasonic measuring system is the *interface unit*, which can be seen in *Figure 5.*

Figure 5
The Sonar Interface Unit (SIU) with the connecting cables

The sonar (bottom left), two GPS antennas: Ant1 and Ant2 (top left), the Ethernet connector for communication with the control computer, and the power cable are connected to the interface unit shown in *Figure 5*. This ultrasonic system unit connects to the multi-beam sonar unit and GPS antennas, performs the NTRIP correction processing, and handles the integrated inertial unit. A schema of the complete system is shown in *Figure 6*.

Before starting the bed survey, we also have to deal with the role of the sonar control software *(Norbit Graphic User Interface)* in the measurement preparation and the initialization of the inertial unit.

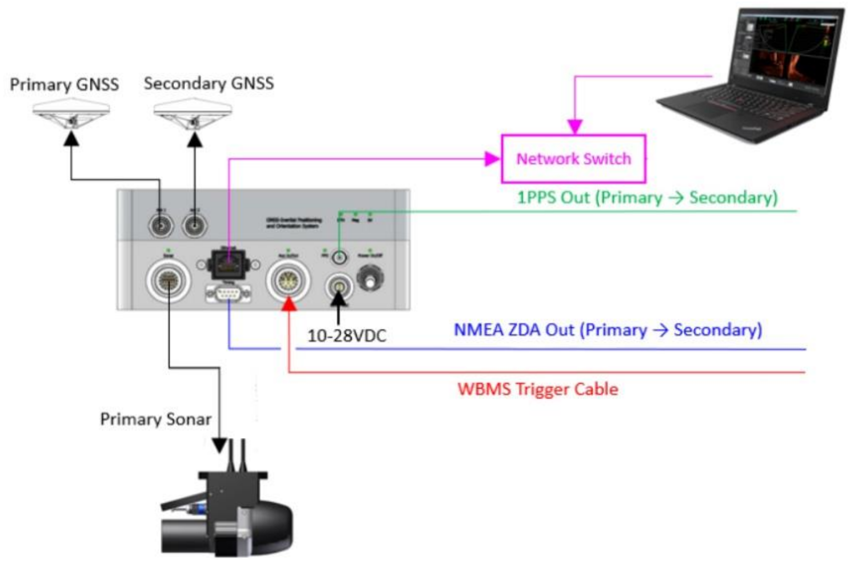

Figure 6

The schema of the sonar system

The sonar is set up and parameterized on a graphical interface, which was created by the manufacturer specifically for the given device. In this software, we can modify the measuring parameters within the range of the survey device, according to the purpose of the measurement and the existing conditions. Once the cable connections and power supply are ready, the ethernet connection between the sonar and the computer controlling it must be set up, and then the frame parameters (antenna distances from each other and the sonar) can be specified *(Figure 7)*, but the RTK correction setting is primary *(Figure 8)*.

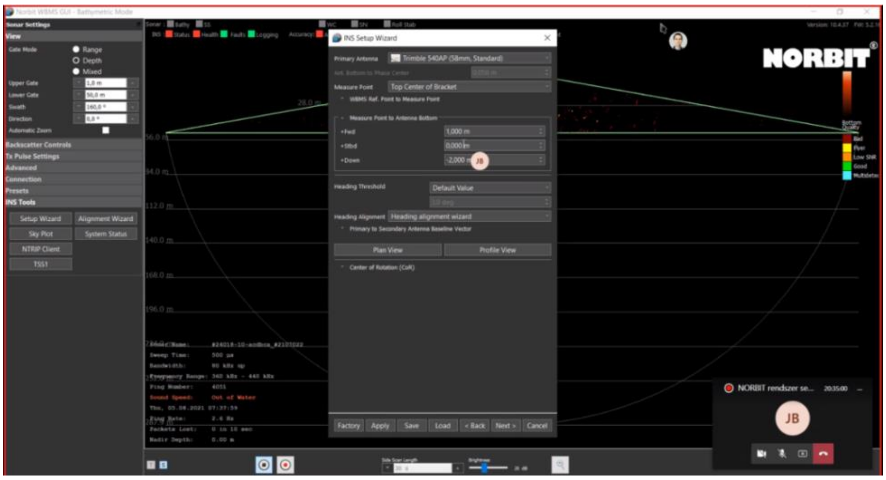

Figure 7. *Setting the frame parameters*

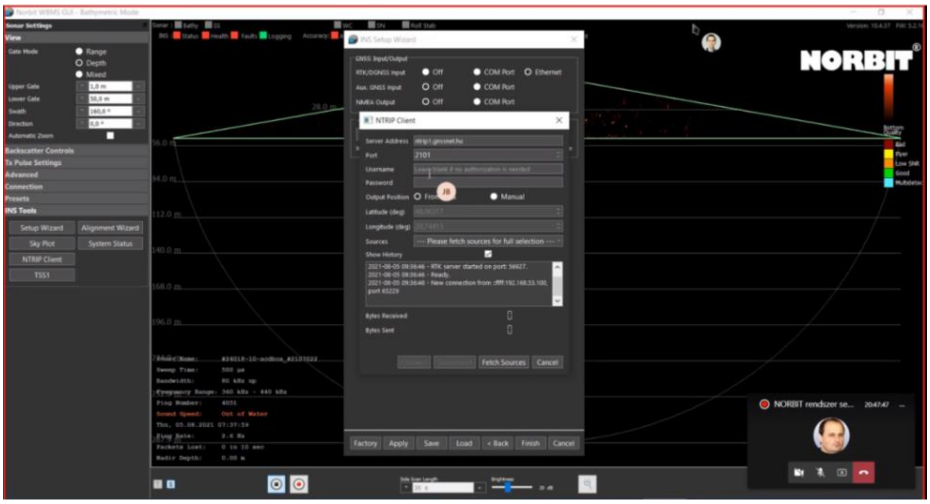

Figure 8
Setting the RTK correction

Then we can set the survey parameters, the most important of which are the depth range to be tested; the opening angle of the sonar “umbrella”; the angle of rotation; the survey frequency; the number of measuring pulses, their geometric arrangement; and the signal strength *(Figures 9–11)*.

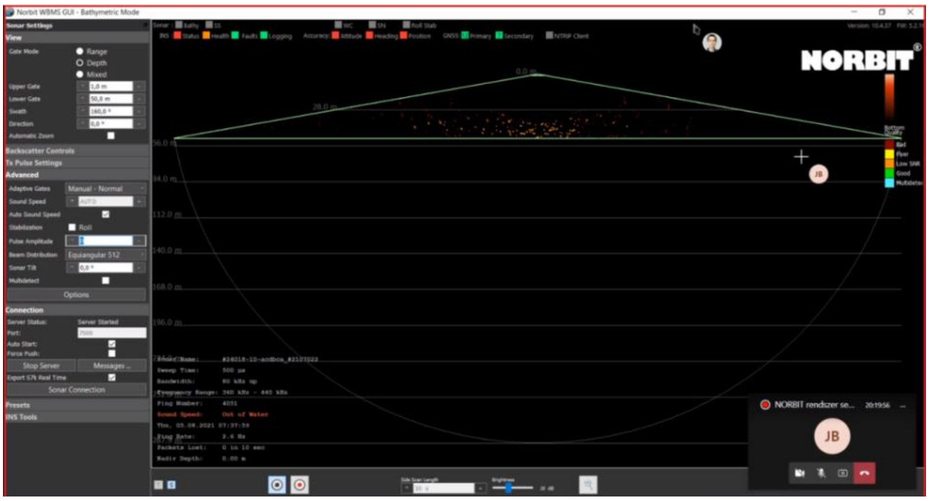

Figure 9
Survey image of the connected sonar in control application

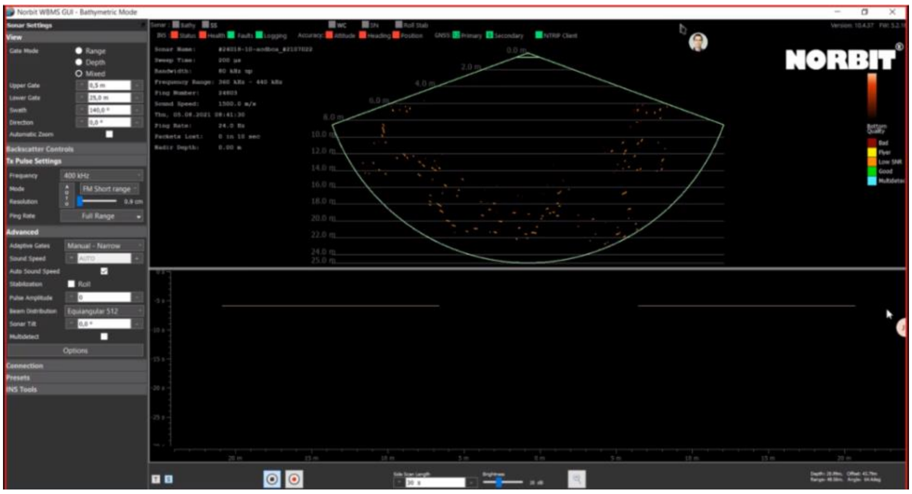

Figure 10
Survey image of the connected sonar in control application with a smaller "umbrella" opening

Figure 11
Measured image of the connected sonar with a rotated "umbrella" in control application

The next step is *to start with the parameterized system* and then *initialize the inertial unit (Figure 12)*. In the latter, the so-called laid-out octagonal shapes must be traversed continuously by the boat until the inertial unit is ready for surveying. Then it is necessary to travel back and forth in one or two test sections. After that, the actual survey can begin.

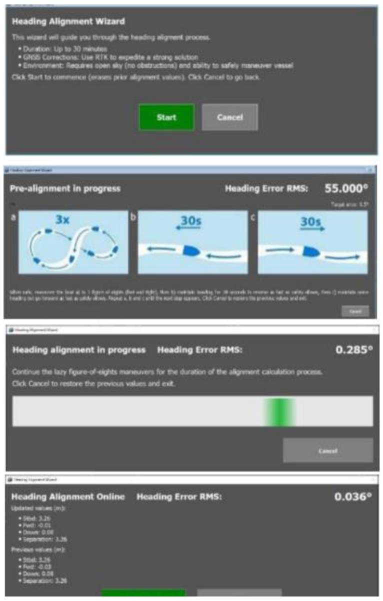

Figure 12. *The process of initializing the inertial unit*

Figures 13–15 illustrate our own demo measurements (two survey samples) performed with the multibeam ultrasonic measuring system. One of them was made on a stretch of the Danube River, and the other was a lakebed survey of a gravel mine. In the latter, our goal was to describe the raw material to be extracted and to gain an overview of the mining exploitation process.

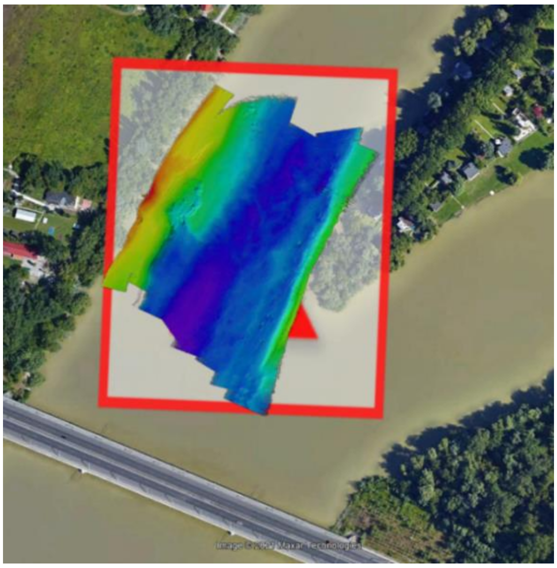

Figure 13. *Survey site of a section of the Danube*

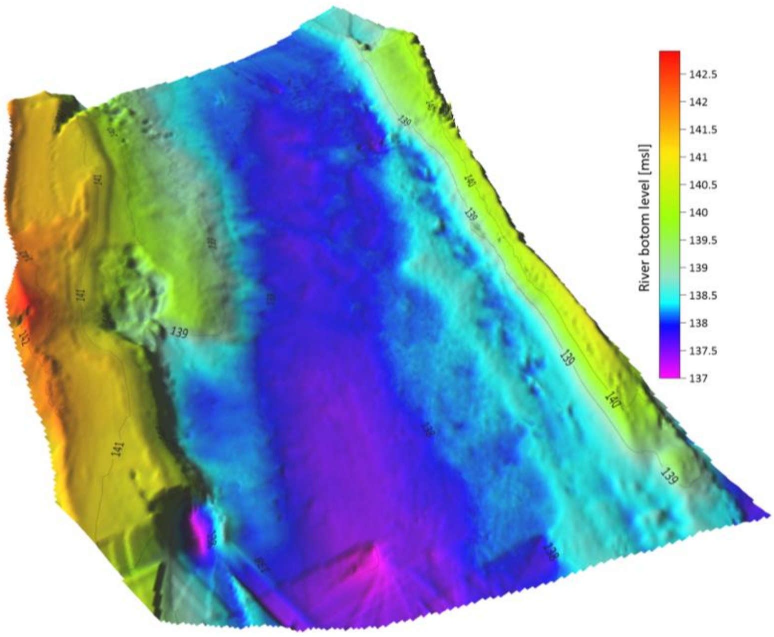

Figure 14. *3D model of the surveyed Danube section (40cm resolution)*

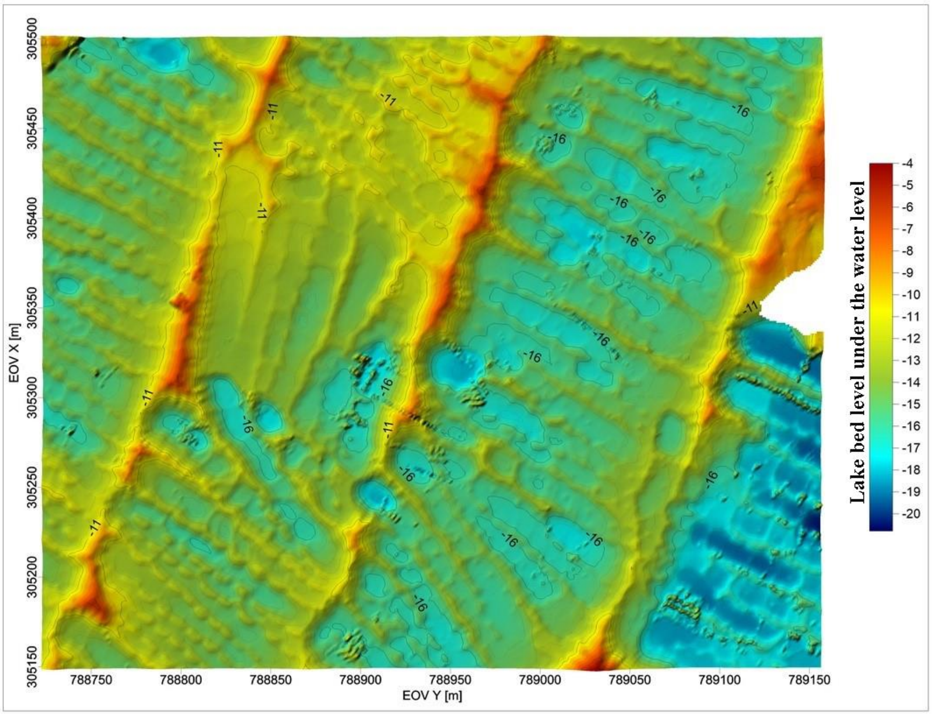

Figure 15. *3D model of a lake bed in a gravel mine*

4. THE LEGAL REQUIREMENTS FOR THE VOLUME COMPUTATION IN MINING

This professional group of problems is regulated by a Hungarian government decree [5] on determining the specific value of mineral resources and geothermal energy and the method of calculating value. Paragraph 2 (Section 2) of this Decree regulates the case of the payment of annual mining rent in the case of solid mineral raw materials, including the following:

"Paragraph 2 (Section 2): The licensee extracting the mineral raw material with the other official permit is obliged to determine the quantity of the extracted mineral raw material by mine surveying (geodetic) methods or in another suitable manner. The method and result of the determination must be substantiated."

"Within 60 days after completing the extraction of the raw material, the licensee is obliged to determine the change in the quantity of the mineral raw material by geodetic calculation (volume computation), and send a report about it to the Mining Authority."

"Paragraph 2 (Section 3): The mining entrepreneur is obliged to determine the amount of extracted mineral raw materials by mine surveying (geodetic) methods. In the case of underground mining, the extracted quantity can also be determined by weighing. The change must be indicated on the mining map. The change in the quantity of the mineral raw material for the current year must be determined by a calculation based on geodetic measurements (volume computation). The result of the determination must be certified."

In addition to the legal background, we would also like to highlight the 3–5% accuracy requirement imposed on this mine surveying task in Hungarian mining practice.

It is important to note that the application of the title "surveying device" in mining for the surveys of mining lake beds – one of which was briefly described above –, is justified not only for the sake of the afore-mentioned legal requirements. This is because periodic measurements, depending on the progress of production, can increase the efficiency of extraction by providing an accurate picture of the bed shape. Thus, it will be possible to identify raw material formations whose extraction has been unintentionally delayed. As a result, the mineral raw material can be extracted with higher efficiency in a mine, and the state receives an annual mining rent considering a larger extracted share of the available theoretical stock.

5. CONCLUSIONS

In our study, after a brief description of today's changing state-of-the-art mine surveying technologies we have reviewed the development history of water depth measurement in Hungary in detail. Subsequently, based on a study [2], we overviewed the single-beam ultrasonic measuring device based on the example of bed surveying of a mining lake. Then we described the iWBMSe multibeam sonar system in detail, emphasizing its application benefits in surveying mining lake beds. Afterwards we discussed the preparation for use of this survey system and illustrated two of our own practical examples as well. Finally we dealt briefly with the legal regulation of mining volume computation and mentioned benefits of using the multibeam echosounder system in the mining process.

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