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Determination of the Territorial Sea Baseline – Aspect of Using Unmanned Hydrographic Vessels

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ABSTRACT: Determining the course of the territorial sea baseline (TSB) of the coastal state is of primary importance to define its maritime borders, and hence it is indirectly a part of the state maritime policy. Besides the legal and methodical aspects described in conventions, laws, standards and regulations, equally important is the issue of measurement methodology with respect to the internal limit of the territorial sea.
The article discusses an effective and optimal method of realization of bathymetric measurements that allows determining the course of the TSB. It proposes - as an alternative method to classic measurements - the use of unmanned hydrographic vessels, justifying their desirability. It reviews the currently available solutions, as well as highlights the advantages and limitations of the proposed method.

1 INTRODUCTION

The territorial sea is an integral part of the Polish territory. It extends as a belt with a width of 12 nautical miles from the so-called „*baseline*”. This line was defined in Art. 5 Paragraph 2 of the Act concerning the maritime areas of the Republic of Poland and the maritime administration [Act, 1991] as: „*a low-water line along the coast or the outer limit of internal waters*”. The amendment of the cited Act of 2015 [Act, 2015] introduces a redefinition of the concept of the TSB as: „*a line joining the appropriate points defining the lowest water level along the coast or other points designated in accordance with the principles set out in the United Nations Convention on the Law of the Sea, signed in Montego Bay on 10 December 1982*” [UNCLOS, 1982].

In Poland, the problem of determining the course of the TSB was also the problem of competence. Only the Act [Act, 2015] solved the division of tasks between: maritime administration authorities, the Hydrographic Office of the Polish Navy (HOPN) and the Head Office of Geodesy and Cartography (GUGiK). In addition, Art. 5 Paragraph 2 of that Act states that the Council of Ministers shall define, by way of a regulation, the detailed course of the TSB in the form of text and graphics in accordance with the national spatial reference system, taking into account the principles set out in the UN Convention.

The need to introduce legislative changes arises due to, among others, the obligation to implement into the Polish legal order, by 18 September 2016, the provisions of Directive 2014/89/EU of the European Parliament and of the Council of 23 July 2014 establishing a framework for maritime spatial planning [Directive, 2014]. The EU Member States are obliged to develop maritime spatial plans until 31 March 2021, that is why the Act includes legislation necessary to prepare spatial plans for Polish maritime areas that don’t arise directly from the Directive but are necessary for its full implementation. In particular, the provisions governing the course of the

TSB and the limits of Polish maritime areas must be introduced [Maritime Institute in Gdańsk, 2016].

2 CLASSICAL HYDROGRAPHIC MEASUREMENTS AND THE TSB MEASUREMENT

Bathymetric surveys in the coastal zone, internal waters and inland waters are specific in terms of hydrography of those reservoirs. They are characterized by the presence of shallow waters (at depths below 1 m) and high variability of seabed, which can significantly hinder or even prevent the implementation of hydrographic measurements.

Determining the course of the TSB is performed on shallow waters, usually at a depth of several tens of cm below the current water level (Fig. 1). Therefore, performing classical hydrographic measurements using manned hydrographic vessels is impossible due to excessive draft of such boats and placing on their bow echo sounder transducers.

After summing up the current limitations of classical measurement methods in hydrography, in the context of determining the TSB, it is clear that:

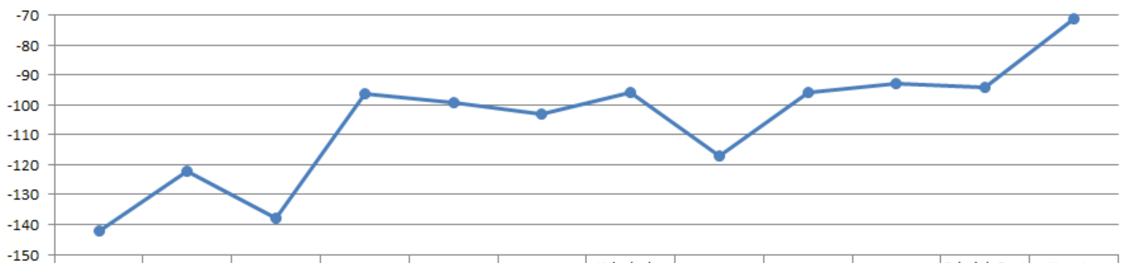
- hydrographic vessels, due to the draft, don't actually perform bathymetric measurements at depths below 1 m;
- common in hydrography the mapping of shallow waters (without real measurement data) is performed on the erroneous assumption of a linear decrease in depth in the area of the smallest depths (0-1 m);
- substantial size of elements of bathymetric systems (echo sounder and sonar transducers) prevent performing measurements on shallow waters;
- lack of the precise positioning system of a vessel in Poland, operating in real time at the expected accuracy of calculating of position coordinates of less than 5 cm (2dRMS);
- significant reduction (low accuracy or lack of the positioning solution by the receiver due to the small number of satellites) of the possibility of positioning of the vessel using only the GPS system, in close proximity to field obstacles (hydraulic structures, vegetation etc.), justifies the use of multi-GNSS solutions;
- the use of GNSS geodetic measurement methods enables the TSB measurements, however, it requires from a measurer working in the water [Specht & Czaplewski, 2016];
- the geodetic method ensures very high accuracy of measurements [Specht, 2016].

Above restrictions lead to considering the use of those unmanned hydrographic vessels available for several years on the market, which specific design features (small draft and considerable time efficiency in implementing measurements) justify their application in determining the TSB.

3 HYDROGRAPHIC MEASUREMENTS WITH THE USE OF UNMANNED VESSELS

The beginning of the 21st century is the era of using unmanned boats in various measurement applications. Modern autonomous and unmanned vessels (*Autonomous Surface Vehicle* – ASV, *Unmanned Surface Vehicle* – USV) offer a variety of design solutions in the construction of the hull and the boat propulsion: single hull, double hull with a screw or screwless propulsion with a small draft. They allow the entry into the reservoir with a difficult access due to the presence of shallow waters [Romano, Duranti, 2012]. Bathymetric surveys as a part of hydrographic measurements (aimed at measuring the seabed topography) require adequate positioning accuracy [IHO, 2008], hence the use of unmanned boats in hydrography can now be regarded as the beginning of a new era in this field.

Depending on the size and displacement of the unmanned vessel the equipment is of vital importance here (in particular echo sounder transducers, single and multibeam). Single beam echo sounders, which can be used here, are small devices that usually don't require Motion Reference Units (MRU) to determine the spatial orientation. Hence, they can be mounted on smaller vessels [Makar & Naus, 2003]. Whereas multibeam echo sounders are placed on larger survey vessels.



	Świnoujście	Dziwnów	Kołobrzeg	Darłowo	Ustka	Łeba	Władysławowo	Puck	Hel	Gdynia	Gdańsk Port Północny	Krynica Morska
Maximum depth [cm]	-142	-122	-138	-96,3	-99	-103	-96	-117	-96	-93	-94	-71
Date of registration	1967-10-18	1979-11-04	1979-11-04	2012-01-14	1979-11-04	1979-11-04	1979-11-04	1949-01-07	1979-11-04	1979-11-04	1979-11-04	2011-11-28

Figure 1. Difference between the level of Kronstadt and the lowest observed water level in Poland, registered on 12 water gauges (own study)

An unmanned hydrographic vessel is a remotely operated floating vehicle, radio-controlled, enabling equipment integration with the GNSS receiver and a single beam echo sounder (the minimum measuring equipment). It is designed to perform hydrographic measurements of: port basins, lakes, rivers and small reservoirs. A comparative analysis of currently used vessels of this type made it possible to determine their preferred technical and operational characteristics, which are:

– radio control;
– remote range – 1 km;
– min. speed – 5 kts;
– battery endurance – 6 h;
– min. recommended size: 150 x 100 cm;
– permissible mass, enabling to move freely – 40 kg;
– double hull vessel is preferred;
– max possible seakeeping.
– Examples of vessels were presented in Fig. 2.

Seafloor EchoBoat-ASV

Seafloor HyDrone-ASV

Seafloor EchoBoat-RCV

Figure 2. Examples of design solutions of unmanned hydrographic vessels by [Seafloor Systems, 2016]

It should be emphasized that commercially available vessels in most cases require direct control, which means that the keeping of a boat on the measurement profile requires from their operator the acquisition of appropriate skills. However, currently available are unmanned hydrographic vessels that enable the realization of measurements (a mission) in a fully autonomous manner.

4 EQUIPMENT REQUIREMENTS FOR UNMANNED VESSELS DURING THE TSB MEASUREMENT

This section will present the technical analysis of unmanned hydrographic vessels and their equipment that allows to perform the expected measurement. It is assumed that the minimum technical equipment to enable the performance of TSB measurements (required to be placed on an unmanned vessel) includes:

– a GNSS receiver using the GNSS geodetic network;
– a portable single beam echo sounder.

The solution that would provide an opportunity to implement bathymetric measurements using GNSS geodetic networks could consist of the following elements:

– basic positioning system – using a commercial geodetic network Leica SmartNet, which has the ability to provide a network solution to a GNSS receiver (located on the vessel) using two satellite systems simultaneously: GPS and GLONASS. It should be noted that the location of reference stations of that network is the most beneficial from the point of view of using it on sea areas (covering the Gulf of Gdańsk by network solution);
– backup positioning system – using a geodetic network ASG-EUPOS, which has the ability to provide
a network solution to a GNSS receiver (located on the vessel) using only the GPS system. Currently, the modernization of the network is under way in order to provide the GPS and GLONASS solutions;
– emergency positioning system – an own reference station (located, for instance, on the building of the Faculty of Navigation of Gdynia Maritime University). This solution prevents the use of the network solution, which results in decreasing the accuracy of the calculating of a hydrographic vessel position in the process of increasing the distance from the station;
– monitoring station – which task is to control the reliability of the positioning solution implemented by a GNSS network, and in the case of exceeding the defined alarm thresholds (too large positioning error, low signal level etc.) to send a warning to a person performing the measurement. In Fig. 3 it was placed in the Gdańsk Harbour Master's Office.

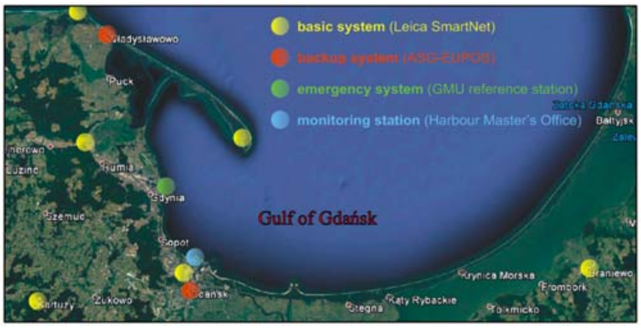


Figure 3. Location of GNSS reference stations, an emergency station and a monitoring station for the sample reservoir (own study)

Using the monitoring station (none of the GNSS geodetic networks has any such station) is necessary to ensure the reliability of geodetic and hydrographic measurements. That reliability of measurements is a key element in geodetic positioning, as well as in navigation. Fig. 4 presents a „*window*" of the software of such station.

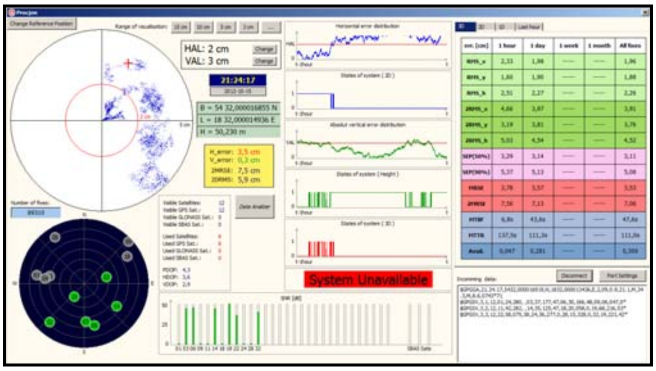


Figure 4. Concept of the main screen of a reliability control station for the subsystem of precise positioning of hydrographic measurements by [Specht & Nowak, 2012]

The basic measurement element of an unmanned hydrographic vessel should be a GNSS receiver primarily capable of integrating the equipment with a hydrographic survey drone, moreover, it should have the option of operating as a stand-alone measuring device (a receiver + a pole and a tripod with a tribrach + a controller). Below are presented selected characteristics of a GNSS receiver, recommended (optimal) for its use during the TSB measurements:

– satellite signals tracked simultaneously: BDS: B1, B2, B3; Galileo: GIOVE-A, GIOVE-B, E1, E5A, E5B; GLONASS: L1C/A, L1P, L2C/A, L2P, L3; GPS: L1C/A, L1C, L2C, L2E, L5; SBAS: L1C/A, L5;
– positioning rate – 20 Hz;
– min. number of tracking channels – 400;
– positioning accuracy (min.): static GNSS surveying: horizontal 3 mm + 0.1 ppm (RMS), vertical 4 mm + 0.5 ppm (RMS); GNSS geodetic networks: horizontal 8 mm + 0.5 ppm (RMS), vertical 15 mm + 0.5 ppm (RMS);
– built-in: radio modem, compass and accelerometer;
– controller controlling operation of the receiver;
– GPRS communication with GNSS geodetic networks;
– performing GNSS measurements during the loss of communication with the GNSS geodetic network;
– supported formats: RTCM 2.1, RTCM 2.3, RTCM 3.0, RTCM 3.1 (input) and NMEA (output);
– carbon fiber pole;
– internal memory – 6 GB.

Fig. 5 presents a few selected types of GNSS receivers - working with GNSS geodetic networks - that meet the quality requirements set out above.

Trimble R10

Leica Viva GS15

TOPCON HiPer SR GSM

Figure 5. Selected GNSS receivers that can be mounted on an unmanned hydrographic vessel by [Leica Geosystems, 2016; TPI, 2016; Trimble, 2016]

The minimum measuring equipment of a hydrographic survey drone should also include a portable single beam echo sounder that should be integrated with the GNSS receiver, capable of easy assembly and disassembly on the pole placed in a drone or other vessel. Its basic characteristics include:

– frequency: 150-250 kHz;
– max beam width – 10°;
– min. ping rate – 5 Hz;
– depth accuracy (min.): 2 cm ± 0.5% depth;
– min. depth range: 0.5-50 m;
– wireless data transfer;
– supported formats: NMEA, ASCII (output);
– battery power;
– max dimensions of the echo sounder: 30 x 20 x 10 cm;
– max dimensions of the transducer: 20 x 10 x 10 cm.

An example of such an echo sounder solution is presented in Fig. 6. It should be noted that since 3-4 years on the market have been also available multibeam echo sounders that significantly accelerate the implementation of bathymetric measurements.

Portable single beam echo sounder

Multibeam echo sounder with two GNSS receivers

Figure 6. Apparatus for measuring the depth with the application of an unmanned hydrographic vessel by [Seafloor Systems, 2016]

The minimum measuring equipment for an unmanned hydrographic vessel is presented in Fig. 7.

GNSS receiver

Portable echo sounder with pole

Complete vessel with measuring equipment

Figure 7. Minimum measuring equipment of an unmanned hydrographic vessel intended for the implementation of TSB measurements by [Seafloor Systems, 2016; Trimble, 2016]

5 DATA ELABORATION AND ROUTE PLANNING SOFTWARES

The software includes two packages for processing the results of geodetic and hydrographic measurements:

- geodetic – a software package that allows the elaboration of geodetic measurement results with the application of GNSS systems (in real time and post-processing). It is advisable to ensure full functionality in the following environments: CAD and GIS. In addition, it should be able to create: terrain models, surface models, profiles, cross sections, alignment of the GPS and TS networks (jointly). An example of the software that meets the above requirements include, among others, Trimble Business Center (TBC);
- hydrographic – a software package used to process hydrographic measurements. It enables the analysis of measurement results, as well as creating: a digital sea bottom model (underwater) and maps in coordinate systems compatible with IHO requirements. An example of the software that meets the above requirements include, among others, HYPACK.

An additional option is the software used for route planning for unmanned hydrographic vessels. It allows planning measurement profiles based on a given measurement area - usually on the basis of an orthophoto map derived from Google Maps (Fig. 8). This type of software is used only by very advanced unmanned hydrographic vessels.

Figure 8. Mission Planner software of the 3DR company for planning the measurement campaign by [3D Robotics, 2016]

Similar software was created by a team of students from the Gdynia Maritime University (AutoDron) in the framework of the Space3ac accelerator. The application requires entering: the coordinates of the selection area, the drone position, the coordinates of the directional point and the distance between the measurement profiles. Based on the drone position and the coordinates of the directional point the direction vector is calculated. Then the entered coordinates are transformed from the geographic coordinate system to the local cartesian coordinate system (the origin of the coordinate system is the drone position), and these in turn are converted to the polar coordinate system. All the points are rotated with respect to the direction vector, that is, from each point in the polar system is subtracted the angle that is formed by that vector with the OX axis. Then the coordinates are transformed back to the cartesian system. In the system prepared in that way are calculated coordinates of the profile points (being the drone route), that are perpendicular to the direction vector. When this is completed all operations are carried out in reverse order until a route in the geographical system is received (Fig. 9). The resulting data are prepared in a format suitable for the Mission Planner software of the 3DR company (used to upload the drone route in the autopilot).

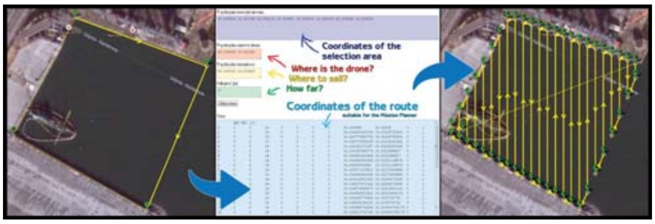


Figure 9. Application window for planning the measurement campaign (own study)

To make the program more accessible they created a simple and intuitive user interface (Fig. 10).

Figure 10. Application user interface for planning the measurement campaign (own study)

6 CONCLUSIONS

For the realization of TSB measurements can be used an unmanned hydrographic vessel (including its measuring equipment), owned by the Gdynia Maritime University. It is characterized by the following advantages (after modernization within the frameworks of the Space3ac accelerator):

- automatic control of the vessel, using the Pixhawk autopilot of the 3DR company;
- planning bathymetric measurements using Google Maps, including both the choice of the reservoir, as well as planning the measurement profiles;
- ensuring the high accuracy and reliability of bathymetric measurements with the application of the GNSS receiver using GNSS geodetic networks and a portable single beam echo sounder;
- small draft of a vessel (20-30 cm) enables the performance of bathymetric measurements at depths below 1 m;

as well as disadvantages:

- control system (for change of course) is based on a (remote) telemanipulator, which requires constant manoeuvring of a vessel in the manual mode, as well as visual keeping of a boat on the measurement profile, plus changing the profile in the direct control mode;
- no system of measurement data transmission to the operator and their display in real time;
- low accuracy of the GPS receiver (several-meter positioning error) from the module dedicated for the Pixhawk autopilot prevents the keeping of the vessel along the selected measurement profile, which results in uneven coverage of the whole reservoir with measurements;
- low seakeeping of a vessel weighing approx. 20 kg allows for bathymetric measurements to be realized only in calm weather with little waving.

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