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Application of GNSS Integrated Technology to Safety of Inland Water Navigation

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ABSTRACT: In the paper the description of some applications of satellite integrated technology, elaborated in the Chair of Satellite Geodesy and Navigation of University of Warmia and Mazury in Olsztyn, to bathymetric survey of Great Masurian Lakes is given. The Lake of Sniardwy, the largest lake in Poland with about 11,000 ha has been measured using this modern technology with precise satellite positioning of underwater stones and shallow waters dangerous for sailors. Next the numerical map was elaborated and edited for sailors, fishermen and tourists. Some conclusions and recommendation for future works on inland navigation charts are also given.

1 INTEGRATED NAVIGATION

1.1 *Safety on inland water reservoirs*

Marine navigation is the process of planning and controlling the safe movement of boat from one place to another (Bowditch, N. 2002). The inland waterways navigation especially includes piloting in narrow canals, channels, rivers and shallow estuaries – mostly lakes. Safe navigation can not be done without actual bathymetric maps, digital bottom visualization and information about under water obstacles.

In north – east part of Poland there is situated Warmia and Mazury region frequently called the Land of a Thousand Lakes. It is the center of recreation for tourists from all over Poland and from abroad. There is an amazing opportunity for sailors and fishermen. In the summer time there is almost 10,000 sailing boats on the Great Mazurian Lakes in Poland, carrying 50,000 tourists every day.

Almost all of lakes do not have up-to-date analogue or digital charts. The most part of them has been measured almost 50 years go. Existing analogue maps do not present the real and accurate bottom surface. Unfortunately many of the mentioned reservoirs have dangerous for sailors shallow regions with stones and reefs. The dangerous places make the inland waterways very difficult to navigate. Therefore it is very important to ensure the general safety which could be reached by creating digital, bathymetric charts, marking the inland waterways and especially dangerous shallow stone reefs on inland waterways of Great Mazurian Lakes.

The team of Chair of Satellite Geodesy and Navigation of Warmia and Mazury University in Olsztyn has developed integrated technology of bathymetry surveying, which makes possible navigation of the small hydrographic boat along the pre-defined profiles, examination of bottom shape, computation of water volume, elaboration of bathymetric charts and monitoring of dangerous shallow places.

For the developed Integrated Bathymetric System a number of professional equipment units are used, as follows: the EGNOS and DGPS/RTK receivers, GPRS modems, EA 501 P Simrad single frequency digital echo sounder, Imagenex SportScan side scan sonar, YSI 600R water quality sonde and special GPS/CAD software.

The hydrographic equipment is mounted on board of the motorboat. The small but safe and easy to use hydrographic boat, called "ORBITA", is used for raw-data collection during these integrated measurements. The implemented technology allows designing of measurement profiles, navigation along the profiles, recording positions and bathymetric data, making correlation of these both data and finally creating digital bathymetric maps. The developed Integrated Bathymetric System combined with side scan sonar gives a great chance to study the underwater environment, especially monitoring underwater dangerous stones and shallow areas.

The paper presents application of GNSS integrated technology to monitoring and safe sailing on Great Mazurian Lakes.

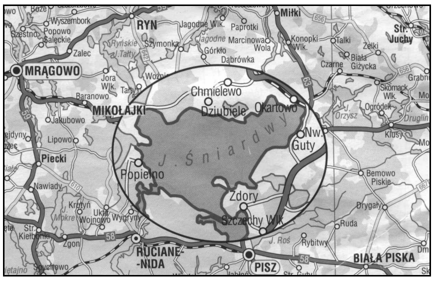

Fig. 1. Lake Sniardwy location

1.2 *Lake Sniardwy – the biggest lake in Poland*

The most dangerous for sailors is the largest lake in Poland called Sniardwy Lake with its surface area over 10,000 ha. The lake is placed in south part of the Land of a Thousand Lakes (see Figure 1). This shallow reservoir has bad reputation due to unexpected strong winds and storms. Thus, inland waterways should be precisely determined and the majority of existing underwater obstacles (mainly stones and very shallow waters), dangerous for sailors, should be precisely positioned on the navigation analogue as well as digital charts.

The results of the experiments carried out on the biggest lake in Poland, Lake Sniardwy, using GPS receivers working in DGPS/GPRS and EGNOS mode will be presented. Differential GPS satellite measurements were based on the GPRS data transmission system, originally developed in the Chair of Satellite Geodesy and Navigation, of Olsztyn University (Oszczak, B. & Oszczak, S. & Ciecko, A. 2004).

2 GNSS INTEGRATED TECHNOLOGY

2.1 *Integrated Bathymetric System*

The research team of Chair of Satellite Geodesy and Navigation has developed the integrated technology of bathymetry surveying in order to examine under water environment (Popielarczyk, D. & Oszczak, S. 2001). The developed Integrated Bathymetric System basically consists of (see Figure 2):

- The GNSS positioning system
- The bottom detection system
- The special GPS and CAD software.

2.2 *GNSS equi pment*

The Differential GPS positioning system uses two Ashtech Z-Xtreme GPS receivers. The first of them, placed at a known mark is a stationary receiver called base or master reference station. There can be used the permanent reference station or a local station set up only for the dedicated project. The base station receiver determines the errors of measurement data between fixed and observed station position (corrections). The DGPS corrections in RTCM v. 2.2 format are sent via GPRS (General Radio Packet Services) to the rover GPS receiver in unknown location and can be applied to measurement data.

The results of our experiments and analysis of accuracy of boat positioning during bathymetric survey show that the comparison of the phase OTF mode horizontal position with coordinates obtained in real time code Differential GPS show differences from -0.95 m to 1.05 m for dB and dL (Popielarczyk, D. & Oszczak, S. 2002). According to IHO Standards for Hydrographic Surveys, where the horizontal accuracy for Special Order reservoirs is 2 m, achieved accuracy is sufficient for majority of bathymetry surveying.

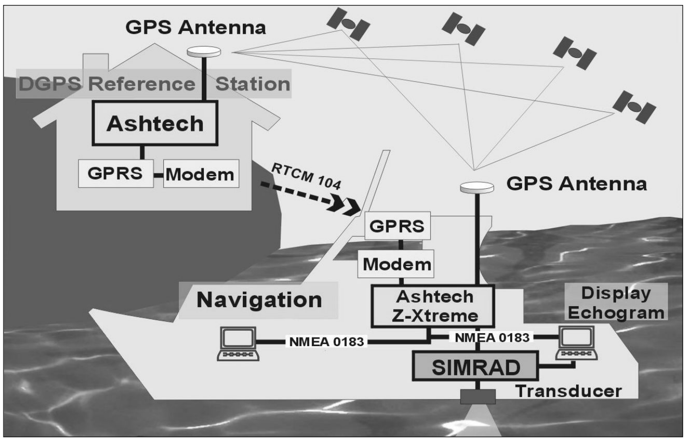

Fig. 2. Integrated Bathymetric System

2.3 *Hydrographic system*

The hydrographic equipment includes EA 501 P Simrad single frequency digital hydrographic echo sounder, Imagenex SportScan Side Scan Sonar and YSI 600R sonde for water quality sampling.

The EA 501 P system basically consists of transducer, transceiver and personal computer. The collected data are processed on-line for generation of colour echograms and tables.

The echogram is presented on the Laptop display. The file system allows recording selected data for further analysis. Sample data may also be stored on hard disk and replayed for demonstration of survey echo data. A navigation receiver can be connected to the Laptop serial port (NMEA-GLL format), and position data can be provisionally combined with the measured echo data. The EA 501 P Simrad general specification is as follows: the transceiver 200 kHz frequency, max. freshwater detection depth – 600 m, accuracy about 0.25% of measured range, transmitting power 50 to 250 W, calculation interval for 0 to 10 per second.

The Imagenex SportScan is a dual channel (2x330kHz), high resolution digital side scan sonar operated directly from PC computer. The towfish operates from a standard 12 Volt DC power supply or boat's battery, and the RS-232 connector plugs directly from the Kevlar towfish cable into the back of a PC computer or laptop.

The SportScan software can read GPS raw data into the PC computer, display it on the screen, and use the speed over ground to adjust the aspect ratio of the sonar image. Objects can have their height and length determined with the click on the sonogram. All data can also be stored on hard disk for later display and analysis. The side scan sonar has maximum operated depth of 30 m and it is used for underwater objects such as big stones and wreck localization. The last summer DGPS/SONAR experiments indicate that the accuracy of underwater object determination is of order of 1-2 m. Figure 3 shows the same object on the echogram (on the right) and sonogram (on the left).

The bathymetric system combined with side scan sonar gives a great chance to study the underwater environment, and especially to monitor underwater objects and dangerous stones.

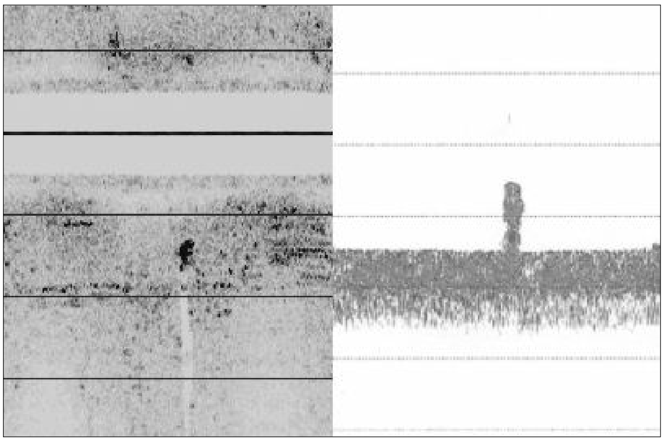

Fig. 3. Under water object on the echogram and sonogram

The YSI 600R provides water quality sampling for both surface water and groundwater. This sonde measures temperature, conductivity, dissolved oxygen, and pH. The speed of sound in water is estimated by a simple empirical formula (Clay, C. S. & Medwin, H. 1977). The YSI 600R sonde is also used for pollution monitoring (Popielarczyk, D. & Oszczak, S. 2002).

The special GPS and CAD software of the system allows the measurement profiles to be designed, enables navigation along the profiles, recording and combining the positioning/bathymetric data, and finally creating bathymetric maps. For elaboration of raw-data the originally developed software Echo Converter is used.

The Integrated Bathymetric System is mounted on board of small, but safe and easy to operate motorboat called "ORBITA". It is perfectly suited for raw-data collection during inland water measurements.

3 SNIARDWY LAKE BATHYMETRIC CAMPAIGN

3.1 *Preparations for experiment*

Some of Great Mazurian Lake has its waterways marked by floating signs and dangerous places by Cardinal Buoys in IALA (International Association of Lighthouse Authorities) system. Unfortunately the biggest reservoir – Lake Sniardwy has not yet such a system. That is why this lake was chosen to be examined as the first. The project on the Lake Sniardwy consists of the following stages:

- DGPS/GPRS permanent and spare local reference stations configuration
- Designing of measurement profiles
- Hydrographic system calibration
- Bathymetric survey
- Localization of underwater objects

- Elaboration of measurement raw-data
- Creation of bathymetric digital chart.

3.2 *DGPS/GPRS permanent and spare local reference stations configuration*

The permanent DGPS/RTK/GPRS reference station is situated about 30 km from test area in Gizycko, a tourist town loated in the very heart of Great Mazurian Lakes. Differential GPS satellite measurements were based on the GPRS (General Radio Packet Services) data teletransmission system, originally developed by the Chair of Satellite Geodesy and Navigation in cooperation with Biatel Company. The level of GSM coverage and GPRS service quality in the specific region of operation (on the lakes) is fully sufficient for the purpose of the bathymetric surveys. The DGPS corrections are sent to the rover Ashtech Z-Xtreme GPS receiver every 3 seconds. In the surroundings of the project area the backup local reference station was activated (Ashtech Z-Surveyor GPS receiver).

Thales Mobile Mapper GPS receiver was also configured to receive EGNOS corrections.

The measurement profiles were designed on digital shore map of the lake parallely, every 50 meters one after another.

3.3 *Hydrographic system calibration*

Before hydrographic sounding the single beam echo sounder was calibrated. The YSI 600R sonde was used to determine temperature and conductivity of the water column from bottom to the surface. The speed of sound in water was estimated by YSI 2SS software using Clay and Medwin formula. The mean value of sound speed was determined to be 1480 m/s. Simrad EA 501 P was also controlled by conducting bar-check calibration. An average speed of sound was entered directly into the echo sounder before data acquisition.

Accurate sensor offsets was measured between the echo sounder transducer and the reference water level and then applied within the acquisition system. The GPS antenna was mounted vertically over the echo sounder transducer, which was placed in the hull of “ORBITA” boat. Therefore no horizontal offsets need to be applied.

3.4 *Bathymetric survey*

After the data acquisition system had been properly configured and all of the necessary calibrations had been completed, on-line data acquisition could begin. The project was conducted by the team of the Chair of Satellite Geodesy and Navigation. The raw-data acquisition process took a lot of time and staff effort. The total amount of data record time was approximately 300 hours.

During the experiment, on board of the motor boat two GPS receivers were installed: Thales Mobile Mapper in EGNOS mode and Ashtech Z-Xtreme working in DGPS/GPRS mode. The DGPS unit was receiving real time corrections from base reference station via GPRS Cellbox modem. At the same time the receiver was sending out differentially corrected boat position to:

- The software ESRI ArcView 8.3, for navigating along the pre-defined profiles using Laptop monitor, in NMEA-GGA message format
- The EA 501 P Simrad echo sounder in NMEA-GLL format.

The memory cards of the base station, rover and back up station receivers, stored raw observation data to make possible computation of the boat positions in post-processing mode.

In the navigation software the position of the boat was displayed against the background of the digital shore map on board screen. This allows the navigation along pre-defined measurement profiles. During the experiment the profiles were designed parallely every 50 meters one after another.

Combined position and depth data were saved on the Laptop hard disk, which was controlling sounding the hydrographic system also.

The mean local water surface was taken as the reference water surface during the project. The kinematic post-processed OTF precise technique was used to control the hydrographic survey and adequate ellipsoidal height/water-level relationships have been developed. The reference water surface was reduced to the vertical datum in Poland based on Kronstadt ’86.

3.5 *Localization of underwater objects*

The measurements on Great Mazurian Lakes included localization of under water stones and reefs and other objects also. Two hand held receivers with ability to achieve EGNOS or DGPS/GPRS corrections were used to collect over 280 coordinates of shallow areas and stones on Sniardwy Lake.

The Imagenex SportScan side scan sonar was used for tests of under water object detection. During measurements two wrecks were found. One of then is a wooden ferry sunk in Lake Kisajno. The second one is a wreck of motorboat in Lake Krzywe (see Figure 4).

All collected bathymetric raw data and side scan sonar data were helpful to identify and elaborate information about shallow areas for bathymetric map preparation. That kind of data gives possibility of creation an Interactive Underwater Surface Object Base.

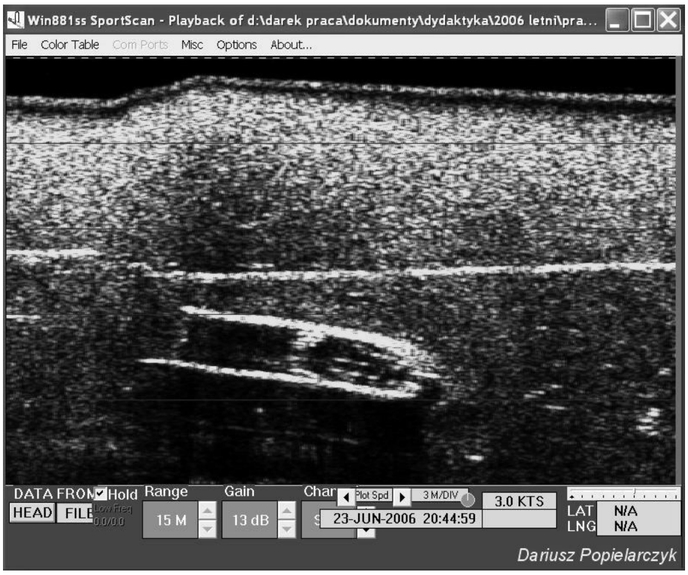

Fig. 4. The wreck of motor boat in Lake Krzywe

3.6 *Elaboration of measurement raw-data*

Hydroacoustic sounding took 31 days of field work. The total length of boat track sounding was about 2000 km. All collected hydrographic and GPS raw-data were initially processed and edited in the field and then recorded for further elaboration.

After field data acquisition was complete, the data elaboration started. The special software Echo Converter has been originally developed by our team. This program can import echograms from Simrad binary format and export as *.txt file. Bad depth and coordinates data can be shown, filtered and stored. Surveyor can take a careful check of the records to ensure that the digital data accurately depicts the true bottom. During depth editing, the digital depth record should be compared to the analog echo sounder trace. This software is open and can be enriched of new options for adjusting and smoothing of survey data.

The Echo Converter includes algorithm, originally developed by the authors, for the time correlation of GPS horizontal position and depth data. During hydrographic measurements the combined position and depth data are being saved on the Laptop's hard disk. Both data sets a short latency. Latency is the time difference between the recorded time positioning data and the recorded time of depth detection. The latency typically depends on the depth detection frequency and boat speed. While surveying at slow speed, depth detection frequency is high, and this shift will be small. At higher speed the displacement increases, proportionally to the speed. The results of the experiment show that the differences of depths range from -0.12 m to 0.13 m, with the maximum depth of 18.58 m (Popielarczyk, D. & Oszczak, S. 2003).

3.7 *Creation of bathymetric digital chart*

During Sniardwy Lake measurement campaign over 600,000 raw-data points were recorded and elaborated. The surface area of the lake is 10,177.44 ha, length of shoreline is 73,259 km, mean depth is 6.86 m and maximum depth 23.93 m, while the height of reference water level is 115.94 m (vertical datum - Kronstadt '86).

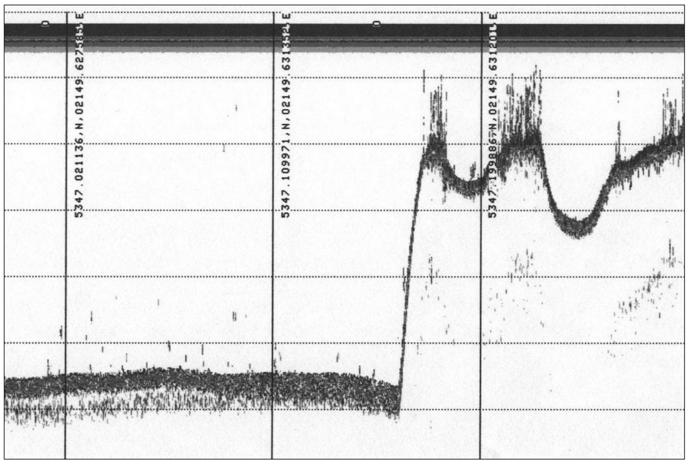

Fig. 5. Lake Sniardwy bottom shape

The bottom surface occurs to be very sophisticated. In this shallow reservoir there are many sudden big slopes and faults (see Figure 5). Some fragments of Lake Sniardwy have no identified on the old maps steep hills from 6-10 m depth to very shallow areas of 0.5-1 m with huge stones. These places are very dangerous for sailors and motor boats especially during strong wind, storm and rough water surface.

The actual publication of digital bathymetric map was elaborated and published in 2006. The new chart was prepared especially for sailors, fishermen and tourists with basic information of dangerous stone reefs, actual shore and reed line, ports and waterways boys (see Figure 6).

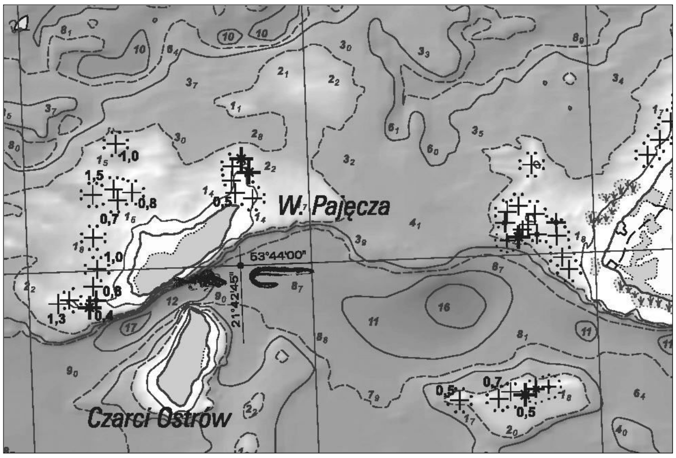

Fig. 6. Lake Sniardwy bathymetric chart

3.8 *Interactive Underwater Surface Object Base*

The sailing safety can be partly ensured by elaborating new up-to-date bathymetric charts and marking the shallow areas by cardinal boys in IALA system.

Moreover, there is a need to creation the Interactive Underwater Surface Object Base (IUSOB). The main idea of preparation such a base is to get more detailed bathymetric raw data of selected shallow parts of the Great Mazurian Lakes. The aim can be achieved by collecting information of underwater objects, especially reefs, big stones, wrecks by using the side scan sonar, direct under water research by divers with the use of the DGPS receiver (underwater GIS) and camera. The collected information should be professionally elaborated in order to create Digital Model Terrain presentations and to prepare three dimensional visualizations.

The concept of creating the interactive www base site expects users to add their own reliable raw data to enrich the main base of information.

4 CONCLUSIONS

4.1 *GNSS positioning techniques*

During experimental measurements EGNOS and DGPS/GPRS positioning techniques were used. Dynamic DGPS positioning with the use of EGNOS corrections shows that the RMS errors achieve max. 10 m. At the same time autonomous horizontal position accuracy was max. 6.50 m (see Figure 7).

Further long-term static EGNOS and DGPS analyses shows that EGNOS horizontal errors reach 7.42 m. Parallel working DGPS system based on LF/MF reference station achieves horizontal accuracy within 1.72 m (Mięsikowski, M. & Nowak, A. & Oszczak, B. & Specht, C. 2006). Observed EGNOS accuracies show, that it can not be used in dynamical applications before the system achieve FOC status.

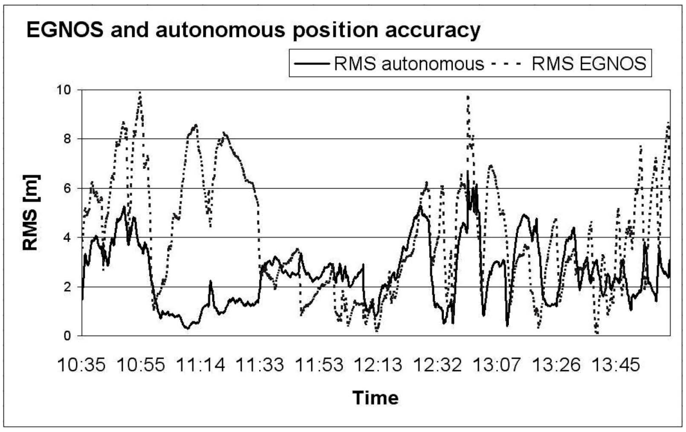

Fig. 7. Dynamic GPS autonomous and EGNOS corrected position accuracy

4.2 *Safe inland water navigation*

The low cost and high efficient Integrated Bathymetric System on board of motorboat called "ORBITA" has been used for bathymetric measurements on Lake Sniardwy, the largest inland reservoir in Poland. Digital bathymetric chart of the lake was elaborated and published. The next step is the elaboration digital map to be ready for use in hand held GPS receivers and echo sounders for sailors and fishermen.

Having actual and up-to-date chart of the lake the DGPS/GPRS system provide reliable and precise satellite navigation service for users, as well as the precise monitoring service for sailing boats in the case of emergency, mainly due to the unexpected strong winds and storms.

Having actual charts the inland waterways should be physically localized by buoys or by navigation signs in the case of underwater stones and reefs.

Additionally the preliminary data base (IUSOB) is currently created, for visualization of dangerous underwater objects. Within the next few months further measurements will be taken with the use of side scan sonar and direct underwater search in order to collect new information about big stones and bottom shape. The experimental project covers a part of Lake Sniardwy.

The Lake Sniardwy hydrographic campaign was run within the confines of realization scientific project *Project on Civil Protection and Safety System for Development of Eco-Tourism in Warmia and Mazury Region with GNSS Applications*, granted by the Ministry of Science and Higher Education in Poland.

The Interactive Underwater Surface Object Base is created within the confines of realization scientific

project *Application of dynamic positionig techniques DGPS/EGNOS/RTK/GPRS and bathymetric measurements for creation of an Interactive Underwater Surface Object Base*, granted by the Ministry of Science and Higher Education in Poland.

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