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Determination of Survey Boat "Heave" Motion with the Use of RTS Technique

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Abstract. The paper presents analysis of determination of vertical movement of the surveying boat called "heave" with the use of Robotized Total Station (RTS) technique. The classical geodetic Total Station was used for sub-centimeter calculation of water level changes during hydroacoustic measurements on the fragment of Vistula river behind the dam and hydropower in Włocławek in Poland. The power station work causes up to 1.7 m movement of vertical reference water surface in aspect of local bathymetric survey. The experimental, hydrographic surveys on the river were conducted where the water level was changing significantly over time depending on the operational schedule of the power plant. Verified hydrographic data had to be brought to the common water level. To determine the final water level, data on the height of the Robotized Total Station prism positioned on the boat during sounding was considered. The RTS technique with 0.02–0.05 m vertical accuracy proved to be very useful and essential in engineering inland bathymetric measurements.

Keywords: bathymetry, "heave", Robotized Total Station.

Conference topic: Technologies of Geodesy and Cadastre.

Introduction

A vertical datum used in hydrography is typically related to a physical surface, such as mean sea level (MSL) or lowest astronomical tide (LAT) (FIG 2006). In inland bathymetry this physical surface is usually stable and can only change slightly in time. An exception to the rule can be reservoirs of a hydroelectric power station, where the water level changes significantly over the time and distance. The example is Włocławek hydroelectric power plant located on one of the cross section on 674.85 km of Vistula river in Poland (Fig. 1). It is the biggest flowing station in Poland (working since 1970). The station includes frontal dam, weir, fish pass and sailing lock. Hydroelectric power plant is placed on the left river bank between the navigable lock and weir form which is separated by the fish pass pillar. There are three sections with two hydro complexes each. The total power of the plant is 160.2 MW. Five hundred meters below the dam the underwater threshold of damming and flow stabilization is located (concrete structure). Despite the threshold the outflow swirled water causes significant bottom erosion. For that reason, the power station reservoir should be periodically surveyed and investigated. Precise bathymetric measurements and digital elevation models analysis are crucial for proper and safe work of the power plant.

Fig. 1. Włocławek power plant

In shallow inland water the bathymetric data are being acquired using Single Beam Echosounders (SBES) or Multi Beam Echosounders (MBES). Both of them need roll/pitch/heave motion corrections. Additionally, all raw depth data should be referenced to the common water level. The key element is the height of the water surface during depth measurements. Integrated Bathymetric System, including echo-sounder transducer, is mounted on the motorboat. This vehicle is in motion, and the state of the surface on which it moves exerts a considerable influence on the dynamics of this movement. A reference water level for bathymetric measurements, the most frequently adopted in surveys on small areas (based on readings from water gauges), is not a flat horizontal surface. The water level changes significantly over time and distance. For this reason, hydroacoustic survey is performed on an unstable floating platform. To reach the final reduced depth measurements, it is necessary to obtain the precise vertical position of the platform (IHO 2008).

The dynamic growth of Global Navigation Satellite Systems (GNSS), geodesy, laser scanning, aerial photography, hydroacoustic techniques, inertial navigation systems, remote sensing and GIS technologies provide a great opportunity to study the underwater environment and analyze bottom shape with high resolution (Popielarczyk *et al.* 2015). The reliability of bathymetry highly depends on the accuracy and precision of positioning and depth detection techniques used. DGNSS supported by GBAS or SBAS/EGNOS augmentation systems gives 1–2 m horizontal accuracy (Grunwald *et al.* 2016a, 2016b). The GNSS Real Time Kinematic (RTK) positioning and new multi GNSS precise solutions provide centimetre three-dimensional accuracy. Unfortunately, in the vicinity of large hydraulic structures e.g. Włocławek power station, there is often a problem with reliable RTK position. For this reason, the author applied the classical technique with the use of geodetic Robotized Total Station to determine vertical movement (heave) of the surveying boat. In this paper the author presents results of bathymetric measurements of Vistula river supported by RTS positioning.

Methodology

The methodology proposed and applied in the study demonstrates the technology of unstable, rough-water level determination with the use of classical RTS geodetic technique. Vertical vessel motion is usually computed using Motion Reference Unit (MRU) and Inertial Navigation System (INS). It can also be monitored with the use of RTK satellite positioning technique or classical geodetic Robotized Total Station (RTS). Recently, the modern automatic TS instruments are widely used in geodesy and even navigation (Kizil, Tisor 2011; Popielarczyk 2016).

During bathymetric measurements behind the dam the water level is usually changing significantly over time depending on the operational schedule of the power plant. The Włocławek power plant causes up to 1.7 m vertical movement of reference water surface. This motion called heave must be precisely determined in aspect of depth measurements. Then verified hydrographic data had to be reduced to the common, reference water level. The Motion Reference Unit usually used in hydrography to calculate roll, pitch and heave motions is not working properly when sudden movements of the motor boat occurs. It is the main reason why the author decided to use RTS technique for precise water level monitoring.

Creation of a Digital Elevation Model of the river bottom requires obtaining both position and depth data. RTS positioning techniques integrated with single beam hydroacoustic technology were used to survey the Vistula River below the power station. The Integrated Bathymetric System basically consists of: an RTS positioning system, a hydroacoustic bottom detection system, special hydrographic and CAD software and a hydrographic motorboat (Łopata *et al.* 2014). The system allows making a design of measurement profiles, navigation along the profiles, recording positions and bathymetric data, correlation of these both data and finally creating digital bathymetric maps. The system is presented in Figure 2.

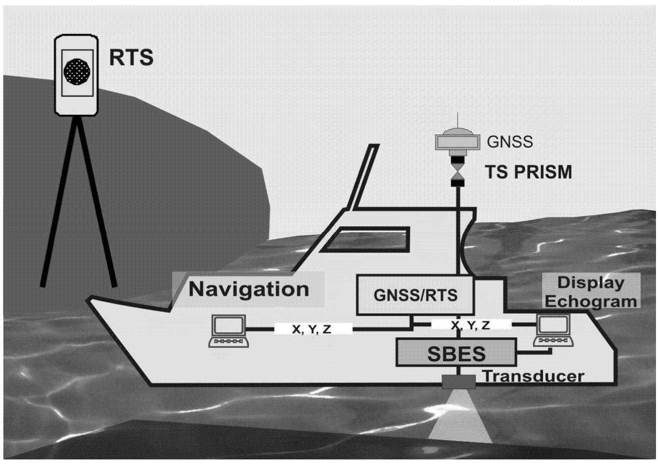

Fig. 2. Integrated Bathymetric System

Measurements

To achieve high accuracy in the digital representation of the river bottom, a hydrographic single beam echosounder (SBES) and RTS geodetic instrument were used. Leica TCRP 1203+ operating in automatic tracking mode was used for determining the boat position during soundings. RTS positioning was determined based on local geodetic control points set up only for the dedicated project (REF1 and REF3). Coordinates of the REF1 and REF3 geodetic points were calculated on the basis of static GNSS measurements connected to the ASG-EUPOS Polish GBAS network.

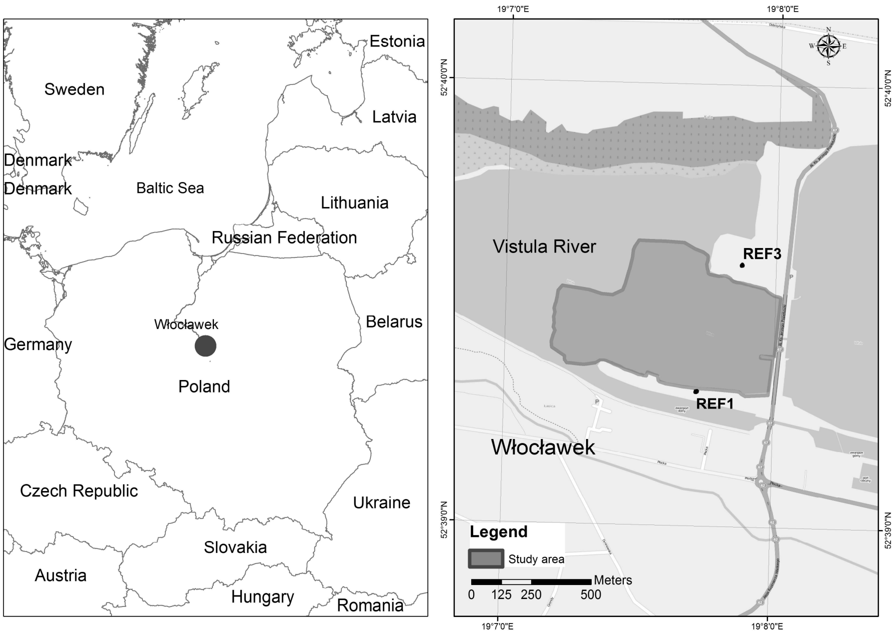

Fig. 3. Włocławek hydroelectric power station location

After testing the correctness of robotized total station work, precise RTS positioning navigation and following calibration of the single beam depth measurement system, the field survey work was started. The bathymetric surveys were conducted in two basic stages over two measurement days. The all measurement stages were made in good weather conditions (no wind and no waves). Geodetic total station operating in the self tracking mode was used for determination of the real time boat position during sounding. The Total Station prism was mounted in the middle of the boat (the same axis as SBES transducer and GNSS ARP). The visibility between the instrument and the mirror usually was not impaired. The boat was traveling at a speed of approximately 1 m/s. Figure 4 presents equipment used during the experiment.

Fig. 4. The hydrographic boat during RTS positioning

The basic cross section measurement profiles were designed at intervals of 5 m against the background of a coastline layer. The boat position, determined in real time, allowed precise navigation of the boat along the earlier designed measurement profiles (Fig. 5).

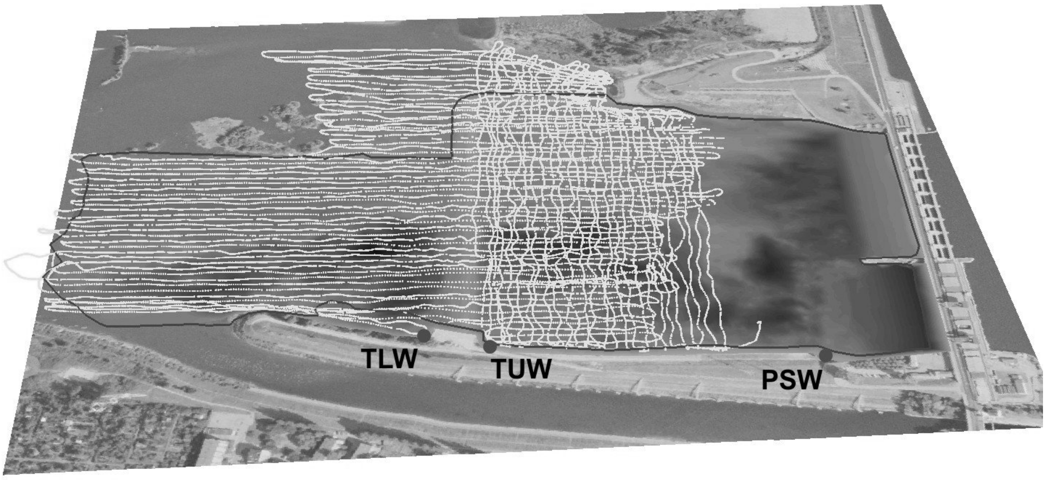

Fig. 5. The boat trajectory during hydroacoustic survey

Results

The RTS data were collected with 1 second interval. Some gaps occurred in TS Leica measurements (no prism visibility). The both stages results of the precise water level survey show that the differences between RTK and TS Leica heights range from –0.09 to 0.16 m. The mean value of the vertical difference was 0.03 m. The comparison of the GNSS/RTK and Total Station heights during the measurements is shown in Figure 6.

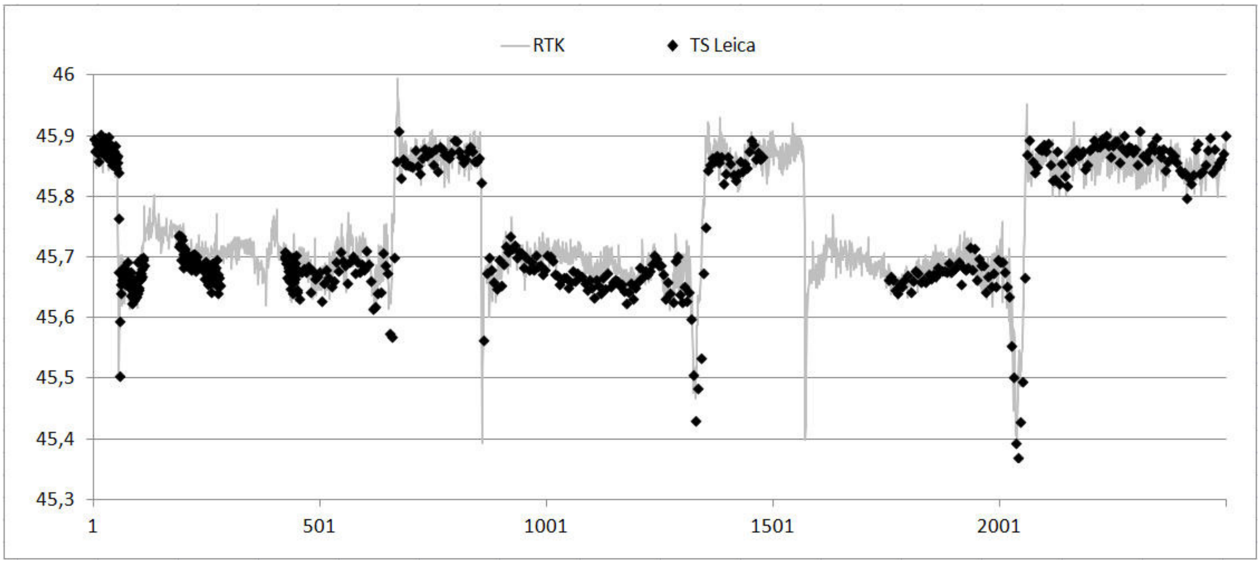

Fig. 6. Vertical boat trajectory

The determined by RTS water level was changing significantly over time and distance. The time depended changes were caused by rough and choppy water. The water flow via hydro complexes varied from 0 m^3/s to 1450 m^3/s depending on operational schedule of the power plant in Włocławek. It caused up to 1.7 m movement of vertical reference water surface in aspect of bathymetric measurements. Digital Elevation Model of water surface during one of the survey stage is presented in Figure 7 (Popielarczyk 2012).

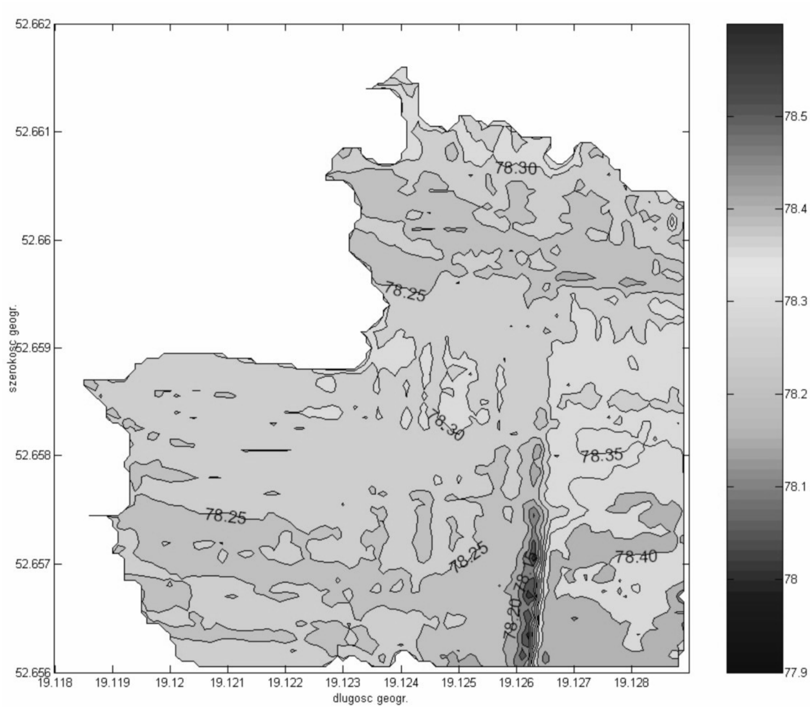

Fig. 7. Water surface below the power station

RTS observations were used to estimate the final vertical boat trajectory for further raw bathymetric depths correction. The finally calculated points formed the database set for development of the Digital Elevation Model of Vistula bottom. The new elaborated digital elevation model of the bottom can be compared to the historical. Spatio–temporal analysis of new and historical bathymetric measurements can help to understand the physical and ecological dynamics of the river below Włocławek power station. The DEM of the bottom below hydroelectric dam is presented in Figure 8.

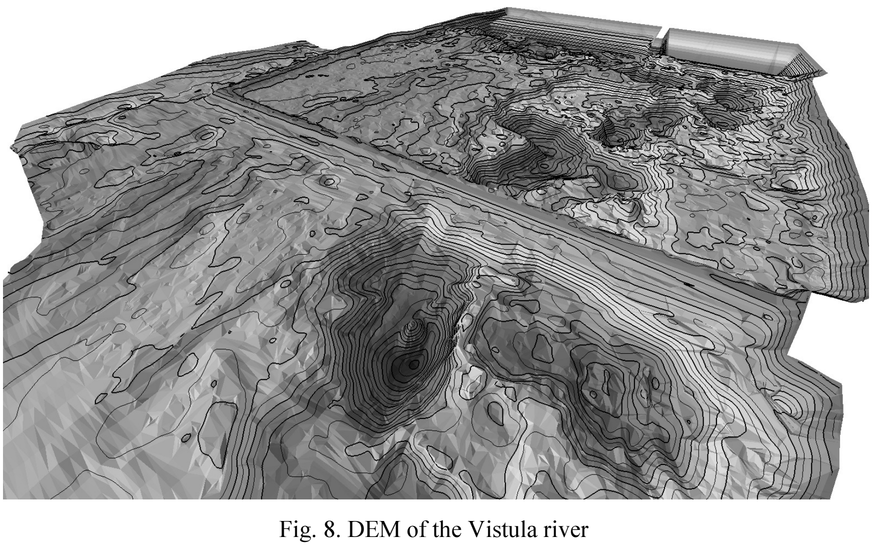

Fig. 8. DEM of the Vistula river

Conclusions

The presented research shows that Robotized Total Station survey provides a sub-centimetre determination of water level changes. The RTS geodetic technique with 0.02–0.05 m of vertical accuracy proved to be very useful in engineering precise inland bathymetric measurements on small water areas in difficult conditions. The presented results of the RTS vertical observations suggest that we can use classical geodetic method to measure vertical motion of the boat (heave) and determine 3D hydrographic boat position. However, a surveyor should take into consideration that the distance from the reference geodetic point is a key element influencing accuracy and precision. Achieved accuracy depends directly on the distance between the prism and the station. Some gaps may occur due to no visibility between the total station and a prism mounted on the boat. The RTS measurements may also have outstanding observations, which should by analyzed, removed or estimated. We can also combine GNSS and RTS techniques to estimate more reliable hydrographic vessel trajectory.

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