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Research on Accuracy of a Boat Position Determination Using GNSS Techniques in Kinematic Mode

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Abstract. The main aim of this work is research on the use of satellite positioning GNSS – RTK / RTN techniques to estimate the trajectory of a hydrographic boat. Modern hydrographic boat is the carrier of advanced bathymetry system, integral with GNSS positioning techniques. The key elements of the correct execution of the hydroacoustic survey are two elements: the height of the water surface and precise determination of the position in the moment of performing depth measurement. Integrated Bathymetric System (ZSB) is installed on a floating platform which is in constant motion. To obtain correct results of the hydroacoustic survey, it is necessary to know the precise (3D) position of the platform. In this paper the author presented his own research on the precise determination of accurate and reliable trajectory of a boat. The proposed method uses Real Time Kinematic (RTK) techniques of satellite positioning GNSS (Global Navigation Satellite Systems). The article presents examples of the results obtained during the research work at the largest Polish river.

Keywords: bathymetric surveys, hydrology, GNSS, RTK.

Conference topic: Technologies of geodesy and cadastre.

Introduction

The essence of the contemporary performed bathymetric works is to measure the depth, in conjunction with the exact situational location based on a precise determination of position. This can be done in a global, regional or local system. This makes it possible to create universal bathymetric maps for different applications and different users. Therefore, modern sonar systems that have revolutionized bathymetric measurements are based on two basic elements precisely, accurately executed integrated geodetic and bathymetric measurements. It should be emphasized, that these measurements are characterized by a high level of automation, which affects the speed of their execution and the elimination of many errors, which occur in conventional methods (Gołuch *et al.* 2010). Geodetic measurements are based essentially on current techniques using professional satellites GNSS receivers, providing positioning of the vessel and measuring device (bathymetric probe). While bathymetric measurements are based primarily on the use of high frequency sound waves based on the digital ultrasound probes. This approach enables efficient and accurate imaging the bottom of the watercourse geometry, in the form of a digital terrain model with high resolution. Currently, three-dimensional bottoms of rivers and reservoirs are commonly used in hydrological studies (Gao 2009; Templin, Popielarczyk 2008; Popielarczyk 2016). These tools are also used in widely understood water engineering, hydrographic works, water tourism and environmental protection.

In this paper, the author concentrated essentially on the first element determining the final quality of hydro acoustic measurements, namely, the aforementioned precise positioning of the measuring device or the whole hydrographic vessel. It presents the results of research and analysis for accuracy and efficiency of such measurements carried out during the hydro acoustic survey on the largest Polish river, Wisła near Sandomierz.

Positioning with the use of multi-constellations GNSS (Multi-GNSS)

Currently, the world of satellite navigation and positioning is going through a period of dynamic development of many constellations of Global Navigation Satellite System (GNSS). Currently, there are over 80 satellites, and ultimately in the next few years, when the four systems (GPS, GLONASS, Galileo, BeiDou) will be fully operational approximately 120 navigation satellites will be available (Visser *et al.* 2017). In addition, satellite augmentation systems SBAS (EGNOS, GAGAN, MSAS, WAAS) are also being developed. SBAS information is broadcasted in the form of special corrections, through special transponders installed on geostationary satellites in the same frequency bands as the basic observations for each base constellation. They strengthen in this way the capabilities of the basic constellation in terms of accuracy, reliability and availability of positioning. All this results in new, great possibilities and challenges for both scientific and engineering applications.

Satellite navigation is a type of radio navigation, in which for determining the coordinates of the users antenna the radio signals emitted by artificial satellites of the Earth are used. Currently, including the SBAS satellites there are more than 100 satellites available, which belong to different positioning and navigation systems (Table 1). They all operate according to the same general rules and are constructed in a similar way.

Table 1. Positioning and satellite navigation systems [status: January 2017] (*Source*: own research)

System name	GPS [G]	GLONASS [R]	Galileo [E]	BeiDou [C]	QZSS [J]	SBASS
The owner	USA	Russian Federation	UE (ESA countries)	China	Japan	USA, UE (ESA), Japan, India
The number of satellites in the system	32	24	12	15	5	13

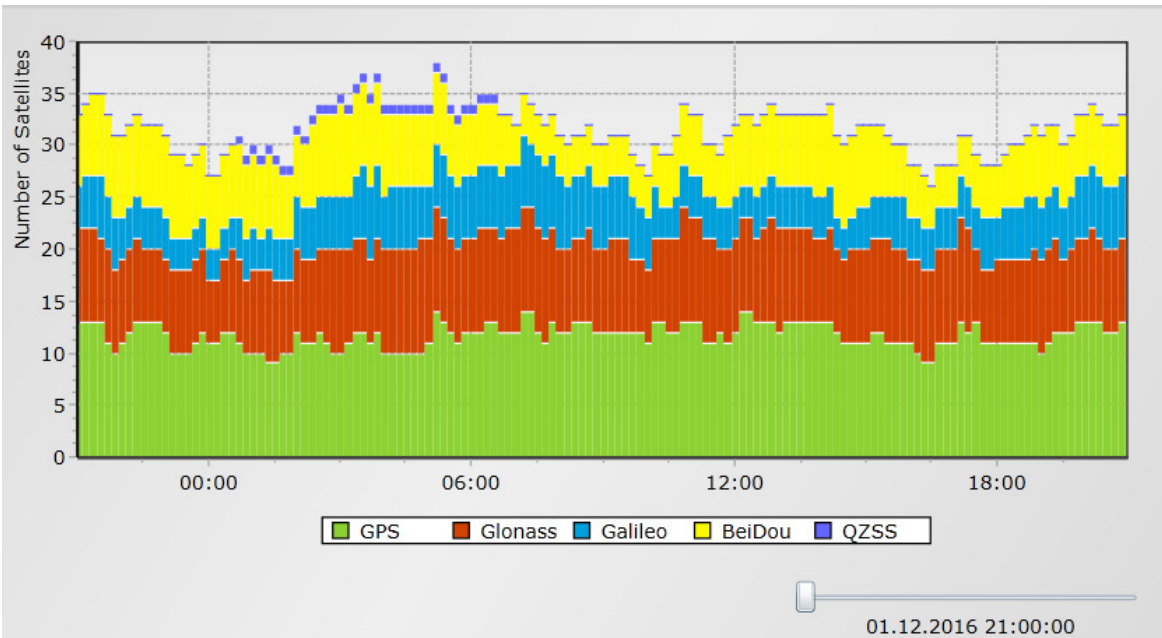

Fig. 1. The number of available satellites during the day for the approximate location of measurements

The paper presents models of positioning with the use of one, two and three positioning systems in order to fully demonstrate the benefits resulting from the use of all observations available currently and in the future from different GNSS. Figure 1 shows the number of available satellites during the day for the approximate time and place of the research measurements. On its basis, we can conclude that the average number of available satellites during the day was 32 satellites. But for individual GNSS it was as follows: 11 satellites for GPS system, 9 satellites for GLONASS, 5 satellites for Galileo and 6 satellites for BeiDou.

If we take into account the fact that each positioning system provides by each of its satellites several (2 to 4) types of measurement observations, we gain the belief that the use of each additional navigation system significantly increases the number of observations and it should affect the improvement of accessibility, reliability and accuracy of measurements. This is particularly important when measurements are performed in difficult conditions for satellite positioning, and such are the valleys and riverbeds, hence the choice of this undertaken research topic.

Satellite augmentation system

Although the current global positioning and navigation systems use the greatest achievements of satellite and space technology, autonomous positioning (based only on satellite signals from navigation satellites) simultaneously performed even to several GNSS, does not provide precise geodetic accuracy. Depending on the type and the number of tracked measuring signals, environmental factors and the equipment class, autonomous measurement accuracy for civilian users ranges from decimeters to several meters (0.5–3.0 m). To ensure the accuracy at sub centimeter or greater level, the so-called differential GNSS measurements (relative) are used. Differential measurement mode requires minimum two receivers tracking signals from the satellites of the same GNSS, one of which operates on a point with known coordinates while the second "rover" performs measurements at determined points (Hofmann-Wellenhof *et al.* 2001). Points with known coordinates are referred to in the scientific and technical literature as reference station. Such stations now in most countries in the world have been developed in the network with a different operating range – from local to global. Furthermore, this type stations are working in a continuous mode (permanent), and additionally connected by advanced teletechnical infrastructure into a single whole, constitute so-called satellite measurements augmentation system.

The main task of satellite augmentation systems is to increase accuracy, reliability and credibility of the position determination. This is mainly done by signal propagation error compensation in the atmosphere and their temporary disruptions and enabling operation of receivers in areas where it is difficult to receive signals from satellites. The most common way of assistance (increasing of accuracy) of contemporary GNSS systems is application of the differential DGNSS (Differential GPS) methods.

Contemporary augmentation systems are divided into two basic groups:

1. *Satellite Based Augmentation Stations* (Noack, Engler 2010) *SBAS*, in which differential corrections are transmitted to users via satellite through a special satellites. This type of augmentation systems operate over large areas, in the world today there are several such systems operating ie.: *EGNOS* (European Geostationary Overlay System), that covers the area of Europe, *WAAS* (Wide Area Augmentation System) operating in the USA, *MSAS* (Multi-mission Satellite Augmentation System) covering the areas of the Far East and Japan.
2. *Ground Based Augmentation Systems* GBAS, where corrections are transmitted for users via radio or via the mobile Internet. Among these augmentation systems, we can distinguish:
   – *Local*, autonomous DGPS systems, composed mostly of one reference station and one or more mobile receivers.
   – Regional DGPS systems, covering with they ranges a larger area, on which permanently installed reference stations network is working nonstop and managed from a single Control and Management Center. An example in Poland may be Małopolski Precise Positioning System (MSPP), which covers two voivodeships – Małopolskie and Silesian.
   – National DGPS systems, which usually cover the entire territory of the given country. They usually consist of a few dozen or a few hundred reference stations built by one standard and create broader multi-positioning and navigation systems.

The basic assumptions of the test object

The paper presents three selected methods of taking the real-time kinematic measurements, diversified in terms of the used GNSS positioning systems. The first method was based on the use in the kinematic RTK (Real Time Kinematic) measurement only one positioning system, American GPS (Global Positioning System). These types of measurements are performed quite commonly in Poland because to their realization cheaper, mono-systemic receivers of older type can be used. The second reason is, that until recently, in Poland, multi-function state system of ground augmentation ASG-EUPOS, did not provide delivery of corrections to real time measurements to GLONASS satellites. The second method was based on the simultaneous use in the kinematic RTK measurements of two systems – American GPS and Russian GLONASS. It should be mentioned at this point, that each of these systems is fully operational, has a global reach and has been available to users for at least several decades. It should be added also, the geodetic measurements made with the simultaneous use of GPS and GLONASS satellites currently are gaining increasing appreciation among surveyors. The third method of measurement was based on the simultaneous use of observations to three GNSS systems (GPS, GLONASS and BeiDou). Beidou is a Chinese navigation system, which is still under construction, and in early 2013 it became operational in the Asia and Pacific regions. Since then it has been systematically expanded and its range extended. Currently, Beidou constellation consists of 16 operational satellites (Table 1) and satellites of this system are available in our latitudes around the clock (Fig. 1). The Chinese navigation system compared to the previous two is characterized by the fact, that its satellites are located on three different types of orbits: Medium Earth Orbit (MEO – as in the following systems: GPS, GLONASS and Galileo), Geosynchronous Earth Orbit (GEO) and Inclined Geosynchronous Earth Orbit (IGSO).

Measuring experiments scheduled by the author, were carried out on the section of 32.8 km, of the largest Polish river – Vistula. The first part of the study, according to the hydrographic division, was performed at "Upper Vistula" section from 254.82 km (Tarnobrzeg – Ferry) to 279.7 km (The mouth of the river San). While the second part was performed on the „Middle Vistula" section, from the mouth of the river San to 287.6 km (Zawichost – Ferry). The aim of the experiment was to analyze the accuracy of trajectory determination of the bathymetric boat on the basis of modern real time positioning techniques using the GNSS / RTK technique.

Fig. 2. The bathymetric boat during the measurement on the Vistula river

Research experiment consisted in the fact that three satellite receivers GNSS (Fig. 2) installed on the boat on a solid basis performed independent, continuous measurements of the moving the boat. The boat was moving at a constant speed of about 1.5 m/s, so that there were no significant changes in the degree of its immersion. The hydrological conditions were good, because the average flow on the test section "Upper Vistula" was about 185 m^3/s, while on the "Central Vistula" section about 225 m^3/s. The essence of this experiment was that each of the receivers, due to the size of the base on which they were located (app. 2 m) worked under the same satellite conditions. At the same time, due to the different configuration method each receiver was observing a different number of satellites. First receiver (R8 GNSS model 3) installed in the middle part of the boat was performing observations only of GPS satellites. The second receiver (R10 GNSS serial number 5350450134) located on the left side was performing simultaneous observations of the two GNSS systems (GPS and GLONASS). The third receiver Trimble (R10 GNSS serial number 5348449050), located on the right side was performing simultaneous observations of the three navigation systems (GPS, GLONASS and BeiDou), Figure 2. The primary purpose of such planned research was to evaluate the actual precision of kinematic measurements performed under real field conditions using combinations of different currently available positioning systems. This was also connected with the performance of observations to different satellites at the same point in time. At this point it should be mentioned, that the most frequently accuracy provided by the manufacturers of equipment for geodetic measurements in the RTK relate to measurements taken at specific checkpoints, where there are "ideal" satellite conditions.

Measurement

The study area as mentioned above, was the section of the river Vistula from mileage 279.7 to 287.6. Figure 3 shows the trajectory of the watercraft on the selected initial fragment (about 4.5 km), from the beginning of the section to Bogoria Skotnicka. The measurement on the examined object was carried out on 9 June 2016 (GPS Week: 1900, DOY: 161). As a result of the measurement on the test area about 20,000 points were recorded with each of the three receivers. The boat was moving with the flow of the river carrying out another task, the aim of which was to make a longitudinal profile of the river and cross sections at distances of about 1 km.

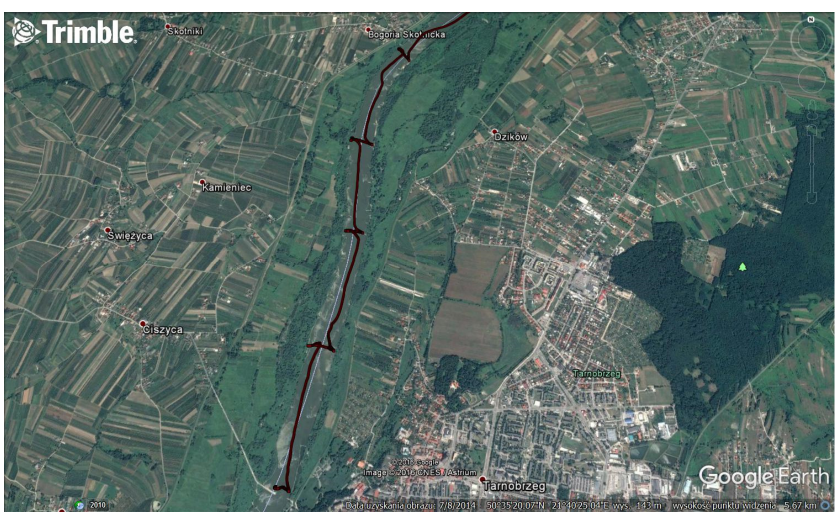

Fig. 3. Distribution of points of measurements on the initial section of approximately 4.5 km length

During the measurement the height of the water throughout the test section has changed gradually in the range of about 8.79 meters. The gradual decrease in the water level was associated with the natural topography of the river bed and the size of the flow in this period. Figure 4 shows a vertical trajectory of the boat associated with its movement over the whole test section. The current state of the water level was related to the height coordinates system PL-KRON86-NH.

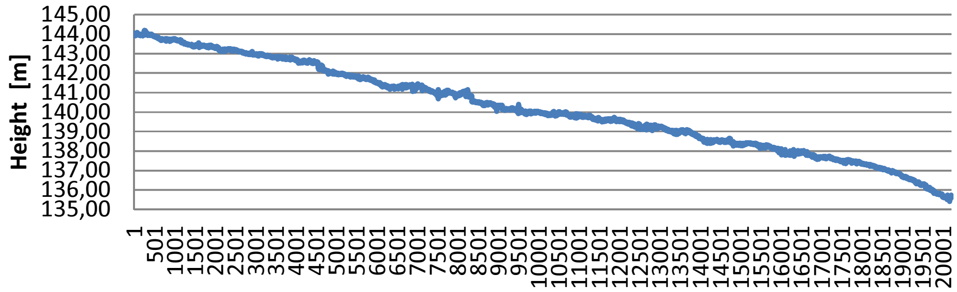

Fig. 4. The water level set on the boat using the GNSS/RTK technique

The irregular, cyclical declines and increases in height visible on the chart are associated with several factors. Firstly with passages of boat over solid concrete or stone underwater hydrotechnical structures, which function is to control and deceleration of the strong current of the river in the vicinity of the tributaries, and also in other locations. These buildings are also designed to protect against excessive erosion and movement of the rock material at the bottom. The second factor is that the satellite observations were carried out under different satellite conditions, both in the open as well as in coastal areas where the access to the satellites was hampered by the high banks of the river as well as growing trees and other vegetation. In addition, the boat flowed under the two bridges, which were also the reason for a temporary disruption of satellite measurements. Precise and accurate monitoring of the vertical trajectory of the bathymetric boat is a very important and necessary element for the reduction of depth measurements and to elaborate the numerical model of the bottom.

Results of the research and discussion

For a detailed examination of the accuracy of the position and the height of the water level determination for the accepted solutions GNSS, basic statistics were calculated (MIN – minimum value, MAX – maximum value, R – dispersion, AV – average value, SD – standard deviation) for the following parameters (Table 2):

- PDOP (Positional Dilution of Precision) – defined as the spatial 3D geometric accuracy coefficient relating to the three-dimensional position;
- Number of satellites;
- Error of the horizontal position determination (m_{Hz}) – measured by RMS value calculated during the measurement by satellite receiver;
- Error of the vertical position determination (m_V) – measured by RMS value calculated during the measurement by satellite receiver.

Using PDOP parameter and the total number of available satellites, the satellite conditions during the experiment, for the satellite height 10° above the horizon were shown. On the basis of Table 2, we conclude, that during the entire period of measurements performing the GNSS satellite situation was variable. The number of satellites observed when using only the GPS system, ranged from 5 to 11, and PDOP coefficient ranged from 1.3 to 6.5. It should be noted that 5 observed satellites is the minimum number at which the initialization can be performed (OTF – On The Fly) required for precise position determination in real time. While for the value of PDOP <6 (according to general standards), geodetic measurements should not be performed, because they are affected by the low credibility of the results.

The total number of satellites observed in the case of simultaneous use of the two GPS and GLONASS systems ranged from 8 to 19, and the coefficient of PDOP ranged from 1.0 to 2.6. However, in the case of using the three GNSS systems (GPS, GLONASS and BDS), simultaneously from 9 to 25 satellites were observed, and the coefficient of PDOP ranged from 1.0 to 2.4. In both cases we were dealing with good and very good GNSS satellite situation during the measurements.

Table 2. Basic quality characteristics obtained for test measurements (*Source*: own research)

GNSS	Statistics	PDOP	Number of satellites	m_{Hz} [m]	m_V [m]
GPS	MIN	1.3	5	0.012	0.018
	MAX	6.5	11	0.079	0.104
	R	5.2	6	0.067	0.086
	AV	1.9	9	0.022	0.031
	SD	0.4	1	0.009	0.011
GPS+GLN	MIN	1.0	8	0.011	0.016
	MAX	2.6	19	0.056	0.067
	R	1.6	11	0.046	0.052
	AV	1.3	16	0.014	0.021
	SD	0.2	2	0.004	0.005
GPS+GLN+BDS	MIN	1.0	9	0.010	0.014
	MAX	2.4	25	0.048	0.066
	R	1.4	16	0.038	0.052
	AV	1.3	19	0.016	0.024
	SD	0.2	3	0.006	0.009

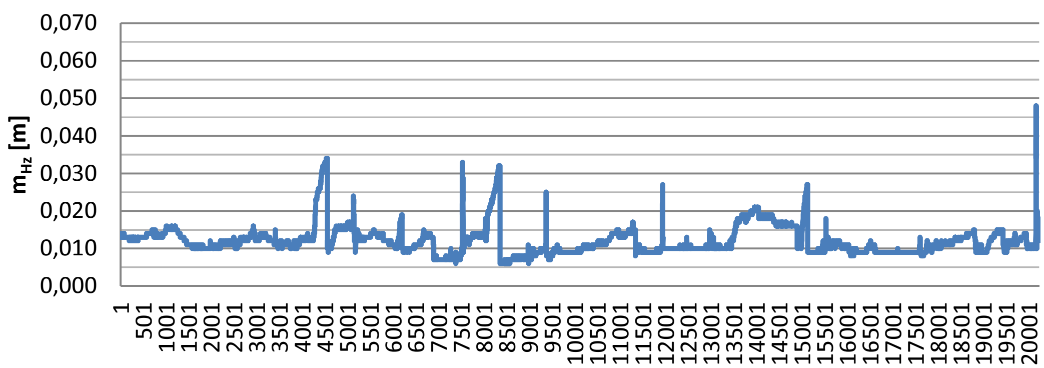

Fig. 5. Errors of the horizontal position determination using 3 GNSS systems (GPS, GLONASS, GALILEO)

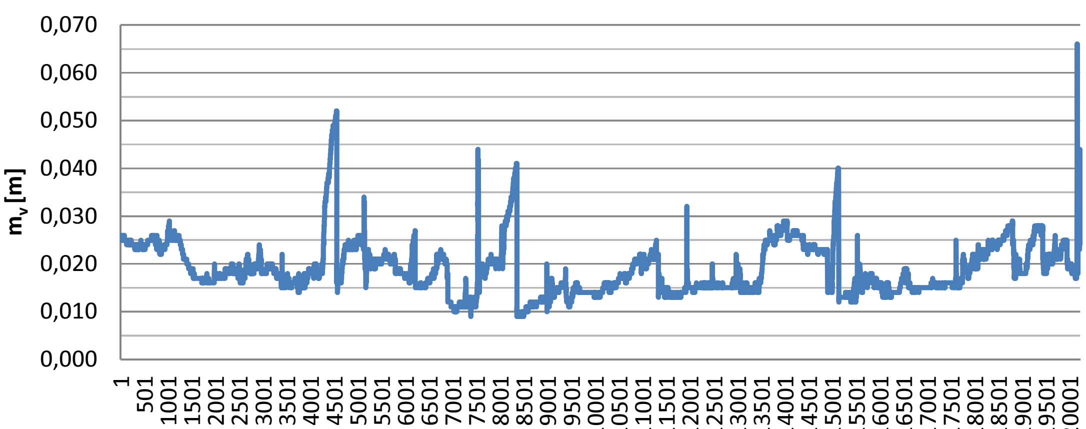

Fig. 6. Errors of the vertical position determination using 3 GNSS systems (GPS, GLONASS, GALILEO)

Figures 5 and 6 show in detail the errors of horizontal and vertical positions determination for the subsequent bathymetric boat positions, in the investigated area performed on the basis of simultaneous observations of the three GNSS systems. On the charts, there are visible some irregular peaks of errors that are associated with the passage of the boat near the high banks of the river, covered with high vegetation or other obstructions, ie. the bridges, which caused interference to the measurement navigation signals.

Conclusions

Research has shown that using kinematic GNSS measurements, it is possible to achieve centimeter accuracy of the horizontal and vertical position determination, when determining the trajectory of a bathymetric boat.

Accuracy of measurements is dependent mainly on the number of observed navigation satellites. While the number of observed satellites depends directly on the number of GNSS systems, to which the measuring receiver can perform observations. This in turn depends on the degree of technological advancement of the receiver and its ability to adapt to the operator's needs at a given time.

Studies and analyzes carried out in the research showed, that the addition to the basic navigation system, which is currently GPS observations from the second positioning system (GLONASS) significantly improves the accuracy of both horizontal and vertical position determination (Table 2). For example in the investigated area average error of a horizontal position determination after including GLONASS observations to the GPS observations declined by about 36%, from 22 to 14 milimeters, and for height was reduced by about 32%, from 31 to 21 millimeters. The addition of another, third positioning system (BDS) resulted in a reduction of the maximum error of position determination but it did not improve the average error of its determination and it even made it slightly worse. This may result from the fact that the Chinese BeiDou navigation system (BDS) is still not fully operational, and thus it is not fully compatible with operating global systems GPS and GLONASS.

In addition, the studies have shown that the use of each additional navigation system, ie. GLONASS or Galileo increases the availability of measurements for the RTK method. Trimble R10 receiver performing during the research observations to three GNSS systems registered about 7% larger number of measurements compared to the receiver (Trimble R8), which performed observations only of GPS satellites.

References

Gao, J. 2009. Bathymetric mapping by means of remote sensing: methods, accuracy and limitations, *Progress in Physical Geography* 33(1). https://doi.org/10.1177/0309133309105657

Gołuch, P.; Dombek, A.; Kapłon, J. 2010. Evaluation of data accuracy obtained from bathymetric measurement using fishfinder LOWRANCE LMS-527C DF iGPS, *Archiwum Fotogrametrii, Kartografii i Teledetekcji,* 21: 109–118.

Hofmann-Wellenhof, B.; Lichtenegger, H.; Collins, J. 2001. *Global positioning system theory and practice.* 5th ed. Wien, New York: Springer, 186–192. https://doi.org/10.1007/978-3-7091-6199-9

Noack, T.; Engler, E. 2010. Integrity concepts for maritime ground based augmentation systems, in *7th ALLSAT Open,* 2010, Hannover, Germany. German Aerospace Center (DLR) Institute of Communication and Navigation.

Popielarczyk, D. 2016. *Precyzyjne pomiary hydrograficzne trudnych akwenów budowli hydrotechnicznych z wykorzystaniem zintegrowanych technik GNSS, RTS, INS oraz SBES.* Wydawnictwo Uniwersytetu Warmińsko-Mazurskiego w Olsztynie.

Templin, T.; Popielarczyk, D. 2008. Tworzenie numerycznego modelu dna zbiornika wodnego w oparciu o jednowiązkowy sondaż hydroakustyczny i system DGPS, *Acta Scientiarum Polonorum. Geodesia et Descriptio Terrarum* 7(3).

Visser, H.; Lapucha, D.; Tegedor, J.; Ørpen, O.; Memarzadeh, Y.; Fugro 2017. *Precise Point Positioning from Combined GNSS* [online]. GIM International [cited 18 February 2017]. Available from Internet: https://www.gim-international.com/content/article/precise-point-positioning-from-combined-gnss