sciendo

CIVIL AND ENVIRONMENTAL ENGINEERING REPORTS

E-ISSN 2450-8594 CEER 2018; 28 (4): 049-061

DOI: 10.2478/ceer-2018-0050

Original Research Article

ACCURACY EVALUATION OF REAL-TIME GNSS PRECISION POSITIONING WITH RTX TRIMBLE TECHNOLOGY

Agnieszka OCHAŁEK[1], Witold NIEWIEM, Edyta PUNIACH,
Paweł ĆWIĄKAŁA
AGH University of Science and Technology, Poland

A b s t r a c t

In this paper, authors present results of accuracy verification of the Trimble RTX technology. The GNSS receiver Spectra Precision SP60 was used in Cyprus (Kato Paphos Archaeological Park). To evaluate the accuracy of the receiver, two measuring test networks (consisting of 30 and 55 control points) were established. All points were determined in four measuring cycles. Additionally, in order to make more advanced analysis of the data, the bases were also measured by using another GNSS receiver - Geomax-Zenith 25. The point positions, in this case, were conducted in the local coordinate system of Kato Paphos Archaeological Park by using RTK positioning technology. To make a comparison, it was necessary to transform the coordinates based on different groups of fitting points. Analysis allowed to conclude that the Spectra Precision SP60 receiver and the RTX Trimble technology guarantee repeatable results (on the level of 4 cm) of point positioning measurements.

Keywords: Global Navigation Satellite System, Data processing, Statistical analysis, Real-time systems

[1] Corresponding author: AGH University of Science and Technology, Kraków, Poland, Department of Mining Areas Protection, Geoinformatics and Mining Surveying, e-mail: ochalek@agh.edu.pl

1. INTRODUCTION

Nowadays, the global navigation and positioning systems belong to modern spatial positioning techniques and they have been developing very fast. Therefore these techniques of positioning had an influence on evolving of the many fields of the industry. The GPS real-time kinematic and real-time network (RTK/RTN) positioning products are used in a wide variety of industrial fields. The current RTK/RTN systems allow cm-accurate positioning, but it have some limitations. They need to have the nearby infrastructure (mainly single base station and radio link or several reference stations with internet connections, a central processing center and communication links to users). For this reason, some researchers recommended precise point positioning (PPP) techniques as an alternative to RTK/RTN. PPP technique is performed using precise satellite orbit and clock information, so this solution usually provides position accuracy of better than 10 cm horizontally [1]. The major disadvantage of PPP techniques is the relatively long convergence time. This time mostly depends on satellites viability and environmental conditions at measurement area [2]. Real-time extended (RTX) technology which is a combination of RTN and PPP technologies is based on the generation and delivery of precise satellite corrections (clocks, orbits, others) on the global scale through the satellite link or via internet [3].

2. GNSS TECHNIQUE OVERVIEW

GNSS measurements are usually performed in two modes: autonomous and differential. In precise applications, the most common methods are differential measurements that allow reducing errors.

Networks of permanent stations significantly contribute to the spread of GNSS technologies in geodetic applications. These networks allows to make coordinate measurements with centimetre accuracy. Their other important task is to provide the reference for mobile receivers operating in RTK (Real Time Kinematic) or RTN (Real Time Network) mode and used in geodetic tasks [4]. Additional, a lot of receivers located in different regions of the Earth are used as sensors and allow to detect and investigate a special type of ionospheric irregularities [5].

The cm-accuracy of these methods was confirmed as a result of many tests and is widely accepted. Basic requirements that are necessary for RTK measurement are the known coordinates base station and the radio link between the base station and rover receiver. On the other hand, the RTN technique needs Internet connection to receive corrections from network of permanent stations. The distance between the base and the rover is limited. They require the use of either a temporary or permanent base station. Performance is mostly dependent on the ionospheric delay witch depends on the distance from the base station [6].

Nowadays, most of the area has cellular coverage. Therefore, it is possible to upload corrections in many places. Areas that have no access to the Internet are problematic. Without the possibility of logging into the RTN service, the receiver cannot download the corrections. Despite the existence of many permanent networks, the station density is sometimes insufficient. The spatial operating range differential GNSS varies from 10 km to several tens of kilometers [7]. Additionally, during foreign measurements, access to the service and the network may be dependent on the country.

In recent years, PPP (Precise Point Positioning) technology has developed. The PPP is a method based on pseudorange measurements and phase measurements. The technology allows obtaining high accuracy position without using differential measurements. It is possible through precise satellite orbit, exact information about satellites clocks and atmosphere delays [8]. In case of PPP, the convergence time might be a huge barrier. The GNSS measurement session time depends on atmospheric influence and geometry of constellation [6]. There is PPP both in static and kinematic mode [9,10]. Researches indicated that north-east precision of static solution can reach millimeter level, whereas in case of ellipsoid elevation is 1-2 cm for daily period of observation [11].

The RTX technology proposed by Trimble Company has been developing at a fairly rapid pace for several years and can permanently increase the possibilities of GNSS measurements [8]. It offers cm-level GNSS positioning through the CENTERPOINT RTX™ service. The core of the new philosophy is the worldwide system of over 100 satellite tracking stations. Data from monitoring station is collected and transmitted to Trimble operation centres at different locations. Then the GNSS satellite data is analysed in order to model orbit shifts, clock errors, measurement biases and other auxiliary information. This network is able to track satellite of GPS, GLONASS, QZSS, GALILEO and COMPAS [12]. Moreover, the studies indicate decrease GNSS measurement session time by 42%, when GPS and GALILEO were used relative to single GPS [14]. The precise satellite data are compressed in the CMRx format, which is especially developed for compact transmission of satellite information. The obtained data messages can be transmitted in two ways: by an uplink station or made available for internet connection access by the users. The use of satellites is novel. They transmit corrections to receivers around the world (the most of the world is covered), despite having no cellular coverage. However, it is necessary to have an L-Band antenna and a system subscription [15]. The scheme of the RTX system is presented in Fig.1.

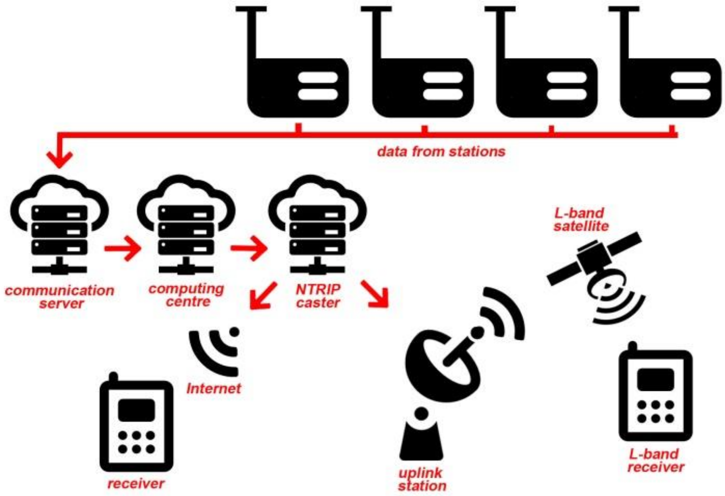

Fig. 1. RTX system scheme (own elaboration based on [16])

The absolute RTX positioning solution is computed using dual frequency pseudorange and carrier phase measurements from the GPS, GLONASS, QZSS and BeiDou and Galileo satellites. Eq. (1) and (2) appoint the simplified equation for the carrier phase and pseudorange measurements from a receiver to a given satellite [17].

$$\Phi_i = \rho + c(dT - dt) + T - I_i + A_i - a_i + \frac{W_i - w_i}{\lambda_i} + B_{\Phi,i} - b_{\Phi,i} + \lambda_i N_i + m_{\Phi,i} + \epsilon_{\Phi,i} \quad (2.1)$$

$$P_i = \rho + c(dT - dt) + T - I_i + A_i - a_i + B_{\Phi,i} - b_{\Phi,i} + m_{P,i} + \epsilon_{P,i} \quad (2.2)$$

where:

Φ_i - carrier-phase measurement for frequency i;
P_i - pseudorange measurement for frequency i;
ρ - receiver antenna to satellite range;
c - speed of light;
dT - receiver clock error;
dt - satellite clock error;
T - tropospheric delay;
I_i - ionospheric delay for frequency i;
A_i - receiver antenna offset and variation for frequency i;
a_i - satellite antenna offset and variation for frequency i;
W_i - receiver antenna phase wind-up;
wi - satellite antenna phase wind-up;

$B_{\Phi,i}$ - carrier phase receiver bias for frequency i;
$b_{\Phi,i}$ - carrier phase satellite bias for frequency i;
$B_{P,i}$ - pseudorange receiver bias for frequency i;
$b_{P,i}$ - pseudorange satellite bias for frequency i;
λ_i - carrier wavelength for frequency i;
N_i - integer ambiguity for frequency i;
$m_{\Phi,i}$- carrier phase multipath for frequency i;
m_{Pi} - pseudorange multipath for frequency i;
$\epsilon_{\Phi,i}$ - carrier measurement error and residual errors;
$\epsilon_{P,i}$ - pseudorange measurement error and residual errors.

The possibility of high-accuracy absolute positioning is based on the assumption that phase and code measurements on the different frequencies or on specific observation combinations are modeled reliably. In the case of RTK most of the unknowns in simplified GNSS observation equations for carrier-phase and code measurements are double differenced with the observations from base stations. In the case of RTX they have to be modelled by the network of tracking stations and the computing centres [17, 18].

Determination of precise orbit parameters in the RTX CenterPoint system is based on a UD-factorized Kalman filter for estimating the satellites position and velocity, conditions of troposphere solar radiation pressure parameters. The determination of integer phase ambiguities is resolved in real time. The satellite clock errors estimation is next crucial issue of the RTX system. It has an important role in positioning efficiency. The clock data processing is vital because of the fact that assessment of clock errors is related to the ambiguity resolution. Therefore, any delay in computation of these errors has an impact on point positioning. The construction of the clock processor of RTX technology allows continuous processing of the data from many of the system reference stations. The purpose is to achieve the time of processing of the data as short as it is possible, in order to allow the system to operate at 1 Hz [14].

3. RESEARCH AREA, MEASUREMENT AND DATA ACQUISITION

Authors used RTX technology in one of the warmest regions of the Mediterranean –Cyprus. The research area mainly covered the area of Kato Paphos Archaeological Park. To determine the accuracy of the positioning two measuring test networks were established. Networks were particularly located to allow the measurements of points both in very good conditions and partially obscured horizons. The first test network consisting of 55 points was located near the sea (COAST), which allowed for measurements with the open horizon. The second with 30 points, was located near the Agora (SHED). This network was covered with trees from the east side and limited by buildings from the west. The location of the points is depicted in the Fig. 2.

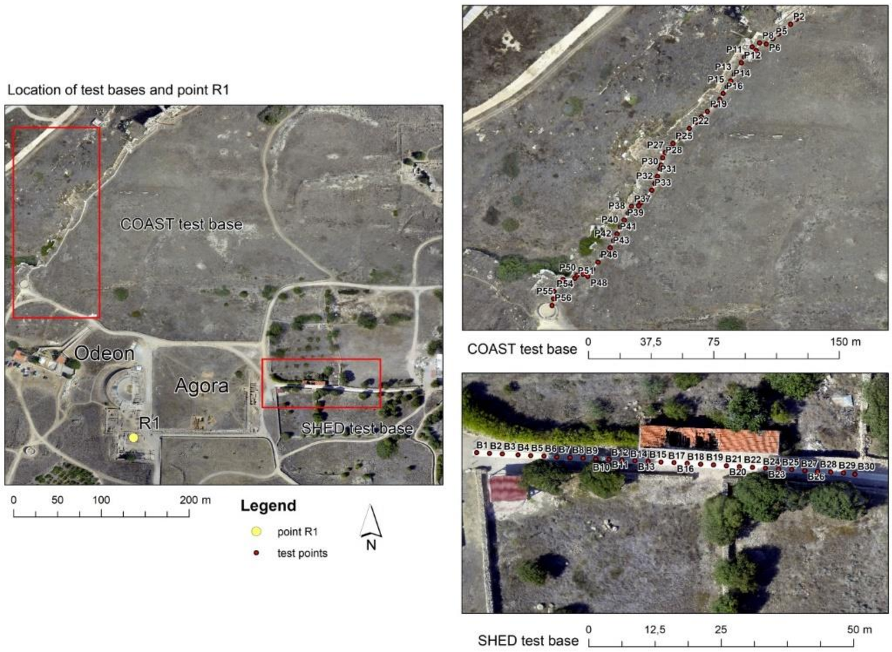

Fig. 2. Location of test bases and R1 (own elaboration based on Google Maps)

The GNSS receiver Spectra Precision SP60 was used in order to verify RTX technology. The receiver is equipped with modern L-Band antenna which allowed to use Trimble RTX correction services. Thanks to that it is possible to perform differential measurements with only one receiver and in areas where there is no network available and a local base and rover set-up is not possible.

Spectra Precision SP60 was used in four measuring sessions for each network at different times of the day. The point positions using SP60 were determined in ETRF2000 (R05) (epoch 2000) coordinate system. It was necessary to transform coordinates to ITRF2008 (epoch 2017), in order to compare with PPP/RTK results [19]. Furthermore, to make a more advanced analysis of the data, the networks were measured with the usage of another GNSS receiver (not supporting RTX technology) – Geomax-Zenith 25. In this case, the point's positions were determined in the local coordinate system of Kato Paphos Archaeological Park (established by the archaeological expedition from

Krakow) by RTK positioning technology. Receivers were working using GPS and GLONASS constellations.

It is worth mentioning that during the measurements of the networks, especially at the SHED network, some problems occurred. From point B1 to B12 there were too high HDOP and VDOP indicators, so sometimes the points measurements were induced by the surveyor. The problems resulted from obscuring the horizon and were induced deliberately in order to perform analyses of the receiver's operation in various conditions.

The headers of even pages should include the authors' surnames, the headers of odd pages should include (in the place of "Instructions to authors") an expression related to the text of the paper (e.g. the whole title of the paper or its part).

4. DATA ANALYSIS

4.1 Repeatability of the RTX method

The entire data set allowed creating the database with all measured coordinates of control points and related values. The subsequent analysis focused on determining the repeatable results of point positioning measurements conducted with the Spectra Precision SP60 receiver and the RTX Trimble technology. To make such analyses the pairwise observation method was used. For both networks – COAST and SHED - the first sessions were established as the based measurement. The results of calculations are shown in Table 1.

Table 1. The results calculations

Test network "SHED"	**Mean difference error dm [cm]**			Error of point measurement	
	dx_mean [cm]	*dy_mean[cm]*	*dh_mean [cm]*		
	4.40	3.11	10.58		
	Mean unit error m0 [cm]				
	mx0_mean [cm]	*my0_mean [cm]*	*mh0_mean [cm]*	*mxy_0 [cm]*	4.12
	3.29	2.47	6.70	*mxyh_0 [cm]*	7.86
Test network"COAST "	**Mean difference error dm [cm]**			Error of point measurement	
	dx_mean [cm]	*dy_mean[cm]*	*dh_mean [cm]*		
	1.71	2.31	7.88		
	Mean unit error m0 [cm]				
	mx0_mean [cm]	*my0_mean [cm]*	*mh0_mean [cm]*	*mxy_0 [cm]*	1.51
	0.86	1.24	4.28	*mxyh_0 [cm]*	4.54

The average differences of the measured coordinates differ in case of both test networks. The maximum differences occurs in SHED test network are a consequence of obscured horizon. The COAST test network confirms that the accuracy of the receiver at the open horizon are within the limits of the error declared by Trimble (4 cm). Additionally, the initialization time was also verified (time, after which the receiver achieved the accuracy of the measurement allowing the user to start the surveys). The initialization time was in the range of 30-40 minutes, therefore it was also within the limits declared by Trimble.

4.2 Evaluation of the local RTX accuracy

The RTK measurement was performed in a local coordinate system based on control points located in the Agora. Before starting the measurement, the system was defined in the receiver. It was necessary to transform coordinates in order to evaluate coordinate differences.

The Helmert transformation (translation and rotation) was made without changing the scale. The transformation was made in two variants, which varied the number of fit points. All of them or 6-7 control points were selected. In the case of points from COAST test network, these were the numbers P01, P10, P20, P30, P40, P50, P56, whereas, in SHED test network points B01, B06, B12, B18, B24, B30 were selected (Fig. 2). The average difference between RTK and RTX was 3.8 cm (Fig. 3). For better illustration the results of measurements in comparison between RTX and RTK methods, the histograms of measured differences in coordinates were created Fig. 3.

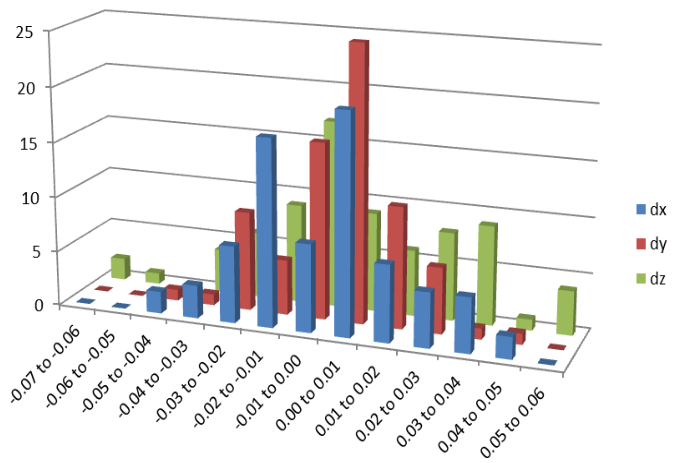

Fig. 3. Histogram of differences in measured coordinates between RTK-RTX methods (own elaboration)

4.3 Global RTX accuracy refer to PPP technology

To assess the global accuracy of the RTX method, it was necessary to convert the coordinates determined by the RTK method into the global system. To this end, static PPP measurements were used. Coordinates of the R1 point were calculated using the online service. The service is provided by Natural Resources Canada CSRS-PPP online precise positioning. Service supply extensive data analyses[20]. Along with the results, a full accuracy analysis was provided. The estimated 3D error (on the significance level α = 0.95) was 2.6 cm. PPP observations for R1 are depicted in Fig. 4.

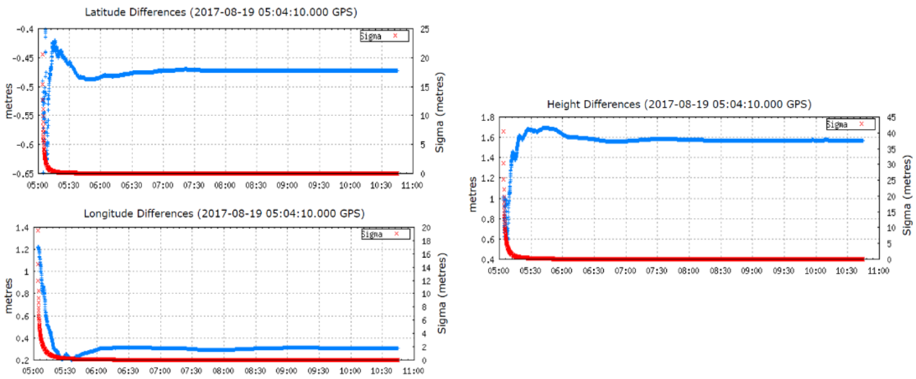

Fig. 4. Corrections to apriori positions (source: CSRS-PPP)

Using the angle of rotation between the systems and global coordinates of the R1 control point, global coordinates of reference networks were calculated. Differences between the averaged RTX measurements and these RTK coordinates were then compared. In the case of the COAST test network, the RMSE is 2.9 cm. The results of the measurement of the SHED test network were much worse, in particular due to obscured horizon caused by buildings, vegetation and terrain, RMSE is 5.2 cm. Linear differences between coordinates calculated using the RTX method and the combination of PPP and RTK methods were presented in the form of histograms Fig. 5.

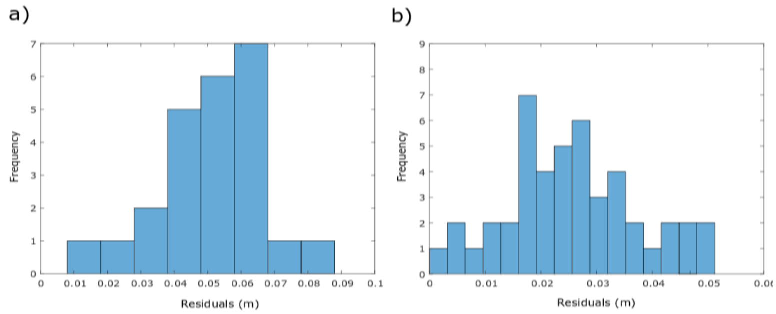

Fig. 5. Histograms - residuals between PPP and RTX a) SHED b) COAST (own elaboration)

5. CONCLUSIONS

In conclusion, the tested RTX method meets the accuracy requirements sets by the manufacturer. Analyses and calculations confirm that the maximum differences between determined coordinates in RTX technology are within the limits of the error - 4 cm (horizontal). Determination of local accuracy of RTX technology allowed to calculate the average difference between RTX and RTK on the level of 3.8 cm. The collected data enabled to determine global RTX accuracy refer to PPP technology. The RMSE of point position resulting from the measurements of control points in unobstructed site is 2.9 cm. However, it must be said that the obscured horizon strongly effects the accuracy of RTX technology.

Certainly, it is very useful to be able to perform a measurement without the cellular coverage, thus without access to the Internet. In addition, a network of permanent stations is not required, it allows you to use RTX technology in even more places. In the future, Trimble RTX and similar technologies will be developed. If problems with the obscured horizon, initialization time and operating costs are solved, it will be a competition for the RTN.

Acknowledgment

The research was possible thanks to Department of Antiques at the Departments of the Ministry of Transport, Communications and Works, Cyprus. The authors are really thankful to Paphos Agora Project for providing the archaeological park area for research. Moreover, we would like to express our very great appreciation to NaviGate Sp. z o.o. company for possibility of hiring receiver Spectra Precision SP60. Researchers was supported by Department of Mining Surveying and Environmental Engineering (AGH University of Science and

Technology). The article was prepared as part of the AGH statutory research No. 11.11.150.005 and No. 11.11.150.949 and No. 11.11.150.195.

REFERENCES

1. Stępniak K., Wielgosz P., Paziewski J.: *Badania dokładności pozycjonowania techniką PPP w zależności od długości sesji obserwacyjnej oraz wykorzystanych systemów pozycjonowania satelitarnego*, Biul. WAT, LXI, 1 (2012) 429–450.
2. Anquela A. B., Martín A., Berné J. L., Padín J.: *GPS and GLONASS Static and Kinematic PPP Results*, J. Surv. Eng.,139,1 Feb.(2013) 47–58. DOI: 10.1061/(ASCE)SU.1943-5428.0000091.
3. Doucet K. *et al.*: *Introducing ambiguity resolution in web-hosted global multi-GNSS precise positioning with trimble RTX-PP*, 25th Int. Tech. Meet. Satell. Div. Inst. Navig. 2012, ION GNSS, 2 (2012) 1115–1125.
4. Krasuski K.: *Wykorzystanie Programu Trimble RTX-PP*, J. Civ. Eng. Environ. Archit., 63 (2016). DOI: 10.7862/rb.2016.112.
5. Nykiel G., Zanimonskiy Y., Yampolski Y., and Figurski M..:*Efficient Usage of Dense GNSS Networks in Central Europe for the Visualization and Investigation of Ionospheric TEC Variations*, Sensors,17,10,Oct. (2017) 2298. DOI: 10.3390/s17102298.
6. Leandro R. *et al.*: *RTX Positioning : The Next Generation of cm-accurate Real-Time GNSS Positioning*, Proc. 24th Int. Tech. Meet. Satell. Div. Inst. Navig. (ION GNSS 2011), (2011) 1460–1475. DOI: 10.2478/arsa-2014-0015.
7. Rizos C., Janssen V., Roberts C., Grinter T.: *Precise Point Positioning: Is the Era of Differential GNSS Positioning Drawing to an End?*,FIG Work. Week, May,17, 2012.
8. Siejka Z.: *Verification of the usefulness of the Trimble RTX extended satellite technology with the xFill function in the local network implementing RTK measurements*, Artif. Satell., 49,4 (2014) 191–209. DOI: 10.2478/arsa-2014-0015.
9. Odijk D., Teunissen P.J.G., Khodabandeh A.: *Single-Frequency PPP-RTK: Theory and Experimental Results*, IAG Symposium Earth on the Edge: Science for a Sustainable Planet, 139, October (2014) 571–578.
10. Angel M. et al.: *Kinematic GNSS-PPP results from various software packages and raw data configurations*, Scientific Research and Essays,7,3 (2012) 419-431. DOI: 10.5897/SRE11.1885.
11. Guo Q.:*Precision comparison and analysis of four online free PPP services in static positioning and tropospheric delay estimation*, GPS Solut., 19,4,Oct.(2015) 537–544. DOI:10.1007/s10291-014-0413-5.

12. Chen X. et al.: *Trimble RTX, an innovative new approach for network RTK*, 24th International Technical Meeting of the Satellite Division of the Institute of Navigation, ION GNSS 2011, 3(2011) 2214–2219. ISBN: 9781618394750.
13. Glocker M., Landau H., Leandro R.: *Global precise multi-GNSS positioning with Trimble CenterPoint RTX*, 6th ESA Workshop on Satellite Navigation Technologies (Navitec 2012) & European Workshop on GNSS Signals and Signal Processin,2012. DOI: 10.1109/NAVITEC.2012.6423060.
14. Li P. and Zhang X.: *Integrating GPS and GLONASS to accelerate convergence and initialization times of precise point positioning*, GPS Solut., 18, 3 Jul. (2014) 461–471.DOI: 10.1007/s10291-013-0345-5.
15. Brandl M. et al. *Advancing Trimble RTX Technology by adding BeiDou and Galileo*, Eur. Navig. Conf. 2014, January 2016, 2014.
16. Krzyżek R.: *Precision Analysis of Trimble Rtx Surveying Technology with Xfill Function in the Context of Obtained Conversion Observations*, Reports Geod. Geoinformatics,97,1 (2015) DOI:10.2478/rgg-2014-0011.
17. Leandro R. et al.: *RTX Positioning : The Next Generation of cm-accurate Real-Time GNSS Positioning*, Proc. 24th Int. Tech. Meet. Satell. Div. Inst. Navig. (ION GNSS 2011), September (2011) 1460–1475.
18. Nardo A. et al.: *Experiences with Trimble CenterPoint RTX with Fast Convergence*, ESA ENC Conference 2015.
19. Figurski M., Nykiel G.: *Investigation of the impact of ITRF2014/IGS14 on the positions of the reference stations in Europe*, Acta Geodyn. Geomater, 14, 43, 188 (2017) 401–410. DOI: 10.13168/AGG.2017.0021.
20. Alkan R. M., Ilci. V.: *Accuracy Comparison of PPP Using GPS-only and Combined GPS+GLONASS Satellites in Urban Area: A Case Study in Çorum*, 2015.

OCENA DOKŁADNOŚCI PRECYZYJNEGO POZYCJONOWANIA GNSS W CZASIE RZECZYWISTYM Z WYKORZYSTANIEM TECHNOLOGII RTX TRIMBLE

S t r e s z c z e n i e

W artykule autorzy przedstawiają wyniki analizy dokładności technologii Trimble RTX. Odbiornik GNSS Spectra Precision SP60 wykorzystano podczas badań na Cyprze (Park Archeologiczny Kato Pafos). Aby ocenić dokładność odbiornika, ustalono dwie bazy testowe (składające się z 30 i 55 punktów kontrolnych). Wszystkie punkty zostały określone w czterech cyklach pomiarowych. Dodatkowo, w celu bardziej zaawansowanej analizy danych, pomiary zostały również wykonane przy użyciu innego odbiornika GNSS - Geomax-Zenith 25. Pozycjonowanie w tym przypadku, zostało przeprowadzone w lokalnym układzie współrzędnych parku archeologicznego Kato Pafos z wykorzystaniem technologii pozycjonowania RTK. W celu porównania wyników badań konieczne było przetransformowanie współrzędnych do jednego układu. Transformację wykonanano na podstawie różnych grup punktów dostosowania. Analiza otrzymanych wyników pozwoliła stwierdzić, że odbiornik Spectra Precision SP60 i technologia RTX Trimble gwarantują porównywalne wyniki pozycjonowania (na poziomie 4 cm).

Słowa kluczowe: GNSS, przetwarzanie danych, analiza statystyczna, systemy czasu rzeczywistego

Editor received the manuscript 29.10.2018