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COMPATIBILITY OF RTN SOLUTIONS IN SELECTED ACTIVE GEODETIC NETWORKS

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Abstract

Results of 24h real-time network (RTN) measurements performed at the same time on two positions with 60 seconds sapling intervals were the subject of analysis. These measurements results were determined on the basis of VRSnet.pl being commercial network of reference stations as well as Małopolski System Pozycjonowania Precyzyjnego (MSPP) which in turn is part of the national ASG-EUPOS network. The absolute error and uncertainty of point position for each observation were computed. Subsequently, uncertainty of point position was compare with values of three dimensional Root Mean Square (3D RMS) which in turn were determined using algorithms of selected systems. Measurements using the RTN method can be used to quickly collect information about the location and geometry of objects for field studies.

Keywords: point position, RTN, RTCM 3.1, CMRx

INTRODUCTION

Development of satellite navigation systems, reference stations, measurement equipment and algorithms made acquisition of spatial information easy. Coordinates of a point in an adopted coordinate system can be considered such information. Traditional methods of obtaining the fieldwork location information are being replaced with real-time methods, which allow to obtain precise coordinates. Real-time methods include Real-Time Kinematic (RTK) method and Real-Time Network (RTN) method. In case of the former method, the position is determined based on the correction which is calculated based on the observation of the given satellite system, registered by a mobile receiver as well as a fixed receiver mounted on a Continuously Operating Reference Station (CORS). The latter method allows to use the correction transmitted to the receiver from a Virtual Reference Station (VRS), where the correction is calculated based on the observations registered by the whole network of reference stations which match the reference station positioning accuracy criteria at the moment of observation. The VRS concept was introduced in real-time positioning in the late 1990s (Chen *et al*., 2011). Use of network amendments in the RTN method provides repeatability of determination of coordinates, which is independent of the distance of the receiver from the physical reference station as opposed to the RTK method. Another advantage of the RTN method is the possibility of better modelling of systematic errors, including those related to the operation of atomic clocks the satellites are equipped with or delays due to signal propagation in the atmosphere (www.asgeupos.pl). This is also confirmed by the research done by Bárta (2005) as well as Byungwoon and Changdon (2010). The RTN measurement technique requires bidirectional communication between the user's receiver and the server which generates the data regarding the virtual reference station as well as correction streams (Chen *et al*., 2011). First, a NMEA GGA (The National Marine Electronics Association) message, containing information about user's approximate position, is transmitted to the computing system. Then, based on the reference station network, a stream of amendments is generated and transmitted to the user by NTRIP protocol (Networked Transport of RTCM via Internet Protocol) with use of RTCM format (Radio Technical Commission for Maritime) or CMR format (Compact Measurement Record). RTCM is a standard of differential correction transmission for DGPS (Differential GPS) satellite system users. The RTCM amendments are transmitted in real time with the minimum speed of 50 bits per second on L1 frequency in case of GPS (Global Positioning System) with use of C/A code. A format characterized by better data compression than RTCM is CMR developed by Trimble company.

Technological development resulted in reference station networks being not only owned by state institutions or research institutes, but increasingly by companies of the industry. This is why, aside from state active geodetic networks we can also distinguish commercial active geodetic networks. As stated in the *Regulation of the Minister of Administration and Digitization of 14 February 2012. On geodetic, gravimetric and magnetic control networks* (Journal of Laws 2012 item 352) the Polish nationwide network of reference stations, governed by the Head Office of Land Surveying and Cartography, is the ASG-EUPOS system. The points of this system make up the basic fundamental and base horizontal network. ASG-EUPOS service usage fees, introduced on July 12th 2014 based on the *Act of 14 February 2014 on act amendment – Geodetic and Cartographic Law and the Law on enforcement proceedings in administration*, resulted in development of private active geodetic networks in Poland. They became an alternative for users interested in more cost-efficient solutions. Among the commercial active geodetic networks in Poland VRSNET.pl, TPI NETpro and SmartNet can be distinguished. These networks differ in many aspects such as used equipment or the degree of coverage of the country. There are many studies regarding accuracy of evaluation of real time services of ASG-EUPOS services (Siejka 2008, Hadaś and Bosy 2009, Plewako 2012, Uznański 2012, Przestrzelski and Bakuła 2014, Siejka and Mielimąka 2015, Kudas, Szylar and Cegielska 2016) and relatively little studies on the VRSNET.pl system (Gabryszuk 2016). ASG-EUPOS system administrators claim that the tests performed by the system contractor and external institutions confirm, that in optimal measurement conditions, all kinds of amendment data allow to achieve positioning repeatability within ±0.03m horizontally and ±0.05 vertically (www.asgeupos.pl).

Real-time methods, implementing network corrections and single station corrections, find their application in gathering information for the purpose of environmental research, such as environmental engineering (Mika 2012, Siejka 2014, McHugh *et al*. 2015, Kudas and Czempas 2016). However, performing measurement with the use of satellite technologies is difficult in forests (Bakuła, Przestrzelski and Kaźmierczak 2015), densely built up areas (Tokura *et al*. 2014) and in conditions of obstructed horizon (Bakuła, Pelc-Mieczkowska and Walawski 2012).

A part of ASG-EUPOS is Precise Positioning System of Malopolska (MSPP, Małopolski System Pozycjonowania Precyzyjnego), consisting of 10 reference stations located in Malopolska and Śląskie voivodships (Figure 1). MSPP allows to obtain satellite observations from physical reference stations and to generate observations from virtual reference stations. Until June 30th 2016 MSPP shared RTK and RTN corrections generated on the basis of the reference stations of the system for free. Their distribution was ceased based on *Annex No. 1 to the agreement on cooperation between the Malopolska Voivodship and the Chief Surveyor-General concerning the use of Precise Positioning System of Maloposka (MSPP) in the nationwide ASG-EUPOS system of February 18th 2016*. The network amendments were shared in both RTCM and CMR formats.

One of the commercial reference station networks is VRSNET.pl. This system offers corrected data for RTN and RTK from a single reference station as well as satellite observations regarding reference stations and produced basing on the GNSS (Global Navigation Satellite System) observation data files sent by users (www.vrsnet.pl). VRSNET.pl consists of 62 reference stations, including 56 stations in Poland (Figure 1.) and 6 stations outside of the country. VRSNET.pl network is divided into 4 subnetworks, covering the following voivodships: Zachodniopomorskie, Świętokrzyskie, Śląskie and the rest of the country. The users may use the amendments in both RTCM and CMR formats. Since the beginning of the year 2016 usage fees apply.

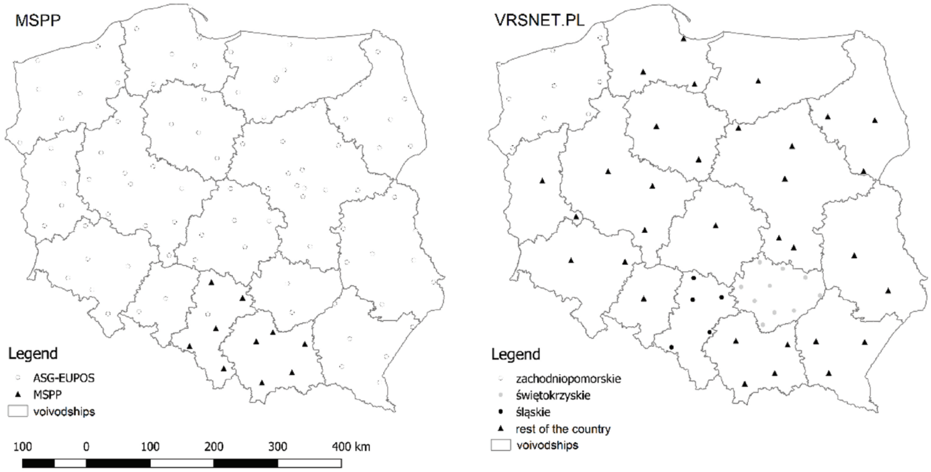

Figure 1. Station locations of MSPP on the background of ASG-EUPOS and location of subnet of VRSNET.pl system

The presented research aims to evaluate the precision of RTN method positioning with the use of NAWGEO_VRS_CMR corrections based on MSPP as well as VRSNET_Polska_test_RTCM32 network correction of the VRSNET.pl commercial system, real-time services of which were in a test phase during the experiment. The experiment was focused on the consistency of the results obtained with RTN method measurement of 24 hours. The obtained coordinates of point's both horizontal (XY) and vertical (H) position were thoroughly evaluated. The results' consistency was also assessed with use of network corrections obtained from two independent reference station networks. This issue is especially important due to the recommendations regarding the use of network streams in RTK measurements whenever possible (www.asgeupos.pl).

MATERIALS AND METHODS

The research material was obtained on the basis of a 24-hour measurement performed on September 7th 2015 (DOY 250, GPS Week #1861) on the campus of Faculty of Environmental Engineering and Land Surveying of University of Agriculture in Krakow with the use of two measurement stations 2.00 meters apart from each other. The stations operated in identical observational conditions and there were no sources that could interfere with satellite measurement techniques.

Two Trimble R8 Model 3 receivers integrated with an antenna were used during the study. According to the data provided by the manufacturer, the kinematic measurement accuracy of this model is 10mm + 1ppm RMS horizontally and 20mm + 1ppm RMS vertically. During the measurement, the antennas mounted on geodetic tripods and were centrically leveled above the measurement points on approximately the same height as a measurement set consisting of a receiver on a pole. This allowed to avoid errors generated during detailed measurements with RTK method (Kowalczyk 2011). The measurement was reinitialized every 4 hours after receiver battery replacements.

Table 1. Configuration of the receivers working on observation stations

	MSPP	**VRSNET.pl**
The manufacturer, model receiver:	Trimble, R8-3	Trimble, R8-3
The manufacturer and model of the antenna:	Trimble R8 GNSS/SPS88x Internal	Trimble R8 GNSS/SPS88x Internal
Used system:	MSPP	VRSNET
Type of solution:	Network	Network
Type of used corrections:	NAWGEO_VRS_CMR	VRSNET_Polska_test_ RTCM32
Adress IP:, Port IP:	46.22.167.208: 8080	194.24.244.35: 2102
Used stream of the system corrections:	CMRx	RTCM 2.3
Elevation mask of the rover:	10	10
PDOP mask of the rover:	6	6
Interval of position registration:	60 s	60 s
Type the firmware:	Trimble General Survey	Trimble General Survey
Software version:	2.50	2.50

The results of RTN point positioning during the day with the use of VRSNET.pl system and MSPP were assessed with use of absolute error value. The error was evaluated for every X, Y and H coordinate value. Moreover, average error of single observation for each of the coordinates was calculated with the use of the following formula:

$$M = \sqrt{\frac{\sum_{i=1}^{n}(a_i-\bar{a})^2}{n-1}}, \tag{1}$$

where: a_i – observation,

$\bar{a}$ – average of observations,

n – number of observations.

The values of the estimated absolute errors for each of the measurement results were then used to determine the positioning error of the point, which was calculated using the following formula:

$$M_P = \sqrt{{M_X}^2 + {M_Y}^2 + {M_H}^2}, \quad (2)$$

where: M_X – absolute error of X coordinate,
M_Y – absolute error of Y coordinate
M_H – absolute error of H coordinate.

In order to verify whether the position of the point, determined in the same terrain conditions with the use of the same equipment, is equally accurate for RTN measurements with use of VRSNET.pl and MSPP corrections, F-test was performed. F-test is based on Fisher-Snedecor distribution and is used to verify two variances. The test states a null hypothesis saying that the empirical inconsistency of the variances is insignificant and the compared variances are considered equal.

RESULTS AND DISCUSSION

During the experiment 1440 positions were determined for each measurement station. The measurement results were compared in terms of the arrangement of registered positions and their multiplicity along with distinction of the positions, whose multiplicity is greater than or equal to 100 (Figure 2.) In each case, the registered positions form a characteristic shape, elongated towards the north and the south. This results from the fact, that the range of registered coordinates is greater for the X axis, as confirmed by existing studies (Uznański 2006, Siejka 2008, Kudas, Szylar and Cegielska 2016).

In order to compare the results obtained using RTN method, three-dimensional shapes were modelled based on the registered coordinates. The vertices of the shapes represented the external points of each set of coordinates. Then, the volume of the shapes was calculated basing on points with multiplicity greater than or equal to 100 (Figure 3). This way, the daily accuracy of the solutions was calculated, characterizing it by the volume of the shapes (Table 2.). This allowed to prove the greater 24 hour period repeatability of the RTN method with the use of VRSNET.pl system, where the volume was equal 0.002620m^3, while in the case of RTN method with the use of MSPP it was equal 0.004100m^3. When analyzing the shapes, formed by limiting the data sets to coordinates whose repeatability in horizontal plane was greater than or equal to 100, it becomes noticeable that RTN MSPP method delivered more consistent solution in terms of elevation (Figure 3.).

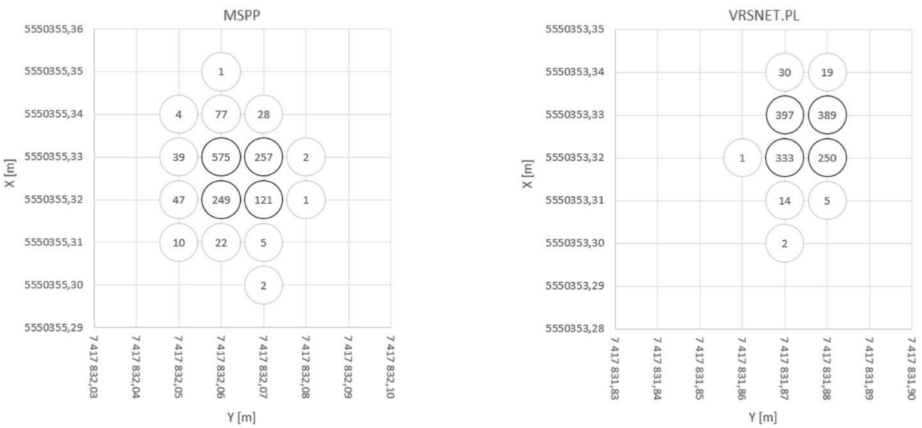

Figure 2. Multiplicity of positions in the XY plane registered during 24 hours

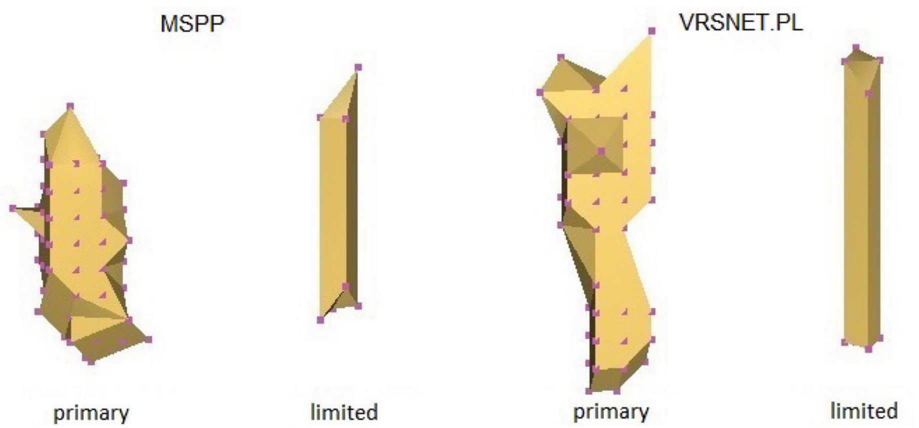

Figure 3. Modeled 3D figures based on recorded results

Table 2. The volume of modeled 3D figures

	MSPP		VRSNET.pl	
Type of figure:	primary	limited	primary	limited
Number of points:	65	8	61	8
Volume[m^3]:	0,004100	0,000740	0,002620	0,001088

In order to assess the measurement results obtained with the use of VRS-NET.pl as well as MSPP corrections, an absolute error was determined for each of the solutions, the values of which are presented by figures 4 and 5. In the case of measurements with the use of VRSNET.pl system, the absolute error value for X coordinates is in the most cases between 0.004 and 0.006 meters, in several cases reaching 0.010m and 0.015m. In the case of Y coordinate, the absolute error has a constant value of 0.005m. In the case of measurement results obtained with use of MSPP system, the absolute error for both X and Y coordinates was in most cases between 0.003 and 0.008m. However, the absolute error values for X axis are more variable than for Y axis, sometimes exceeding 0.015m.

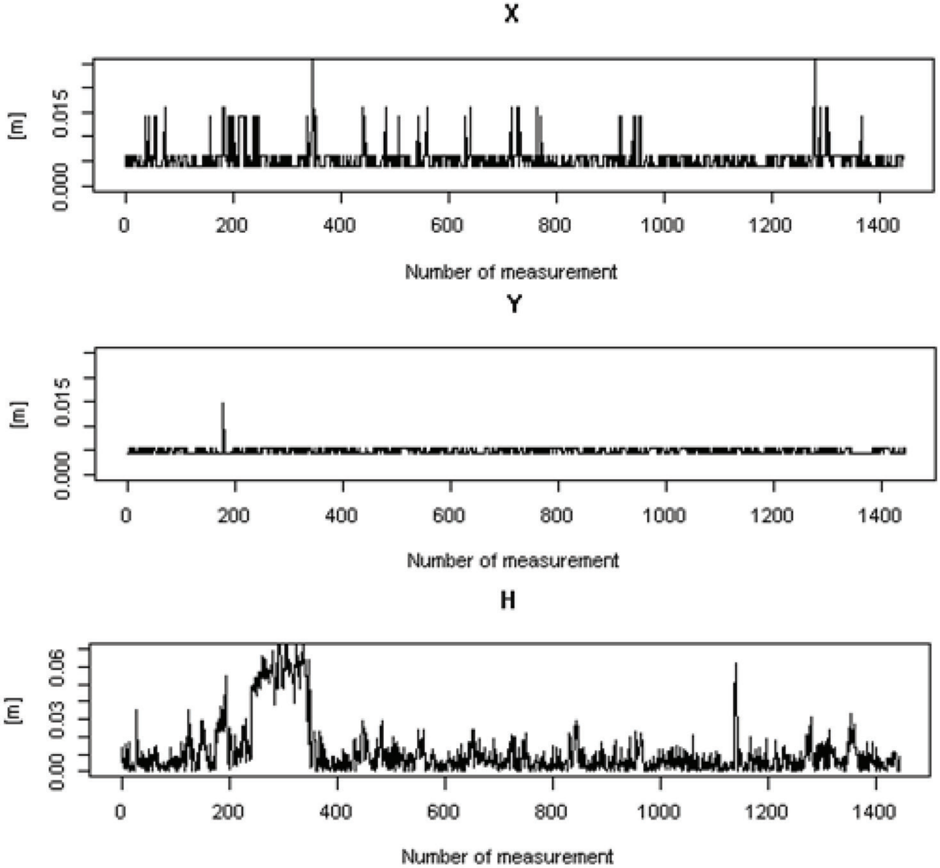

Figure 4. The absolute error of coordinates for subsequent VRSNET.PL results of measurements

The maximum value of absolute error for X and Y coordinates is respectively 0.026m and 0.014m for VRSNET.pl solutions and 0.027 and 0.017 for MSPP. The absolute error was also determined for the obtained values of elevation H. The absolute error for elevation is in most cases between 0.010 and

0.020m, with the maximum values of 0.078m for results obtained with use of VRSNET.pl solutions and 0.054m for MSPP solutions. Moreover, the absolute error for elevation in both cases is characterized by high variability.

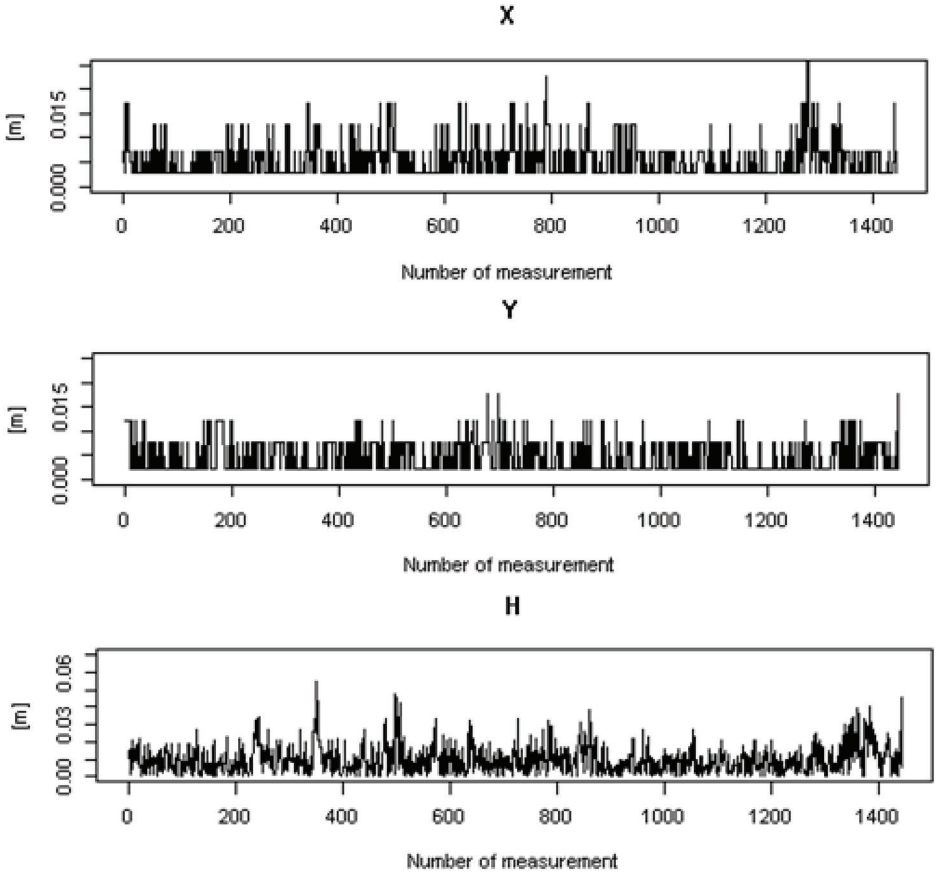

Figure 5. The absolute error of coordinates for subsequent MSPP results of measurements

Additionally, for VRSNET.pl and MSPP, the average error of single measurement for X, Y and H coordinates was calculated. For X and Y components, the error is equal 0.006m in case of MSPP and for VRSNET.pl the average error is equal 0.006 and 0.005m for X and Y axes respectively. The average error for H equals respectively 0.019 and 0.012m for VRSNET.pl and MSPP solutions.

The calculated positioning error for each consecutive measurement was then compared with three-dimensional RMS (Root Mean Square) value. RMS 3D determines the radius of a sphere in which the obtained coordinates of a point have a 66% probability to be in its geometric center. Figure 6. presents the differences between the positioning error of individual points and the corresponding RMS values. The maximum difference is equal 0.063m for VRSNET.pl solutions and 0.039m for MSPP solutions. The estimated point positioning error is greater than the RMS value for VRSNET.pl and MSPP solutions respectively in 626 and 523 cases.

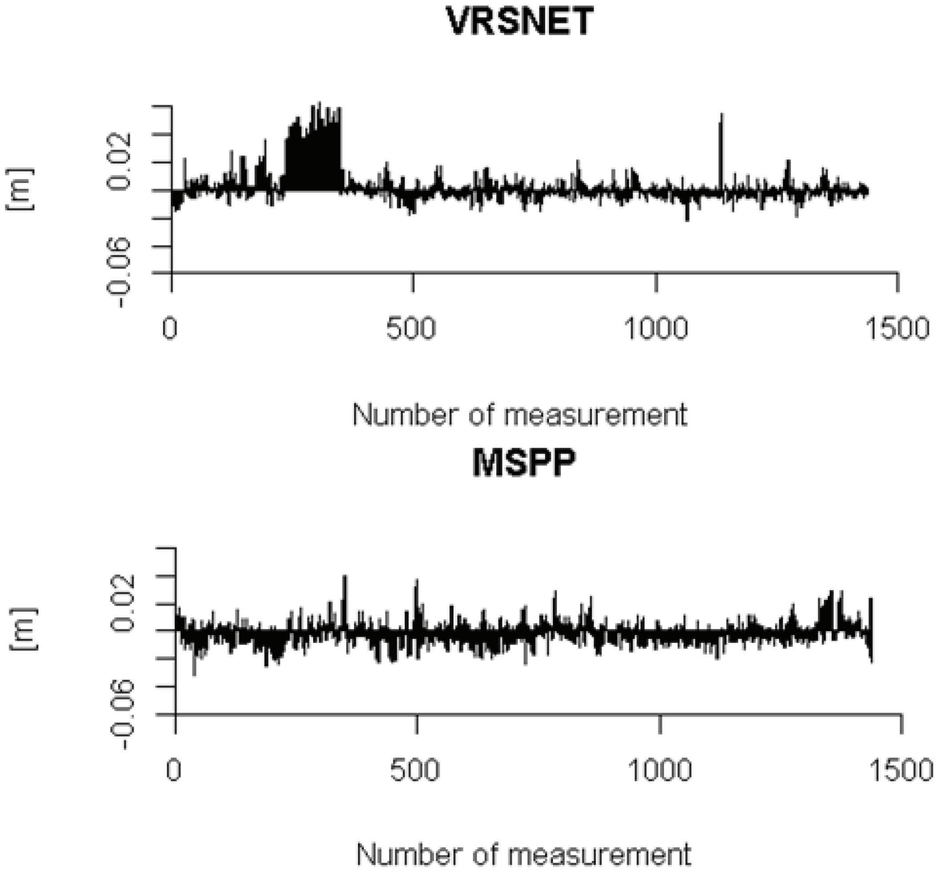

Figure 6. Differences between uncertainty of point position for each observation and corresponding RMS values

The coefficient of correlation between positioning error and RMS was also calculated. In case of VRSNET.pl the correlation coefficient is equal 0.30 and 0.15 for MSPP, which shows poor correlation between RMS and both of the solutions.

In all of the cases of solutions, the greatest influence on the increase of the positioning error had the change of its elevation. The positioning error, calculated only for planar coordinates, reaches a maximum value of 0.028m for VRSNET.pl solutions and 0.026m for MSPP solutions. Figure 7. presents the difference between the positioning error value estimated on the basis of measurement data from the experiment and the value of the position of the point error given in the measurement reports. Positioning error estimated on the basis of the measurement reached values greater than the positioning error presented in the report for VRSNET.pl and MSPP in 758 and 543 cases respectively.

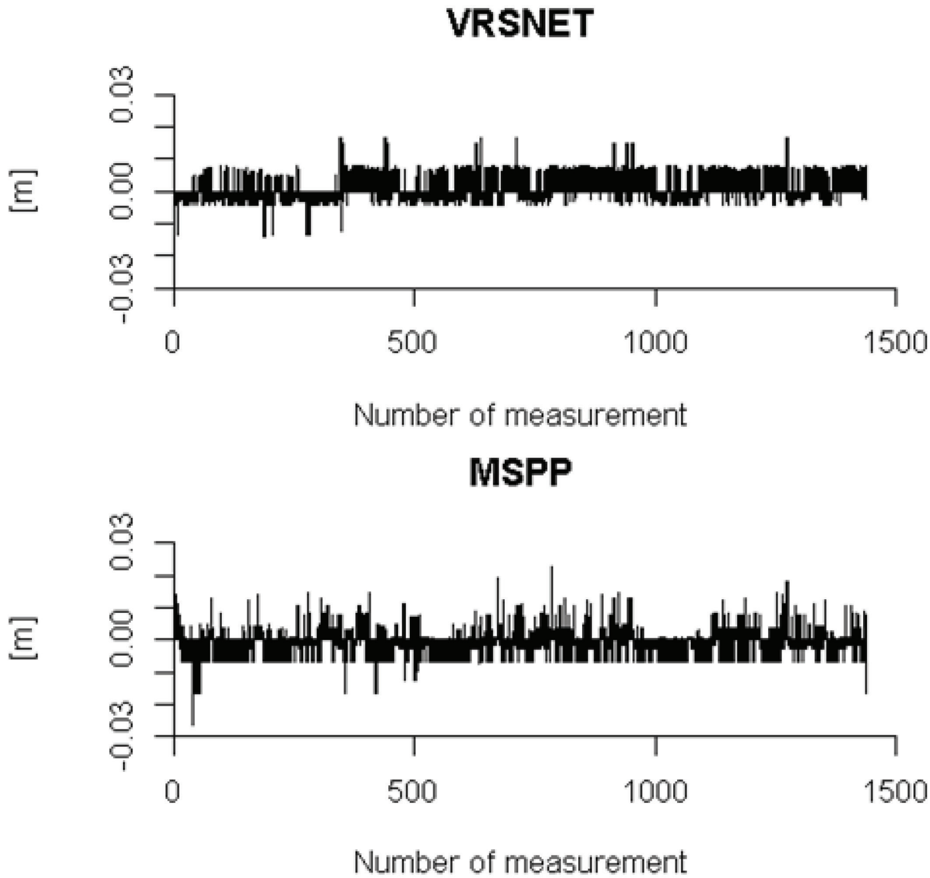

Figure 7. Differences between the uncertainty of point position with rectangular plane coordinates estimated on the basis of measurements data and listed in the report

When analyzing the experiment, it is worth noting in what distance from the measurement location the computational algorithm of a particular system generates a VRS. In the case of MSPP service, the virtual reference station was located 5 kilometers from the measurement station during the whole measurement. The situation was slightly different in the case of measurement with the use of VRSNET.pl, where the distance between the antenna phase center and the VRS was on average 99.52m during the first 6 hours of measurement, after which it decreased to 99.35m. During the first 6 hours of measurement, the length of the 3D vector between the VRS and the nearby CORS of the VRSNET.pl system was oscillating around 0.70m and then decreased to about 0.01m. Therefore, it can be assumed, that after 6 hours the VRS aligned with the physical reference station and the VRSNET.pl algorithm was transmitting corrections from the physical station.

For the coordinates and elevations of the points, obtained using VRSNET.pl and MSPP solutions, an F-test was performed aiming to verify the equality of the variances. On the significance level of 0.10 it was verified that the difference of series variances for VRSNET.pl and MSPP solutions is significant both for X and Y coordinates and for elevation H. Therefore, the selection of algorithms used to calculate the coordinates of a point in both services has significantly different impacts on the accuracy of obtained results. Moreover, it was found that on a significance level of 0.05, in case of the elevation H, the variance of VRSNET.pl solutions significantly exceeds the variance of MSPP solutions. As a result, the measurements with use of VRSNET.pl and MSPP corrections cannot be treated as equally accurate.

CONCLUSIONS

The study assessed the positioning accuracy of RTN method with the use of network corrections of MSPP and VRSNET.pl services. First, an attempt was made to evaluate the daily accuracy of the obtained coordinates by calculating the volumes of the shapes they formed. Basing on this, it was found that higher repeatability of the results occurs for the solutions obtained with use of VRSNET.pl service. This result was confirmed by the analysis of the absolute error (Figures 4 and 5). In case of solutions obtained with use of MSPP corrections, the maximum values of the absolute error for X and Y coordinates were respectively 0.027 and 0.017m, which fit in the range of repeatability of measurements declared by ASG-EUPOS system administrators. As a part of the analyses it was also noted that the value of elevation H measured with use of VRSNET.pl system rapidly changed between the 240th and the 346th measurement. The registered elevation variability was around 0.050m and its cause is hard to determine and is most likely related to a random error of VRSNET.pl system, which was in a test phase during the measurement. The study also compares the values of positioning error of a point of planar coordinates, which were compared in the reports from VRSNET.pl and MSPP measurements with the error values estimated basing on the measurement data. It was found, that in the case of solutions obtained with use of VRSNET.pl in more than half of the cases the estimated positioning error value exceeds the values declared by the service. Moreover, the comparison of the measurement results obtained with the use of VRSNET.pl and MSPP services showed that the computational methods in both of the services have significantly different impacts on the accuracy of the results.

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Aneks nr 1 do umowy o współpracy pomiędzy Województwem Małopolskim a Głównym Geodetą Kraju dotyczącej wykorzystania Małopolskiego Systemu Pozycjonowania Precyzyjnego (MSPP) w ogólnokrajowym systemie ASG-EUPOS z dnia 18 lutego 2016 r.

Rozporządzenie Ministra Administracji i Cyfryzacji z dnia 14 lutego 2012 r. w sprawie osnów geodezyjnych, grawimetrycznych i magnetycznych (Dz.U. 2012 poz. 352)

Ustawa z dnia 5 czerwca 2014 r. o zmianie ustawy – Prawo geodezyjne i kartograficzne oraz ustawy o postępowaniu egzekucyjnym w administracji (Dz.U. 2014 poz. 897) www.asgeupos.pl (23.02.2016 r.)

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