GeoTerrace Conference

EAGE

GeoTerrace-2021-004

Analysis and comparison of static and RTK measurements: case study for GNSS network of the Dnister PSPP

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SUMMARY

The use of GNSS technologies for monitoring man-made structures has allowed to bring to a qualitatively new level the accuracy, reliability and speed of the results. Modern hardware and software systems allow for in-depth analysis of accumulated observations over a long period of time on the one hand and get instant results on the other, using real-time monitoring technologies. As input sensors, these complexes can combine GNSS equipment, electronic total stations, piezometers, inclinometers, meteorological stations, etc. In this work method for determining the spatial vector of the GNSS method in the RTK mode using two simultaneously operating receivers is proposed and tested.

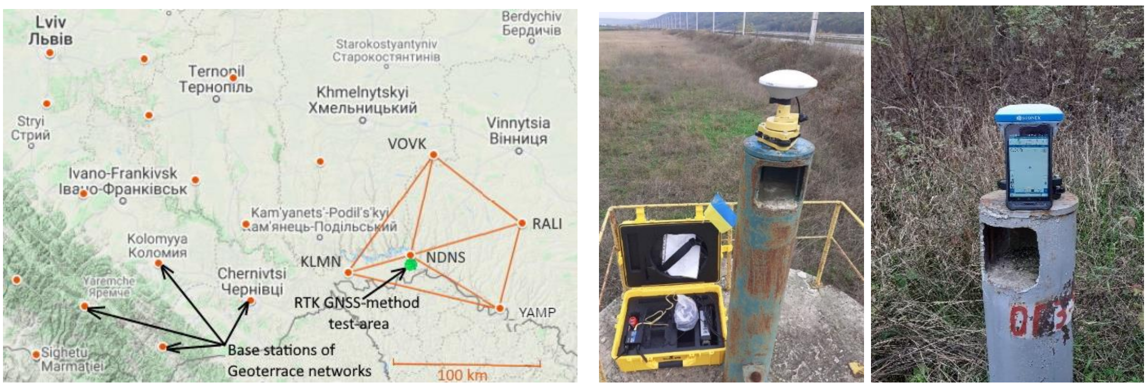
Keywords: GNSS measurements, static mode, RTK mode

Introduction

The method of static observations is the most informative and accurate for determining coordinates. The advantage of the method is a fairly high accuracy of determining the coordinates, and the disadvantage is the duration of observations. Using the RTK mode (differential method), it takes seconds to determine the coordinates, but the accuracy remains in centimeters. In the works (Gumus, 2016, El-Mowafy, 2012, Aykut, 2015, Vivat, 2011) the specified accuracy of RTK mode of determination of coordinates in different countries of the World from national networks is investigated. The operation of network interchanges (VRS) and the operation of CORS - a single physical base station - were analyzed. The RTK method is effective for performing topographic surveying, because you can quickly get a large number of measurement results at many points. However, RTK mode is associated with the use of communication, which is significantly affected by delays in data transmission, which imposes certain restrictions. At present, the general characteristic of the accuracy of coordinate determination in RTK mode from GNSS networks is the ionospheric index i95 and the values of IRIM and GRIM, respectively, the values of which are available from the GNSS network operator. When modeling the conditions of observations using network solutions according to different algorithms (VRS, FKP, iMAX, RTCM3Net, etc.), as well as in the case of a close physical base station, it is reasonable to assume systematic errors in determining the coordinates in RTK mode for a certain local area lines) at a certain point in time. RTK technology has undergone some changes in recent years, which are primarily aimed at improving the reliability of the result and are based on the use of network solutions by different algorithms.

Methods of investigation

Studies of the accuracy of determination of spatial vectors in the RTK mode were performed at the epoch GNSS stations of the GNSS network of the Dnister PSPP (Savchyn & Pronyshyn. 2020). This GNSS network, consists of 49 points, which are located in different conditions of visibility of satellites, rugged terrain and vegetation. The centers of the points are fixed by a metal plate with a hole that provides a centering error within 0.05 mm. At these points, long-term observations of satellite technology in static mode are performed annually. In the cycle of observations, each vector is determined 2–3 times, using 8–10 multifrequency receivers. Thus, about 700 vectors are determined, optimized and balanced. A large number of redundant measurements guarantees the accuracy of determining the centers of the holes of the signs of 1 mm, which is an estimate of the balance of the network. Therefore, the increments and lengths of vectors determined by spatial coordinates can be taken as reference.



a *b* *c*

Figure 1 *The GeoTerrace GNSS network and points of GNSS network of the Dnister PSPP*

To study the proposed method, we performed a network compression of GeoTerrace reference stations by six mobile stations based on Trimble R9s receivers with Trimble TRM105000.10 antennas. Reference stations are equipped with special equipment: stand-alone power supply, GPRS router for data transfer to network servers in real time, stand with stand screw for centering over the point, tape measure to determine the ratio of antenna height, mobile phone to connect to the receiver's web interface and send data to caster. To establish reference stations, Dnister PSPP reference points were used (Fig. 1 b). For each session, reference stations were set to points that together formed different geometric configurations. Separate vectors were measured with respect to these reference stations simultaneously by two rover receivers. The coordinates of the reference stations were determined based on the results of balancing the cycle of the static GNSS network of the Dnister PSPP. In addition, these coordinates were included in the Trimble Pivot Platform software, which allowed you to instantly connect base stations to the general solution with constant monitoring of network integrity. Therefore, the installed base stations were immediately used to provide corrections to rover receivers in RTK mode using VRS technology (network interchange) and as conventional single. The effectiveness of the proposed technique is to quickly monitor (several minutes) the integrity of the network after changing the configuration of reference stations. In addition, the operator remotely monitors the status of the network and its accuracy parameters, which eliminates poor quality measurements. One of the conditions for the study of the accuracy of the determination of spatial vectors in RTK mode is the simultaneous use of two receivers to compensate for random and systematic errors that occur at both rover stations. To do this, the receivers were installed in pairs at the planned points of the GNSS network of the Dnister PSPP with forced centering (Fig. 1c). Measurements were performed in four sessions. Three vectors were identified in the first, second, and third sessions, and five vectors were identified in the fourth session. Each vector was determined four times according to the program given in Table 1. This program is based on the typical options of rover software in terms of the number of measurements (seconds), control initialization, the use of satellite constellations. The program also includes obtaining a solution using VRS technology and from a single station.

Table 1 *The program determines coordinates synchronously with two receivers in RTK mode*

№ Program	Frequency, G	Duration, c	Initialization	The solution RTK	Satellite constellations
1	1	300	1	VRS	GPS, GLO
2	1	30	2	VRS	GPS, GLO
3	1	30	2	Single	GPS, GLO
4	1	30	2	Single	GPS, GLO, GAL, BDU

In total, 56 vectors were identified in pairs by the RTK method, at ten points of forced centering, which form closed figures. Coordinates of rover receivers from simultaneous RTK measurements determined the increments of coordinates and distances between them. These same vectors were determined from static GNSS measurements by a six-hour session. The differences of the vectors defined in RTK and static modes are given in Table 2. Where DXS, DYS, DZS, SS are the parameters of the static vector, DXR, DYR, DZR, SR are the parameters of the RTK vector. Vectors are sorted by length from smallest to largest. The range of vector lengths is from 30 to 2000 m. These differences are one of the criteria for assessing the accuracy of vector determination in RTK mode. The table also shows the standard, absolute error of all vectors and the scale. From table 2 - each element of the spatial vector is determined with different accuracy. No decrease in accuracy from an increase in the distance of the vector was detected. There is a decrease in the accuracy of the vectors that are identified at points with poor visibility of the horizon. The points ogz-4, ogz-5, ozs-1-1 located in the forest have a closed horizon on the south-western side with a slope of up to 60 °. Point 22-g is also closed by a slope of up to 60 ° on the southwest side. There is no correlation with the PDOP parameter with the accuracy of vector determination. By removing the vectors defined at the points with a closed horizon, decreased UPC = 3.0 mm, absolute = 6.2 mm and Scope = 10.1 mm. Table 3 shows the root mean square errors of all RTK vectors determined by different observation programs. The description of the observation program is given above in table 1. In order to establish the efficiency of creating precision combined GNSS networks constructed by static and simultaneous RTK measurements, a posteriori optimization of the whole set of measured static and RTK vectors was performed. The paper (Tretyak, 2003) distinguishes two parameters: μ is the root mean square error of a unit of weight and q is the stiffness of the network. It is investigated that these parameters have almost similar appearance for networks with any number of points and configuration of their location. It is also established that there is a certain relationship between the parameters μ and q, which is determined by the relationship between the accuracy of determining the components of the network and its reliability. In this paper, the total set of vectors is divided into three groups and their boundaries are delineated. In the first group, the parameter μ - decreases rapidly, the parameter q - remains unchanged. In the second group, the parameter μ - slowly decreases, the parameter q - slowly increases. In the third group, the parameter μ decreases slowly, but q increases rapidly. That is, the third group is the minimum number of vectors that cannot be filtered because the stiffness of the network is violated.

Table 2 *Differences of vectors defined simultaneously in RTK and static modes*

Point	Point	DX_R - DX_S, mm	DY_R - DY_S, mm	DZ_R - DZ_S, mm	S_R - S_S, mm
ogz-4	ogz-5	0 .1	4 .7	0 .8	3,5
ogz-5	ozs-1-1	12 .9	18 .7	0 .9	15,1
ogz-4	ozs-1-1	10 .9	10 .1	3 .5	9,8
ozs-5a-2n	portal-n	1 .5	0 .1	2 .9	0,8
ogz-2-1a	bn	8 .3	7 .4	15 .1	3,9
bn	stvr	3 .4	4 .2	11 .5	0,1
ozs-5a-2n	bn	4 .0	2 .7	3 .1	0,3
bn	znak-14	0 .5	9 .6	5 .7	6,2
ogz-2-1a	ozs-5a-2n	1 .0	1 .5	3 .7	2,5
ogz-2-1a	portal-n	11 .8	4 .9	13 .4	0,8
22-g	bn	12 .0	4 .4	3 .6	6,3
bn	22-g	0 .9	11	2 .8	8,7
22-g	stvr	25 .7	0 .3	8 .7	0,9
22-g	znak-14	4 .7	20 .3	5 .5	15,5
MSE		**9,4**	**9 .1**	**7 .5**	**5 .9**
Absolute error		**25,7**	**20 .3**	**15 .1**	**15 .5**
Range		**37,5**	**31 .3**	**26 .6**	**19 .4**

Table 3 *Differences of vectors defined in RTK and static modes*

Vector	Program 1, MSE, mm	Program 2, MSE, mm	Program 3, MSE, mm	Program 4, MSE, mm
DX, mm	9 .4	11 .0	6 .6	8 .6
DY, mm	9 .1	12 .0	4 .9	6 .1
DZ, mm	7 .5	12 .2	8 .4	8 .2
DS, mm	5 .9	10 .4	4 .8	4 .4

We will use this technique to filter the whole set of vectors of the network we study. The total number of vectors at the input is 605; of which 519 are determined by static technology and 86 - RTK. We use the algorithm for filtering (extracting) the vector with the maximum error (after removing such a vector, the network is re-balanced, find the vector with the maximum error and remove. This is continued until there is a minimum number of vectors needed to determine the coordinates of the points (the boundary of the second and third groups). In fig. In Fig. 2 shows a graph of sequential extraction of vectors. Static vectors are shown in red and RTK in green. The boundaries of the three groups, the number of extracted vectors in each group and their percentage are also given. In the first group, 80 vectors were removed: 49 static (61%) and 31 RTK (39%). Statistics show almost the same accuracy of static and RTK vectors of the first group, but their accuracy is low and they seem to distort the network. In the second group, 401 vectors were removed: 353 static (88%) and 48 RTK (12%). Paying attention to the percentage of the total number of vectors (86% - static and 14% - RTK), we can conclude about the almost uniform exclusion of static and RTK vectors. This is an indicator of the high quality of our proposed method. In the third group remained the most accurate 114 vectors, of which 107 (94%) - static and 7 (6%) - RTK. In addition, we compare certain vectors from simultaneous RTK measurements with similar vectors defined from non-simultaneous. Table 4 shows the differences between the vectors determined from non-simultaneous RTK measurements and static. The differences of the vectors and their errors are one third larger compared to table 2, which indicates the removal of a significant part of the errors using two rover receivers and the method of simultaneous determinations.

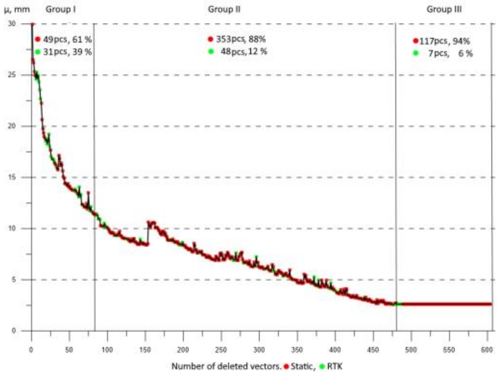


Figure 2 *A posteriori optimization of static and RTK vectors*

Table 4 *Differences of vectors defined by one receiver in RTK mode and static mode*

Point	Point	DX_R - DX_S, mm	DY_R - DY_S, mm	DZ_R - DZ_S, mm	S_R - S_S, mm
ogz-4	ozs-1-1	-19 .7	-20 .9	-3 .5	15,7
ogz-2-1a	bn	-7 .7	-0 .5	0 .1	-5,1
bn	stvr	-11 .2	1 .0	-6 .6	-9,1
ogz-2-1a	portal-n	9 .9	2 .3	8 .6	2,4
22-g	bn	-23 .2	-19 .6	-11 .3	16
22-g	stvr	-34 .4	-18 .6	-17 .9	9,9
MSE		15,2	11 .4	9 .2	10 .6
Absolute error		34,4	20 .9	17 .9	16 .0
Range		44,3	23 .2	26 .5	25 .1

Recommendations and conclusions

A method for determining the spatial vector of the GNSS method in the RTK mode using two simultaneously operating receivers is proposed and tested. The possibility of partial replacement of the determination of GNSS vectors by the RTK mode in high-precision geodetic networks is proved. Studies of the accuracy of determination of spatial vectors by GNSS method in RTK mode in the spatial coordinate system confirm the goal; namely. The root mean square error of the fourteen vectors was 6 mm. Rejection of vectors identified at points with a closed horizon increased the accuracy to 3 mm. A posteriori optimization of the whole set of static and RTK vectors confirmed the high accuracy of the proposed technique and the possibility of partial replacement of static GNSS mode with RTK mode.

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