TESTING THE REPEATABILITY OF RESULTS USING THE GNSS-RTK MEASUREMENT METHOD

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Abstract: *The paper presents the concept of the AGROS network of permanent stations and describes the procedure for implementing the service for real-time kinematic positioning (AGROS-RTK). Experimental research was conducted with the aim of testing the reliability and accuracy of the AGROS network of permanent stations in the RTK mode. Testing was carried out on a polygon of stable geodetic points. Observations were performed once a year for a period of three years. The results analysis shows that there are differences among the epochs and that the possible causes need to be further examined.*

Keywords: *Network of permanent stations, AGROS, RTK, GPS, GNSS, quality control.*

1. INTRODUCTION

The network of permanent stations CORS (Continuously Operating Reference Stations is a set of properly distributed GNSS receivers, operating within a single system, continuously for 24 hours a day. The main task of the system is to enable precise positioning using one GNSS receiver. Reference stations are linked to the control centre that controls their work and distributes the necessary data. Networks are most often formed at the national or regional levels and represent the reference framework of the system present in the area [6].

The network of permanent GNSS stations, officially in use on the territory of the Republic of Serbia, is called the Active Geodetic Reference Network of Serbia (AGROS) and is owned by the Republic Geodetic Authority. It is comprised of 30

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operating GNSS receivers properly distributed on the territory of the country with an average distance of about 70 km [4]. The AGROS User Centre offers several services to its users, the most commonly used being corrections for real-time kinematic positioning (AGROS-RTK). Within the AGROS-RTK service, it is possible to carry out all geodetic measurements for the purpose of geodetic surveying, as well as for various engineering projects.

The prescribed accuracy allowed by the AGROS system can be achieved only if the prescribed procedure is followed during measurement, and it is therefore of utmost importance to comply with all the measurement instructions. Regarding monitoring accuracy and reliability of the results obtained by using the AGROS-RTK service, there are no established parameters that can efficiently monitor the declared accuracy at any time and place.

2. RESEARCH OBJECTIVE AND METHODS

The aim of the research is to perform quality control of the GNSS measurement results within the AGROS-RTK, using the methodology for setting up the geodetic basis. One of the ways to control quality is to do the measurements on a stable and reliable polygon in several time epochs.

The measurements for setting up the geodetic basis are carried out according to the Professional Guidelines of the Republic Geodetic Authority [5]. All the calculations and tests for quality control purposes should be performed on the WGS84 ellipsoid, and in the reference framework of the AGROS network (ETRF2000), in the Cartesian orthogonal coordinates. The emphasis is placed on the control of the achieved results of the direct measurements, and accordingly, it is not necessary to make transformations in the plane of the state projection.

Quality control of the obtained results is done by comparing several measurement epochs. The measurement plan envisages that, for duration of 30 seconds, with a 1 second interval of observation, the final coordinates for each point are obtained from each epoch.

The estimation of coordinates for each measurement epoch is made according to the formulas [1]:

$$(X_i, \mathrm{Y}_i, \mathrm{Z}_i) = \frac{1}{n}\sum_{j=1}^{n}(X_j, \mathrm{Y}_j, \mathrm{Z}_j) \tag{1}$$

where:

X_i, Y_i, Z_i - mean value of the epoch coordinate,
i - ordinal number of the measurement epoch,
j - ordinal number of repetitions in one epoch,
n - total number of repetitions in one epoch.

The measured value error for each repetition within one measurement epoch is obtained from the instrument. The mean value error of definite coordinates in a single measurement epoch is obtained by the expression [1]:

$$\sigma_{(X_i,Y_i,Z_i)} = \frac{\sum_{j=1}^{n} \sigma_{(X_j,Y_j,Z_j)}}{\sqrt{n}} \tag{2}$$

where:

$\sigma_{(X_i,Y_i,Z_i)}$ - standard deviation of definitive coordinates of the measurement epoch,

i - ordinal number of the measurement epoch,

j - ordinal number of repetitions in one epoch,

n - total number of repetitions in one epoch.

The importance of deviation of coordinates can be determined by a statistical test of the equality of two values with known standards. The test is conducted with a probability of 95%, assuming that the measurements have a normal distribution [1]:

$$T = \frac{\left|(X_g, Y_g, Z_g) - (X_r, Y_r, Z_r)\right|}{\sqrt{\sigma^2_{(X_g,Y_g,Z_g)} + \sigma^2_{(X_r,Y_r,Z_r)}}} \sim N[0,1] \tag{3}$$

Decision is made based on the hypothesis:

$N_o : \left|(X_g, Y_g, Z_g) - (X_r, Y_r, Z_r)\right| < G$ - Statistically, the coordinates <u>are</u> matched in two measurement epochs (TRUE).

$N_o : \left|(X_g, Y_g, Z_g) - (X_r, Y_r, Z_r)\right| > G$ - Statistically, the coordinates <u>are not</u> matched in two measurement epochs (FALSE).

where:

$G = q_{95\%} \cdot \sqrt{\sigma^2_{(X_g,Y_g,Z_g)} + \sigma^2_{(X_r,Y_r,Z_r)}}$ - Limit value of test statistics;

$q_{95\%}$ - quantile of normal distribution for the probability of 95%,

g, r - ordinal numbers of the measurement epochs that are being tested.

3. EXPERIMENT AND RESULTS

3.1. Description of the experiment and the measurements

The polygon where the experiment was carried out is located on the territory of the cadastral municipality of Čajetina (CM Čajetina) located on the mountain of Zlatibor. For the purpose of the experiment, all the necessary data of relevance were available. The basic satellite images were downloaded from public Internet portals [7] showing the position of points and the area of research (Figure 1).

The measurements were conducted using the GNSS (GPS) technology. The real-time kinematic positioning method (RTK) was used. The active geodetic reference network of the Republic of Serbia (AGROS network) was used as the basis.

Figure 1: The polygon of the experiment

For the research purposes, the GPS instrument Trimble 5700 was used. It is a universal dual-frequency (L1, L2) GPS receiver, of the geodetic type, which has 24 channels. The instrument supports only the satellites from the GPS – NAVSTAR constellation. The equipment has all the necessary characteristics to be used within the network of permanent stations (AGROS). The instrument has the stated positioning accuracy of 5 mm + 0.5 ppm in the static mode, and 10 mm + 1 ppm in the kinematic mode. The Trimble Zephyr antenna was used during the experiment.
Within the three years of the experiment (epochs: 2013, 2014 and 2015) one measurement was performed each year, according to the Professional Guidelines for using the AGROS network, in three permanently stabilised geodetic points. In each epoch, the measurements were carried out in June, the day and time of measurement were chosen randomly, without previous planning. In line with the instructions for the implementation of the Active Geodetic Reference Network, within one epoch, the measurements were carried out in three repetitions within a period of 30 seconds with the registration interval set to 1 second.
The aim of the experiment was primarily focused on simulating the activity of an average user of the network of permanent stations that uses the AGROS-RTK method for setting up the basic geodetic network.

3.2. Results

The estimation of definite coordinates was made for each measurement epoch separately. The calculations were made in the Cartesian orthogonal coordinates on the WGS84 ellipsoid and in the reference framework of the AGROS network (ETRF2000).

The results of the definite coordinates are shown in Table 1.

Table 1 Definite coordinates in all the epochs

Epoch	Point	X [m]	Y [m]	Z [m]	σ_p [m]	σ_h [m]	PDOP
2013	T1	4347626.252	1556778.117	4386208.724	0.014	0.026	2.0
	T2	4347102.992	1556815.140	4386683.407	0.014	0.020	2.3
	T80	4347611.453	1556146.027	4386433.581	0.013	0.023	1.7
2014	T1	4347626.300	1556778.121	4386208.707	0.020	0.028	1.3
	T2	4347102.996	1556815.191	4386683.435	0.020	0.030	1.6
	T80	4347611.456	1556146.039	4386433.514	0.019	0.029	1.5
2015	T1	4347626.300	1556778.101	4386208.749	0.013	0.024	1.1
	T2	4347102.990	1556815.179	4386683.466	0.013	0.023	2.5
	T80	4347611.475	1556146.045	4386433.595	0.010	0.018	1.9

Differences of definite coordinates among the epochs are presented in the graph in Figure 2.

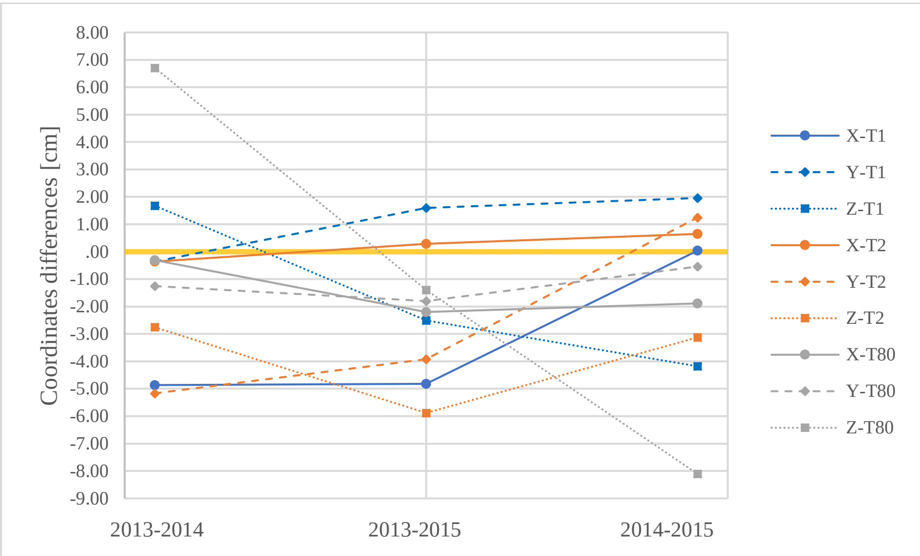

Figure 2: Graph of the coordinates differences among the epochs

3.3. Testing the point coordinates' matching

Statistical testing of the definite coordinates' matching among the measurement epochs was performed. The statistical test on the equality of two values with known standards was applied to the results at each measuring point, along all three coordinates. The test was carried out with a probability of 95%, assuming that the measurements had a normal distribution.

The results of testing the coordinates' differences are shown in Table 2.

Table 2 Results of testing the coordinates' equality

Point	$\|X_g-X_r\|$ [cm]	G_X	Decision testing	$\|Y_g-Y_r\|$ [cm]	G_Y	Decision testing	$\|Z_g-Z_r\|$ [cm]	G_Z	Decision testing
T1 (2013-2014)	4.87	5.07	TRUE	0.36	5.07	TRUE	1.68	6.30	TRUE
T1 (2013-2015)	0.36	4.26	TRUE	5.17	4.26	**FALSE**	2.76	5.90	TRUE
T1 (2014-2015)	0.31	4.18	TRUE	1.26	4.18	TRUE	6.71	6.13	**FALSE**
T2 (2013-2014)	4.82	3.08	**FALSE**	1.60	3.08	TRUE	2.50	5.76	TRUE
T2 (2013-2015)	0.29	3.09	TRUE	3.92	3.09	**FALSE**	5.88	5.00	**FALSE**
T2 (2014-2015)	2.20	2.63	TRUE	1.80	2.63	TRUE	1.40	4.74	TRUE
T80 (2013-2014)	0.04	5.01	TRUE	1.96	5.01	TRUE	4.18	6.03	TRUE
T80 (2013-2015)	0.65	4.18	TRUE	1.25	4.18	TRUE	3.13	6.19	TRUE
T80 (2014-2015)	1.89	3.95	TRUE	0.54	3.95	TRUE	8.11	5.64	**FALSE**

Decision testing in Table 2 has the following meaning:

'TRUE' – statistically, in two tested epochs, the coordinates can be considered equal,

'FALSE' – statistically, in two tested epochs, the coordinates CANNOT be considered equal.

4. DISCUSSION AND CONCLUSION

Measurements for this research were carried out in three epochs with a time interval of one year. In each epoch, permanently stabilised points were observed, which were stable and invariant from other influences during the realisation of the experiment. The measurements were conducted according to the Professional Guidelines instructed by the Republic Geodetic Authority, which stipulate the proper use of the active geodetic basis of the Republic of Serbia. In all the measurement epochs, the same GNSS receiver was used, with a valid calibration certificate.

Upon processing the measurement results and calculating definite coordinates for each measurement epoch, the coordinate differences among the epochs were calculated, in all the combinations. The differences are shown in Figure 3. Table 3 shows the range of the values of definite coordinates of the points in all the epochs.

By analysing the results from Table 3 and taking into account the accuracy of measurements, it was established that the coordinates among the epochs differ significantly. Statistical testing of equality of coordinates with known standards was carried out in all the combinations of the epochs. The testing results are presented in Table 2. Based on the obtained results it can be concluded that none of the geodetic points coordinates are matching in all the epochs of observation.

Table 3 Difference range along the axes

Point	X_{max}-X_{min} [cm]	Y_{max}-Y_{min} [cm]	Z_{max}-Z_{min} [cm]
T1	4.9	2.0	4.2
T2	0.7	5.2	5.9
T80	2.2	1.8	8.1

The reasons for significant differences in the coordinates cannot be accurately determined on the basis of such an experiment. It is evident that all the effects that come from users and equipment are reduced to a minimum by using adequate and calibrated equipment, as well as by strict adherence to the Professional Guidelines for using the AGROS network. Further analysis of the causes could be directed to the quality of corrections distributed by the AGROS network or the quality of the data obtained from the satellite. Certainly, this could be the subject of some further research.

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