OPTIONS FOR TESTING KINEMATIC GPS MEASUREMENTS IN TERMS OF ACCURACY

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Abstract

Accuracy of GPS kinematic measurements is analysed. Several GPS apparatus were tested in the geodetic network stabilized in the Central Slovak Region. GPS measurements were complemented by 2D terrestrial measurements using total stations. Possibilities of using the tested GPS apparatus and selected kinematic GPS methods were considered for their application for a purpose of real estate register, geological survey and GIS applications.

Keywords: GPS, kinematic methods, accuracy, testing

Introduction

The testing kinematic GPS (Global Positioning System) measurements in determining the 2D (two-dimensional) positions of surveying points and assessment of these satellite navigation surveying technologies in terms of their accuracy is of some importance especially for cadastral and geological mapping and GIS applications (Hofierka, 2003, 2012; Kanuk, 2009; Kanuk et al., 2013; Kavan & Krocova, 2013; Kriha, 2011, Nemcova & Sedlak, 2006; Pana, 2012; Sedlak, 2000, 2005, 2013; Sedlak et al., 2002, 2005, 2007; Stankova & Cernota, 2010; Svatos, 2012). For the testing of a series of GPS kinematic methods, contributions were chosen method STOP and GO. This method belongs to the group of so-called semi-kinematic GPS methods, which means that it is in associating the kinematic and static methods. Satellite navigation measurements were carried out by selected GPS apparatus ProMark2 (Ashtech)[1], which in terms of application of kinematic GPS methods seem appropriate, because its handling is simple and operational. GPS measurements were supplemented by the position (2D) terrestrial measurements in which were used electronic utter station Nikon 352. Verification and testing measurements were made at points of the

[1] Ashtech Company product

geodetic network - the test station in the village of Badin[2] (*Fig.1*). Devices (all measuring equipment - apparatus and related software) were lent by the company Ornth ltd. Banska Bystrica (Nemcova & Sedlak, 2006; Sedlak et al., 2007; Sedlak, 2013).

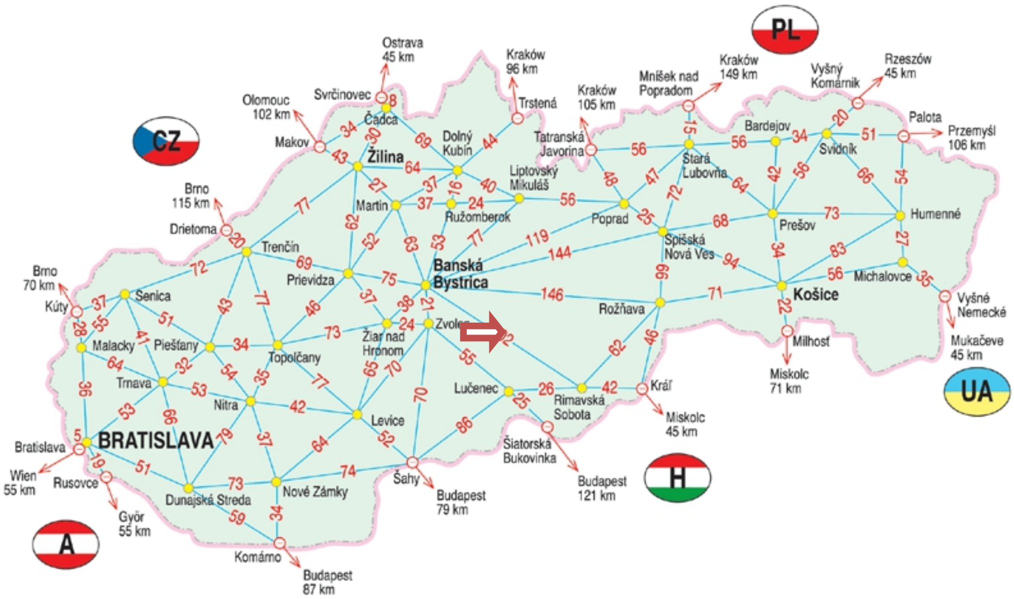

Fig.1: Map of the Slovak Republic. The arrow locates the village of Badin.

Field measurements and processing of measurements

One of the conditions for successful measurement by GPS technology is measurement outside the densely built-up areas and outside vegetation. Our measurements were made in the area of Badin village in Banska Bystrica region. This site is characterized by just such a suitable environment. The geodetic network - the test station in the village of Badin consists of four points No. 5001 to No. 5004, on which it is measured by the static GPS measurements (the benchmarks - base) and fifteen points No. 1 to No. 15 (the object points), which are focused by the kinematic GPS method. The geodetic network - the test station in the village of Badin is used to testing GPS apparatus and also other surveying instruments for terrestrial measurements. The owner of the test station is the private geodetic company Ornth ltd. Banska Bystrica, while the service of this station also uses several private geodetic companies in the region of Banska Bystrica. The GPS and terrestrial testing and verification measurements were performed on the 11th of September, 2013. On this day the sky was clear without any obstructions,

[2] Badin is a typical Slovak village between the towns Banska Bystrica and Zvolen in the central Slovakia.

thus the additional condition for successful GPS measurements has been met (i.e. so-called "clean" reception of signals from the GPS satellites).

During the measurement, the value of PDOP (Positional Dilution Of Precision) was ranging from 1.1 to 2.4, which is a very good indicator (*Fig.2*). The values of PDOP up to 3.0 are considered for excellent. If the values of PDOP are over 4.0, the quality of GPS measurements is greatly reduced.

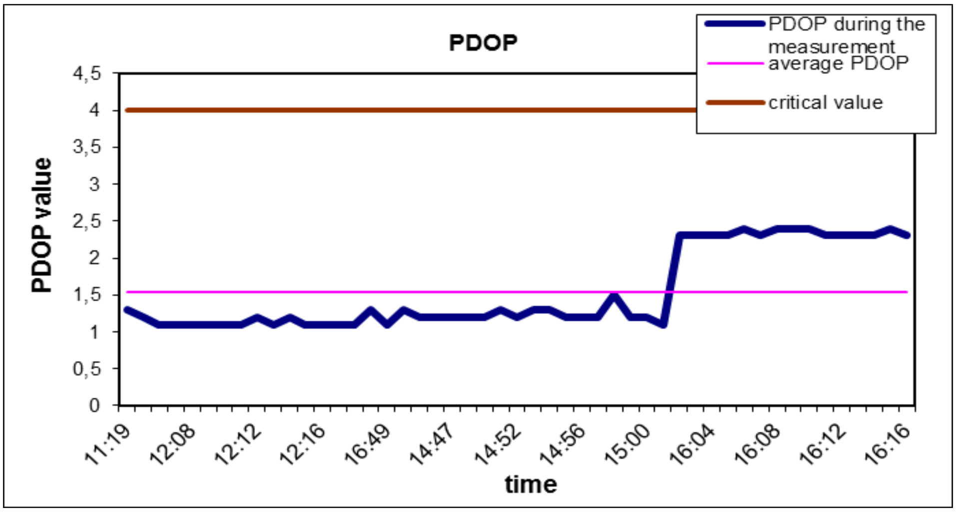

Fig.2: PDOP value during measurement (11.09.2013).

During GPS measurements were also fulfilled the condition of necessity reception of satellite signals from at least four satellites by the GPS receiver. Number of satellites from which to receive signals during our measurements was between 7 to10 (*Fig.3*).

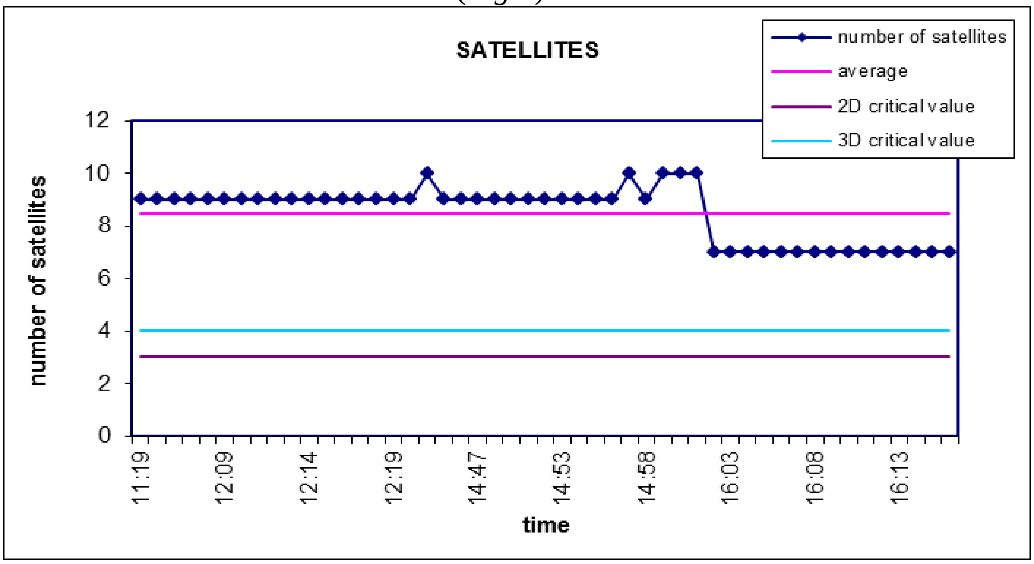

Fig.3: Number of satellites during GPS measurement (11.09.2013).

The antenna of one apparatus ProMark2 (PM 20304709) (*Fig.4*) during the first period of the GPS measurements was on the point No. 5001. This antenna was the first base. Another antenna of the second apparatus ProMark2 (PM 20304710) was on the point No. 5002 - i.e. the second base. Both apparatus operated under the static GPS mode measurements. The data collection time was about 40 minutes. After this time the antenna of ProMark2 (PM 20304710) apparatus was carefully moved from the tripod to the measuring rod and the kinematic GPS measurements were realized. The positions of all fifteen points (the object points No. 1 to No. 15) were measured using the apparatus ProMark2 (PM 20304710) by the kinematic GPS method STOP and GO. Measurement at each point (No. 1-15) took 30 seconds. A reception of signals from the satellites was not allowed during displacement between the points. Therefore it was necessary for the movement to hold a pole with the antenna precisely perpendicular to the ground. By this measurement the first period was ended. The procedure of this measurement was repeated twice (2^{nd} and 3^{rd} period of measurements). The antenna of ProMark2 (PM 20304709) apparatus remained on the point No. 5001 and the antenna of ProMark2 (PM 20304710) apparatus was moved gradually over the points No. 5003 and No. 5004. The pair of such GPS measurements, i.e. the static GPS measuring method on the object points No 5003 - 3^{rd} base and No. 5004 – 4^{th} base and the kinematic GPS measuring method on the object points (the points No. 1 to No. 15) was again realized.

Fig.4: ProMark2 (Ashtech).

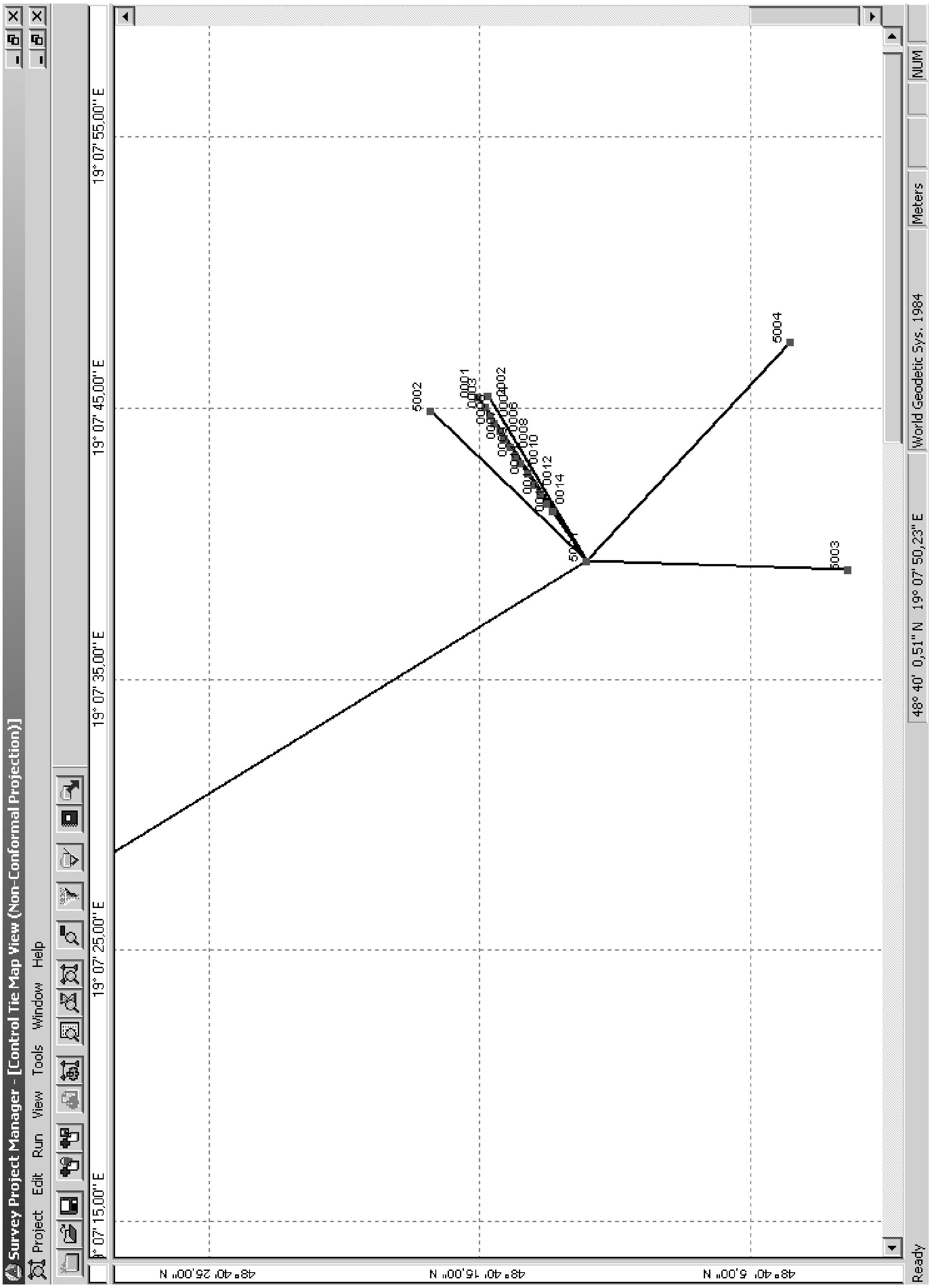

Fig.5: 2D position of the object points in WGS-8; (The test station in the village of Badin).

2D coordinates of the determined points of the geodetic network – the test station in the village of Badin expressed in WGS-84 (World Geodetic System 1984) were the results of GPS measurements. These coordinates were transformed into the Slovak national binding 2D coordinate system S-UTCN (System of the Uniform Trigonometric Cadastral Network,)[3] (Nemcova & Sedlak, 2006; Sedlak, 2000, 2005, 2013; Sedlak et al., 2002, 2005, 2007; Stankova & Cernota, 2010). The software "KROVAK" was used to transformation. 2D position of the object points in WGS-84 of the geodetic network – Badin test station is shown in *Fig.5* (Nemcova & Sedlak, 2006; Sedlak et al., 2007).

Finally, the GPS measurements were made connecting measurement on three identical (homologous) points under the name FLOS - No. 59140030, 59080300, 59080710, 59150110, as specified in the databank Ornth Company, ltd. Banska Bystrica. The homologous points are the points whose coordinates are in S-UTCN also in WGS-84. The connecting measurement was made using a static GPS method, while the apparatus ProMark2 (PM 20304709) was on the point No. 5001, i.e. the base point and the apparatus ProMark2 (PM 20304710) was replaced on the connecting homologous points.

In order to compare the accuracy in determining the 2D coordinates of the object points (No. 1 to No. 15), which were achieved from the realized GPS measurements, the conventional terrestrial measurements (polar method) were more performed using the total geodetic electronic station Nicon 352 (*Fig.6*).

Fig.6: Total geodetic electronic station Nicon 352.

[3]S-UTCN is the State Trigonometric Network of the Slovak Republic.

The opinion was on the base point No. 5001. The next base points No. 5002 to No. 5004 as well as the object points (No. 1 to No. 15) were measured by means of using a polar method. Measurement by the total geodetic electronic station Nikon 352 was carried out three times. From these terrestrial measurements were calculated coordinates of all targeted points in S-UTCN using software "GEUS" (Nemcova & Sedlak, 2006; Sedlak et al., 2007).

Evaluation of the testing measurement results

The calculated 2D coordinate differences Δ_{XY} incurred by determination of 2D points positions at two measurement methods (the GPS method - STOP and GO and the terrestrial polar method) were evaluated according to the Guidance of the Geodesy, Cartography and Cadastre Authority of the Slovak Republic No. KO-4108/2003 of the 4th of November, 2003[4] (Guidance, 2003).

Currently, SSN (State Spatial Network) of the Slovak Republic representing the binding coordinate system WGS-84 is not yet completed on whole territory of the Slovak Republic. 3D (three-dimensional) Cartesian coordinates: *X*, *Y*, *Z*, respectively, the polar (also geodetic or ellipsoidal) coordinates respectively (geodetic latitude *B*, geodetic longitude *L*, geodetic height *H*), based on a measurement by GPS method, shall be submitted in WGS-84. As the identical points are preferably used SSN points and then points of the State Trigonometric Network (S-UTCN). After validation of WGS-84 by the points of SSN the coordinates *X*, *Y*, *Z*, (*B*, *L*, *H*, respectively) will be handed in WGS-84.

For a vector of corrections, the following criteria of accuracy are valid: The absolute value of the correction position, i.e. value of the horizontal (2D) error (coordinate differences) Δ_{XY} must be less than 3 times the mean error of the connecting point (*Tab.1*). If the absolute value of the position correction exceeds 3 times the mean error, but it is less than 5 times this mean error, it is also possible to that point to reduce a weight and thereby weaken its effect on the resulting transformation key. If the absolute value of the correction position exceeds the critical value of 5 times the mean error, this point is excluded from the calculation and that point is replaced by another point so that the key transformation could be calculated from at least three convenient identical points.

[4] If the results of measurements are taken into the Real Estate Register of the Slovak Republic, this Guideline sets out the terms and the accuracy of measurements using Global Positioning System (GPS method).

Tab.1: Accuracy of positional measurement for the Real Estate Register requirements.
Legend: SSN: State Spatial Network; 1st – 5th order: degrees of accuracy in SSN;
[m]: values in meters.

Order of SSN	3 times the mean error [m]	5 times the mean error [m]
1st order	0.04	0.2
2nd order	0.035	0.175
3rd order	0.03	0.15
4th order	0.025	0.125
5th order	0.02	0.1

Based on the relationship: $\Delta_{XY}=(dB^2+dL^2)^{1/2}$[5], respectively, $\Delta_{XY}=(dx^2+dy^2)^{1/2}$, the differences in position (2D) coordinates Δ_{XY} could be determined by means of using the kinematic GPS measurement method (STOP and GO) and terrestrial measurement by means of the total station. The differences are listed in *Tab.2*. The values of the position (2D) coordinate differences Δ_{XY} emerged between the individual kinematic GPS measurements with each other are listed in *Tab.3*.

Tab.2: 2D Cartesian coordinate difference values Δ_{XY} between GPS kinematics measurement (KIN) and terrestrial measurement (TS).
Legend: KIN1-TS1, KIN2-TS2 and KIN3-TS3: 2D Cartesian coordinate difference values between 2D Cartesian coordinate difference values from GPS kinematic (KIN) and terrestrial (TS) measurements in 1st, 2nd and 3rd measurement period; KINA-TSA: 2D Cartesian coordinate difference values between the average 2D Cartesian coordinate difference values from GPS kinematic (KIN) and terrestrial (TSA) measurements from all (1st, 2nd and 3rd) measurement periods; [m]: values in meters.

Point No.	Δ_{XY} [m]			
	KIN1-TS1	**KIN2-TS2**	**KIN3-TS3**	**KINA-TSA**
1	0.041	0.009	0.026	0.025
2	0.035	0.018	0.025	0.024
3	0.022	0.019	0.022	0.018
4	0.033	0.015	0.023	0.023
5	0.03	0.007	0.027	0.019
6	0.025	0.014	0.022	0.017
7	0.031	0.006	0.026	0.017
8	0.009	0.008	0.02	0.003
9	0.013	0.021	0.015	0.007
10	0.021	0.028	0.016	0.01
11	0.018	0.010	0.018	0.01
12	0.024	0.002	0.011	0.012
13	0.019	0.009	0.015	0.01
14	0.015	0.004	0.017	0.011
15	0.01	0.012	0.017	0.012

[5] The geodetic coordinates *B* and *L* must be transformed into the Cartesian coordinates *X* and *Y*.

Tab.3: 2D Cartesian coordinate difference values Δ_{XY} between GPS kinematic measurements (KIN).

Legend: KIN1-KINA, KIN2-KINA, KIN3-KINA: 2D Cartesian coordinate difference values between 2D Cartesian coordinate difference values from the individual GPS kinematic measurements (KIN) in 1st, 2nd and 3rd measurement period and the average 2D Cartesian coordinate difference values from GPS kinematic measurements (KINA) obtained from all (1st, 2nd and 3rd) measurement periods; [m]: values in meters.

Point No.	**Δ_{XY} [m]**		
	KIN1-TSA	**KIN2-TSA**	**KIN3-TSA**
1	0.004	0.003	0.007
2	0.007	0.006	0.004
3	0.004	0.003	0.003
4	0.008	0.007	0.001
5	0.01	0.013	0.007
6	0.012	0.011	0.007
7	0.013	0.018	0.007
8	0.009	0.010	0.015
9	0.013	0.019	0.008
10	0.014	0.019	0.006
11	0.006	0.009	0.003
12	0.007	0.009	0.002
13	0.009	0.011	0.001
14	0.006	0.009	0.004
15	0.003	0.003	0.002

According to the results Δ_{XY} (*Tab.2* and *Tab.3*) and standard error (*Tab.1*) it can be concluded that the presented tested kinematic GPS measurement methods met the required criteria on an accuracy of the position measurement (Directives, 2000; Guidance, 2003).

Conclusion

The issues presented focused mainly on the position (2D) coordinates determination by means of using GPS technologies and testing their accuracy were presented in this paper. The goals of this contribution, i.e. verify the accuracy of kinematic GPS measurements using the GPS device ProMark2 were achieved. GPS measurements were realized by semi kinematic STOP and GO method and the results of this measurement, i.e. the coordinates WGS-84 transformed into S-UTCN, were compared with the results of terrestrial measurements using the total station Nikon 352. Measurements are carried out in a suitable location, which is the geodetic network – the test station in the village of Badin close to Banska Bystrica. Measurements were carried out under favourable weather conditions, and also very good value

PDOP throughout the measurement period, testified about the quality of the measured data.

Detected differences in the heights are less satisfactory, what is persistent problem in all GPS measurements. To pinpoint the Z-coordinates using GPS technology, it is necessary to perform certain actions, e.g. to establish a local geoid, or to perform levelling measurements, or to use the appropriate software. The height error will appear in the position of the point only slightly (100 m error of causes the error in the position a few millimetres), therefore the position measurement not negatively affected. Whereas in the real estate registration or GIS applications, respectively in the geological mapping, the height coordinate is not priority (dominant), this issue did not be yet dealt and may and it can be the content for further scientific research in testing GPS technologies.

Within the application of satellite navigation methods in determining the coordinates of points of geodetic networks the satellite navigation system NAVSTAR GPS is greatly applied in more and more widely in the field of the real estate register, geological mapping, GIS applications, etc. (Hofierka, 2003, 2012; Kanuk, 2009; Kanuk et al., 2013). Primary a benefit of measurements with GPS technology is mainly in operational and accuracy not only made observables, but also operability processing GPS data.

Based on the obtained results it can be concluded that kinematic GPS measurement method fulfilled the requirements for positional accuracy of GPS measurements. Individual results of accuracy, especially for positional coordinates, are acceptable for various applications in geodetic practice, such as cadastral and geological mapping and GIS applications.

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