QUALITY CHECK OF VERTICAL COMPONENT USING GPS RTK METHOD AND LASER SYSTEM

PREVERJANJE KAKOVOSTI VERTIKALNE KOMPONENTE Z UPORABO METODE GPS RTK IN LASERSKIM SISTEMOM

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ABSTRACT

For the most common geodetic tasks such as surveying, staking out and monitoring, GNSS RTK method has in many cases been limited by its measuring quality. Combining laser system with GNSS RTK system enables the increase of vertical accuracy of measurement to a millimetre level. Testing the above mentioned systems for height determination will be presented in this paper. Since December 2008 CROatian POsitioning System (CROPOS) has been operational. GPS RTK system combined with laser system has been tested with CROPOS service, because more and more users are using this system in every day geodetic tasks. Testing the vertical accuracy of measuring modes has been done on the calibration baseline of the Faculty of Geodesy in Zagreb. Heights were determined by four different measuring modes; GPS RTK method in combination with laser system, GPS RTK method in combination with laser system linked with CROPOS service (VPPS – Very Precise Positioning Service), GPS RTK method and GPS RTK method linked with CROPOS service (VPPS). The authors of the paper will try to examine whether it is possible to achieve higher accuracy of vertical component when GPS RTK system is combined with laser system. Finally, the advantages, possible disadvantages, and vertical quality comparison of all measuring modes will be shown in this paper

KEY WORDS

GNSS RTK method, laser system, vertical accuracy, CROPOS

IZVLEČEK

Največja omejitev pri uporabi metode izmere GNNS RTK za običajne geodetske naloge je merska kakovost. V kombinaciji z laserskim sistemom lahko povečamo natančnost določitve višinske komponente metode GNSS RTK na milimetrsko raven. V prispevku je opisano testiranje kombinacije laserskega sistema z opremo GNSS RTK za določitev višin. Testne meritve smo izvedli na kalibracijski bazi Geodetske fakultete v Zagrebu. Višine smo določali na štiri načine: s samostojno metodo GPS RTK v kombinaciji z laserskim sistemom, z metodo GPS RTK s podatki servisa CROPOS v kombinaciji z laserskim sistemom ter z obema metodama GPS RTK (samostojno in s podatki servisa CROPOS) brez uporabe laserskega sistema. Podani so rezultati primerjave vseh metod ter njihove prednosti in slabosti za določitev višinske komponente.

KLJUČNE BESEDE

GNSS RTK, laserski sistem, vertikalna natančnost, CROPOS

1 INTRODUCTION

Modern rapid development of science and technology is affecting also the geodetic profession. The development is affecting measuring equipment as well as the methods of collecting, processing and managing the data. Under the influence of development the demands of users are also increasing. The quality of requested data must meet the highest expectations. The most important part of measuring information, apart from the measurement result, is the quality of that result. The quality of data is the basic characteristic according to which users pick them up for their needs.

The usage of GNSS RTK method for surveying, staking out and monitoring was in many cases limited by system accuracy, especially in vertical component. The highest achievable accuracy is in centimetre level. Classical height determination methods allow the highest accuracy. By using trigonometric levelling method (using electronic tacheometer), it is possible to achieve subcentimetre accuracy, and differential levelling method (using level with parallel plate micrometer) enables the achievement of submillimetre accuracy. The Topcon manufacturer claims that combining LazerZoneTM system with GNSS RTK HiPer Pro system provides the increase of the accuracy of height determination from centimetre to millimetre level. By increasing the vertical accuracy of GNSS RTK measurements, the usage of GNSS RTK method in every day geodetic tasks could be expanded. The authors of this paper have tried to examine whether is it possible to increase vertical accuracy of standard GNSS RTK system by combining it with laser systems.

The testing of measuring methods has been done at the calibration baseline of Faculty of Geodesy in Zagreb. The first eight pillars of the calibration baseline, stabilized at the distances from 0 to 300 meters were used. The distance of 300 meters was defined due to a working range of LazerZoneTM system. The heights of the baseline pillars were determined by four different measuring RTK modes. Measuring interval in all tests was set to 30 seconds with 1 second sampling rate. The height of each pillar was measured using 30 registrations. The results of height comparison, analysis of vertical accuracy and precision of measuring methods are presented in this paper. The statistical tests were used to examine whether there are significant differences between achieved precision of tested measuring modes.

2 HEIGHT DETERMINATION USING GPS RTK METHOD AND LASER SYSTEM

New technology called Topcon *LazerZone*^{TM} allows height determination and staking out height differences with millimetre accuracy according to the manufacturer (URL 1). System can only be used in combination with Topcon GNSS RTK HiPer Pro systems. That integrated system comprises of GNSS RTK system and LazerZone^{TM} system. LazerZone^{TM} system comprises of laser transmitter PZL-1 (Positioning Zone Laser) and laser sensor PZS-1 (Positioning Zone Sensor for mobile rover applications).

2.1 GNSS RTK Hiper Pro system

Topcon GNSS RTK HiPer Pro system was one of the first systems which allowed the simultaneous usage of NAVSTAR GPS satellites and GLONASS satellites. GPS plus GLONASS systems allow the usage of 31 NAVSTAR GPS satellites and 22 GLONASS satellite (20. 03. 2011, URL 6), centimetre accuracy in RTK mode of measuring, and better satellite coverage of Earth within 24 hours. More satellites mean higher accuracy, more places to work at, and shorter time used for the first fix (initialization), (for new receivers it is about 15 s).

The accuracy of Hiper Pro RTK system is 10 mm + 1 ppm in horizontal plane and 15 mm + 1 ppm in vertical plane (Topcon, 2006). Other technical characteristics and specifications of the Hiper Pro system can be found on Topcon (2006) and URL 3. The components of the GNSS RTK system are shown on Fig. 1

Fig. 1: GNSS RTK HiPer Pro system.

LazerZone™ system combined with GNSS RTK HiPer Pro system will be shown in the following chapter.

2.2 Topcon LazerZone™ system

The parts of the Topcon LazerZone™ system are PZL-1 transmitter (Fig. 2a) and PZS-1 sensor (Fig. 2b). The system operates in the following manner. GNSS reference receiver (i.e. base receiver) is placed on the known point (Croatian Terrestrial Reference System/Transverse Mercator – HTRS/TM and normal-orthometric heights) and transmits differential corrections by radio or GSM connection to GNSS rover receiver under which PZS-1 laser sensor is placed (Fig. 2b). PZS-1 laser sensor is connected by RS-232C connection with GNSS rover receiver. PZS-1 laser sensor receives laser signal from PZL-1 laser transmitter which is also placed on the known point (the point with known normal-orthometric height – using Croatian Reference Geoid – HRG2009; Bašić, 2009). Through the controller of GNSS RTK HiPer Pro system, all components are connected and coordinated. PZS-1 laser sensor detects laser beam from PZL-1 laser transmitter and immediately calculates the height difference with the accuracy of 2.5 mm/50 m. Height differences are calculated by system controller in real time with millimetre accuracy with regard to laser transmitter. PZL-1 laser transmitter is not a regular horizontal or graded plane laser that transmits a narrow beam in horizontal or tilted plane, instead it transmits a "wide beam" laser signal with the width of 10 meters in radius of 300 meters. This way, PZS-1 laser sensor calculates the height differences with regard to PZL-1 laser transmitter. Technical characteristics and specifications of the LazerZone™ system can be found on URL-1.

Fig. 2: (a) PZL-1 laser transmitter and (b) PZS-1 sensor connected to GNSS rover receiver.

An unlimited number of GPS receivers in RTK measuring method can operate within the range of one transmitter simultaneously. One laser sensor can distinguish signals from four different transmitters, enabling the coverage of the working area of almost 2.4 km (transmitter has the working radius of 300 m, e.g. diameter of 600 m, so four transmitters cover the working area of 2.4 km), and the vertical working area of around 40 m (transmitter transmits a laser signal in the range of 10 m in vertical plane, so four transmitters cover 40 m) (Fig. 3). The laser sensor that is fixed under the rover receiver of GNSS RTK HiPer Pro system, can move within the working range of one laser transmitter to the other, without any additional interventions (new initialization) by the user. In the moment when the sensor detects laser signal from laser transmitter, the height is determined from GNSS and laser measurements.

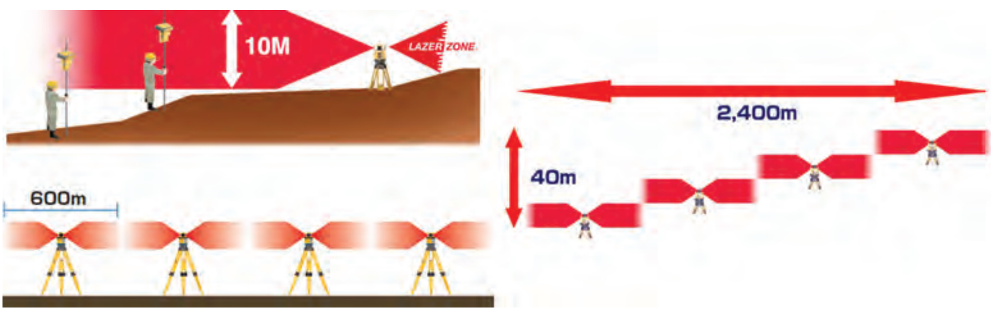

Fig. 3: Horizontal and vertical laser transmitter working range (URL 1).

2.2.1 Application in engineering geodesy

The above described system can be implemented in construction machine managing and navigation (Fig. 4a, 4b). Tight horizontal and especially vertical tolerances are required from building machinery during construction works.

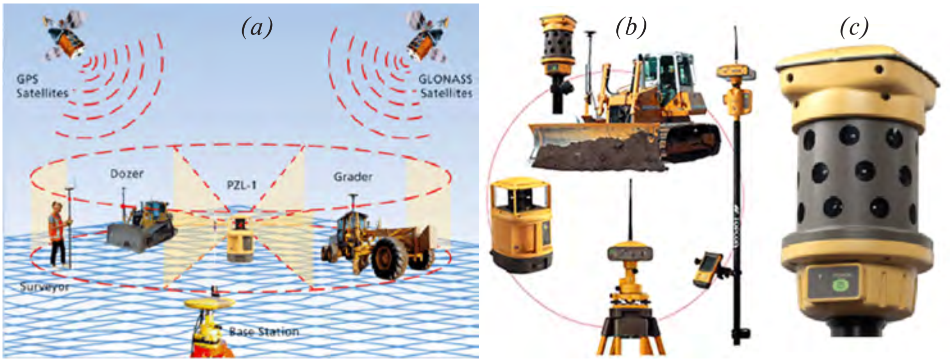

Fig. 4: (a, b) LazerZone™ system in workout, and (c) PZS-MC sensor (URL 1; URL 2).

For the projects where millimetre height accuracy was required, GNSS RTK method could not be used in navigation because of insufficient accuracy in height determination. The mounting of PZS-MC sensor (Positioning Zone Sensor for Machine Control applications) (Fig. 4c) with GNSS RTK receivers on different construction machines (pavers, graders, bulldozers and other machines) can improve the accuracy of height determination to millimetre level, and the system then becomes suitable for almost every job on construction site.

LaserZoneTM system, except in managing and navigation of construction machines, can be implemented in everyday geodetic tasks of surveying, staking out and monitoring. GNSS equipment, due to its many advantages, has become indispensable in deformation monitoring projects. For deformation monitoring projects that are characterized by millimetre displacements, GNSS RTK method in combination with laser system can be applied if it is possible to achieve millimetre vertical accuracy with that system. In the following chapter the accuracy testing will be shown and according to the obtained results, the assessment of the possibility to apply this system will be done.

3 CROPOS

The application of satellite methods in the Republic of Croatia has been improved after the establishment of CROPOS (CROatian POsitioning System) on December 9, 2008. CROPOS consists of 30 GNSS permanent stations at the mutual distance of 70-100 km, distributed to cover the entire area of the Republic of Croatia. The system mentioned above has been tested with CROPOS also, because more and more users are using this system every day. CROPOS supports three services (URL 4):

- Differential Positioning Service (DPS) – differential positioning service in real time that has the accuracy of less than 1 m (from ±0.3 to ±0.5 m). It is applied in: geoinformation systems, navigation, traffic management, environmental protection, agriculture and forestry.

- Very Precise Positioning Service (VPPS) – high precision positioning service in real time that provides the accuracy of ±2 cm (2D) and ±4 cm (3D). It is applied in: geodetic surveying, cadastre, engineering geodesy, surveying the state borders, aerial photogrammetry and hydrography.
- Geodetic Precision Positioning Service (GPPS) – geodetic precision positioning service that provides subcentimeter accuracy (horizontal and vertical) with post-processing. It is applied in: the establishment of geodetic basis, geodetic networks for special purposes, reference systems, scientific and geodynamic studies.

Measurement methods and the determination of coordinates (Croatian Terrestrial Reference System/Transverse Mercator – HTRS/TM and normal-orthometric heights) were significantly changed after the establishment of CROPOS network (Rezo and Bačić, 2009). When we use conventional GNSS methods depending on the method of surveying (RTK or static), we must use two or more GNSS receivers. When we use CROPOS in our work, only one GNSS receiver is needed for the determination of the position of unknown point (RTK or static).

For the purpose of establishing a new geodetic base with static GNSS surveying method, there is no need to put GNSS devices on known points the number of which depends on the dimension of the network (1D, 2D, 3D). CROPOS generates RINEX file for virtual reference station (VRS) by means of GPPS service. In this way the position of unknown points can be determined from the cross-section between VRS stations and unknown stations. Fig. 5 shows GNSS RTK HiPer Pro system connected with PZS-1 sensor, and equipped with modem for CROPOS. For this measuring mode we need additional point with known normal-orthometric height for laser transmitter station.

Fig. 5: GNSS RTK HiPer Pro with PZS-1 sensor and modem for CROPOS.

4 QUALITY COMPARISON OF FOUR MEASURING RTK MODES

To test the quality of height determination using GPS RTK method and laser system, the calibration baseline of the Faculty of Geodesy in Donja Lomnica near Zagreb (Fig. 6) has been selected. The calibration baseline has been built in 1982 (Solarić et al., 1992).

The calibration baseline consists of 25 concrete pillars with force centering device, and maximum distance of 3100 m. The calibration baseline was initially designed to test electro-optical distance meters (EDM), distances, periodical error, zero correction, scale error (phase inhomogeneities) and cyclic error (Solarić et al., 1992; Zrinjski, 2010).

Fig. 6: Calibration baseline of the Faculty of Geodesy in Zagreb (Zrinjski, 2010).

4.1 Analysis of measurements

The aim of the testing was to define the acceptability of the measuring modes for different engineering geodetic tasks. The testing of the measuring modes was done at the calibration baseline of the Faculty of Geodesy in Zagreb. There were the first eight pillars of the calibration baseline, stabilized at the distances from 0 to 300 meters used. The distance of 300 meters was defined due to a working range of LazerZone™ system.

Pillar No. 0 was chosen as a base point for GNSS reference receiver, and pillar No. 1 was chosen as a base point for laser transmitter. The pillar No. 1 is placed at the distance of 2.5 m from the pillar No. 0. On the other six pillars stabilized at the distances at 20, 40, 70, 100, 200 and 300 meters from pillar 0, the heights were determined by four different measuring modes:

- Mode 1: GPS RTK method in combination with LazerZone™ system,
- Mode 2: GPS RTK method in combination with LazerZone™ system linked to CROPOS service – VPPS,

- Mode 3: GPS RTK method and
- Mode 4: GPS RTK method linked to CROPOS service – VPPS.

The heights of the pillars were determined before testing by means of precise differential levelling method – using level Leica NA2 with parallel plate micrometer (Zrinjski, 2010). With level Leica NA2, the standard deviation of 0.3 mm per 1 km double-run levelling is achievable (Benčić and Solarić, 2008; URL 5). Due to its achievable accuracy, the heights of the pillars determined by means of differential levelling method were taken as a reference. The heights determined by all four measuring RTK modes were compared with the reference heights. Measuring interval in all tests was set to 30 seconds with 1 second sampling rate. The height of each pillar was measured using 30 registrations. Table 1 shows achieved results.

Distance [m]	Ref. Height *H* [m]	Mode 1 [m]		Mode 2 [m]		Mode 3 [m]		Mode 4 [m]	
		H	Δ*h*	*H*	Δ*h*	*H*	Δ*h*	*H*	Δ*h*
20	114.6578	114.659	0.001	114.657	-0.001	114.661	0.003	114.671	0.013
40	114.6786	114.680	0.001	114.681	0.002	114.673	-0.006	114.689	0.010
70	114.7008	114.702	0.001	114.698	-0.003	114.697	-0.004	114.707	0.006
100	114.7183	114.716	-0.002	114.713	-0.005	114.721	0.003	114.733	0.015
200	114.7865	114.784	-0.003	114.782	-0.005	114.793	0.006	114.800	0.013
300	114.8515	114.847	-0.005	114.859	0.007	114.848	-0.004	114.843	-0.009

Table 1: Measured pillar heights (arithmetic mean of 30 registrations on every point).

From the results shown in Table 1 we can see that the best coincidence with the reference heights was achieved using mode 1. The largest differences from reference heights were achieved using mode 4. The heights determined using mode 3 and mode 2 have nearly the same level of coincidence with the reference heights. Graphical presentation of achieved results is shown on Fig. 7.

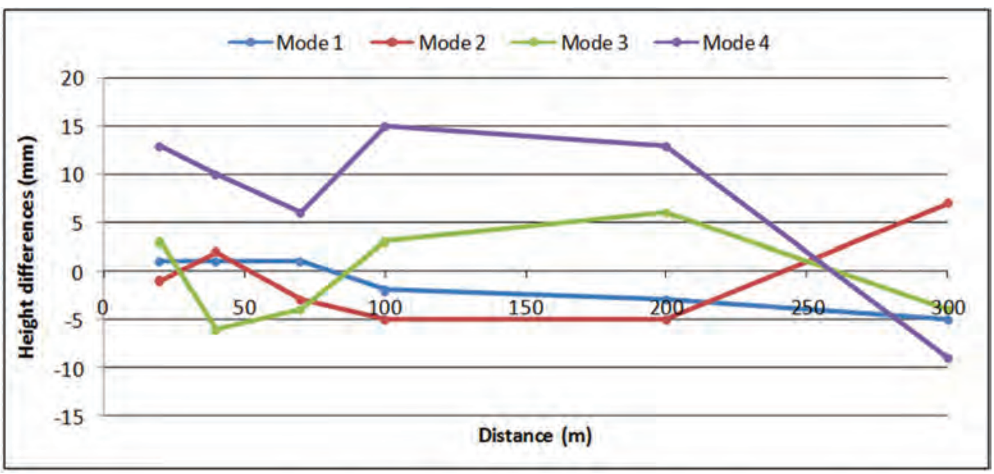

Fig. 7: Graphical representation of differences between reference and measured pillar heights.

4.2 Comparison of the precision and accuracy of tested methods

The quality of the achieved results can be expressed by means of precision and accuracy. In statistics, the precision characterizes the degree of mutual agreement among a series of individual measurements, and indicates spreading or dispersion of random errors (Paar et al., 2009). The accuracy presents the measurement coincidence with the true or agreed value determined by the most precise and accurate method.

The precision is expressed by means of standard deviation of measurement (s) and the accuracy is expressed by means of the root mean square error (m). The values (expressions) s and m are computed (Feil, 1989; Rožić, 2007; Zrinjski, 2010):

$$s=\sqrt{\frac{\sum_{i=1}^{n}(\overline{H}-H_i)^2}{n-1}} \qquad m=\sqrt{\frac{\sum_{i=1}^{n}(H_{ref}-H_i)^2}{n}}, \qquad (1)$$

where:

$\overline{H}$ – calculated arithmetic mean of 30 registrations,

H_i – each height measurement of point (pillar),

H_{ref} – reference heights of pillars determined by precise differential levelling,

n – number of measurements.

For all measuring modes described in this paper, standard deviation of measurements and root mean square error were calculated. The results are shown in Table 2.

Distance [m]	**Mode 1** [mm]		**Mode 2** [mm]		**Mode 3** [mm]		**Mode 4** [mm]	
	s	*m*	*s*	*m*	*s*	*m*	*s*	*m*
20	0.2	0.3	0.5	1.3	3.3	3.8	6.0	14.1
40	0.4	1.1	0.7	2.3	2.9	5.8	4.2	11.3
70	0.7	0.9	1.7	3.1	3.8	4.7	4.8	7.1
100	1.1	1.3	2.2	6.2	3.0	4.3	6.0	17.1
200	2.2	3.8	5.0	6.8	2.7	6.3	5.3	15.6
300	3.4	5.5	6.5	8.8	3.3	5.3	6.3	10.4

Table 2: Standard deviation of measurements and root mean square error.

The results and analysis of quality show that the best results in these tests were obtained using mode 1. Much better results were especially noticed for the measuring distances up to 200 meters. Better results were also obtained using mode 2 in comparison with the results obtained by using mode 4. Slightly inferior results were obtained using laser system for distances nearby 300 meters representing the working area boundaries of the system. Standard deviations of measurement for all measuring modes are shown on Fig. 8.

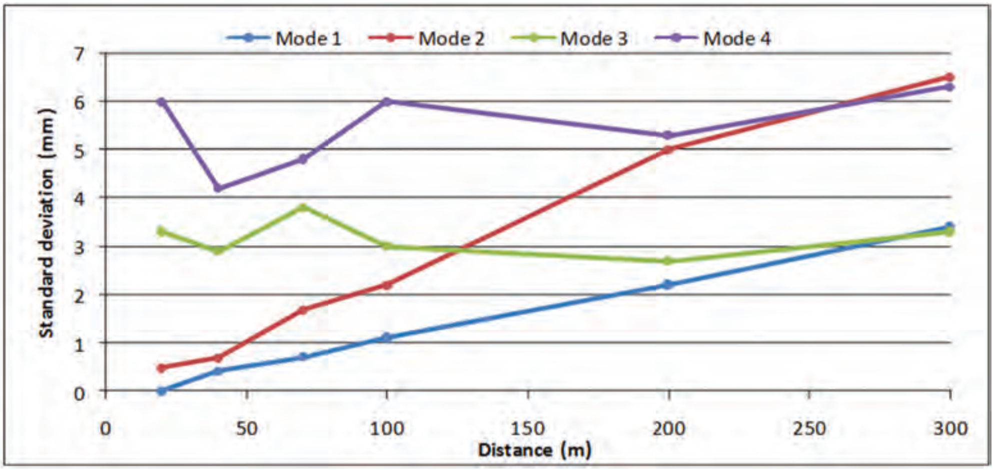

Fig. 8: The precision of measurements (standard deviations).

Root mean square error for all measuring modes is shown on Fig. 9. From Fig. 9 it can also be seen that the most accurate method is mode 1. Slightly inferior methods are mode 3 and mode 2, while the worst results were obtained using mode 4.

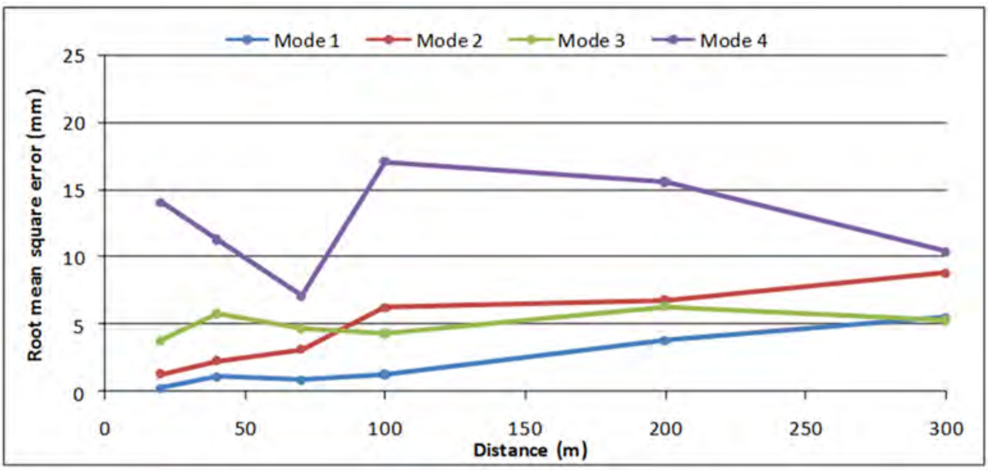

Fig. 9: The accuracy of the measurements (root mean square error).

The next step in the analysis was the testing of the homogeneity of variances. Cochran's test was used to test the significant differences between variances. Test statistics in Cochran's test is the ratio of maximal variance ($s_{\max}^2$) to the sum of all group variances (Klak, 1982; Novaković, 2006):

$$C = \frac{s_{\max}^2}{\sum s_i^2} \,. \tag{2}$$

Calculated test values are then compared to critical value C_{max} from the tables (Klak, 1982) of the sampling distribution. Table 3 shows the achieved results.

Distance [m]	Cochran's test	
	C	C_{max} (α=0.05)
20	0.76	0.39
40	0.66	0.39
70	0.56	0.39
100	0.71	0.39
200	0.43	0.39
300	0.40	0.39

Table 3: Cochran's test results.

Since the computed ratio for all measuring modes at all measuring distances is greater than the critical value, it can be assumed that the measuring modes do not have equal variances.

5 CONCLUSION

The aim of this paper was to define the acceptability of the GPS RTK method and laser system for different engineering geodetic tasks. The testing of the vertical accuracy of GPS RTK method and laser system was done at the calibration baseline of the Faculty of Geodesy in Zagreb. The heights of the baseline pillars were determined by four different measuring modes.

The analysis of the achieved results shows that the best coincidence with the reference heights was achieved using mode 1. The largest difference from the reference heights was achieved using mode 4. The heights determined using mode 3 and mode 2 have nearly the same level of coincidence with the reference heights. The results of statistic testing showed that all systems do not have the same level of precision. The achieved results show that the combination of GPS RTK method with laser system results in the increased quality (precision and accuracy) of vertical component.

Every day more and more users are using the established CROPOS of network reference stations in their everyday tasks. For the projects in which the declared height accuracy of CROPOS system (URL 4) is not satisfactory, laser technology presents the right solution for achieving much better results concerning vertical measurement quality.

The disadvantages of laser systems refer to the fact that the mobile GPS RTK device with PZS-1 sensor must be very precisely directed to PZL-1 transmitter so that a laser beam can be detected, and in the visual visibility between them. Those facts can be mentioned as the only disadvantage of the system. It is obvious that beam detection window ±10° to ±10° is too small. It is possible that the 360° sensor would be the right solution for the problem concerning laser beam detection, but the problem concerning visibility between laser transmitter and sensor can't be resolved.

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