Vertical Component Quality Comparison of GPS RTK Method in Combination with Laser System vs. Conventional Methods for Height Determination

Paar, R., Novaković, G. and Kolovrat, D.

University of Zagreb, Faculty of Geodesy, Kačićeva 26, HR-10000 Zagreb, Croatia
Web site: www.geof.unizg.hr, E-mail: rpaar@geof.hr, ngorana@geof.hr, dakolovrat@geof.hr

Abstract

For the most common geodetic tasks such as surveying, staking out and monitoring, GPS RTK method has been in many cases limited by its vertical measuring quality. Combining laser system with GNSS RTK system enables the increase of vertical accuracy of measurement to a millimetre level. In this paper testing the mentioned system (developed by Topocon i.e. mmGPS) and its comparison with conventional methods for height determination will be presented. Testing the vertical accuracy using different measuring methods has been done on the calibration baseline of the Faculty of Geodesy in Zagreb. Heights were determined using four different measuring methods; differential levelling, trigonometric levelling, GPS RTK and GPS RTK method in combination with laser system. The authors of the paper tried to examine whether it is possible to achieve higher accuracy of vertical component when GNSS RTK system is combined with laser system. The results of height comparison, analysis of vertical accuracy and precision of measuring methods is presented in this paper. The statistical tests were used to examine whether there are significant differences in accuracies obtained by different measuring methods.

Key words: GPS RTK method, laser system, vertical precision and accuracy.

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 GPS 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 trigonometric levelling (using electronic tacheometer), it is possible to achieve subcentimetre accuracy, and differential levelling (using level with parallel plate micrometer) enables the achievement of submillimetre accuracy. The Topcon manufacturer claims that combining LazerZone™ 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 GPS RTK measurements, the usage of GPS 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 system.

2 HEIGHT DETERMINATION USING GPS RTK METHOD AND LASER SYSTEM

The technology called *Topcon LazerZone™* allows height determination and staking out of height differences with millimetre accuracy according to the manufacturer (Geocentar, 2013). The system can only be used in combination with Topcon GNSS RTK HiPer Pro systems. That integrated system comprises GNSS RTK system and LazerZone™ system called mmGPS. LazerZone™ system comprises laser transmitter PZL-1 (Positioning Zone Laser) and laser sensor PZS-1 (Positioning Zone Sensor for mobile rover applications).

2.1 TOPCON GNSS RTK HIPER PRO SYSTEM AND TOPCON LAZERZONE™ SYSTEM

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 Geocentar (2014). The parts of the Topcon LazerZone™ system are PZL-1 transmitter (Fig. 1a) and PZS-1 sensor (Fig. 1b). 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. 1b).

Figure 1 (a) PZL-1 laser transmitter and (b) PZS-1 sensor connected to GNSS rover receiver

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 Geocentar (2013). An unlimited number of GNSS 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. 2). 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.

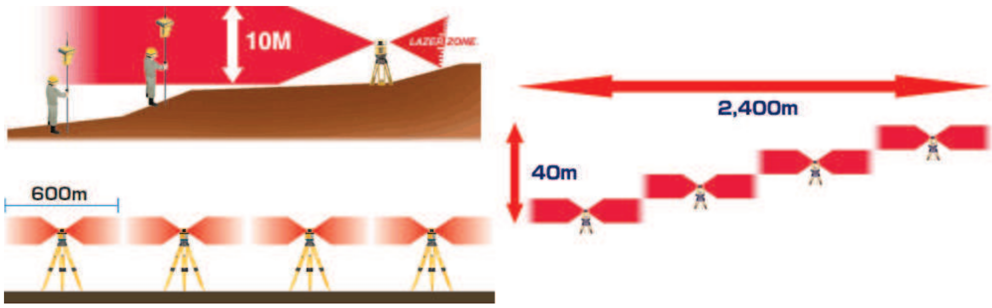

Figure 2 Horizontal and vertical laser transmitter working range

3 QUALITY COMPARISON OF FOUR MEASURING METHODS

To test the quality of height determination using GNSS RTK system in combination with laser system, the calibration baseline of the Faculty of Geodesy in Donja Lomnica near Zagreb has been selected. The calibration baseline was built in 1982 (Solarić et al., 1992). The calibration baseline consists of 25 concrete pillars with forced centring 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 inhomogeneity) and cyclic error (Solarić et al., 1992).

3.1 ANALYSIS OF MEASUREMENTS

The purpose of the testing was to define the acceptability of the measuring methods for different engineering geodetic tasks. 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 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 methods:

- Mode 1 – differential levelling (using level Leica NA2 with parallel plate micrometre),
- Mode 2 – trigonometric levelling (using total station Leica TPS1201),
- Mode 3 – GPS RTK method (using Topcon HiPer Pro GNSS RTK system) and
- Mode 4 – GPS RTK method (using Topcon HiPer Pro GNSS RTK system) in combination with laser system (using Topcon LazerZone^{TM} system) – mmGPS.

Differential levelling using level with parallel plate micrometer was conducted with Leica NA2, the standard deviation of 0.3 mm per 1 km double-run levelling is achievable (Benčić and Solarić, 2008; Leica, 2011). Due to its achievable accuracy, the heights of the pillars determined by means of differential levelling were taken as a reference. The heights determined by the next three measuring methods were compared with the reference heights. Measuring interval in tests with other three methods was set to 1 second with 30 registrations to measure the height of each pillar. Table 1 shows achieved results (the arithmetic mean of 30 measurements for every method).

Table 1 Measured pillar heights

Distance [m]	**Mode 1 Ref. Height** ***H*** [m]	**Mode 2** [m]		**Mode 3** [m]		**Mode 4** [m]	
		H	***Δh***	***H***	***Δh***	***H***	***Δh***
20	**114.658**	114.660	0.002	114.660	0.002	114.659	0.001
40	**114.677**	114.681	0.004	114.673	-0.004	114.680	0.003
70	**114.702**	114.706	0.004	114.702	0.000	114.702	0.000
100	**114.720**	114.723	0.003	114.719	-0.001	114.718	-0.002
200	**114.785**	114.786	0.001	114.788	0.003	114.785	0.000
300	**114.845**	114.849	0.004	114.846	0.001	114.845	0.000

From the results shown in table 1 it can be seen that the best coincidence with the reference heights was achieved using mode 4. The largest differences from reference heights were achieved using mode 2. Graphical presentation of the results is shown on figure 3.

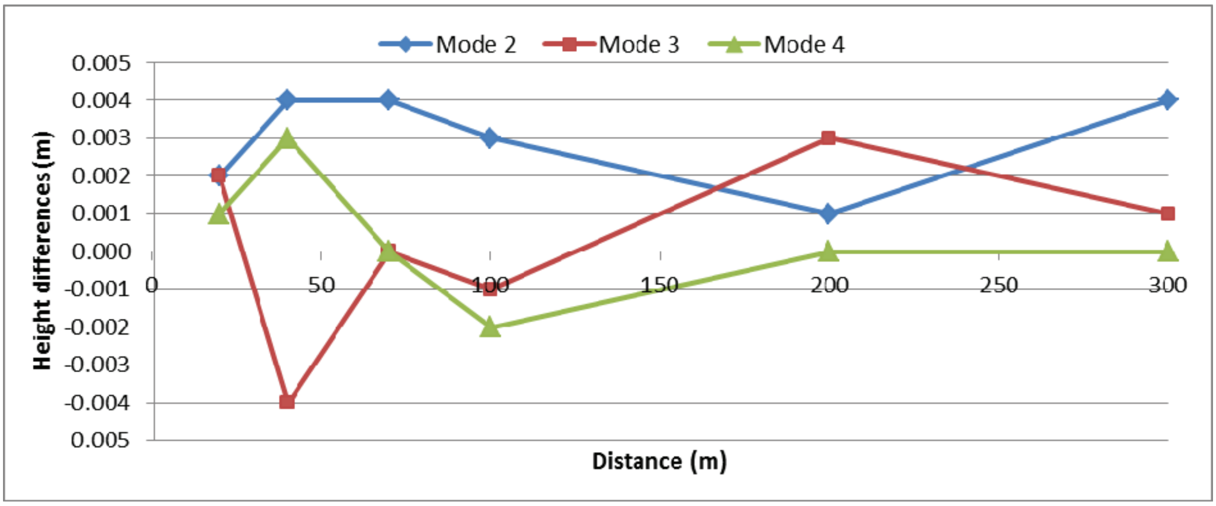

Figure 3 Graphical presentation of differences between the reference and measured pillar heights

3.2 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 *s* and *m* are computed (Rožić, 2007):

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

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 methods described in this paper, the standard deviation of measurements and root mean square error were calculated. The results are shown in Table 2.

Table 2 Standard deviation of measurements and root mean square error

Distance [m]	**Mode 2** [m]		**Mode 3** [m]		**Mode 4** [m]	
	s	***m***	***s***	***m***	***s***	***m***
20	0.0001	0.0023	0.0042	0.0044	0.0002	0.0009
40	0.0006	0.0039	0.0044	0.0059	0.0005	0.0030
70	0.0002	0.0037	0.0042	0.0041	0.0008	0.0008
100	0.0009	0.0032	0.0045	0.0046	0.0013	0.0023
200	0.0023	0.0025	0.0042	0.0051	0.0024	0.0024
300	0.0023	0.0039	0.0048	0.0048	0.0031	0.0031

The results and analysis of quality show that the best results in these tests were obtained using mode 4 (taking into account precision and accuracy). The best results regarding only to the precision were obtained using mode 2. Very good results were obtained using mode 4, while the worst results were achieved using mode 3. The precision expressed by means of standard deviation of measurement (*s*) for all measuring modes are shown in Fig. 4.

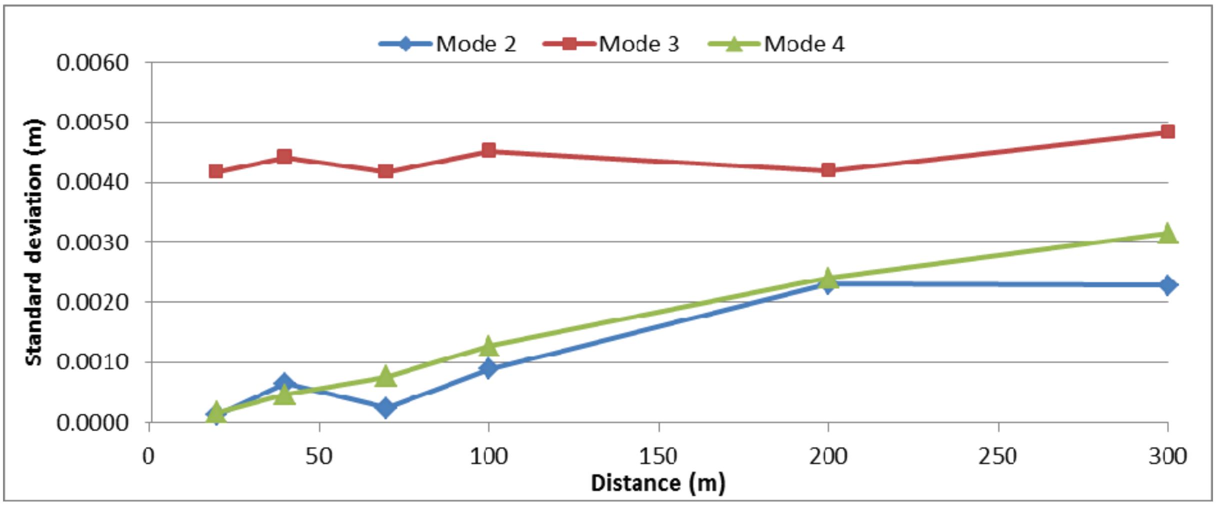

Figure 4 The precision of measurements (standard deviations)

The accuracy expressed by means of the root mean square error (m) for all measuring methods is shown in Fig. 5. From Fig. 5 it can be seen that the most accurate method is mode 4. Slightly inferior method is mode 2, while the worst results were obtained using mode 3.

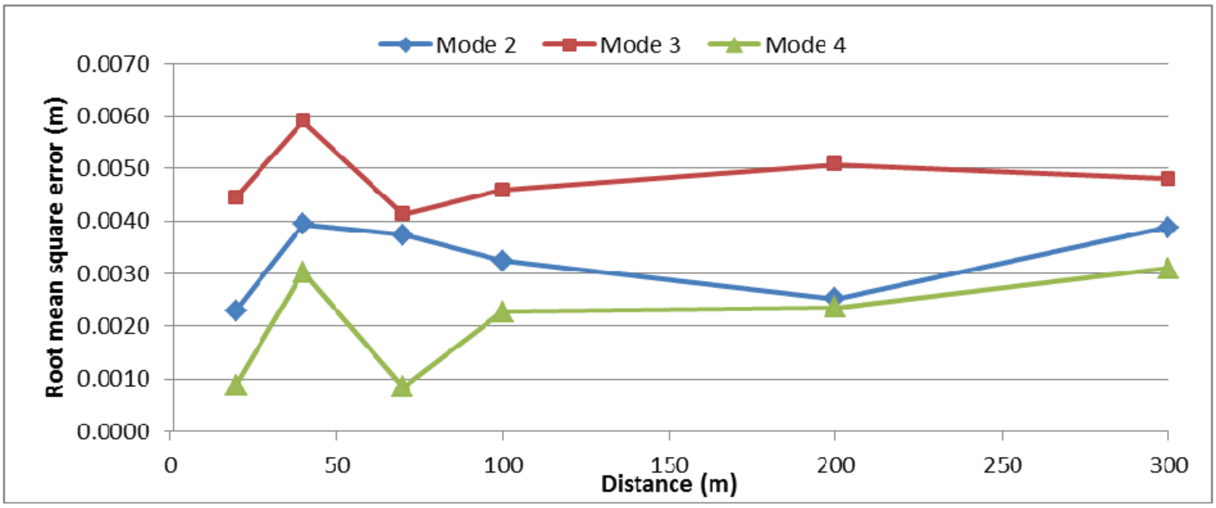

Figure 5 The accuracy of the measurements (root mean square error)

The next step in the analysis was the testing of the homogeneity of variances. Cochran's test was used for that purpose. Test statistics in Cochran's test is the ratio of maximal variance ($s^2_{\max}$) to the sum of all variances (Cochran, 1941; Klak, 1982; Novaković, 2006):

$$C = \frac{s^2_{\max}}{\sum s_i^2} \tag{2}$$

Calculated test values are then compared with critical value C_{max} which can been found in the tables (Klak, 1982) of the sampling distribution. Table 3 shows the achieved results.

Table 3 Cochran's test results

Distance [m]	**Cochran's test**	
	C	***C_{max}* (α=0.05)**
20	1.00	0.49
40	0.97	0.49
70	0.96	0.49
100	0.90	0.49
200	0.61	0.49
300	0.61	0.49

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

4 CONCLUSION

The purpose of the testing explained in 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 4 (combination of GPS RTK method with laser system). The results of quality testing showed that all systems do not have the same level of precision and accuracy. The results and analysis of quality show that the best results in these tests were obtained using mode 4 (taking into account precision and accuracy). The best results regarding only the precision were obtained using mode 2, while the best results regarding only the accuracy were obtained using mode 4. The results regarding the mode 4 are expected, because we assume that GNSS system has no influence on the height accuracy while working in combination with laser system (that information was provided to us from local dealer), but on the other hand laser system cannot work separately. Contributing to this is the fact that results regarding mode 4 and mode 2 coincide, so it can be concluded that precision depends on the measuring distance, which is no characteristic of GNSS measurements.

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 the laser beam can be detected, with no visibility obstructions 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.

REFERENCES

BAŠIĆ, T. (2009). New Geoid Model of the Republic of Croatia and Improvement of T7D Model Transformation. Zagreb: Faculty of Geodesy, University of Zagreb.

BENČIĆ, D., SOLARIĆ, N. (2008). Measuring Instruments and Systems in Geodesy and Geoinformatics. Zagreb: Školska knjiga.

COCHRAN, W. G. (1941). The distribution of the largest of a set of estimated variances as a fraction of their total, Annals of Human Genetics, 11 (1), 47–52, London.

Geocentar (2013). http://www.geocentar.com/cms/system/editor/ uploads/files/ produkti/ mmGPS1.pdf.

Geocentar (2014). http://www.geocentar.com/cms/system/editor/uploads/files/produkti/ Topcon%20proizvodiDr.pdf.

KLAK, S. (1982). Theory of Errors and Adjustment Computations. Zagreb: Sveučilišna naklada Liber.

LEICA (2011). http://www.leica-geosystems.com/en/Leica-NA2-NAK2_4457.htm.

NOVAKOVIĆ, G. (1996). Examination of compensator functions of geodetic instruments, PhD thesis. Zagreb: Faculty of Geodesy, University of Zagreb.

PAAR, R., NOVAKOVIĆ, G., ZULIJANI, E. (2009). Positioning Accuracy Standards for Geodetic Control. Allgemeine Vermessungs-Nachrichten, 7, 280–287.

ROŽIĆ, N. (2007). Mathematical Processing of Geodetic Measurements. Zagreb: Faculty of Geodesy, University of Zagreb.

SOLARIĆ, N., SOLARIĆ, M., BENČIĆ, D. (1992). Design and Construction of Calibration Baseline of the Faculty of Geodesy of the University of Zagreb. Geodetski list, 1, 7–27.

Topcon (2006). Operator's manual Topcon HiPer Pro. Topcon Positioning Systems, Inc.