Determining and Analyzing the Quality of GNSS RTK Positioning

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Abstract: The constant development of technology brought many changes into the geodetic profession. One of those changes is the usage of GNSS RTK measurement systems. The International Organization for Standardization (ISO) defines procedures to determine the precision of GNSS RTK measurement systems. This paper gives an overview of standard ISO 17123-8:2015 which specifies and defines field procedures to be adopted when determining and evaluating the precision of GNSS RTK field measurement systems and their ancillary equipment. The testing of the precision of GNSS RTK measuring systems Topcon HiPer SR was performed on March 8 and 9, 2018 in the test field at Klaićeva Street in Zagreb, near the Faculty of Geodesy. Coordinates and normal orthometric height present measuring data and based on them empirical standard deviations were calculated and statistical tests performed. Based on the results obtained in testing, it was concluded that the used GNSS RTK measuring system Topcon HiPer SR meets the measuring uncertainty declared by the manufacturer of the instrument.

Keywords: precision, ISO standard, GNSS RTK, CROPOS, positioning

Introduction

The International Organization for Standardization (ISO) is a worldwide organization which consists of national standards bodies. For creating and defining standards in respective fields, technical committees are founded. ISO standards that are defined for geodetic profession are defined by the ISO Technical Committee TC 172 (Optics and Photonics), Subcommittee SC 6 (Geodetic and Surveying Instruments).

The overview of international and national standards for testing and calibration of geodetic measuring instruments directly regulated by ISO/TC 172/SC 6 can be found in Zrinjski et al., (2010), Zrinjski et al., (2011), Zrinjski et al., (2013), Barković et al., (2014) and Zrinjski et al., (2015).

ISO 17123-8:2015

Standard ISO 17123-8:2015 specifies field procedures to be adopted when determining and evaluating the precision (repeatability) of Global Navigation Satellite System (GNSS) field measurement systems in real-time kinematic (RTK) and their ancillary equipment when used in building, surveying and industrial measurements. Primarily, these tests are intended to be field verifications of the suitability of an instrument for the required application at hand and to satisfy the requirements of other standards. They are not proposed as tests for acceptance or performance evaluations that are more comprehensive in nature (ISO, 2015).

Before commencing surveying, it is important to check that the receiver, antenna and their auxiliary equipment are in acceptable condition according to the methods specified in the manufacturer reference manual. Also, the centering precision and precision of the measured antenna height must be considered and be achieved with a standard deviation of 1 mm. The standard specifies two different field procedures: simplified test procedure and the full test procedure (ISO, 2015).

For both test procedures, the test field consists of a base point and two rover points with unknown coordinates which are selected on the field at convenience. The distance between the two rover points must be between 2 and 20 meters. The horizontal distance and height difference between the two rover points must be determined by means of geodetic methods other than RTK and with a precision greater than 3 millimeters, e.g. a total station and a precise level. These values are considered as nominal quantities.

In this paper only the full test procedure is presented. The test is intended for determining the experimental standard deviation for a single position and height measurement (ISO, 2015). The test consists of three series of measurements and each series consists of five sets. Each measurement set consists of successive measurements at points rover 1 and rover 2. The time interval between two consecutive measuring sets should be approximately 5 minutes. That means that the duration of one measuring series will be about 25 minutes. The start of consecutive measuring series should be at least 90 minutes. Hence, the repeated measuring series are intended to eliminate the influence caused by changes in the satellite configuration, changes in ionospheric and tropospheric conditions and other factors (Zrinjski et al., 2015).

When all the field measurements were performed, preliminary checking must be done, i.e. all the individual measurements are compared with the nominal quantities to detect any outlier. For each set $j = 1, \ldots, 5$ of every series $i = 1, 2, 3$, the horizontal distance and height difference between the two rover points and their deviations from the nominal quantities are calculated (ISO, 2015):

$$\begin{aligned} D_{i,j} &= \sqrt{\left(x_{i,j,2} - x_{i,j,1}\right)^2 + \left(y_{i,j,2} - y_{i,j,1}\right)^2} \,, \\ \Delta h_{i,j} &= h_{i,j,2} - h_{i,j,1} \,, \\ \varepsilon_{D\,i,j} &= D_{i,j} - D^* \,, \\ \varepsilon_{h\,i,j} &= h_{i,j} - h^* \,, \end{aligned} \tag{1}$$

where $x_{i,j,k}$, $y_{i,j,k}$, $h_{i,j,k}$ are measurements from the j set at the rover point k (k = 1, 2) in the series i, $D_{i,j}$ and $\Delta h_{i,j}$ are the calculated horizontal distance and height difference, respectively, in the j set in series i, D^* and h^* represent the nominal quantities, and finally, $\varepsilon_{D\,i,j}$ and $\varepsilon_{h\,i,j}$ represent the deviations as stated. To determine if any gross errors are present, the calculated deviations must satisfy the following conditions (ISO, 2015):

$$\begin{aligned} \left|\varepsilon_{D\,i,j}\right| &\le 2.5 \cdot \sqrt{2} \cdot s_{xy} \,, \\ \left|\varepsilon_{h\,i,j}\right| &\le 2.5 \cdot \sqrt{2} \cdot s_{h} \,, \end{aligned} \tag{2}$$

where s_{xy} and s_h are predetermined standard deviations according to the full test procedure or the values specified by the manufacturer of the instrument. If any of the two criteria hasn't been fulfilled for any of the calculated distances of height differences, it is possible there are gross error present in the raw measurements and the whole field procedure should be repeated.

After the preliminary checking has been done, and it is determined whether there are any outliers present, the statistical values of interest are calculated. Firstly, by applying the least square adjustment on overall measurements in all the series, the best estimates of x, y and h for every rover point (k = 1, 2) are calculated (ISO, 2015):

$$\begin{aligned} \bar{x}_k &= \frac{1}{15}\sum_{i=1}^{3}\sum_{j=1}^{5} x_{i,j,k} \,, \\ \bar{y}_k &= \frac{1}{15}\sum_{i=1}^{3}\sum_{j=1}^{5} y_{i,j,k} \,, \\ \bar{h}_k &= \frac{1}{15}\sum_{i=1}^{3}\sum_{j=1}^{5} h_{i,j,k} \,. \end{aligned} \tag{3}$$

The individual residuals of measured coordinates x, y and h for all the measurements are calculated by subtracting every calculated measurement from the best estimates of the rover point coordinates (ISO, 2015):

$$r_{x\,i,j,k} = \bar{x}_k - x_{i,j,k},$$
$$r_{y\,i,j,k} = \bar{y}_k - y_{i,j,k}, \qquad (4)$$
$$r_{h\,i,j,k} = \bar{h}_k - h_{i,j,k}.$$

Furthermore, the above residuals are all squared and summed including measurements for all point index $k = 1$ and $k = 2$ for x, y and h separately as (ISO, 2015):

$$\sum r_x^2 = \sum_{i=1}^{3}\sum_{j=1}^{5}\sum_{k=1}^{2} r_{x\,i,j,k}^2,$$
$$\sum r_y^2 = \sum_{i=1}^{3}\sum_{j=1}^{5}\sum_{k=1}^{2} r_{y\,i,j,k}^2, \qquad (5)$$
$$\sum r_h^2 = \sum_{i=1}^{3}\sum_{j=1}^{5}\sum_{k=1}^{2} r_{h\,i,j,k}^2.$$

The empirical standard deviation of a single measured coordinate x, y and h are calculated as (ISO, 2015):

$$s_x = \sqrt{\frac{\sum r_x^2}{28}},$$
$$s_y = \sqrt{\frac{\sum r_y^2}{28}}, \qquad (6)$$
$$s_h = \sqrt{\frac{\sum r_h^2}{28}},$$

where number 28 in the denominator presents the number of freedom degrees in the measurements of individual coordinates (x, y and h). The third formula in the expression above (s_h) gives the empirical standard deviation of the height h.

Finally, the empirical standard deviation of coordinates (x, y) is calculated as (ISO, 2015):

$$s_{xy} = \sqrt{s_x^2 + s_y^2}\,. \tag{7}$$

In general, statistical tests are used to determine whether an experiment belongs to the same population as a given theoretical value, in other words, we determine whether a hypothesis is acceptable or not. The purpose of applying statistical tests is to determine whether the calculated experimental standard deviations belong to the same population as the given theoretical values and to determine whether two samples from different experiments belong to the same population. Statistical tests are carried out using overall standard deviation of coordinates s_{xy} and height s_h obtained from the measurements. Statistical tests can only be applied to the full test procedure. Statistical tests must answer the questions given in Table 1.

Table 1 – Overview of statistical tests (ISO, 2015)

Question	Null hypothesis	Alternative hypothesis
a)	$s_{xy} \le \sigma_{xy}$	$s_{xy} > \sigma_{xy}$
b)	$s_h \le \sigma_h$	$s_h > \sigma_h$
c)	$\sigma_{xy} = \tilde{\sigma}_{xy}$	$\sigma_{xy} \ne \tilde{\sigma}_{xy}$
d)	$\sigma_h = \tilde{\sigma}_h$	$\sigma_h \ne \tilde{\sigma}_h$

Question a)

The null hypothesis is accepted if the calculated empirical standard deviation s_{xy} is smaller than or equal to the corresponding value σ_{xy}, declared by the instrument manufacturer, i.e. if it is fulfilled (ISO, 2015):

$$s_{xy} \le 1.15 \cdot \sigma_{xy}\,. \tag{8}$$

Question b)

The null hypothesis is accepted if the calculated empirical standard deviation s_h is smaller than or equal to the corresponding value σ_h, declared by the instrument manufacturer, i.e. if it is fulfilled (ISO, 2015):

$$s_h \le 1.22 \cdot \sigma_h\,. \tag{9}$$

Question c)

For two different measuring series, the test will indicate if the calculated empirical standard deviations s_{xy} and $\tilde{s}_{xy}$ belong to the same population. The null hypothesis is accepted if it is fulfilled (ISO, 2015):

$$0.59 \le \frac{s_{xy}^2}{\tilde{s}_{xy}^2} \le 1.70 . \tag{10}$$

Question d)

For two different measuring series, the test will indicate if the calculated empirical standard deviations s_h and $\tilde{s}_h$ belong to the same population. The null hypothesis is accepted if it is fulfilled (ISO, 2015):

$$0.47 \le \frac{s_h^2}{\tilde{s}_h^2} \le 2.13 . \tag{11}$$

All the above given expressions for statistical tests are given for the confidence level $k = 0.95$.

Testing and Analysis of the Precision of GNSS RTK Measurement System

The measurements were made in the test field at Klaićeva Street in Zagreb, near the Faculty of Geodesy, University of Zagreb on two points (A – rover 1, B – rover 2). Horizontal distance and height difference between these two points were determined during the first day of measurement on March 8, 2018. Horizontal distance was measured by means of a geodetic total station Topcon ES-65 (Ser. No. YL0085) with declared distance measuring accuracy of ±(2 mm + 2 ppm) (Topcon, 2018a) in four repetitions (two in both instrument positions). Nominal horizontal distance was calculated as arithmetic mean from repeated measurements and is 16.309 m. Height difference was determined by means of a precise level Leica NAK2 (Ser. No. 5048229) with the declared accuracy of 0.3 mm in two independent repetitions (Leica, 2018). Nominal height difference was calculated as arithmetic mean of these two measurements and it amounts 0.871 m.

The receiver used to collect measurements was Topcon HiPer SR (Ser. No. 1054-16245) with a declared measuring uncertainty for RTK measurements of ±(10 mm + 0.8 ppm) horizontally and ±(15 mm + 1 ppm) vertically (Topcon, 2018b).

To perform GNSS RTK measurements, the receiver was connected to CROatian POsitioning System (CROPOS) using High Precision Real-time Positioning Service (VPPS), which guarantees the accuracy of RTK measurements ±0.02 m horizontally and ±0.04 m vertically (CROPOS, 2018). The first measuring session (containing 3 series with 5 sets of measurements) was held on March 8, 2018 from 11:00 until 14:30 (Table 2 and Table 3), and the second session was held on March 9, 2018 from 7:30 until 11:00 (Table 4 and Table 5). The coordinates (*E*, *N*) of the two rover points (A, B) were determined in the Croatian Terrestrial Reference System 1996/Transverse Mercator (HTRS96/TM) and (*H*) in the Croatian Height Reference System 1971 of normal orthometric heights (HVRS71) (Official Gazette, 2004). All data was collected in a single epoch.

Measurement data was processed using Microsoft Excel 2016 according to the above presented ISO 17123-8:2015 full test procedure.

Table 2 – Measurements and nominal data deviations (first session)

Seq. No.	Series	Set	Rover point	Measurement			Horizontal distance	Height difference	Deviations	
				m			m	m	mm	
	i	j	k	y (E)	x (N)	h (H)	D_j	Δh_j	$\varepsilon_{D\,i,j}$	$\varepsilon_{h\,i,j}$
1	1	1	1	458390.508	5074463.974	119.178	–	–	–	–
2	1	1	2	458405.314	5074470.737	118.309	16.277	–0.869	–1	2
3	1	2	1	458390.509	5074463.975	119.188	–	–	–	–
4	1	2	2	458405.315	5074470.742	118.312	16.279	–0.876	1	–5
5	1	3	1	458390.506	5074463.981	119.186	–	–	–	–
6	1	3	2	458405.313	5074470.743	118.307	16.278	–0.879	0	–8
7	1	4	1	458390.508	5074463.984	119.183	–	–	–	–
8	1	4	2	458405.309	5074470.740	118.312	16.270	–0.871	–8	0
9	1	5	1	458390.508	5074463.974	119.192	–	–	–	–
10	1	5	2	458405.310	5074470.740	118.311	16.275	–0.881	–3	–10
11	2	6	1	458390.501	5074463.975	119.194	–	–	–	–
12	2	6	2	458405.308	5074470.736	118.319	16.278	–0.875	0	–4
13	2	7	1	458390.504	5074463.977	119.185	–	–	–	–
14	2	7	2	458405.305	5074470.737	118.328	16.272	–0.857	–6	14
15	2	8	1	458390.499	5074463.977	119.186	–	–	–	–

Seq. No.	Series	Set	Rover point	Measurement			Hori-zontal distance	Height differ-ence	Deviations	
				m			m	m	mm	
	i	j	k	y (E)	x (N)	h (H)	D_j	Δh_j	$\varepsilon_{D\,i,j}$	$\varepsilon_{h\,i,j}$
16	2	8	2	458405.311	5074470.737	118.307	16.282	–0.879	4	–8
17	2	9	1	458390.502	5074463.976	119.189	–	–	–	–
18	2	9	2	458405.312	5074470.726	118.318	16.276	–0.871	–2	0
19	2	10	1	458390.507	5074463.964	119.205	–	–	–	–
20	2	10	2	458405.312	5074470.727	118.329	16.277	–0.876	–1	–5
21	3	11	1	458390.504	5074463.972	119.191	–	–	–	–
22	3	11	2	458405.301	5074470.726	118.321	16.266	–0.870	–12	1
23	3	12	1	458390.503	5074463.978	119.181	–	–	–	–
24	3	12	2	458405.309	5074470.720	118.317	16.269	–0.864	–9	7
25	3	13	1	458390.500	5074463.974	119.178	–	–	–	–
26	3	13	2	458405.300	5074470.731	118.310	16.270	–0.868	–8	3
27	3	14	1	458390.502	5074463.979	119.168	–	–	–	–
28	3	14	2	458405.298	5074470.738	118.310	16.267	–0.858	–11	13
29	3	15	1	458390.502	5074463.975	119.191	–	–	–	–
30	3	15	2	458405.300	5074470.732	118.302	16.268	–0.889	–10	–18
Limit of each deviation [mm]				–	–	–	–	–	±39	±57

Table 3 – Measurements, residuals and experimental standard deviation (first session)

Seq. No.	Series	Set	Rover point	Measurement			Residual			Squared residual		
				m			mm			mm²		
	i	j	k	y (E)	x (N)	h (H)	r_y	r_x	r_h	r_y^2	r_x^2	r_h^2
1	1	1	1	458390.508	5074463.974	119.178	–4	2	8	16	4	64
2	1	1	2	458405.314	5074470.737	118.309	–6	–3	5	36	9	25
3	1	2	1	458390.509	5074463.975	119.188	–5	1	–2	25	1	4
4	1	2	2	458405.315	5074470.742	118.312	–7	–8	2	49	64	4
5	1	3	1	458390.506	5074463.981	119.186	–2	–5	0	4	25	0
6	1	3	2	458405.313	5074470.743	118.307	–5	–9	7	25	81	49

Seq. No.	Series	Set	Rover point	Measurement			Residual			Squared residual		
				m			mm			mm^2		
	i	*j*	*k*	*y (E)*	*x (N)*	*h (H)*	r_y	r_x	r_h	r_y^2	r_x^2	r_h^2
7	1	4	1	458390.508	5074463.984	119.183	–4	–8	3	16	64	9
8	1	4	2	458405.309	5074470.740	118.312	–1	–6	2	1	36	4
9	1	5	1	458390.508	5074463.974	119.192	–4	2	–6	16	4	36
10	1	5	2	458405.310	5074470.740	118.311	–2	–6	3	4	36	9
11	2	6	1	458390.501	5074463.975	119.194	3	1	–8	9	1	64
12	2	6	2	458405.308	5074470.736	118.319	0	–2	–5	0	4	25
13	2	7	1	458390.504	5074463.977	119.185	0	–1	1	0	1	1
14	2	7	2	458405.305	5074470.737	118.328	3	–3	–14	9	9	196
15	2	8	1	458390.499	5074463.977	119.186	5	–1	0	25	1	0
16	2	8	2	458405.311	5074470.737	118.307	–3	–3	7	9	9	49
17	2	9	1	458390.502	5074463.976	119.189	2	0	–3	4	0	9
18	2	9	2	458405.312	5074470.726	118.318	–4	8	–4	16	64	16
19	2	10	1	458390.507	5074463.964	119.205	–3	12	–19	9	144	361
20	2	10	2	458405.312	5074470.727	118.329	–4	7	–15	16	49	225
21	3	11	1	458390.504	5074463.972	119.191	0	4	–5	0	16	25
22	3	11	2	458405.301	5074470.726	118.321	7	8	–7	49	64	49
23	3	12	1	458390.503	5074463.978	119.181	1	–2	5	1	4	25
24	3	12	2	458405.309	5074470.720	118.317	–1	14	–3	1	196	9
25	3	13	1	458390.500	5074463.974	119.178	4	2	8	16	4	64
26	3	13	2	458405.300	5074470.731	118.310	8	3	4	64	9	16
27	3	14	1	458390.502	5074463.979	119.168	2	–3	18	4	9	324
28	3	14	2	458405.298	5074470.738	118.310	10	–4	4	100	16	16
29	3	15	1	458390.502	5074463.975	119.191	2	1	–5	4	1	25
30	3	15	2	458405.300	5074470.732	118.302	8	2	12	64	4	144
Average over series			1	458390.504	5074463.976	119.186	–	–	–	–	–	–
			2	458405.308	5074470.734	118.314						
Summation of the squared residual				–	–	–	–	–	–	592	929	1847
Experimental standard deviation s				4.60	5.76	8.12	–	–	–	–	–	–

Table 4 – Measurements and nominal data deviations (second session)

Seq. No.	Series	Set	Rover point	Measurement			Horizontal distance	Height difference	Deviations	
				m			m	m	mm	
	i	j	k	y (E)	x (N)	h (H)	D_j	Δh_j	$\varepsilon_{D\,i,j}$	$\varepsilon_{h\,i,j}$
1	1	1	1	458390.500	5074463.972	119.188	–	–	–	–
2	1	1	2	458405.307	5074470.735	118.319	16.278	–0.869	0	2
3	1	2	1	458390.499	5074463.968	119.195	–	–	–	–
4	1	2	2	458405.307	5074470.728	118.327	16.278	–0.868	0	3
5	1	3	1	458390.498	5074463.968	119.195	–	–	–	–
6	1	3	2	458405.312	5074470.730	118.329	16.284	–0.866	6	5
7	1	4	1	458390.501	5074463.965	119.198	–	–	–	–
8	1	4	2	458405.314	5074470.727	118.336	16.283	–0.862	5	9
9	1	5	1	458390.499	5074463.970	119.196	–	–	–	–
10	1	5	2	458405.312	5074470.734	118.317	16.284	–0.879	6	–8
11	2	6	1	458390.498	5074463.970	119.180	–	–	–	–
12	2	6	2	458405.311	5074470.736	118.312	16.285	–0.868	7	3
13	2	7	1	458390.496	5074463.972	119.186	–	–	–	–
14	2	7	2	458405.312	5074470.733	118.312	16.286	–0.874	8	–3
15	2	8	1	458390.499	5074463.970	119.186	–	–	–	–
16	2	8	2	458405.307	5074470.733	118.319	16.279	–0.867	1	4
17	2	9	1	458390.502	5074463.970	119.181	–	–	–	–
18	2	9	2	458405.307	5074470.729	118.321	16.275	–0.860	–3	11
19	2	10	1	458390.502	5074463.969	119.183	–	–	–	–
20	2	10	2	458405.310	5074470.730	118.317	16.278	–0.866	0	5
21	3	11	1	458390.498	5074463.971	119.182	–	–	–	–
22	3	11	2	458405.309	5074470.733	118.316	16.282	–0.866	4	5
23	3	12	1	458390.501	5074463.971	119.179	–	–	–	–
24	3	12	2	458405.308	5074470.735	118.306	16.279	–0.873	1	–2
25	3	13	1	458390.500	5074463.965	119.182	–	–	–	–
26	3	13	2	458405.312	5074470.735	118.310	16.286	–0.872	8	–1
27	3	14	1	458390.497	5074463.966	119.189	–	–	–	–
28	3	14	2	458405.309	5074470.731	118.308	16.284	–0.881	6	–10
29	3	15	1	458390.496	5074463.969	119.187	–	–	–	–
30	3	15	2	458405.306	5074470.734	118.317	16.282	–0.870	4	1
Limit of each deviation [mm]				–	–	–	–	–	±39	±57

Table 5 – Measurements, residuals and experimental standard deviation (second session)

Seq. No.	Series	Set	Rover point	Measurement m			Residual mm			Squared residual mm²		
	i	*j*	*k*	*y (E)*	*x (N)*	*h (H)*	r_y	r_x	r_h	r_y^2	r_x^2	r_h^2
1	1	1	1	458390.500	5074463.972	119.188	–1	–3	–1	1	9	1
2	1	1	2	458405.307	5074470.735	118.319	3	–3	–1	9	9	1
3	1	2	1	458390.499	5074463.968	119.195	0	1	–8	0	1	64
4	1	2	2	458405.307	5074470.728	118.327	3	4	–9	9	16	81
5	1	3	1	458390.498	5074463.968	119.195	1	1	–8	1	1	64
6	1	3	2	458405.312	5074470.730	118.329	–2	2	–11	4	4	121
7	1	4	1	458390.501	5074463.965	119.198	–2	4	–11	4	16	121
8	1	4	2	458405.314	5074470.727	118.336	–4	5	–18	16	25	324
9	1	5	1	458390.499	5074463.970	119.196	0	–1	–9	0	1	81
10	1	5	2	458405.312	5074470.734	118.317	–2	–2	1	4	4	1
11	2	6	1	458390.498	5074463.970	119.180	1	–1	7	1	1	49
12	2	6	2	458405.311	5074470.736	118.312	–1	–4	6	1	16	36
13	2	7	1	458390.496	5074463.972	119.186	3	–3	1	9	9	1
14	2	7	2	458405.312	5074470.733	118.312	–2	–1	6	4	1	36
15	2	8	1	458390.499	5074463.970	119.186	0	–1	1	0	1	1
16	2	8	2	458405.307	5074470.733	118.319	3	–1	–1	9	1	1
17	2	9	1	458390.502	5074463.970	119.181	–3	–1	6	9	1	36
18	2	9	2	458405.307	5074470.729	118.321	3	3	–3	9	9	9
19	2	10	1	458390.502	5074463.969	119.183	–3	0	4	9	0	16
20	2	10	2	458405.310	5074470.730	118.317	0	2	1	0	4	1
21	3	11	1	458390.498	5074463.971	119.182	1	–2	5	1	4	25
22	3	11	2	458405.309	5074470.733	118.316	1	–1	2	1	1	4
23	3	12	1	458390.501	5074463.971	119.179	–2	–2	8	4	4	64
24	3	12	2	458405.308	5074470.735	118.306	2	–3	12	4	9	144
25	3	13	1	458390.500	5074463.965	119.182	–1	4	5	1	16	25
26	3	13	2	458405.312	5074470.735	118.310	–2	–3	8	4	9	64
27	3	14	1	458390.497	5074463.966	119.189	2	3	–2	4	9	4
28	3	14	2	458405.309	5074470.731	118.308	1	1	10	1	1	100
29	3	15	1	458390.496	5074463.969	119.187	3	0	0	9	0	0
30	3	15	2	458405.306	5074470.734	118.317	4	–2	1	16	4	1
Average over series			1	458390.499	5074463.969	119.187	–	–	–	–	–	–
			2	458405.310	5074470.732	118.318						
Summation of the squared residual				–	–	–	–	–	–	144	186	1476
Experimental standard deviation s				2.27	2.58	7.26	–	–	–	–	–	–

Table 6 – Results of statistical tests

Question	Null hypothesis	Obtained result
a)	$s_{xy} \leq \sigma_{xy}$	7.37 ≤ 12.65
	$\tilde{s}_{xy} \leq \sigma_{xy}$	3.43 ≤ 12.65
b)	$s_h \leq \sigma_h$	8.12 ≤ 19.52
	$\tilde{s}_h \leq \sigma_h$	7.26 ≤ 19.52
c)	$\sigma_{xy} = \tilde{\sigma}_{xy}$	0.59 ≤ !4.61 ≤ !1.70
d)	$\sigma_h = \tilde{\sigma}_h$	0.47 ≤ 1.25 ≤ 2.13

The statistical test according to question a) is fulfilled and the null hypothesis is accepted. With a 95% probability it's concluded that the calculated experimental standard deviations of coordinates (*x*, *y*) for both measuring sessions (s_{xy} and $\tilde{s}_{xy}$) are smaller or equal to a corresponding theoretical value stated by the manufacturer (Table 6). Measurements were carried out with the expected precision.

The statistical test according to question b) is fulfilled and the null hypothesis is accepted. With a 95% probability it's concluded that the calculated experimental standard deviations of height for both measuring sessions (s_h and $\tilde{s}_h$) are smaller or equal to a corresponding theoretical value stated by the manufacturer (Table 6). Measurements were carried out with the expected precision.

The statistical test according to question c) is not fulfilled, the null hypothesis stating that the experimental standard deviations s_{xy} and $\tilde{s}_{xy}$ belong to the same population is rejected at the confidence level of 95% and alternative hypothesis is accepted (Table 6).

The statistical test according to question d) is fulfilled, the null hypothesis stating that the experimental standard deviations s_h and $\tilde{s}_h$ belong to the same population is accepted at the confidence level of 95% (Table 6).

Conclusions

Quality testing and calibration of surveying instruments are the basis of geodetic profession. Surveyors carry great responsibility in their work since they have a direct impact on property-legal affairs as well as forming important industrial, traffic and construction objects in the field. The accuracy guarantee of geodetic field works is possible only by thorough testing of surveying instruments. The best way to perform testing is by using ISO standards, since they are a set of standardized steps necessary to perform a reliable testing.

This paper gives a detailed review of standard ISO 17123-8:2015 for testing GNSS RTK measuring systems, as well as gathering measurements in the test field at Klaićeva Street in Zagreb, near the Faculty of Geodesy, University of Zagreb and their processing according to this standard. Subject of testing was Topcon HiPer SR GNSS receiver (Ser. No. 1054-16245), with declared accuracy of ±(10 mm + 0.8 ppm) horizontally and ±(15 mm + 1 ppm) vertically. RTK measurements are performed by connecting to CROPOS and using VPPS service. Coordinates of measured points are given in current official horizontal and vertical reference coordinate systems in Croatia (*E*, *N*, *H*).

Testing yielded the results of horizontal accuracy with a standard deviation of 7.37 mm for the first and 3.43 mm for the second measuring session. The achieved vertical accuracy was with a standard deviation of 8.12 mm for the first and 7.26 mm for the second measuring session. Null hypothesis was accepted in statistical tests according to questions a), b) and d), and alternative hypothesis was accepted in a statistical test according to question c). The conclusion is that measuring system Topcon HiPer SR meets measurement uncertainty needed for RTK measurements declared by the instrument manufacturer; however experimental standard deviations in horizontal plane did not belong in the same population.

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