IN-SITU TESTING OF GNSS RECEIVERS IN COMPLIANCE WITH ISO 17123-8 PROCEDURE

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Summary: The paper presents the ISO 17123-8:2015 standard, for calibrating GNSS receivers in RTK mode. This standard calibrating method uses the principle of trilateration, determining a receiver location based on the known satellites coordinates and lengths from the satellite to the receiver in real-time. Measurement is done by the static and the RTK method in three measuring sessions. It is explained in details here, with illustration of the results obtained on the polygon designed according to the recommendations from the standard. The polygon is temporarily fixed in an appropriate place, allowing the modification of the standard method. Statistical results for the lengths are congruent, but for the height differences, the differences are noticed. One of the reasons is, certainly, presence of artificial and natural objects producing multipath reflection, which influence the quality of received signals and accuracy.

Keywords: GNSS, calibration, ISO 17123, RTK

1. INTRODUCTION

Field testing and instrument calibration are counterparts of all metrology orientated geodetic engineers, which, in that way, confirm their competence and quality of obtained results. It is known that all measuring results are loaded with random and systematic errors. A task of each engineer is to find systematic impacts and to include it in the measurements or to eliminate them. New technologies and integration of measurement devices force, also, development of new calibration methods. The calibration methods go through a validation process and become eligible as methods specially developed in the
6. МЕЂУНАРОДНА КОНФЕРЕНЦИЈА

laboratories accredited by the ISO 17025 standard. GNSS equipment is present on the market decades ago, while the ISO 17123-8 for RTK GNSS calibration is published in 2007, enabling the conditions for the accredited laboratories to incorporate this method into their activities.

2. BACKGROUND

2.1. STANDARDIZATION AND INTERNATIONAL STANDARDS

ISO (International Organization for Standardization) is the biggest volunteer developer of the international standards. The international standards give products specifications, services and practice, and help the industry to be more efficient and effective. They are developed through general agreement and help to remove the barriers of the world trade. The ISO standards represent strategic tools which lower the costs, by minimizing the errors and increase of productivity. They give the possibility to companies to access new markets, help the developing countries and allow global and fair trade. The organization is founded in 1947. Up to now, it published over 19 000 international standards which its member have bought.

According to the Serbian Standardization Law, Institute for Standardization of Serbia (ISS) is the only body for standardization of the Republic of Serbia (URL 1). Beside its other activities, ISS: publishes, develops, tests, changes, edits, and withdraws the Serbian standards and related documents; cooperates with European and international organizations for standardization and the national bodies; provides availability of Serbian standards to the public, and performs other tasks according to obligations from international contracts in the field of standardization, which obligates the Republic of Serbia.


2.2. STANDARD ISO 17123 - Part 8

In 2007, ISO presented the overall standard method for testing the GNSS receivers, for the real-time measurements. The development of the methods, 8 countries from the subcommittee took part, the measurements are performed in 10 countries, by the representatives of the main manufacturers of the GNSS equipment. This standard prescribed the procedure of calibrating the GNSS receivers in the RTK mode, intended for use in surveying, civil engineering, and industrial measurements. Basically, the testing results show whether the GNSS equipment functions correctly, and whether is possible to achieve precision stated by the instrument manufacturer. The testing concept reduces to comparison of the distance \( D^M \) and a height difference \( h^M \) between two points, with previously determined nominal-standard values \( (D^T, h^T) \). The standard values \( D^T, h^T \) are determined by the surveying methods that provide better precision. The polygon
assumes points fixed at the distance smaller than 20 m. Receivers testing according to ISO 17123-8 comprises [1] [2]:

- the simplified field test procedure, and
- the full field test procedure.

The former method consists of the measuring session in the static mode, resulting in the baseline \( D_{1,2} \), between the points \( R_1 \) and \( R_2 \). Afterwards, the baseline is moved up to 10 m, proceeding to the latter method which consists of three base-rover measuring sessions (\( B-R_1, B-R_2 \)), done in different time intervals. The full field test procedure is used for removing the gross errors, estimation of the measuring uncertainty, and statistical testing. After the standard, the series consists of five measurements at the points \( R_1 \) and \( R_2 \), which are performed in five minutes intervals. It takes about 25 min to complete one series of measurements, i.e., determining the coordinates of the points \( R_1 \) and \( R_2 \). The result of each measurement are the orthogonal coordinates of the points \( R_2(x_{ij,2}, y_{ij,2}) \) and \( R_1(x_{ij,1}, y_{ij,1}) \), as well as the heights \( h_{ij,2} \) and \( h_{ij,1} \).

![Figure 1: The baseline \( R_1-R_2 \)](image)

The next step, after completion of the measurements, is two-step estimation process. The first step is testing and extraction of the gross errors, which are excluded from the further analysis. In the second step, for each measurement set \( j = 1, \ldots, 5 \) within the three series \( i = 1, \ldots, 3 \), the distance and the height difference are determined using:

\[
D_{i,j} = \sqrt{(x_{i,j,2} - x_{i,j,1})^2 + (y_{i,j,2} - y_{i,j,1})^2}; \Delta h_{i,j} = h_{i,j,2} - h_{i,j,1} \tag{1}
\]

with the differences:

\[
\varepsilon_{D_{i,j}} = (D_{i,j})^M - (D_{i,j})^T; \varepsilon_{h_{i,j}} = (h_{i,j})^M - (h_{i,j})^T \tag{2}
\]

The gross error test is expressed as:

\[
|\varepsilon_{D_{i,j}}| \leq 2.5 \cdot \sqrt{2 \cdot s_{xy}}; |\varepsilon_{h_{i,j}}| \leq 2.5 \cdot \sqrt{2 \cdot s_h} \tag{3}
\]

where \( s_{xy} \), \( s_h \) are standard deviations. In the case the conditions (3) are not fulfilled, it means that there are the gross errors and the measurements should be repeated. After the gross error testing is over, one should estimate the unknown parameters by forming the mean values:

\[
\bar{x}_k = \frac{1}{15} \sum_{i=1}^{15} \sum_{j=1}^{5} x_{i,j,k}; \bar{y}_k = \frac{1}{15} \sum_{i=1}^{15} \sum_{j=1}^{5} y_{i,j,k}; \bar{h}_k = \frac{1}{15} \sum_{i=1}^{15} \sum_{j=1}^{5} h_{i,j,k} \tag{4}
\]

Deviations from the arithmetical mean are calculated as:

\[
\hat{r}_{i,j,k} = \bar{x}_k - x_{i,j,k}; \hat{r}_{i,j,k} = \bar{y}_k - y_{i,j,k}; \hat{r}_{i,j,k} = \bar{h}_k - h_{i,j,k} \tag{5}
\]

the residuals:
6. МЕЂУНАРОДНА КОНФЕРЕНЦИЈА

Савремена достигнућа у грађевинарству 20. април 2018. Суботица, СРБИЈА

\[
\sum_{j=1}^{n} x_{j}^2 = \sum_{i=1}^{n} y_{i}^2 = \sum_{i=1}^{n} z_{i}^2 = \sum_{i=1}^{n} r_{i,j}^2
\]

and the empirical standard deviation of single values:

\[
s_x = \sqrt{\frac{\sum x_i^2}{m}}; \quad s_y = \sqrt{\frac{\sum y_i^2}{m}}; \quad s_h = \sqrt{\frac{\sum h_i^2}{m}}
\]

Experimental standard deviation for a single position \((x,y)\) and experimental standard deviation for a single height \((h)\):

\[
s_{\text{ISO-GNSS RTK } xy} = \sqrt{s_x^2 + s_y^2}; \quad s_{\text{ISO-GNSS RTK } h} = \sqrt{s_h^2}
\]

where \(m = (3 \cdot 5 - 1) \cdot 2 = 28\) is a degree of freedom (ISO 17123-8).

After that, a hypothesis tests are done, in order to answer the question: whether the calculated empirical standard deviation is lower or greater from the one claimed by the manufacturer.

1.

\[
H_0: s_{\text{ISO-GNSS RTK } xy} \leq \sigma_{xy}; \quad H_1: s_{\text{ISO-GNSS RTK } xy} > \sigma_{xy};
\]

\[
s_{\text{ISO-GNSS RTK } xy} \leq \sigma_{xy} \cdot \sqrt{\frac{X_i^2 - \alpha \cdot m}{m}}
\]

2.

\[
H_0: s_{\text{ISO-GNSS RTK } h} \leq \sigma_h; \quad H_1: s_{\text{ISO-GNSS RTK } h} > \sigma_h
\]

\[
s_{\text{ISO-GNSS RTK } h} \leq \sigma_h \cdot \sqrt{\frac{X_i^2 - \alpha \cdot m}{29}}
\]

\[
s_h \leq \sigma_h \cdot 1.22
\]

The theoretical values of the standard deviations of the position \(\sigma_{xy}\) and the height difference \(\sigma_h\) are declared by the manufacturer and, congruent to testing, the hypotheses can be accepted or rejected.

In the case of two series, Fisher test shows whether the experimental standard deviations of the position \(\left(s_{\text{ISO-GNSS RTK } xy}, \bar{s}_{\text{ISO-GNSS RTK } xy}\right)\) and the height difference \(\left(s_{\text{ISO-GNSS RTK } h}, \bar{s}_{\text{ISO-GNSS RTK } h}\right)\) belong to the same population. The following hypothesis is tested:

3.

\[
H_0: \bar{s}_{\text{ISO-GNSS RTK } xy} = \bar{s}_{\text{ISO-GNSS RTK } xy}; \quad H_1: \bar{s}_{\text{ISO-GNSS RTK } xy} \neq \bar{s}_{\text{ISO-GNSS RTK } xy}
\]

\[
0.59 \leq \frac{F_1 - \alpha \cdot m}{\bar{s}_{\text{ISO-GNSS RTK } xy} < 1.7}
\]

\[
H_0: \bar{s}_{\text{ISO-GNSS RTK } h} = \bar{s}_{\text{ISO-GNSS RTK } h}; \quad H_1: \bar{s}_{\text{ISO-GNSS RTK } h} \neq \bar{s}_{\text{ISO-GNSS RTK } h}
\]

\[
0.47 \leq \frac{F_1 - \alpha \cdot m}{\bar{s}_{\text{ISO-GNSS RTK } h} < 2.13}
\]
3. RESULTS AND DISCUSSION

3.1. TEST POLYGON

Field testing was performed at the temporary fixed polygon (Fig. 2). The test equipment comprises the base receiver (Topcon Legacy E) and the rover (Topcon HiPer GGD) with L1 + L2 accuracy of 3 mm + 0.5 ppm, L1 accuracy of 5 mm + 0.5 ppm. RTK L1 + L2 accuracy is 10 mm + 1.5 ppm, while on L1 it is 15 mm + 2 ppm.

![Figure 2. Disposition of the test polygon](image)

First measurement phase comprises determining the baseline between the rover (R1 point) and the base (R2). The distance and the height difference are determined according to the coordinate differences obtained from the 30 min long session. In the second phase, the base is moved about 10 m from R1 and R2, when 10 measurements in 5 series between R1 and R2 are taken.

3.2. MEASUREMENT RESULTS PROCESSING

Gross error testing
Conditionally accurate values for the distance and the height difference are obtained from the static measurements as:

\[ D_{1-2} = 3.018 \text{ m}; \ h_{1-2} = 0.123 \text{ m} \]  \hspace{1cm} (17)

After that, the base is moved, while 10 baselines for both R1 and R2 points are determined by the rover. The distances and the height differences are calculated using (1). The results are given in Table 1 (distances) and Table 2 (height differences).
The next step is calculation of the distances and height differences deviations, as the difference between the conditionally accurate values and the measured ones. The results of this phase are given in the Table 3 and Table 4.

**Table 1 Distances obtained by kinematic positioning**

<table>
<thead>
<tr>
<th>$D_{1,1}$ [m]</th>
<th>$D_{1,5}$ [m]</th>
<th>$D_{1,10}$ [m]</th>
<th>$D_{1,15}$ [m]</th>
<th>$D_{1,20}$ [m]</th>
<th>$D_{1,25}$ [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>105-106</td>
<td>3.019</td>
<td>203-204</td>
<td>3.005</td>
<td>303-304</td>
<td>3.003</td>
</tr>
<tr>
<td>107-108</td>
<td>3.010</td>
<td>205-206</td>
<td>3.027</td>
<td>305-306</td>
<td>3.000</td>
</tr>
<tr>
<td>109-110</td>
<td>3.010</td>
<td>207-208</td>
<td>3.010</td>
<td>307-308</td>
<td>3.009</td>
</tr>
<tr>
<td>113-114</td>
<td>3.016</td>
<td>211-212</td>
<td>3.018</td>
<td>311-312</td>
<td>3.013</td>
</tr>
<tr>
<td>117-118</td>
<td>3.027</td>
<td>215-216</td>
<td>3.014</td>
<td>315-316</td>
<td>3.008</td>
</tr>
<tr>
<td>119-120</td>
<td>3.015</td>
<td>217-218</td>
<td>3.017</td>
<td>317-318</td>
<td>3.017</td>
</tr>
</tbody>
</table>

**Table 2 Height differences obtained by kinematic positioning**

<table>
<thead>
<tr>
<th>$\Delta h_{1,1}$ [m]</th>
<th>$\Delta h_{1,5}$ [m]</th>
<th>$\Delta h_{1,10}$ [m]</th>
<th>$\Delta h_{1,15}$ [m]</th>
<th>$\Delta h_{1,20}$ [m]</th>
<th>$\Delta h_{1,25}$ [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>103-104</td>
<td>0.109</td>
<td>201-202</td>
<td>0.114</td>
<td>301-302</td>
<td>0.078</td>
</tr>
<tr>
<td>105-106</td>
<td>0.113</td>
<td>203-204</td>
<td>0.107</td>
<td>303-304</td>
<td>0.121</td>
</tr>
<tr>
<td>107-108</td>
<td>0.122</td>
<td>205-206</td>
<td>0.087</td>
<td>305-306</td>
<td>0.162</td>
</tr>
<tr>
<td>109-110</td>
<td>0.105</td>
<td>207-208</td>
<td>0.124</td>
<td>307-308</td>
<td>0.122</td>
</tr>
<tr>
<td>111-112</td>
<td>0.095</td>
<td>209-210</td>
<td>0.122</td>
<td>309-310</td>
<td>0.102</td>
</tr>
<tr>
<td>113-114</td>
<td>0.152</td>
<td>211-212</td>
<td>0.096</td>
<td>311-312</td>
<td>0.110</td>
</tr>
<tr>
<td>115-116</td>
<td>0.126</td>
<td>213-214</td>
<td>0.103</td>
<td>313-314</td>
<td>0.115</td>
</tr>
<tr>
<td>117-118</td>
<td>0.079</td>
<td>215-216</td>
<td>0.097</td>
<td>315-316</td>
<td>0.110</td>
</tr>
<tr>
<td>119-120</td>
<td>0.096</td>
<td>217-218</td>
<td>0.098</td>
<td>317-318</td>
<td>0.117</td>
</tr>
<tr>
<td>121-122</td>
<td>0.086</td>
<td>219-220</td>
<td>0.113</td>
<td>319-320</td>
<td>0.095</td>
</tr>
</tbody>
</table>
The measurements that do not fulfil the criteria (18) are marked grey in the Tables 3 and 4, based on the boundary allowed values of the length and height differences deviations.

\[
\begin{align*}
\rho_{LB}^{\max} &= 2,5\sqrt{2}\sigma_{LB} = 10 \text{ mm}; \\
\rho_{H}^{\max} &= 2,5\sqrt{2}\sigma_{H} = 15 \text{ mm}
\end{align*}
\]
Calculation of the standard deviation

The standard deviation of the length is obtained following the Error propagation law:

\[ s_{xy} = \sqrt{\left( \frac{\partial D}{\partial x} \sigma_x^2 \right)_1^2 + \left( \frac{\partial D}{\partial y} \sigma_y^2 \right)_2^2 + \left( \frac{\partial D}{\partial z} \sigma_z^2 \right)_3^2} \]  

(19)

with \( \frac{\partial D}{\partial x}, \frac{\partial D}{\partial y}, \frac{\partial D}{\partial z} \) – partial derivatives of the length \( D_{1-2} \) giving:

\[ s_{xy} = 7.8 \text{ mm} \]  

(20)

The standard deviation of the height difference is calculated as:

\[ s_h = \sqrt{(\sigma_h^2)_1 + (\sigma_h^2)_2} = 22.8 \text{ mm}. \]  

(21)

Hypotheses testing

To test the distance accuracy, we tested the hypothesis:

\[ H_0: s_{xy} = \sigma_{xy}; H_1: s_{xy} \neq \sigma_{xy} \]  

(22)

with the test statistics: \( \chi^2 = 24.082 \), which is compared to \( \chi^2_{f, 0.05} \) for the confidence level \( \alpha = 0.05 \) and \( f = m \cdot (n - 1) \cdot p = 5 \cdot (10 - 1) \cdot 1 = 45 \) degrees of freedom, giving \( \chi^2_{f, 0.05} = 61.656 \). Since \( \chi^2 < \chi^2_{f, 0.05} \), there are no reason to reject the null hypothesis, which leads to the conclusion that the achieved accuracy is congruent to the requested one.

To test the accuracy of the height difference, we test the hypothesis:

\[ H_0: s_h = \sigma_h; H_1: s_h \neq \sigma_h \]  

with the test statistics: \( \chi^2 = 103.616 \). It is compared to the probability \( \chi^2_{f, 0.05} \) using the confidence level \( \alpha = 0.05 \) and \( f = m \cdot (n - 1) \cdot p = 5 \cdot (10 - 1) \cdot 1 = 45 \) degrees of freedom. The obtained value is \( \chi^2 > \chi^2_{f, 0.05} = 61.656 \). Herein, \( \chi^2 > \chi^2_{f, 0.05} \), which means that we are accepting the alternative hypothesis, concluding that the accuracy of the height differences is not congruent with the one declared by the manufacturer.

After the completed measurements and data processing, we conclude that the desired positional accuracy \( s_{xy} \) is achieved by the accuracy of the height differences \( s_h \) is out of the boundary conditions. These deviations are caused by the bad satellite constellation during the measurements and high multipath reflection from a number of high artificial objects in the vicinity of the receivers. That fact leads to a conclusion that an extreme caution should be paid on the location of the polygon and the characterization and location of the surrounding objects.

4. CONCLUSIONS AND REMARKS

In ISO 17123-8, it is not prescribed whether the base receiver belongs to the owner of the rover, or the laboratory receiver is used. That is why a CORS network’s receiver can be used, as well as any other RTK capable receiver. There is a possible problem with the permanent network reflected in absence of communication with the control centre, which could cause the interruptions during the measurements. Instead of real-time measurements, post-processing kinematic method can be applied, with no loss in
accuracy. Other influences that could degrade the accuracy of the calibration results are the errors of: clock, ephemeris, receiver phase centre, multipath reflection, troposphere and ionosphere and satellite geometry. Also, using the GNSS processing software [3] can include some errors related to the applied mathematical model.

REFERENCES


TERENSKO ISPITIVANJE GNSS PRIJEMNIKA
U SKLADU SA PROCEDUROM ISO 17123-8

Rezime: U radu je predstavljen pregled međunarodnog standarda ISO 17123-8: 2015 za etaloniranje sistema GNSS RTK. Ova standardna metoda etaloniranja koristi princip trileteracije tako što se na osnovu poznatih koordinata satelita i dužine od satelita do prijemnika u realnom vremenu može odrediti položaj prijemnika. Merenje se vrši statičkom metodom i RTK metodom u tri merne sesije i detaljno je opisano u ovom radu sa ilustracijom dobijenih rezultata na poligonu dizajniranom u skladu sa preporukama u standardu. Poligon je privremeno stabilizovan na odgovarajućem mestu, omogućivši modifikaciju standardne metode. U statističkim testiranjima za dužinu su dobijeni adekvatni rezultati ali je za visinsku razliku uočeno odstupanje. Jedan od razloga je svakako i prisustvo veštačkih i prirodnih objekata koji proizvode višestruke refleksije i utiču na kvalitet primljenog signala i tačnost.

Ključne reči: GNSS, etaloniranje, ISO 17123, RTK