Accuracy Assessment for 5 Commercial RTK-GNSS Systems using a New Roadlaying Automation Test Center Calibration Track

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Abstract –

In Finland several work sites reported errors of several centimeters between the height results when using different commercial virtual reference station networks and receiver brands. The real time kinematic results are calculated by manufacturer-provided software containing in-house know-how. Further complications for calculations will arise when using physical or especially virtual base stations. In the study five commercial RTK-GNSS systems using a local base station and three virtual reference networks are tested for static accuracy at the OuluZone construction automation center at high precision static GNSS track. Errors on the several-centimeter level were found, and for one manufacturer, even larger gross errors were seen, possibly caused by operator error.

Keywords –

RTK-GNSS, Accuracy of measurement, Virtual reference station

Introduction

Automated 3-D machine control systems have been active research and developments targets during the last decade. The use of the present commercial systems is nowadays very common especially in the Northern countries such as Finland (estimated at over 1500 systems in 2016), Norway and Sweden. These automated machine control systems operate using specific, partly automated, guidance or control methods. When using the guidance method (such as a road grader), the operator drives the machine movements and control blade based on a graphical user interface to the machine control model, where online location and position of the blade are shown. In the control method (such as road grader and bulldozer), the blade is automatically moved according to the machine movements driven by the operator, and the calculated difference of the blade to the machine control model. Continuous accurate 3-D positioning of moving machines and/or blades is the key function for automated 3-D machine control. Two alternative 3-D measurement techniques are typically used on construction sites, i.e. real-time kinematic global navigation satellite system (RTK-GNSS) or kinematic robotic total stations. Robotic total stations need accurate reference points with 200-300 m intervals in order to locate themselves in the site coordinate system used. These instruments typically do not use a model of the local geoid, though error caused by this is likely negligible.

During 2013-2014 in Finland several work sites have reported deviations at the several-centimeter level (even 5-10 cm) between the height results of commercial RTK-GNSS systems with real base stations on site, different commercial RTK correction services and total station systems used. No specific and solvable reasons for the deviations were found by the studies made on the sites. Based on the observations, University of Oulu planned and started a new research project "3D measurement base". The aim was focused to study the improvement of the accuracy and reliability of 3D measurements on road and railway construction sites utilizing RTK-GNSS measurement systems and robotic total stations.

In the literature, the achievable precision of RTK-GNSS using both real base stations and network corrections, has been studied, e.g., Berber & Arslan (2013), Martin & McGovern (2012) and especially Bae et al. (2015). A recurring theme is, that discrepancies with ground truth may be in the 5-10 cm ball park, rather than the 2-3 cm tolerances that are often specified and also assumed by us. So, while not new in principle, our results should sound a warning bell.

Method

The study was carried out in the Ouluzone center located about 30 km North-East of Oulu City. A new reference measurement network with three reference points was built and measured in the Ouluzone center area. The coordinates of the reference points (A, B, C) were measured using the static GNSS measuring method in ETRS-GK26 map co-ordinates [1] and the N2000 height system [2]. The maximum random error after adjustment was found to be 7 mm (horizontal) and 12 mm (vertical). As initial reference points, two points (95M8121, 09M5402) measured earlier by the National Land Survey of Finland were used.. The Mobile 3G network was available for the wireless communication during measurements.

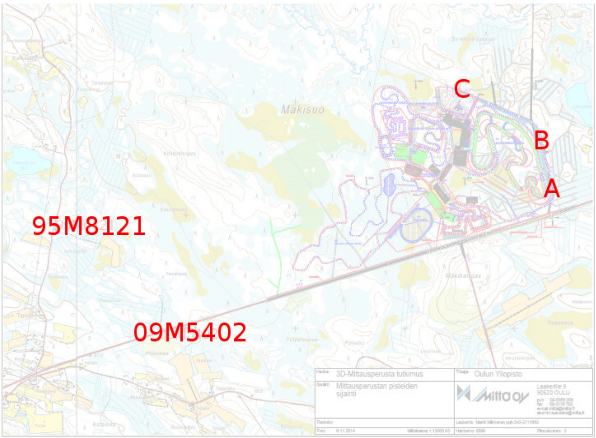

Figure 1. Map of the reference target points (A, B, C) with the global coordinate references (95M6121, 09M5402). Map is approx. 5 km wide.

Figure 2. Setting up a base station.

In total, five different commercial RKT-GNSS systems were found to have been imported and sold in Finland in 2014-2015. All of the companies involved (Leica Geosystems Oy, Geotrim Oy, Sitech Finland Oy, Topgeo Oy, Geolaser Oy and Geostar Oy) were invited to execute measurements of the reference points. University of Oulu was observing and documenting the measurements and observations.

Figure 3. Measurement of a reference point in Ouluzone by a commercial RTK-GNSS system.

In the measurement test, each of the reference points A, B and C were measured using different available measurement modes. The first series was measured using the own base station located on the reference point 09M5402. Position correction information was sent real-time by radio modem or 3G network. Measurements were repeated using sequentially Trimble Trimnet, Leica Smartnet and the correction service of Finnish Geospatial Research Institute FGI. All the GNSS observations above 5 degrees angles above horizon level were accepted into the adjustments. As measurement modes, quick point mode (1 observation), mapping mode (5 observations) and benchmark mode (60 s observations) were used. From the observations, GK26 coordinates with N2000 height coordinate as well as WGS84 coordinates (latitude, longitude) and GRS80 ellipsoidal height were calculated for later analysis.

Results

The measurement results compared to the reference coordinates are presented considering the five different commercial systems available and used in Finland 2014-2015. The tested systems were Trimble SPS985 (Sitech Finland Oy), Trimble R10 (Geotrim Oy), Leica iCON iCG60 (base) and Leica Viva GS14 (rover, Leica Geosystems Oy), Topcon (GR5) and Geomax.

We summarize as examples the measurement results in point A by the Geomax system (table 1) and the Trimble SPS985 system (figures 4-6). The results for all systems are verbally summarized below.

Table 1. Measurement results of the reference point A in Ouluzone by the Geomax system. A means point A, R own base station, S Smartnet, G FGI, V Trimnet, 1 quick point mode, 5 mapping mode, 60 benchmark mode. The *xy* co-ordinates are, in whole metres: x = 73230796 m, y = 26503151 m, decimal fractions in table.

Point, mode	x	y	dx	dy	dz	dxy
AR1	.132	.568	-0.004	-0.003	+0.044	0.005
AR5	.137	.572	+0.001	+0.001	+0.048	0.001
AR60	.133	.572	-0.003	+0.001	+0.046	0.003
AS1	.119	.588	-0.017	+0.017	+0.033	0.024
AS5	.112	.588	-0.024	+0.017	+0.013	0.029
AS60	.124	.588	-0.012	+0.017	+0.020	0.021
AG1	.157	.588	+0.021	+0.017	+0.027	0.027
AG5	.167	.588	+0.031	+0.017	+0.036	0.035
AG60	.169	.582	+0.033	+0.011	+0.014	0.035
AV1	.123	.577	-0.013	+0.006	+0.044	0.014
AV5	.115	.575	-0.021	+0.004	+0.030	0.021
AV60	.142	.576	+0.006	+0.005	+0.102	0.008

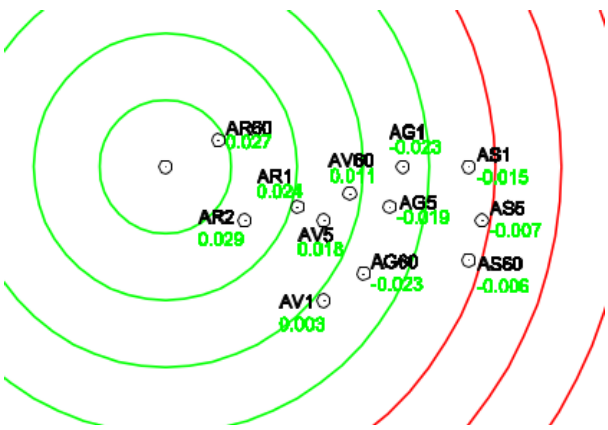

Figure 4. Measurement results at the reference point A (Trimble SPS985). In the dartboard, *xy* deviations were illustrated by circle lines with 5 mm intervals, green lines are inside the tolerance and red lines outside the allowed tolerance. Vertical *z* deviation is presented numerically, where the deviations inside the tolerance (±30 mm) are green and the deviations outside the tolerance red ones.

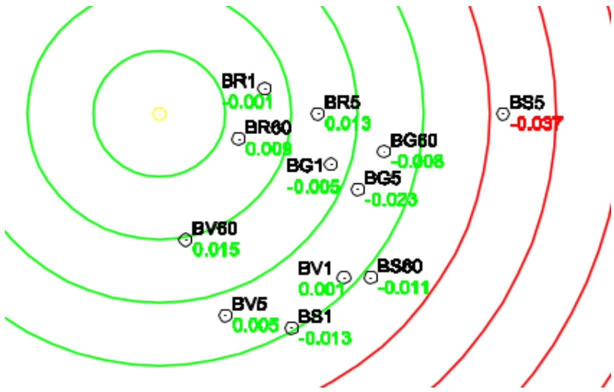

Figure 5. Measurement results at the reference point B (Trimble SPS985).

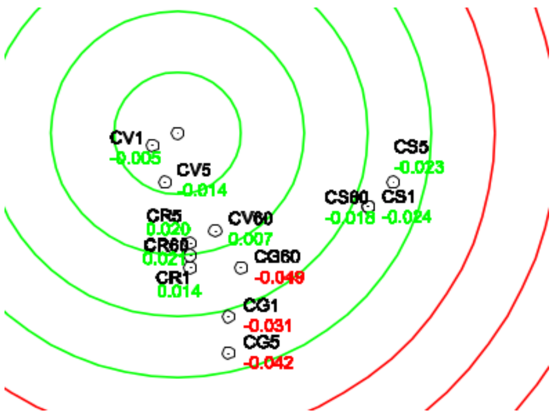

Figure 6. Measurement results at the reference point C (Trimble SPS985).

Considering the **Trimble SPS985** system, all the measurement results with own base station at the points A, B and C were accurate and inside the tolerances. The results using the Trimnet correction service were also accurate at all the points. When using Smartnet corrections, the results were accurate at all points except point A, where a +0.024 m deviation was found. Using FGI corrections all the results were good with the exception of point C, where height deviations were -0,031 m, -0,042 m and -0,049 m.

Considering the **Trimble R10** system, the measurement results using own base station were nearly within tolerances at the A and B points, at C there were *z* deviations of -0.031…-0.033 m. The results using Trimnet were accurate at point B, at point A there were *z* deviations of +0.033…+0.044 m. When using the Smartnet corrections, the point A was measured accurately, at points B and C there were minor deviations outside tolerances like -0.029…+0.022 m. When using FGI corrections, all the points and coordinates were measured accurately.

Considering the **Leica RTK-GNSS system** (Leica iCON iCG60 antenna, iCON CC65 control unit, Viva GS14 performance, Viva CS15 control unit), all the *xy* results with own base station were good and inside tolerances at all the points A, B and C. The *z* deviations at points B and C were -0.032…-0.042 m. The *xy* results when using Trimnet corrections were good at points A and B, but at point C there were *xy* deviations of -0.028…-0.033 m. At points A and B there were *z* deviations of -0.045…+0.058 m. When using Smartnet corrections, point C was measured accurately with all the correction methods, but at point A there were *y* deviations of +0.029…+0.033 m, and at points A and B, +0.033…+0.054 *z* deviations. When using FGI correction, points A and B were measured accurately enough, at point C there were z deviations as -0.042…-0.048 m.

Considering the **Topcon GR5** RTK-GNSS system, the results with own base station were good except at point C, where the *z* deviation was 5-6 cm. The *xy* results when using Trimnet corrections were good, however there were some 4-5 cm deviations especially at points B and C. When using Smartnet or FGI corrections, there were significant deviations as follows: point A – *xy* deviations of 8-9 cm and *z* deviations of 17-23 cm when using Smartnet corrections, *xy* deviations 6-7 cm and *z* deviation 10 cm when using FGI correction. Point B – *xy* deviations of 4-7 cm when using Smartnet corrections. Point C – *xy* deviations 7-12 cm and *z* deviation 12-20 cm when using Smartnet corrections.

Considering the **Geomax RTK-GNSS** system, the results with own base station were inside the tolerances at points B and C. At point A there were +0.044…+0.048 m *z* deviations. The *xy* results with Trimnet correction were good at all the points, but there were +0.044…+0.048 m deviations in *z* direction. When using Smartnet corrections, all the coordinates were quite accurate at points A and B, at point C there were *xy* deviations of +0.024…+0.032 m. When using FGI corrections, the results of point C were within tolerance, at points A and B there were *xy* deviations of +0.021…+0.033 m and *z* deviations of +0.036… -0.047 m.

Considering the **overall results** in terms of worst-case errors per measurement system /correction source combination (figure 7), we found that, with the exception of two Topcon combinations, all combinations perform similarly slightly poorer than the set tolerances, without any clear single cause being implicated.

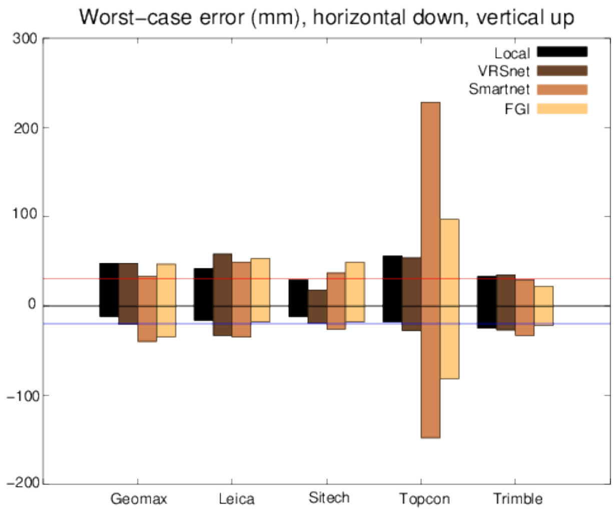

Figure 7. Worst-case error, over nine measurements each for every measurement system / correction source combination, separately for horizontal and vertical errors. Tolerances plotted as red/blue lines.

Conclusions

In the study, five different commercial RTK-GNSS systems used in Finland were used for research experiments at the Ouluzone test center. Also the different RTK correction methods on offer in Finland were used for comparisons in the tests. A significant observation was that the results of the Topcon GR5 system used were quite inaccurate when using the

Smartnet or FGI correction services. No obvious reason was found, but, with complex systems like this, operator error is always possible as an explanation. The best of the tested systems was, according to the test results, the Trimble SPS985 system presented by Sitech Finland, but the difference with the other systems appears not to be statistically significant.

However, even when the most obviously poor results are left outside consideration, there remain largish discrepancies that could not be clearly tied to GNSS system used, RTK correction source used, or observation mode. It would appear that the RTK-GPS technique is not quite as robustly precise as some would like to believe. This is something users would ignore at their peril.

It would appear, and this agrees with literature studies, e.g., Bae et al. (2015), that the RTK-GNSS technique is not quite as robustly precise as some would like to believe. This is something users would ignore at their peril. A solution to this conundrum may be two-fold: often the specified tolerances of 2-3 cm are unnecessarily tight, and may be relaxed. Where this is not possible, the RTK-GNSS technique should not be used but rather, e.g., terrestrial guidance systems.

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