Evaluation of low cost GNSS receivers based on the ISO RTK standards

Antonis SIOULIS, Maria TSAKIRI, Dimosthenis STATHAS

School of Rural and Surveying Engineering, National Technical University of Athens

Key words: GNSS, high-sensitivity navigation-type receivers, ISO standards

SUMMARY

The emergence of single-frequency, navigation-type receivers capable to provide carrier phase data (the so-called high sensitivity carrier phase positioning) has been steadily growing over the recent years. The level of positioning accuracy obtained with navigation-type receivers has raised interest to various communities that use positioning information.

Over the last years, various researchers have investigated the potential of high-sensitivity navigation-type receivers and antennas with analysis on their positioning performance in post-processing and RTK modes. Although the above efforts express valuable guidelines for the practical use of navigation-type receivers, they lack standardized test procedures. In addition, these procedures are not always easily tractable and the time and effort required to perform these are not insignificant.

The main purpose of this study is evaluate the performance of high-sensitivity carrier phase-based positioning using navigation-type equipment based on the official International Standards Organisation (ISO) specifications for real-time kinematic (RTK) GNSS receivers. A number of standardised experiments will be described using as rover receiver the u-blox NEO-7P XXL bundle package that contains the NEO-7P module and the low-cost antenna Tallysman TW2410. Based on the ISO 17123 part 8 GNSS RTK standards, the experiments include a number of simplified and full test procedures in different observation periods and under varying satellite geometry. The results demonstrate the suitability of the u-blox NEO-7P XXL bundle package with the NEO-7P module for different type positioning applications.

Evaluation of low cost GNSS receivers based on ISO RTK standards

Antonis SIOULIS, Maria TSAKIRI, George PINIOTIS, Athanasios BIMIS,
Dimosthenis STATHAS

1. INTRODUCTION

The emergence of single-frequency, navigation-type receivers capable to provide carrier phase data (the so-called high sensitivity HS carrier phase positioning) has been steadily growing over the recent years as a cost-effective option over the geodetic-grade receivers. The level of positioning accuracy obtained with navigation-type receivers has raised interest to various communities that use positioning information (e.g. Schwieger and Gläser, 2005).

The HS navigation type receivers are attractive because they are significantly cheaper (in the order of couple hundred euros) compared to the geodetic or survey-type receivers. Additionally, the navigation-type receivers are up to 30 dB more sensitive and thus enable higher GNSS signal availability in places such as urban canyons or even indoor environments. In brief, there are two common ways to improve the "sensitivity" of a GPS receiver. One way is to increase the time for the integration within the receiver of the received signal. For example, conventional GPS receivers integrate the received GPS signals for 1ms resulting to operate with signal strengths down to around the -160dBW level assuming no attenuation occurs whereas a HS receiver can acquire signals below -180 dB. A second way is to increase the number of the correlators thus enabling the use of fast GPS signal search techniques. For example, the navigation type receiver ublox-5 chip has over a million correlators whereas typical GPS receivers work with 36 correlators only (e.g. Zhang et al., 2010).

The above advantages along with the sub-decimetre level coordinate determination in differential post-processing mode have created for the HS navigation-grade receivers much interest to surveyors. For this reason, many researches have analysed the performance of this type of receivers in order to assess their precision and accuracy over various tests and environments. For example, Carver (2005) assesses six navigation type HS receivers by using certain key measures such as position fix, accuracy, sensitivity and consistency. The HS receivers were tested under various conditions and operating configurations designed to approximate common scenarios for a number of GPS applications. In all cases, HS GPS testing was conducted independent of any wireless network, to focus on actual chipset performance rather than total solution performance that would also depend on the wireless network performance. It was shown that the HS GPS provided solutions that are capable of handling high dynamics (e.g moving platform), in an urban area but the same receivers were not the most accurate in a static environment. In a low dynamic and low signal environment the tested HS receivers gave a CEP (circular error probable) in the order of 19m. Schwieger and Gläser (2005) investigated the performance of Garmin eTrex Vista navigation type receivers in a number of test fields and reported that for baselines up to approximately 8 km which were measured for over two hours produced deviations from the nominal values up to 8 cm under low multipath conditions. They also found that the accuracy of the baseline determination is independent of the baseline length up to 8 km. Schwieger (2008) performed tests for three different HS receivers and assessed their accuracy and signal availability in different environments. His results indicated that for all three HS receivers the accuracy is at the level of 2cm for baselines up to 1.1km and measurement times of approximately 30 minutes. Takasu and Yasuda (2008) performed RTK-GPS evaluation tests with HS navigation receivers and low-cost single-frequency antennas and well as geodetic type antennas. The results from the field tests proved that with a low-cost antenna the performance degradation is large and replacing it with a geodetic-grade antenna the position performance is very much improved. Andrei et al. (2011) have conducted various tests in the Helsinki Metropolitan Area in order to investigate the positioning performance and accuracy of the u-blox LEA-6T receivers. The receivers were deployed at several locations to measure baselines with various lengths in a static mode and within a CORS network using virtual reference station (VRS) technique. All the measurements were repeated with geodetic-type, dual-frequency GNSS receivers in order to generate the reference baselines and coordinates at all occupied points. It was found that the high sensitivity navigation type receivers gave accuracy level better than 2cm in a multipath-free environment and the differences from the geodetic coordinates ranged between -3.6 to 6.3cm. Zhang and Schwieger (2013) performed a series of tests using HS receivers and a number of geodetic and navigation types antennas in order to examine the variation in performance. The tests were carried out in Stuttgart by measuring a number of pillars which were also measured using total stations, geodetic GNSS receivers and levelling. The baseline lengths varied from 255 m to 470 m. Also, pillars with different shadowing condition were selected for the test. They obtained accuracies which varied from sub-mm up to a few mm in horizontal position and up to 6 mm in height when the HS receivers used geodetic type antennas with choke ring.

All the above efforts express valuable guidelines for the practical and experimental use of navigation-type receivers but they lack of standardized test procedures. In addition, these procedures are not always easily tractable and the time and effort required to perform these are not insignificant. For this reason, this paper proposes the use of established field procedure standards in order to evaluate the performance of HS navigation type receivers and specifically the u-blox NEO-7P XXL bundle package which is supported by the module u-blox NEO-7P and is used as the rover receiver. The tests follow the ISO 17123 part 8 GNSS RTK field procedures. Primarily, these tests are intended to be field verifications of the suitability of a particular instrument for a required application. The paper is organised as follows: in section 2 a brief description of the ISO 17123 part 8 GNSS RTK standard is given, and in section 3 the equipment used and the field test procedures are described. Section 4 provides the test results and their statistical evaluation and concluding remarks are drawn in section 5.

2. ISO 17123 RTK GNSS standards

The ISO 17123 series Optics and optical instruments — Field procedures for testing geodetic and surveying instruments —Part 8: GNSS field measurement systems in real-time kinematic

(RTK) was published in 2008 (web site of ISO). This part of ISO 17123 describes two different field procedures, namely the simplified test procedure and the full test procedure.

The simplified test procedure consists of a single series of measurements and provides an estimate as to whether the precision of the equipment in use is within a specified allowable deviation. The simplified test procedure is based on a limited number of measurements and thus, a significant standard deviation cannot be obtained and the statistical tests are not applied.

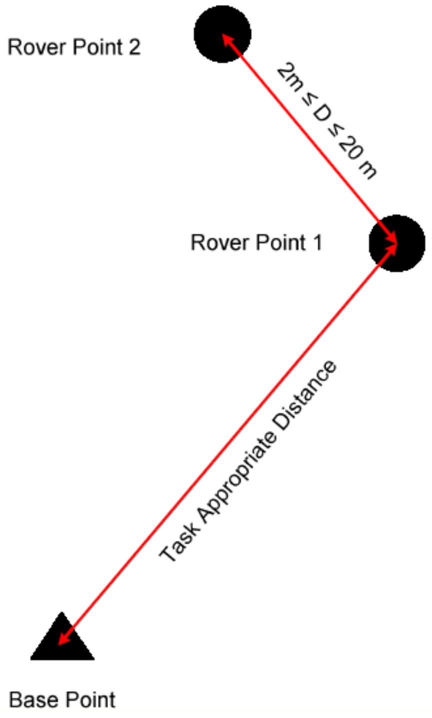

Figure 1. Schematic of test field as per the ISO 17123 —Part 8

The full test procedure is adopted to determine the best achievable measure of precision of the equipment in use. The full test procedure consists of three series of measurements. The full test procedure is intended for determining the experimental standard deviation for a single position and height measurement. Further, this procedure may be used to determine: the measure of the precision of equipment under given conditions (including typical short and long term influences); the measure of the precision of equipment used in different periods of time or under different conditions (multiple samples); the measure of the capability of comparison between different precision of equipment achievable under similar conditions. Statistical tests shall be applied to determine whether the sample from the experiment belongs to the same population as the one giving the theoretical standard deviation and to determine whether two samples from different experiments belong to the same population.

The test field consists of a base point and two rover points. The location of the rover points shall be close to the area of the task concerned. The separation of two rover points shall be a minimum of 2 m and shall not exceed 20 m. The positions of two rover points may be selected at convenience in the field (see Figure 1). The horizontal distance (D) and height difference (Δh) between two rover points shall be determined by methods with precision better than 3 mm other than RTK. These values are considered as nominal values and are used in the first step of both test procedures. The horizontal distances and height differences calculated from the measured coordinates in each set of measurements shall be compared with these values in order to ensure that the measurements are free from any outlier. However, the nominal values are not used in the statistical tests.

In the standardised tests, the RTK data should be exported to horizontal coordinates (x, y) and ellipsoidal heights (h) and only these types of coordinate are treated as the original observables. The data collection includes five sets of x, y and h coordinate measurements. The difference between the measured nominal distances ε_D and heights ε_h and those determined independently must satisfy the following:

$$\begin{aligned} |\varepsilon_D| &\leq 2.5 \times \sqrt{2} \times s_{xy} \\ |\varepsilon_h| &\leq 2.5 \times \sqrt{2} \times s_h \end{aligned} \qquad (1)$$

where s_{xy} and s_h are the a priori uncertainties.

For the full test procedure, the:

$s_{\text{ISO } xy} = \sqrt{s_x^2 + s_y^2}$ **,** which is the experimental standard deviation of a single point (x, y);

$s_{\text{ISO } h} = s_h$, which is the experimental standard deviation of a single height (h)

are statistically compared to a corresponding value s_{xy} and s_h respectively, stated either by the manufacturer or another predetermined value based on the type of application.

3. Data collection and processing

3.1 Equipment

For the tests described below the u-blox NEO-7P XXL bundle package with precise point positioning (PPP) capability which is supported by the module NEO-7P was used. The built-in USB interface provides both power supply and high-speed data transfer, and eliminates the need for an external power supply. The u-blox NEO-7P XXL bundle package is compact with a user-friendly interface and power supply. Like the predesessor models, this can be used with a PDA, smartphone, tablet or a notebook PC. The main feature is that supports AssistNow Online and AssistNow Offline A-GNSS services, as well as GLONASS data acquisition. Also, it supports raw data output at an update rate of 5 Hz and includes carrier phase, code phase and Doppler measurements.

The NEO-7P module uses PPP and has also the ability to use SBAS data, thus providing high precision in clear-sky applications without the need for a reference station. For world-wide application, it also supports Differential GPS (DGPS) operation as an alternative to SBAS and

PPP, using RTCM correction messages from a local reference station or aiding network.

Figure 2 illustrates the weatherproof u-blox NEO-7P XXL bundle package, that contains the compact box (with dimensions 105 x 64 x 26 mm), the **u-blox NEO-7P** module, assembled with a **connectBlue OBS411** Bluetooth SPP module, internal power supply with reduntand Li-Po cells for 40-50 hours (6600 mAh total) runtime (including controlled charging by USB power and cell protection circuits for each LiPo cell), additional assembled pressure compensation element with GORE membrane, the low-cost GNSS antenna **Tallysman TW2410** (bulkhead SMA female), bundled with custom-specific ground plane for improved GNSS reception. The built-in USB interface is used for both power supply and high-speed data transfer.

Figure 2. The u-blox NEO-7P XXL bundle

The data acquisition and processing in real-time is performed using the RTKLIB open-source program library for GNSS standard and precise positioning (Takasu and Yasuda, 2008; www.rtklib.com). RTKLIB is a compact and portable program library to provide several application programs for RTK-GNSS applications, such as RTKPOST (post-processing analysis), RTKNAVI (real-time positioning) RTKPLOT (plot raw observation data and solutions) and RTKCONV (RINEX converter for raw receiver log). The library implements fundamental navigation functions and carrier-based relative positioning algorithms. The integer double-difference ambiguities are determined by the LAMBDA (Least-squares AMBiguity Decorrelation Adjustment) method (Teunissen, 1995). The RTKLIB program also supports precise point positioning (Takasu, 2010). This study uses RTKLIB version 2.4.1.

3.2 Tests

The field test was set up on the building roof of the School of Rural and Surveying Engineering of NTUA (Figure 3). The selected two roving points were measured independently by total station surveying and levelling. The least squares solution gave the following results for the nominal values of horizontal distance between the points 1, 2 and ellipsoidal height difference: D_{12} = 11.381 ±0.004m and Δh = -0.003±0.005m.

The hardware configuration consisted for the base station the geodetic receiver and its choke ring antenna Trimble 5800 a and for the rover station the EVK-7P kit package and the low-cost antenna Tallysman TW2410. The tests were performed in two days, i.e. obtaining two populations of data. The first data populations comprises one series while the second data population comprises the full series as described in the ISO RTK standard.

According to the ISO RTK standard, the data collection consists of three series of measurements. The collected data (x, y) and h are referred to the projection of the Greek datum (EGSA87). For the height values these can be either orthometric or ellipsoidal because their difference is of significance in the numerical evaluation procedure, as discussed in section 4. Each series comprises five successive sets of the two points' measurements. The time lag between successive sets is approximately 5 min resulting to a total span of a series of measurements to be about 25 min. This requirement is based on the fact that the variation cycle of a typical multipath influence is of similar time length, and the measuring procedure should cover this influence factor. The time lag between each series is at least 90 min and this is so that multiple series of measurements tend to reflect influences such as changes mainly in the satellite configuration.

Figure 3. Photo of test configuration

4. Results

Based on the collected data, two numerical tests are used to verify the performance of the rover station. Initially, the simplified test requires the calculation of the horizontal distance and height difference between the two rover points 1, 2 (for each set in the series). Then , their deviations from the nominal values should satify the conditions of equation 1. Due to the fact that the navigation type receeivers have no manufacturer specification on the precision, a number of predetermined values for s_{xy} and s_h have been used depending on the application. Listed below is a table that gives the various classes of real time (RT) GNSS based on the achieved accuracy on the horizontal (H) and vertical (V) at a certain statistical confidence interval (95%) (Henning, 2011). The values of Table 1 are used in the following analysis to determine the performance of the tested equipment. Specifically, Table 2 provides the precision limits of each RT Class based on the ISO standards given by equation 1, which is used for the simplified test. Based on these limits, for any deviation that fails to satisfy either of the two conditions in Equation 1, the inclusion of outliers in the corresponding measurements is suspected.

	CLASS RT1	CLASS RT2	CLASS RT3	CLASS RT4
Accuracy to base station	0.015m H 0.025m V	0.025m H 0.040m V	0.050m H 0.060m V	0.150m H 0.250m V
RMS	≤0.001m	≤0.015m	≤0.03m	≤0.05m
Typical applications	Project control, construction control points, check on traverse and levels, paving stake out, scientific studies	Densification control, topographic control, photogrammetric control points, utility stake out	Topography, cross sections, agriculture, road grading, site grading	Site grading, GIS mapping, environmental applications

Table 1. Accuracy Classes at 95% for RTK GNSS (Henning, 2011)

	CLASS RT1	CLASS RT2	CLASS RT3	CLASS RT4
$\lvert\varepsilon_D\rvert \le 2.5 \times \sqrt{2} \times s_{xy}$	$\lvert\varepsilon_D\rvert \le 0.005\text{m}$	$\lvert\varepsilon_D\rvert \le 0.09\text{m}$	$\lvert\varepsilon_D\rvert \le 0.18\text{m}$	$\lvert\varepsilon_D\rvert \le 0.53\text{m}$
$\lvert\varepsilon_h\rvert \le 2.5 \times \sqrt{2} \times s_h$	$\lvert\varepsilon_h\rvert \le 0.07\text{m}$	$\lvert\varepsilon_h\rvert \le 0.14\text{m}$	$\lvert\varepsilon_h\rvert \le 0.21\text{m}$	$\lvert\varepsilon_h\rvert \le 0.88\text{m}$

Table 2. Precision limits for the horizontal distance and height difference in each RT Class

The results for the field tests showed that RT Class 2 is satisfied for the precision limits of both the horizontal and the vertical (at 95% confidence level), for the two different populations. Based on the ISO standard, for RT Class 2 all deviations ε_D, ε_h satisfy simultaneously the condition of Equation 1 and no outlier is suspected.

Regarding the full test procedure, the experimental standard deviation of the position $s_{\text{ISO xy}}$ and the height $s_{\text{ISO h}}$ are computed and compared to predetermined ones in order to answer specific questions. Table 3 tabulates the results of the full test procedure as per the ISO standard. In the table, questions c) and d) refer to two different samples and whether the experimental standard deviations ($s_{\text{ISO xy\_1}}$, $s_{\text{ISO xy\_2}}$), ($s_{\text{ISO h\_1}}$, $s_{\text{ISO h\_2}}$) belong to the same populations.

According to the design of the measurements followed in the experiment, the value of the degrees of freedom is $\nu_x = \nu_y = \nu_h = 60$, which is required in the calculations of Table 3. At the 95% confidence level, the calculated experimental standard deviations $s_{ISO\ xy}$ and $s_{ISO\ h}$ are compared to the predetermined values of s_{xy} and s_h for each RT Class using a chi-square test (i.e., $\chi^2_{0.95}(120)$ for the horizontal and $\chi^2_{0.95}(60)$ for the vertical). This means that $s_{ISO\ xy} \leq s_{xy} \times 1.105$m and $s_{ISO\ h} \leq s_h \times 1.14$m.

Question	Null hypothesis	Alternative hypothesis	CLASS RT1	CLASS RT2	CLASS RT3	CLASS RT4
a)	$s_{ISO\ xy} \leq s_{xy}$	$s_{ISO\ xy} > s_{xy}$	$s_{ISO\ xy} \leq$ 0.016m	$s_{ISO\ xy} \leq$ 0.027m	$s_{ISO\ xy} \leq$ 0.055m	$s_{ISO\ xy} \leq$ 0. 166m
b)	$s_{ISO\ h} \leq s_h$	$s_{ISO\ h} > s_h$	$s_{ISO\ h} \leq$ 0.028m	$s_{ISO\ h} \leq$ 0.046m	$s_{ISO\ h} \leq$ 0.068m	$s_{ISO\ h} \leq$ 0.285m

Table 3. Full test procedure results for questions a) and b) (95% confidence level)

Question	Null hypothesis	Alternative hypothesis	F-test
c)	$s_{ISO\ xy\_1} = s_{ISO\ xy\_2}$	$s_{ISO\ xy\_1} \neq s_{ISO\ xy\_2}$	$0.529 \leq \frac{s^2_{ISOxy\_1}}{s^2_{ISOxy\_2}} \leq 0.553$
d)	$s_{ISO\ h\_1} = s_{ISO\ h\_2}$	$s_{ISO\ h\_1} \neq s_{ISO\ h\_2}$	$0.5113 \leq \frac{s^2_{ISOh\_1}}{s^2_{ISOh\_2}} \leq 0.5482$

Table 4. Full test procedure for questions c) and d) (95% confidence level)

From the results obtained in the tests, it has been found that $s_{ISO\ xy}$ = 0.009m and $s_{ISO\ h}$ = 0.014m. Therefore, it can be concluded that the 3-dimentional position measurement separated into position x, y and height h, and obtained using the u-blox NEO-7P XXL bundle package with the NEO-7P module clearly follows the Class RT1 based on the ISO specified procedure and is not influenced by any biases (Table 3).

Regarding questions c) and d), it has been tested to verify that the data obtained from days 1 and 2 of the test belong to the same population using a Fischer test at the 95% confidence level. It has been found that for day 1 with only one series of data the estimated values are $s_{ISO\ xy}$ = 0.019m and $s_{ISO\ h}$ = 0.032m, which means that $s_{ISO\ xy\_1} \neq s_{ISO\ xy\_2}$ and $s_{ISO\ h\_1} \neq s_{ISO\ h\_2}$, thus the alternative hypothesis is accepted. From table 4 it is seen that the test condition is fulfilled, the null hypothesis stating that the standard deviations regarding xy and h, for both days, belong to the same population at the confidence level of 95%.

5. Concluding remarks

High sensitivity GNSS receivers are widely used for many positioning applications. The performance of the receivers from different manufacturers varies but clearly receivers with many more characteristics and capabilities are released more often nowadays due to their low cost.

Many tests have been proposed in the literature about the HS receivers that indicate the limits and metrological particularities of the various systems, as well as express valuable guidelines for the practical use of TLS but they lack of standardized test procedures.

It is suggested in this paper that the ISO 17123 part 8 GNSS RTK field procedure is used to test the HS receiver u-blox NEO-7P XXL bundle package with the NEO-7P module. This would not only be quicker than having to do many different tests, but also more purposeful prior to any field operation. The tests indicated that the specific receiver follows Classes RT1 and RT2. Further tests are required with longer spans of data in order to define data correlation issues.

REFERENCES

Andrei, C.-O., Vermeer, M., Kuusniemi, H., and Koivula, H. (2011). Evaluation of absolute and relative carrier phase positioning using observations from navigation-grade u-blox 6T receiver. Proc. 3rd Int. Colloquium on Scientific and Fundamental Aspects of the Galileo Programme, Copenhagen, Denmark, ESA.

Carver, C. (2005) Myths and Realities of Anywhere GPS. High Sensitivity versus Assisted Techniques. GPSWorld, Issue Sept.

Henning, W. (2011) User Guidelines for single base Real Time GNSS Positioning. Vers. 2.1, National Geodetic Survey, NOAA, USA.
Schwieger, V. (2008) High-Sensitivity GPS - an availability, reliability and accuracy test. Proc. FIG Working Week, 14-19 June, Stockholm, Schweden.

Schwieger V. and Gläser A., (2005) Possibilities of Low Cost GPS Technology for Precise Geodetic Applications. Proc. FIG Working Week 2005 and GSDI-8, April 16-21, Cairo, Egypt.

Stathas D., Sioulis A., Piniotis G., Bimis A. (2014) Topographic map referencing in the Greek National Reference System using low-cost GNSS receivers and smartphone or tablet.
4th Panhellenic congress of Rural and Surveying Engineers 2014, Sep. 26-27, Thessaloniki, Greece.

Takasu T. (2010) Real-time PPP with TRKLIB and IGS real-time satellite orbit and clock. Proc. IGS Workshop, Vol. 216, 28 June, pp216.

Takasu T., and Yasuda A. (2008) Evaluation of RTK-GPS Performance with Low-cost Single-frequency GPS Receivers. Proc. 13th GPS/GNSS Symposium 2008, Nov. 11-14, Tokyo, Japan.

Teunissen P. (1995) The least-squares ambiguity decorrelation adjustment: a method for fast GPS integer ambiguity estimation. J. Geodesy 70:65-82.

Zhang J., Li B., Dempster A.G., Rizos C. (2010) Evaluation of High Sensitivity GPS Receivers. Proc. Int. Symposium on GPS/GNSS, October 26-28, Taipei, Taiwan.

BIOGRAPHICAL NOTES

Antonis Sioulis is a Research Associate in the School of Rural and Surveying Engineering of the National Technical University of Athens, Greece.

Maria Tsakiri is an Associate Professor in the School of Rural and Surveying Engineering of the National Technical University of Athens, Greece.

Dimosthenis Stathas is a Professor in the School of Rural and Surveying Engineering of the National Technical University of Athens, Greece.

CONTACTS

Antonis Sioulis
School of Rural and Surveying Engineering
National Technical University of Athens
9 Polytehniou str., Zografos Campus, Athens 15780, Greece
E-mail: asioulis@central.ntua.gr