# Evaluating Repeatability of RTK GPS/GLONASS Near/Under Forest Environment

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***Abstract – Nacrtak***

*Until the mid-1990s, post-processing was the only method available to determine survey-grade positions using GPS. A new method was then introduced called Real-Time Kinematic (RTK). Real Time Kinematic surveying is an advanced form of relative GPS carrier phase surveying in which the base station transmits its raw measurement data to rovers, which then compute a vector baseline from the base station to the rover. RTK GPS shows a really efficient and fast improvement within today's technological developments. The most important reason for using it is that this technique enables obtaining coordinates instantaneously and in the centimeter level accuracy. This technique is widely used in construction and survey applications because of its above mentioned properties. The aim of this paper is to evaluate the repeatability of RTK measurement accuracy under different satellite configurations near/in forest and unobstructed environments. Testing was performed by using GPS+GLONASS receivers under these conditions, i.e. tall trees forest and unobstructed areas. The obtained results of RTK testing were compared with results of total station surveying as a further quality check. Nevertheless, it appears that RTK measurements under forest environment with 1 cm accuracy cannot be guaranteed on all occasions, since difficult situations may lead to greater errors. These results indicate that integrating RTK GPS/GLONASS system with total station is favored for surveying under forest environment.*

*Keywords: RTK GPS/GLONASS, Forest Environment, Total Station, Accuracy*

## 1. Introduction – *Uvod*

The Global Positioning System (GPS) has become a widely used tool for a number of positioning applications. The two GPS carrier signals, L1 and L2, are used extensively for cadastral, topographic and engineering survey applications. The use of the carriers requires the identification of the integer cycle ambiguity inherent in the phase measurement of the carrier signal. Once the integer ambiguities are identified and constrained, the position of a roving receiver can be estimated to an accuracy of, generally, better than two centimeters with respect to a stationary reference receiver. The application of a reference and roving receiver is referred to as differential positioning. There are a number of errors affecting GPS observations that are removed by the differential technique. The residual errors remaining in position estimates are primarily due to multipath, orbital errors and unmodeled atmospheric errors. It is these influences that limit the use of GPS for high precision applications. For kinematic GPS applications, occupation periods are typically less than one minute, thus limiting the averaging of residual errors. The use of a data link, to transfer measurements acquired at the reference receiver to the roving receiver, permits the calculation of the rover coordinates at the time of measurement. This survey technique is termed Real Time Kinematic (RTK) and is continuing the revolution that GPS is having in survey practice. The development of RTK enables surveyors to coordinate marks of interest in a rapid and efficient manner. The real time capability enables performing field checks of computed positions, a requirement of cadastral survey legislation in many states and countries. The technique also facilities the placing of marks at pre-determined coordinate (Boey et al. 1996, El-Rabbany 2006, Hoffmann-Wellenhof 2001, Schofield 2001, El-Mowafy 2000).

## 2. Real Time Kinematic (RTK) Technique *Metoda kinematičkoga prikupljanja podataka u stvarnom vremenu*

Precise positioning, using GPS measurements, requires the measurement and processing of the L1 and/or L2 carrier phase signals. The phase of the satellite carriers can be measured to a few millimeters by almost all commercially available GPS receivers. The Cartesian coordinate difference, or baseline, between a stationary reference receiver and other roving receivers can be computed to accuracy suitable for many surveying tasks if the integer cycle ambiguity of the carrier phases can be correctly determined and constrained. Ambiguity resolution techniques, such as known baseline occupations and on-the-fly resolution, in particular, are extremely effective in rapidly identifying the ambiguities. The on-the-fly technique has the advantage of being able to operate successfully while the roving receiver is in motion. In most surveying applications, the position of the receiver while in motion is not of interest. Regardless of this, the most efficient operation occurs when the receiver continuously tracks at least four satellites (and preferably five or six) for the duration of the survey. In the 1980s and early 1990s, the results from all GPS surveys were only available after the survey had been completed and the data post-processed. Post-processing provides robust baseline estimates as all measurements can be manipulated a number of times using least squares estimation techniques. The restrictions of post-processing from the surveyors perspective are that field checks and setouts cannot be performed. Real time kinematic (RTK) surveying introduces a mechanism for transferring the measurements acquired at the reference receiver to the roving receiver as soon as they are collected. This transfer mechanism, termed the communications link, is usually performed by a form of radio modem. The roving receiver processes the measurements from both receivers and displays the computed position information to the user in the field. As the position of the roving receiver is required in a timely manner, there is limited time for the rover to pass through previous measurements. Therefore, real time surveying is less robust than post-processing, and however, the accuracy and precision attainable is still suitable for a large number of surveying applications. Real time processing at the roving receiver provides Cartesian coordinates, computed relative to the reference station coordinates. As the reference station coordinates are not always known, the coordinates of the roving receiver are generally presented as a three-dimensional Cartesian coordinate difference from the reference station. Coordinates of points are then propagated using these baselines and knowledge of at least one point with known coordinates. In many countries, the transfer of data from the reference receiver to the rover is regulated by State and Federal communication agencies. To preserve frequency allocation, there are frequency and power restrictions which regulate the use of such communication devices. The carrier phase corrections are transmitted in real time via some (wireless) data link; e.g., via very-high frequency (VHF), HF, or ultra-HF (UHF) radio transmission and applying the OTF (On The Fly) algorithm to fix the related phase ambiguities in small parts of a second. To avoid licensing of radios, low power radios are often used as the output signal is not considered strong enough, by regulation, to cause interference with other signal transmissions. The outcome of this approach is that users are restricted by these radios which often require line of sight operation and a limited range. Although repeater radios can be used to propagate transmissions, most RTK surveys have been performed over small areas ranging from a few hundred meters to, typically, less than five kilometers. With the development of permanent tracking receiver networks, users will expect to survey in real time over significantly larger distances than currently surveyed. The limits of RTK positioning are generally considered to be in the range of ten to fifteen kilometers; however, there is little information available in the literature that defines the level of performance that surveyors can expect under these conditions. RTK surveying is appropriate for any application that requires both high precision and high productivity. Applications such as topography, construction, control point densification, GIS data collection, oil exploration, forest and mining are just a few of the many applications that are good uses of RTK surveying technology (Bilker and Kaartinen 2001, British Columbia, 2005, El-Mowafy 2000, Fuhlbrügge 2004, Langley 1998, Pirti 2007, Schofield 2001, Lemmon 1999, Lin 2003).

The GLObal NAvigation Satellite System (GLONASS) is another GPS-like global positioning system. As of October 2009, the GLONASS system consists of 19 satellites, of which 16 are operational, and 3 are undergoing maintenance. The system requires 18 satellites for continuous navigation services covering the entire territory of the Russian Federation, and 24 satellites to provide services worldwide. The availability of GLONASS would bring two significant benefits to geodetic applications of global positioning systems. First, the GLONASS solution could be employed as an independent verification of GPS solution to improve quality control. Second, GPS and GLONASS observations could be combined directly in the process of solution; as a result, the geometry of observed satellites could be enhanced by increasing the number of available satellites. With the recent revitalization of GLONASS, higher precision geodetic GLONASS receivers are brought to market, and GPS/GLONASS receivers have been equipped in some International GNSS Service (IGS) tracking stations all over the world. So it becomes worthwhile to investigate the advantages and disadvantages of combined GPS/GLONASS solution in geodetic application. In order to process combined GPS/GLONASS observations, we should address the problems that arise from the difference in the coordinate systems of the satellite systems, as well as the time and frequency systems employed by GPS and GLONASS. GLONASS satellites transmit signals using FDMA (Frequency Division Multiple Access). GLONASS satellites have available 12 allocated radio frequency carriers in L1 frequency band and 12 carriers in L2 band. Each satellite transmits signals at two frequencies, using one assigned radio frequency carrier in L1 frequency band and one assigned carrier in L2 frequency band (Each satellite transmits a different frequency on L1 (=1602 + Kx0.5625 MHz; KOE[–7.24]) and L2 (=1246 + Kx0.4375 MHz; KOE[–7.24]). Scaling both GLONASS signals observations to a common frequency would not have any sense. While some clock errors can be removed in the double difference procedure, negative side effects will arise simultaneously (Diggelen 1997, El-Rabbany 2006, Naesset 2001, Schofield 2001, Kleusberg 1990, El-Mowafy 2000).

As explained above, RTK performs significantly better when tracking both GPS and GLONASS satellites, than when tracking GPS satellites only. Adding GLONASS to GPS improves all aspects of satellite navigation and RTK operation (availability, reliability, stability, time of RTK initialization, and so on). If more satellites are observed using both GPS and GLONASS satellites at the same time, the main advantages of the constellations are (Lemmon 1999):

- Saving in acquisition time
- High accurate precisions
- Reduction of values of Position Dilution of Precision (PDOP) and Geometric Dilution of Precision (GDOP). Dilution of Precision (DOP) is an indicator of satellite geometry for a unique constellation of satellites used to determine a position. Positions tagged with a higher Dilution of Precision value generally constitute poorer measurement results than those tagged with lower Dilution of Precision. There are a variety of Dilution of Precision indicators, such as Geometric Dilution of Precision (it is an indicator of the geometrical strength of a GPS constellation used for a position/time solution), Position Dilution of Precision (Measure of the geometrical strength of the GPS satellite configuration for 3-D positioning), etc.
- Greater productivity in phase of relief especially in cases where natural obstacles (trees, houses, etc.) limit the opening to the sky and therefore the reception of signals.

In order to determine a position in GPS-only mode the receiver must track a minimum of four satellites, representing the four unknowns of 3-D position and time. In combined GPS/GLONASS mode, the receiver must track five satellites, representing the same four previous unknowns and at least one GLONASS satellite to determine the GPS/GLONASS time offset. With the availability of combined GPS/GLONASS receivers, users have access to a potential 48+ satellite-combined system. With 48+ satellites, performance in urban canyons and other locations with restricted visibility, such as forested areas, improve as more satellites are visible in the non-blocked portions of the sky. A larger satellite constellation also improves real-time carrier phase differential positioning performance (Diggelen 1997, El-Rabbany 2006, Naesset 2001, Schofield 2001, British Columbia, 2005, Fuhlbrügge 2004).

### *2.1* Limitations and Repeat Observations
### *Ograničenja i ponavljanje mjerenja*

Like other precision measurement methods, RTK does have limitations that affect its ability to perform some of the survey tasks discussed above. Being aware of these limitations will ensure successful results from RTK surveys. The limitations of RTK come from the GPS system itself, and not from GPS receivers. GPS depends on receptions of radio signals transmitted by satellites approximately 20 000 km from the earth. Being of relatively high frequency and low power, these signals are not very effective in penetrating through objects that obstruct the line of sight between the satellites and the GPS receiver. Any object that blocks the path between the GPS receiver and the satellites will be detrimental to the operation of the system. Some objects, such as buildings, will completely block out the satellite signal. Other objects, such as trees, will partially obstruct or reflect/refract the signal. Reception of GPS signals is very difficult in a heavily forested area. In some cases, enough signals can be observed to compute a rough position, but in virtually every case, the signal is not clean enough to produce centimeter-level positions. While enough signals can often be observed to compute a rough GPS position, surveying requires a higher positional accuracy and thus, a larger quantity of clean data. RTK is usually not a tool for surveying in a dense forest, just as an optical total station is not a tool for precisely measuring angles and distances in the dark. This does not mean that RTK is only useful in areas with a wide-open view of the sky. The critical factor is to be able to observe, at any given time, enough satellite signals to accurately and reliably compute a position. In the good parts of the satellite window (the part of the day when most satellites are visible) 5–10 GPS satellites may be visible and available for use in RTK surveying. Accurate and reliable positions can be determined with 5 satellites distributed throughout the sky (not clustered in one part of the sky). Therefore, an obstructed location can be surveyed if at least 5 satellites can be observed. This makes RTK useful in obstructed areas such as along a tree line. Manufacturers are creating new receivers that can use both GPS and GLONASS satellites. GLONASS satellites can also be used for RTK in an integrated approach with GPS satellites in order to increase the number of observed satellites and thus increase accuracy and speed ambiguity resolution. GPS/GLONASS system may be integrated at the user level to improve geometry and positioning accuracy, particularly under poor satellite visibility, such as in forest and urban areas. This advanced RTK systems can be used very effectively and accurately in partially obstructed areas (Diggelen 1997, El-Rabbany 2006, Naesset 2001, Schofield 2001, Hasegawa 2003, Parkinson 1996).

This method involves re-observing features, which had been previously measured using the same method. Ideally the re-observation should occur when there has been a significant change in the satellite constellation and the reference station and rover station have been dismantled and re-assembled. A change in the constellation occurs in varying degrees from one to five hours. It should be noted that satellites have an orbiting period of 12 sidereal hours and constellation configuration repeats itself every sidereal day (1 Solar Day≈0.997 Sidereal Day). If a repeat measurement must be done immediately due to logistical difficulties, it is recommended that the antenna be inverted briefly to lose satellite signal lock. This procedure will reset the ambiguity resolution algorithms and also the signal processing methods which perform multipath effects reduction. Surveying repeat points without re-assembling the reference and rover stations will not provide a means for detecting blunders in antenna heights or reference station coordinates (Diggelen 1997, El-Rabbany 2006, Hoffmann-Wellenhof 2001, Schofield 2001, El-Mowafy 2000, Lin 2003).

## 3. Case Study Fieldwork – *Terensko istraživanje*

The work was performed in the Campus of Yildiz Technical University Davutpaþa/Esenler, Istanbul, Turkey. The site chosen for the survey is located in the town outskirts, see Fig. 1. Two methods were performed, one using a Topcon Hiper Pro RTK (GPS/GLONASS) field unit and base station with a radio link and another using Topcon GTS 701 total station. The Hiper Pro RTK field unit provides up to 6 kilometers of coverage with the internal radio, 1 Watt transceiver that operates on all European frequencies. HiPer Pro incorporates advanced radio technology called »Free Channel Scan«, which automatically detects disruptive radio interference and changes channels to compensate. The receiver incorporates an internal, Satel UHF transmitter/receiver at 4MHz bandwidth or a UHF receiver at 20 MHz bandwidth, with a 25 kHz channel spacing, and a maximum 1 W power output for data transmission. The performance specifications of the Topcon Hiper Pro RTK are 10 mm+1.0 ppm for horizontal and 15 mm+1.0 ppm for vertical positioning. They may be degraded in regions of high multipath and high values of the Position of Dilution of Precision (PDOP) as well as during high ionospheric activity. Robust checking procedures are highly recommended in a location of extreme multipath or under dense foliage. The Topcon HiPer Pro also has the option of dual-constellation (GPS plus GLONASS) tracking, which

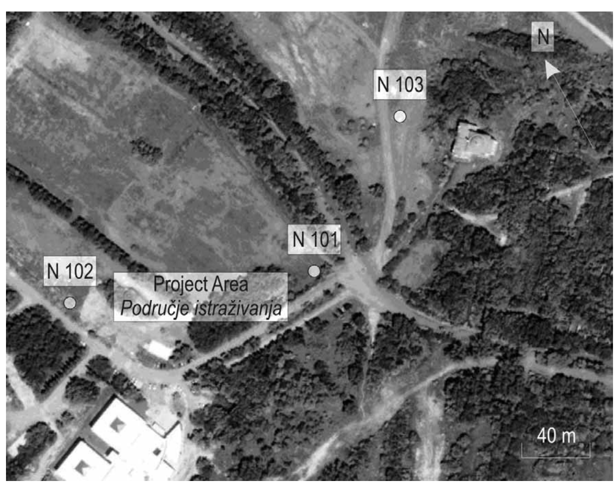


**Fig. 1** Project area and reference points

***Slika 1.*** *Područje istraživanja i referentne točke* provides 40% more satellite coverage than GPS alone. That means downtime due to poor satellite coverage or obstructions is virtually eliminated, and only Topcon brings dual frequency GPS/GLONASS positioning technology to its users.

Two tests were carried out in order to evaluate the performance of the RTK (GPS/GLONASS) method under the unobstructed and obstructed (forest) environments. For this project, two reference points (N101 and N102) were selected in the project area (Davutpaşa region of Istanbul-Turkey, see Fig. 1). A static GPS survey was conducted in order to determine the coordinates of these two reference points. The measurements in this primary network were performed with at least 4 hours of observation time. The minimum elevation cut-off angle and the sample rate were 10 degrees and 10 seconds, respectively. All static GPS measurements were carried out using Ashtech Z Max GPS receivers. The data processing and network adjustments were conducted using the Ashtech Solution 2.60 GPS Software. In the adjustment procedure, the ED 50 coordinates of N103 were held fixed (Fig. 1 and Table 1).

The objective of the tests was to assess the RTK GPS/GLONASS achievable accuracy and to check the repeatability of the results under different satellite configurations by using two different reference points (N101 and N102). So, the RTK software and survey performance were evaluated under the unobstructed (the first three points, see Fig. 2) and the forest environments (the other thirteen points), under varying site conditions and where problems due to signal blockage/attenuation were expected, see Fig. 2. The accuracy and repeatability assessment of the RTK survey was carried out by comparing the coordinates of a group of points (16 points). The RTK GPS/GLONASS survey was performed in the sequence of number of points. As explained above, two different survey methods were used to coordinate a group of 16 points, marked on the ground. Fig. 2 illustrates the distribution of the tested points. The maximum distance between the points in the North-South direction was about 30 m. In the East-West direction the maximum distance was about 100 m.

**Table 1** Coordinates of reference points in the project area

***Tablica 1.*** *Koordinate referentnih točaka na području istraživanja*

| Point *Točka* | *Y*, m | *Std.*, m | *X*, m | *Std.*, m | *H*, m | *Std.*, m |
|---|---|---|---|---|---|---|
| 101 | 406930,834 | 0.002 | 4543909,912 | 0.002 | 65,895 | 0.004 |
| 102 | 406739,361 | 0.002 | 4543871,860 | 0.002 | 71,020 | 0.004 |
| 103 | 407010,897 | 0.000 | 4544074,144 | 0.000 | 80,081 | 0.000 |

### *3.1* RTK Survey Results and Comparisons *Terenski rezultati i usporedba mjerenja RTK prijamnikom*

#### 3.1.1 Horizontal Accuracy – *Horizontalna točnost*

To evaluate the RTK GPS/GLONASS repeatability, two independent RTK surveys were carried out using two different reference points, each time occupying all of the test points. The surveys were conducted on consecutive days and at different times of the day from N101 (11 November 2008, 9:00–15:30 h local time (LT)), N102 (12 November 2008, 13:00–19:05 h local time (LT)) with changed satellite configurations to ensure the independence of the results. The reference station N101 was about 0.1 km away from the RTK GPS measurement site, N102 about 0.1 km, see Fig. 1. The satellite visibility was 8–9 and 8–10 (GPS/GLONASS) satellites in open areas and the recorded Position Dilution of Precision average values were 1.5–2.1 and 1.6–2.3 on 11 November 2008 and

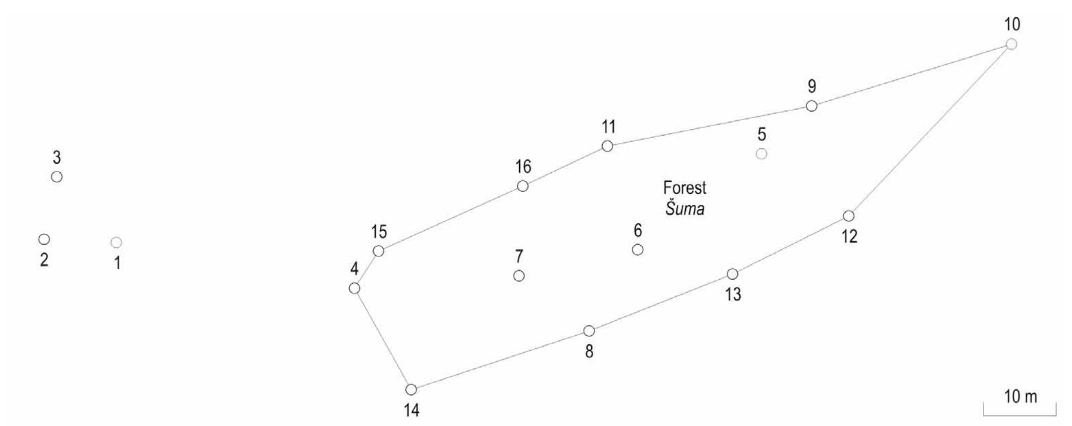


**Fig. 2** Distribution of test points in the project area

***Slika 2.*** *Pojavnost točaka na području istraživanja*

12 November 2008, respectively. However, the satellite visibility was 6–8 and 6–7 (GPS/GLONASS) satellites in the forest areas and recorded Position Dilution of Precision average values between 3.1–4.2 and 3.7–4.8 on 11 November 2008 and 12 November 2008, respectively. It is obvious that Position Dilution of Precision value has direct influence on positioning error. A total of 32 point observations for the 16 test points were obtained over the two days. In the analysis step, the differences of the coordinates of the 16 test points obtained from N101, N102 were calculated. Fig. 3 shows the differences and their means and standard deviations for the 16 points. The analysis of the test for the RTK GPS/GLONASS results shows that the discrepancies of the horizontal coordinates were a few mm to 4 cm. The discrepancies of the height coordinates were a few centimeters to about 10 cm (Fig. 3). The first three points (Points 1, 2 and 3) have clear lines of sight to the satellites because of the unobstructed area, see Fig. 2. The results for the Points 1, 2 and 3 in Fig. 3 (first 3 data points on left) show that the RTK positioning was good in general. As shown in Fig. 3, the average differences of the RTK system were less than 0.5 cm for horizontal plane coordinates, and less than 1 cm along the vertical direction for these three points. On the other hand, the forest (trees) caused severe obstruction of the sky for the other thirteen points in the project area, see Fig. 2. Even though several satellites were shaded by the trees, they could still be tracked by the receiver. As explained above, 6–8 satellites were visible in this period. The Position Dilution of Precision value was between 3.1 and 4.8 for both tests. All of the results for thirteen points also show that tree canopies and forests were harmful to RTK positioning, as they frequently blocked the signals of the satellites and affected radio signals. Thus, even with the presence of good satellite windows, signal blockage due to tree canopies or forest could be considered as the main problem affecting the use of RTK GPS/GLONASS in forest areas. Due to the above reasons, the RTK GPS/GLONASS measurements on thirteen points took a very long time on two days. The ambiguity resolution time was approximately 300–350 minutes for these thirteen points on both days. The horizontal coordinate differences of these 13 points were greater than 2 cm between the first and the second day of RTK GPS measurements (Fig. 3). The maximum differences of the horizontal coordinates are about 3–4 cm. In these thirteen points, ambiguity is fixed and the number of satellite is 6–8 but signal attenuation occurs because of the forest area. Using the dual-frequency carrier phase as main observable and fixing the initial integer phase ambiguities, i.e. a fixed solution, gave the best accuracy. However, searching for fixed solutions increased the risk of large individual positional errors due to false fixed solutions.

### 3.1.2 Vertical Accuracy – *Vertikalna točnost*

GPS is based on a three dimensional coordinate system. This means that both the horizontal (X, Y) and vertical coordinates (H) are required for the points. The required accuracy of the heights at the points depends on the task. To apply the RTK method under forest, it is necessary to achieve a high horizontal accuracy, whereas for the determination of the H coordinate it is sufficient to use the height from a topographical map. All 16 points are also used for technical tasks, which often require a high accuracy of the H coordinate. Fig. 3 also demonstrates that the greatest differences have occurred in the vertical coordinates of 13 points between each day's measurements. The height component was however less consistent as to horizontal components, and sometimes differed up to 10 cm at the same point between the two RTK sessions. For the other three points, height differences were as little as a few centimeters. In these experiments, the baselines were typically quite short where the effect of the troposphere was less significant.

## *3.2* Comparison of RTK GPS Measurement Results with Total Station Measurement Results – *Usporedba mjerenja prijamnikom RTK i geodetskom mjernom stanicom*

In the second step of the test, the 16 point coordinates were determined by a total station (Topcon GTS-701). The N102 reference point and the N101 reference point were taken as control points for the total station surveys (Fig. 1). Both terrestrial and RTK GPS measurements were carried out in an increasing sequence of identification number of points. In order to compute the coordinates of the 16 points, horizontal directions, zenith angles and slope distances were recorded with Topcon GTS–701 (angle accuracy: ±2'', distance measurement accuracy: 2 mm+2 ppm). In order to minimize the errors introduced by curvature and refraction, the sight distances should be less than 300 meters. The maximum distance was about 200 meters in this study. The total station measurements were carried out in two faces (FL, FR) since the manufacturer's accuracy specification refers to the mean of measurements taken in two faces. Three reflector/tripod sets were available. Tripods were used for the reflector set-ups on the points. Each point was observed using a reflector mounted on a tripod, which was optically plumbed over the point. Point heights were determined by subtracting the reflector heights above the

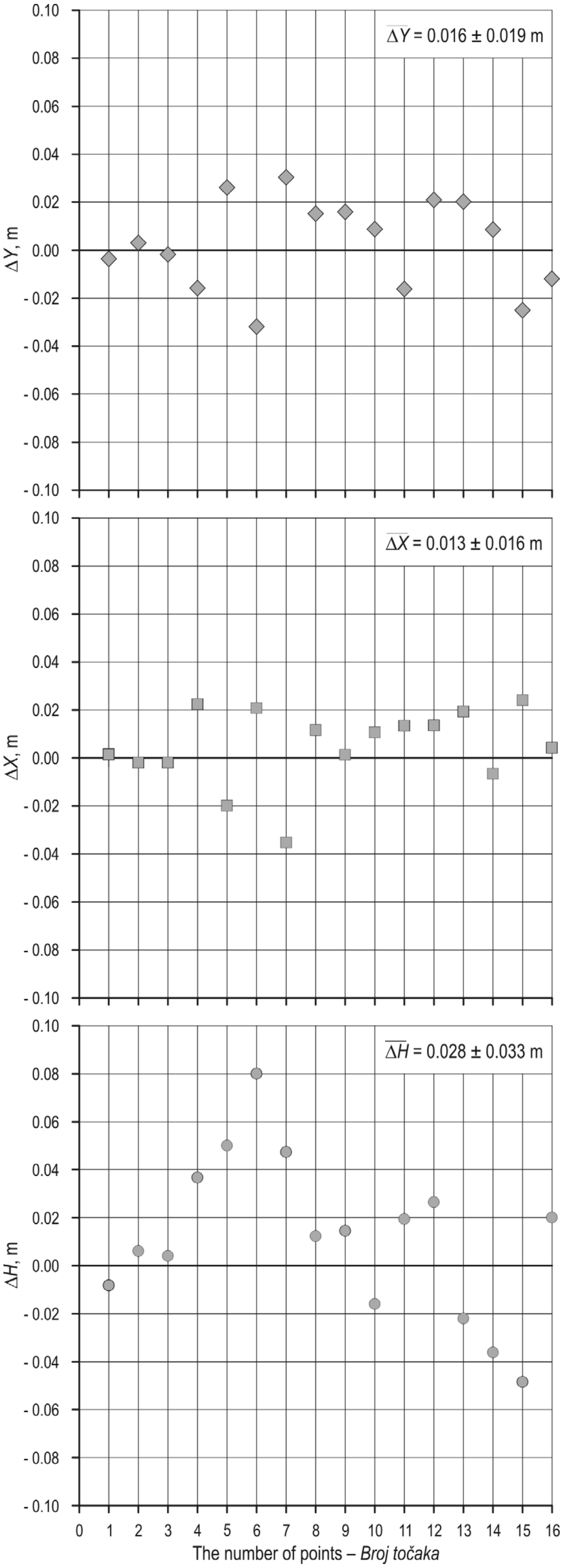


**Fig. 3** Comparison of coordinates of test points using N101, N102 as reference points

***Slika 3.*** *Usporedba koordinata ispitivanih točaka korištenjem referentih točaka N101 i N102*

points. The test points (16) were observed from one reference point N102. It took about 60 minutes to survey the 16 points from N102.

In the test, total station survey was carried out to check the performance of the RTK GPS/GLONASS survey. RTK GPS/GLONASS can be used depending on the project requirements, location, and other factors. The RTK surveying method seems to be the most suitable in unobstructed areas. This is mainly because of its ease of use and availability of the results in the field. Inaccessible locations or obstructed areas can be surveyed with an integrated system such as a GPS+GLONASS/total station. RTK does not handle all kinds of survey problems as other survey techniques do. RTK is only suitable for environments with reasonably good GPS/GLONASS tracking conditions (limited obstructions, multipath, and radio frequency noise) and with reliable communication from the GPS/GLONASS base to the rover (Diggelen 1997).

In this test, the accuracy and repeatability assessment of the RTK survey was carried out by comparing the coordinates of a group of points (16 points) obtained from N101, N102 with the coordinates determined by the total station from N102, see Fig. 4. The term »geodetic« is used to loosely refer to bearings and coordinates related to the European Datum 1950 (ED50). The total station survey was reduced onto the ED50 system for the comparison of the two methods, as the RTK measurements were all made on the ED50 system. Fig. 4 gives the coordinate differences between the RTK and the traditional survey. Orthometric heights (ED50) were used for the total station survey.

The comparison of the results of the RTK GPS/GLONASS and total station surveys shows that the variations were greater in height and smaller in horizontal coordinates. Fig. 4 shows the differences and their means and standard deviations for the 16 points. The standard deviation of the horizontal coordinate differences was about 1–2 cm on the first day and 1–2 cm on the second day. The standard deviation of the height differences was 3.3 cm on the first day, 2.8 cm on the second day. As shown in Fig. 4, the two-day mean differences between the RTK survey and the total station survey were less than 2 cm for the horizontal coordinates and less than 3 cm for the vertical coordinates. Again, the largest variations in horizontal and vertical coordinates were recorded for thirteen points in the project area, see Fig. 4. The variations were about 2–5 cm in the X–Y coordinates and about 3–10 cm in the H coordinates. We are likely to encounter significant differences in the horizontal and vertical coordinates at difficult points. Our results are consistent with those of many other groups

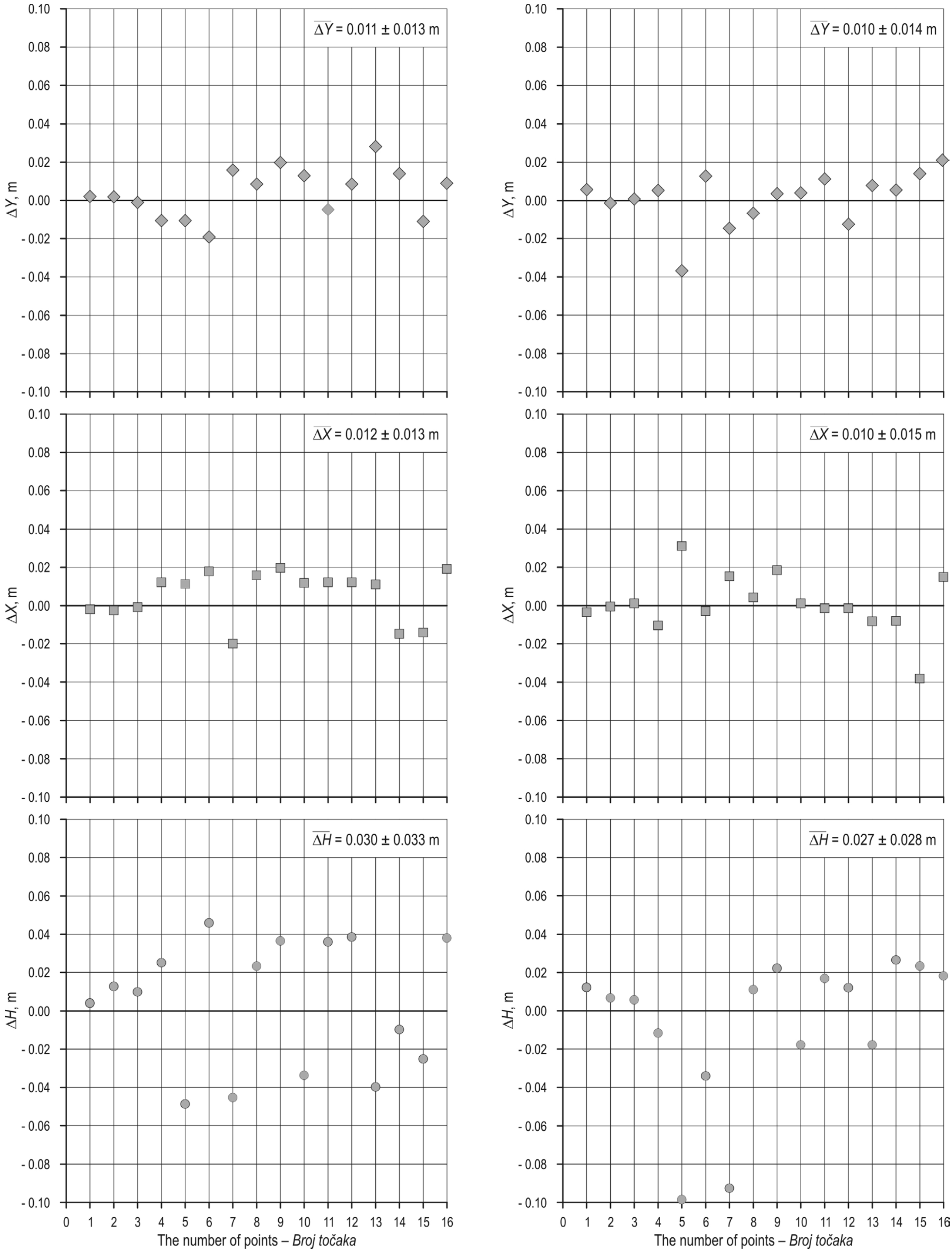


**Fig. 4** Comparison of coordinates of 16 points in the project area between total station and two days of RTK GPS (N101 (1st day), N102 (2nd day)) surveys

**Slika 4.** *Usporedba prostornih koordinata snimljenih geodetskom mjernom stanicom i prijamnikom RTK* that made similar tests. The horizontal and vertical accuracy in clear and obstructed areas discussed in this paper are in agreement with those of the other authors.

Except for the changing geometry of satellites within a forest environment (thirteen points, see Fig. 2), the results clearly show that the RTK technique is a stable method and a cm level of accuracy is generally obtainable under various operational conditions. The RTK method is problem free particularly where a centimeter level horizontal accuracy is required. This study shows that the technique of RTK GPS/GLONASS is able to deliver results equivalent to those expected from a traditional total station survey. Another conclusion is that the RTK method does not give a vertical accuracy, which can be used for those types of leveling tasks that are usually carried out by geometric leveling (millimeter accuracy).

## 4. Conclusions and Discussion – *Zaključci i rasprava*

Dense forest canopy posed a significant physical barrier to quality GPS signal reception. The signals are noisier, weaker and therefore more likely to be subject to multipath and diffraction. Therefore, there are still some problems about the difficulties to receive the signal in close area such as the area covered with dense forest. In the forest environment there is a problem of a very high attenuation of the satellite signals, which are hardly sufficient for normal operation of the GPS receiver. The trees and foliage cause mainly dispersion of the radio signal, and reflected signals have usually so little energy that they can not have any serious influence on GPS receiver performance as multipath signals. The surveyor should be aware that positions may not be accurate despite quality indicators pointing to good solutions. In cases of signal blockages, such as in forest areas, RTK needs to be aided by a total station.

For the unobstructed environment considered in this experiment, the average differences between the RTK and the total station surveys were less than 1 cm for the horizontal plane coordinates and less than 2 cm in vertical coordinates. For thirteen points (multipath environment) the horizontal plane coordinates differed up to 5 cm and the heights approximately 10 cm. So, special attention should be paid to the selection of the working area. It appears that in difficult environments, measurements with 1 cm accuracy cannot be guaranteed in all situations.

In this paper, we have shown that RTK GPS/GLONASS can be used for forest surveying, although a common obstacle, the sky blockage, hinders its full effectiveness. But this problem can be overcome if supplemented by conventional survey techniques. Despite the accuracy problems in obstructed areas, the RTK method is a very efficient replacement for difficult total station survey situations. In this study, the RTK GPS/GLONASS method using only one reference point required approximately 6–6.5 hours to survey 16 points. The total station survey of 16 points required approximately 1 hour in the field. The RTK GPS/GLONASS required about 10 minutes in the office for data transfer and processing. The total station data required about 15 minutes in the office for transfer and processing.

The RTK technique has one major advantage over the other methods; positions are directly determined on the terrain and many independent ambiguity values might be resolved, allowing redundancy of RTK positioning. It is clear that the time of RTK positioning in forest conditions should be chosen during the best satellite constellation and in the season when there are no leaves on trees. When total station methods are used in the projects one can meet with some difficulties such as lack of sight between two control points, inaccessible angle points and loss of time. Projects carried out using total station methods employ much more people. RTK GPS surveying method has some advantages over traditional surveying methods in that RTK GPS needs no sight between control points. In addition, RTK GPS can be managed by only one person and whole surveying process can be carried out by using only one reference point, depending on the quality of the radio transmitter and the distance between the points and reference station. Another advantage of RTK GPS is that the coordinates of the points can be determined in national coordinate reference frame in real time. The only handicap of the system is that the RTK GPS requires at least five satellites simultaneously and an open sky view. RTK GPS has the capability to operate the system in every weather condition.

In the near future, after GLONASS and GALILEO (Galileo is a global navigation satellite system (GNSS) currently being built by the European Union (EU) and European Space Agency (ESA). The 3.4 billion project is an alternative and complementary to the U.S. Global Positioning System (GPS) and the Russian GLONASS. On 30 November 2007 the 27 EU transportation ministers involved reached an agreement that it should be operational by 2013) are fully deployed, the satellite positioning systems will have different dimensions. Finally, the improvements in GALILEO, GLONASS and modernized GPS will increase the signals for the GNSS user community. This will bring numerous benefits for applications requiring fast and accurate positioning. The combination of GPS with GLONASS and/or GALILEO provides more robust, accurate and cost effective studies as compared with GPS only. GLONASS and GALILEO are proposed to be fully deployed; more than 80 satellites will cover the world (El-Rabbany 2006, URL1).

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## Sažetak

### *Ocjenjivanje ponovljivosti sustava RTK GPS/GLONASS u neposrednoj blizini šumskoga područja*

*Do sredine 1990-ih korekcija je prostornih podataka (post-processing) bila jedina metoda za utvrđivanje prostornih položaja korištenjem uređaja GPS (Global Positioning System), potom je uvedena nova metoda naziva kinematička metoda u stvarnom vremenu (Real-Time Kinematic). Kinematička metoda u stvarnom vremenu napredni je oblik relativnoga uređaja GPS kojom se podaci s bazne stanice prenose na rover, koji potom vektorski izračunava liniju od bazne stanice do rovera. Metoda RTK omogućuje prijenos podataka s bazne stanice na rover čim su podaci prikupljeni. Ovaj mehanizam za prijenos podataka, nazvan komunikacijska veza (communications link), najčešće je radijski modem. Rover zaprima podatke obaju prijamnika i prikazuje izračunati trenutačni položaj korisnika na terenu.*

*Položaj je rovera potrebno dobiti u određenom vremenskom roku, pa je i obrada prijašnjih mjerenja položaja otežana. Mjerenja su u stvarnom vremenu stoga prikladnija od same korekcije prostornih podataka, a točnost je mjerenja i dalje prikladna za većinu korisnika.*

*Obrada podataka u stvarnom vremenu omogućuje roveru pribavljanje Kartezijevih koordinata, izračunatih relativno prema koordinatama referentne stanice. RTK GPS pokazuje učinkovitost i brz napredak u današnjem razvoju tehnologija, najviše zbog mogućnosti pribavljanja koordinata trenutačno i na razini centimetarske točnosti.*

*Ova se metoda najviše koristi u terenskim istraživanjima zbog spomenutih svojstava. Prednosti mjerenja RTK nad korekcijom prostornih podataka kinematičkih i »stani-kreni« mjerenja (stop-and-go) jesu smanjenje dodatnoga rada u uredu te mogućnost provjere na terenu tijekom snimanja. Korištenjem RTK-a podaci se mogu odmah obrađivati preko GIS-a, što povećava ukupnu učinkovitost.*

*Cilj je ovoga rada ocijeniti točnost mjerenja RTK pri različitim satelitskim konfiguracijama u blizini šume, u šumi te u neometanom okruženju. Ispitivanje je provedeno pomoću prijamnika GPS + GLONASS (Global Navigation Satellite System) pod tim uvjetima, tj. na područjima pokrivenima šumom i u neometanom okruženju. Dostupnost sustava GLONASS donijet će dvije značajne koristi geodetskim programima globalnoga sustava pozicioniranja. Prvo, GLONASS bi mogao neovisno potvrditi točnost GPS-a i drugo, mjerenja pomoću GPS-a i GLONASS-a mogu se izravno upotrijebiti kao rezultat jer je geometrija satelita poboljšana povećanjem broja dostupnih satelita. Sateliti GLONASS mogu se koristiti za RTK zajedno sa satelitima GPS kako bi se povećao ukupan broj dostupnih satelita, a samim tim će se povećati točnost te brzina pri neodređenim rezolucijama. Sustavi GPS i GLONASS mogu se uklopiti radi poboljšanja geometrije i točnosti pozicioniranja u prostoru, osobito pri slaboj vidljivosti satelita kao što je često u šumskim i urbanim područjima. Ti se napredni sustavi RTK mogu koristiti vrlo učinkovito i točno u djelomično nedostupnim područjima.*

*Kao što je prije objašnjeno, sustav RTK snima položaje mnogo bolje kada koristi i satelite GPS i GLONASS, nego samo satelite GPS. Korištenje satelita GLONASS zajedno sa satelitima GPS poboljšava dostupnost, pouzdanost, stabilnost, inicijalizacijsko vrijeme sustava RTK i tako dalje. Uz dostupnost prijamnika GPS i GLONASS korisnici imaju omogućen pristup sustavu od 48+ satelita. Takav sustav omogućuje vidljivost u urbanim područjima i drugim područjima ograničene vidljivosti, kao što su šumske površine, jer veća količina satelita poboljšava pozicioniranje u prostoru. Veća dostupnost vidljivih satelita također poboljšava diferenciranje faze nosača u realnom vremenu (real-time carrier phase differential).*

*Gust šumski sklop je značajna fizička prepreka za kvalitetan prijam signala GPS-a. Signal je slabiji te je stoga više vjerojatno da će dolaziti do pogrešaka u pozicioniranju, zato još uvijek postoje teškoće u zaprimanju signala u područjima pokrivenima gustom šumom. U šumi se javlja problem prigušenja signala jer drveće uzrokuje raspršivanje uglavnom radijskoga signala, dok odbijanje signala zbog njegove male energije nema veći utjecaj na rad prijamnika GPS, kao što to ima višestazni signal. Korisnik uređaja mora biti svjestan da snimljeni položaji možda i nisu točni, unatoč pokazateljima koji upućuju na suprotno. U slučaju nedostupnosti signala, kao što je često u šumskim područjima, sustav RTK treba biti potpomognut radom totalne stanice.*

*U ovom je radu prikazano da se sustav RTK GPS/GLONASS može koristiti za izmjere u šumskim područjima, ali se zbog ograničene vidljivosti satelita mora nadopuniti uobičajenim tehnikama istraživanja. Unatoč problemima u točnosti mjerenja, metoda RTK vrlo je učinkovita zamjena za korištenje totalnih stanica pri terenskim istraživanjima. Dobiveni su rezultati mjerenja RTK uspoređeni s rezultatima mjerenja totalnom stanicom radi provjere kakvoće izmjerenih podataka. Ipak, čini se da točnost mjerenja RTK od 1 cm u šumskom okruženju nije zajamčena u svim prilikama, što će u konačnici dovesti do većih pogrešaka. Dobiveni rezultati istraživanja pokazuju da je integracija sustava RTK GPS/GLONASS s totalnom stanicom najpoželjniji sustav za mjerenja u šumskim područjima.*

*Ključne riječi: RTK GPS/GLONASS, šumsko područje, totalna stanica, točnost*

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