TESTING REAL TIME KINEMATIC GNSS (GPS AND GPS/GLONASS) METHODS IN OBSTRUCTED AND UNOBSTRUCTED SITES

PRESKUŠANJE METOD KINEMATIČNE IZMERE GNSS V REALNEM ČASU (GPS IN GPS/GLONASS) NA ZASTRTIH IN NEZASTRTIH LOKACIJAH

Atinc Pirti, Mehmet Ali Yucel, Kutalmis Gumus

UDK: 528.024:528.54

Article classification according to 1.01 (original scientific article)

ABSTRACT

This paper describes an experiment carried out with the GNSS RTK method to combine GPS and GLONASS measurements in obstructed and unobstructed sites. This study investigates the RTK achievable accuracy and repeatability under different satellite constellations and site conditions in Samatya (coastal area), Istanbul, Turkey. The RTK (GPS and GPS/GLONASS) measurement techniques are described and compared in terms of productivity and precision. Surveyed area, control and test points as well as the impact area of trees where the precision decreases are visualised using Autodesk LandXplorer Studio ProfessionalTM Software. These obtained results indicate that integrating RTK GPS system with GLONASS is favoured for surveying applications.

IZVLEČEK

V tem prispevku je opisan poskus, ki je bil izveden z metodo GNSS – RTK in s katerim naj bi uporabili kombinacijo opazovanj GPS in GLONASS na zastrtih in nezastrtih lokacijah. V študiji se preučuje natančnost in ponovljivost določitve položaja z metodo RTK, ki jo je mogoče doseči ob različnih geometrijskih razporeditvah satelitov in v drugih različnih razmerah. Praktična izvedba študije je potekala na obalnem območju Samatya v Istanbulu v Turčiji. Opisane so merske metode RTK (GPS in GPS/GLONASS), podana je tudi njihova primerjava na podlagi učinkovitosti in dosegljive natančnosti določitve položaja. Opazovano območje, kontrolne in testne točke ter območje vpliva dreves, na katerem se natančnost določitve položaja zmanjša, so prikazani s programsko opremo AutodeskLandXplorer Studio ProfessionalTM. Rezultati kažejo, da ima pri določitvi položajev z metodo RTK prednost združitev sistemov GPS in GLONASS.

KEY WORDS

GPS, coordinates, accuracy, maps, GLONASS, RTK

KLJUČNE BESEDE

GPS, koordinate, natančnost, zemljevidi, GLONASS, RTK

1 INTRODUCTION

Real-Time Kinematic (RTK) surveying as implied by its name, enables positions of points to be determined instantaneously (ITRF frame or ED50 coordinate systems) as the roving receiver (or receivers) occupy each point. Real-time kinematic surveying requires that two (or more) receivers have to operate simultaneously. One receiver occupies a reference station and broadcasts raw GPS observations to the roving unit. At the rover, the GPS/GLONASS measurements from both receivers are processed in real-time by the unit's on-board computer to produce an immediate determination of its location. The radio link used with RTK can limit the distance between the base receiver and rover to under 10 km. Tests of real-time kinematic surveying have shown that it yields position accuracies that approach those obtained by kinematic methods that employ post-processing. Because point positions with high accuracy are immediately known, real-time kinematic surveying is applicable for construction stake-out. It is also convenient for locating details for mapping and for many other surveying tasks. Manufacturers are creating new receivers that can use both GPS and GLONASS satellites. The obvious advantage of using both systems is that nearly twice as many satellites will be available for observation by receivers. Both increased initialisation and improved accuracy are expected by combining the two systems. Furthermore, the combined system may provide a viable method of bringing satellite positioning to difficult areas such as forest, canyons, deep surface mines, and urban areas surrounded by tall buildings (urban canyons) (El-Rabbany, 2006; Fuhlbrügge, 2004; Hoffmann-Wellenhof et al., 2008; Leicket al., 1998; Martin and Ladd, 1997; Schofield, 2001; Van Diggelen, 1997; Veersema, 2004; El-Mowafy et al., 1997; Subari and Anuar, 2004).

The main objective of the article was to assess the RTK GPS and RTK GPS/GLONASS coordinate results, and check the repeatability of the results under different satellite constellations. The other objective was to check the RTK software, and evaluate RTK performance in the tree environment, under varying site conditions, and the expected problems due to signal blockage. For this purpose the coastal area was chosen in this paper because it has varying site conditions where problems due to signal blockage were expected.

2 RTK GPS AND RTK GPS/GLONASS TECHNIQUES

The Real Time Kinematic approach is a differential positioning technique that uses known coordinates of a reference station occupied by one receiver to determine the coordinates of unknown points visited by a rover receiver. The technique employs carrier-phase measurements, and processing is carried out in real time, giving computed coordinates at the cm level of the visited points while still occupying it for a few seconds if the initialisation is well done (When initialising, always choose a site that has a clear view of the sky and is free of obstructions that could cause multipath). If base corrections are being received and there are four or more satellites, the survey is initialised automatically when you start the survey. A survey must be initialisation before centimetre-level surveying can begin. At least five L1/L2 satellites are required for OTF initialisation. Initialisation must be maintained throughout the survey by continuously tracking a minimum of four satellites. If initialisation is lost at any time, reinitialise and then continue the survey. A higher DOP indicates poor satellite geometry, and an inferior measurement configuration (URL 2), (URL 3)). To process the data in real time, the reference station coordinates and measurements are transmitted to the rover via data links. The data-link requirements are a function of amount of data to be transmitted (number of satellites, data type and format), reliability and integrity requirements, operating conditions, and the distance between the reference and rover stations. UHF, VHF or spread spectrum radios are currently the most used types of data links. UHF radios are usually used for distances less than 15 km. Transmission of data is also possible using cellular phones employing special modems (using for instance GSM technology). However, currently this is limited to the network coverage RTK systems. Until 2004 data have been transmitted using the RTCM SC-104 version 2.1 and 2.2 format, transmitted primarily message types 18 and 19, which contain the raw phase and code measurements, respectively. They are intended for use in the common differential processing scheme. There are other message types, like 20 and 21, which contain corrections to corresponding measurements, similar to messages types 1 and 9 used for DGPS. Single frequency receivers (L1 only) can be used as well as dual frequency ones (L1 and L2) for RTK. However, for long base-to-remote distances dual frequency receivers are preferred for faster acquisition of correct ambiguities. In practice, fixing the integer ambiguities with high reliability is somewhat difficult using the single frequency data, which in general gives a float solution, which, in return, gives positioning accuracy at the decimetre level. This problem is not valid with dual frequency systems, where fixing the integer ambiguities is usually possible for short to medium distances (less than 15 km), giving an accuracy at the cm level. 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 up ambiguity resolution. A combined GPS/GLONASS RTK system in single frequency is as good as GPS dual frequency system for fixing the ambiguities, provided that enough GLONASS satellites are available. However, once distance increases, a dual frequency RTK system performs better (Borjesson et al., 1999; El-Mowafy et al.,1997; El-Rabbany, 2006; Fuhlbrügge, 2004; Langley, 1998; Leick et al., 1998; Martin and Ladd, 1997; Subari, 2004).

The combined GPS/GLONASS (GNSS) offers many advantages compared with GPS only use for positioning applications especially in areas where the number of visible satellites is limited. Because of signal blockages in the project area caused by buildings, forests, trees, etc. the number of tracked satellites dropped below four.The inclusion of the GLONASS signals can increase the accuracy of positioning as well as the availability and reliability. The combination of GPS and GLONASS allows the users to derive the most advantages from both navigation satellite systems. The key technique for precise positioning using combined GPS/GLONASS is a reliable and correct ambiguity resolution method. It would be useful to sum up advantages of state-of-the art combined GPS/GLONASS receivers in the light of current GPS and GLONASS status. All of those advantages are, in fact, the consequence of increased redundancy, which is provided by combined use of GPS and GLONASS status (Borjesson et al., 1999; El-Mowafy et al., 1997;Van Diggelen, 1997; Wolf and Ghilani, 2002).

- ability to work under environments with limited visibility of satellites (an increased number of operational satellites, from the usually 7-8 for the GPS system to around 10-11 for the GPS/GLONASS system)
- fast OTF (on the fly) ambiguity resolution
- GNSS receivers remove periods of time when total number of current GPS satellites may not be enough for reliable positioning at any given location
- more robust detection and exclusion of anomalies
- improved quality of observables
- improved estimation of tropospheric and ionospheric parameters
- time, which is required for collecting static data, can be reduced

It should be noted, also, that the use of GLONASS can provide additional advantages when working in high latitudes (Alaska, Canada, Scandinavia, etc.) because of higher inclination of GLONASS orbits in comparison with GPS ones (64.8 vs. 55 degrees). Due to the work at different frequencies, GLONASS is also more resistant to interference and jamming. The GPS satellite clocks are all synchronised. Similarly to GLONASS satellites are all synchronised with each other, but GPS time is not synchronised with GLONASS time. So now the receiver clock has two errors, plus latitude, longitude and altitude giving 5 unknowns, which are solved by having 5 satellites (or more) in view (Borjesson et al., 1999; Leicket al., 1998; Martin and Ladd, 1997; Parkinson and Spilker, 1996; Schofield, 2001; Van Diggelen, 1997; Veersema, 2004; Wolf and Ghilani, 2002).

Future European Galileo System, which is being developed, has to provide further advantages. Galileo is in a more advantageous position with respect to GPS and GLONASS in the sense that many issues related to interoperability with existing navigation systems have been taken into consideration in the initial design of Galileo. Future GPS/GLONASS/Galileo receivers have to become a standard for high-precision positioning (Schofield, 2001; Wolf and Ghilani, 2002, Hoffmann-Wellenhofet al., 2008).

3 TESTING RTK GPS AND RTK GPS/GLONASS TECHNIQUES

To evaluate performance of the RTK GPS and RTK GPS/GLONASS method a test was carried out. In the test, accuracy and repeatability assessment of the RTK was carried out by comparing the coordinates of a group of points, determined separately from a number of RTK GPS tests to their coordinates as precisely determined using RTK GPS/GLONASS.

3.1 Test Description

The work was performed in Samatya (coastal area), Istanbul, Turkey. The site chosen for the survey is located near the Marmara Sea in Istanbul; see Figure 1. Two methods were performed, one using a Topcon Hiper Pro RTK field unit and base station with radio link and the other using Ashtech Z Max GPS receivers. The receivers have dual frequency system with 12 channels. The Hiper Pro RTK GPS field unit provides up to 6 kilometres of coverage with the internal 1 Watt radio modem available with all European frequencies. The performance specifications of the Topcon Hiper Pro RTK GPS are 10 mm+1.0 ppm for horizontal and 15 mm+1.0 ppm for vertical positioning (URL1). They may be degraded in the regions of high multipath and high values of the Positional 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. For this project, three reference points (N1, N2 and N3) were selected in the project area (Samatya region of Turkey, see Figures 1 and 2). A static GPS survey was conducted in order to determine the coordinates of these three 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 Software. In the adjustment procedure, the ED50 coordinates of N15 Point (triangulation point being used in Marmaray project in Samatya) were held fixed (Table 1).

Point Number	*Y [m]*	*Std [mm]*	*X [m]*	*Std [mm]*	*H [m]*	*Std [mm]*
N15	410246.346		4540914.272		3.418	
N1	410255.867	1	4540981.112	1	3.406	1
N2	410335.126	1	4541186.62	1	3.300	1
N3	410682.201	1	4541381.615	1	2.512	2

Table 1: Coordinates and their standard deviations of the three reference points in ED50 coordinate system.

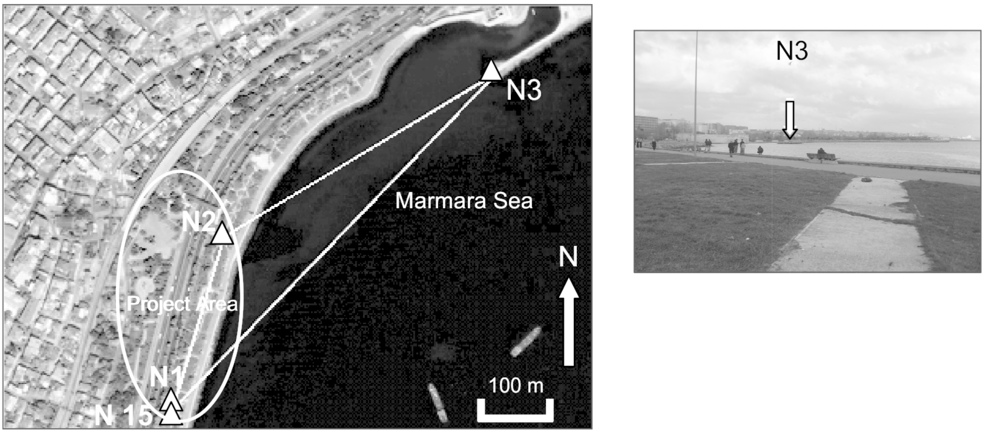


Figure 1: Project area and reference points

The objective of this study was to assess the RTK (GPS and GPS/GLONASS) coordinate results and to the check the repeatability of the results under different satellite constellations by using three different reference points (N1, N2 and N3). So, the RTK (GPS and GPS/GLONASS) Software (Ashtech Fast Survey RTK Software, Topcon TopSurvey RTK Software) and survey performance were evaluated in a surveying application, under varying site conditions and where problems due to signal blockage were expected. The data acquisition and processing rate was set to one second, with a cut-off elevation mask angle of 10 degrees. To evaluate the RTK repeatability, two independent RTK tests were carried out occupying all of the test points. The two tests were conducted on different days and different times of a day, with substantial changes in satellite constellation to ensure the independence of the results. The accuracy and repeatability assessment of the RTK survey was carried out by comparing the coordinates of a group of points (292 points). RTK survey was performed according to number of points. As explained above, two different survey methods were used to coordinate a group of 292 points, marked on the ground. Figure 2 illustrates the distribution of the tested points. The maximum distance between the points in the North-South direction was about 400 m. In the East-West direction the maximum distance was about 50 m.

3.2 Test Results

To evaluate the RTK GPS and GPS/GLONASS repeatability, three independent RTK surveys using three different reference points (N1, N2 and N3) were carried out, each time occupying all of the test points. Receivers capable of using both GPS and GLONASS satellite signals will reduce the time required at each station in a RTK GPS survey due to the increased number of visible satellites, and the improved satellite geometry. Another consequence of satellite availability is that centimetre accuracy is possible, and the time required achieving accuracy decreases as the number of satellite increases.

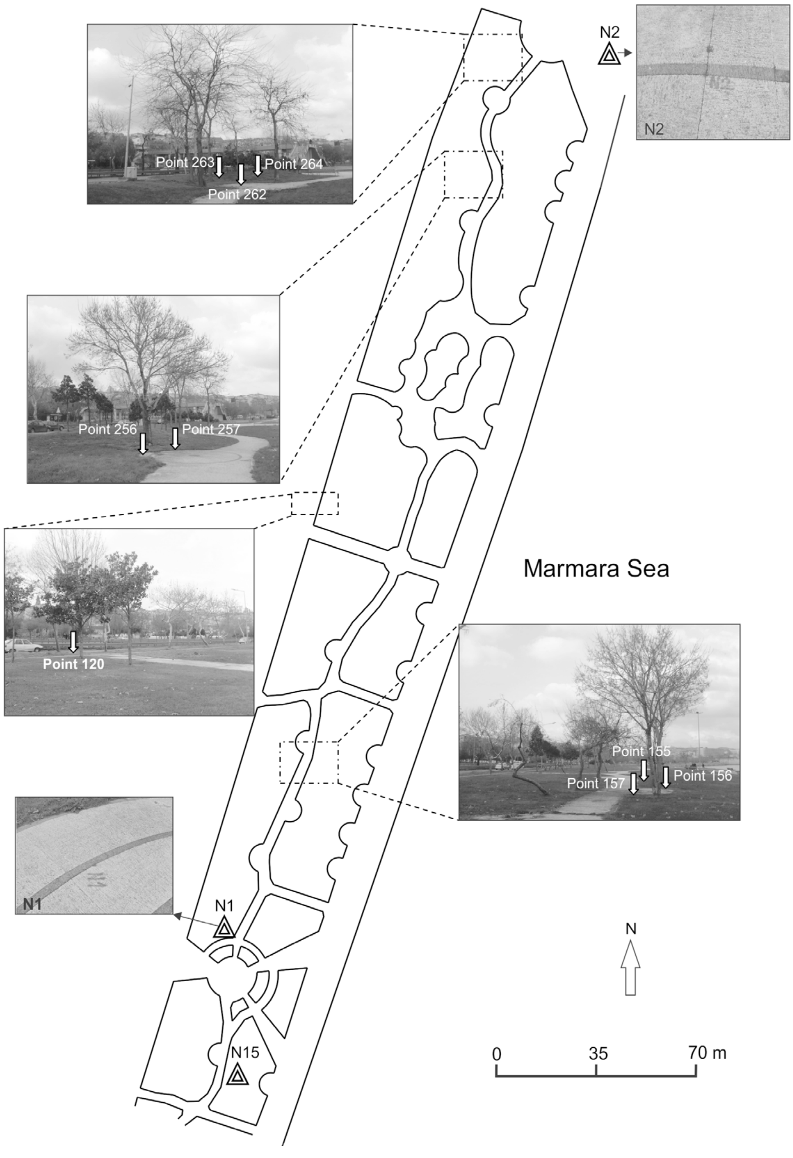


Figure 2: The distribution of the test points in the project area.

3.2.1 Horizontal and vertical repeatability of RTK GPS

The surveys for RTK GPS were conducted on consecutive days and at different times of the day from N1 (25 November 2008, 15:00 – 17:30 h local time (LT)), N2 (26 November 2008, 12:00 – 14:40 h) and N3 (27 November 2008, 08:00 – 11:00 h) with changed satellite constellations to ensure the independence of the results. The reference stations N1 and N2 were in the project area, N3 was about 0.5 km away from the project area, see Figure 1. The satellite visibility was 6-8 satellites in open areas and the recorded PDOP average values were between 1.5 and 2.8 on three days. A total of 876 point observations for the 292 test points were obtained over the three days. In the analysis step, the differences of the coordinates of the 292 test points obtained from N1, N2 and N3 were calculated, such as N1 - N2, N1 - N3 and N2 - N3, respectively. Figure 3 shows the differences and their means and standard deviations for the 292 points. The analysis of the three tests for the RTK GPS results shows that the discrepancies of the horizontal coordinates are a few mm to 3 cm. The discrepancies of the height coordinates were a few centimetres to about 10 cm (see Figure 3). In the project area, the nine points (Points 120,155, 156, 157, 256, 257, 262, 263, and 264) have poor lines of sight to the satellites because of the tree areas, see Figure 2. The results for these nine points in Figure 3 (the marked points) show that the RTK GPS positioning was degraded by the trees as they frequently blocked the signals of the low-medium satellites and affected the signals.

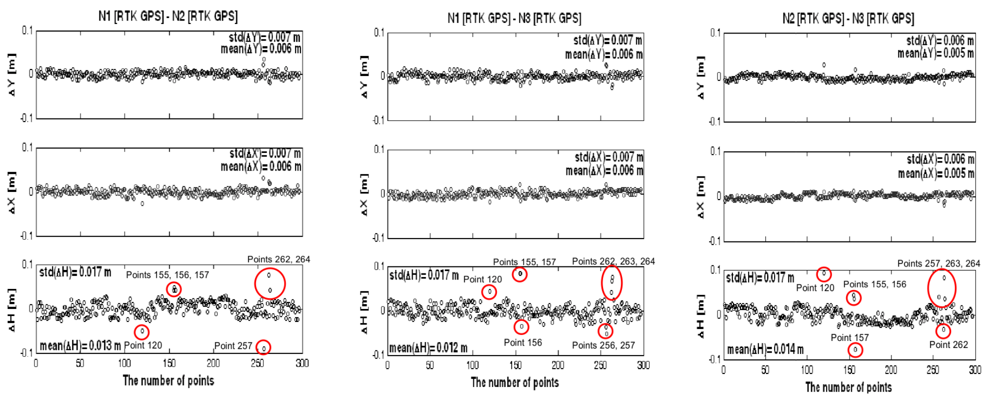


Figure 3: Comparison of the coordinates of the test points using N1, N2 and N3 as reference points (using RTK GPS)

The trees and bushes caused severe obstruction of the sky for those nine points in the project area (Figure 2). Even though several satellites were shaded by the trees and bushes, they could still be tracked by the receiver. Five and six satellites were visible in this period on three days. The PDOP value was between 3.4 and 4.8 for all three tests. Due to the above mentioned reasons, the RTK GPS measurements on these nine points took a very long time on three days. The ambiguity resolution time was approximately 90-120 minutes for those nine points. The differences for the horizontal coordinates of these nine points were larger than 1-2 cm for the RTK GPS measurements of the first, second and third day, see Figure 3. The first day's measurements, using the reference point N3, yielded the largest coordinate differences of the three days, see Figure 3. This may be partially due to the fact that the measurements were taken in the morning of 27th November 2008, when the satellite configuration was not favourable, resulting in a poor accuracy of these nine points in the obstructed area.

To apply the RTK method for surveys, it is necessary to achieve a high horizontal accuracy (1-2 cm). All 292 points are also used for technical tasks, which often require a high accuracy of the H coordinate. An analysis of the first, second and third day measurements at the project area resulted in differences of about 10 cm for the vertical coordinates for the nine points, see Figure 3. For the other points, the height differences were at the level of a few centimetres, see Figure 3. The third day measurements (reference point N3) yielded the largest coordinate differences of the three days.

3.2.2 Horizontal and vertical repeatability of RTK GPS/GLONASS

Topcon Hiper Pro RTK allows the collection of GNSS observations. GLONASS is the Russian navigation satellite system, which has approximately half the number of satellites as the US system, and unlike the GPS system, they all operate on different frequencies. By using a number of different frequencies instead of only two that GPS uses, the RTK lock can be acquired much more quickly, and once it has lock, it is also more robust. Traditionally this has been done by locking onto the second GPS frequency called L2, but because this is a military encoded signal, you cannot lock onto this very robustly, so you will lose lock quite often near trees, buildings, metal fences and bridges. The GLONASS signal is fully trackable, and is in fact slightly more robust than normal GPS. GPS only RTK systems are best used in a completely open test area, as it is not very tolerant of obstructions caused by trees. However, a GPS/GLONASSRTK system will work much better in these conditions and re-acquire satellites after a drop out very rapidly (Martin and Ladd, 1997;Schofield, 2001; Veersema, 2004, Hoffmann-Wellenhofet al., 2008; Yamada, 2010).

When GPS and GLONASS are used together, the receiver uses one extra satellite in the solution to account for the different reference times used by the two systems (GLONASS time). A combined GPS/GLONASS RTK system is therefore very useful, particularly for ambiguity resolution in the obstructed environment. In this project, the surveys for RTK GPS/GLONASS were conducted on consecutive days and at different times of the day from N1 (28th November 2008, 9:00 – 11:00 h local time (LT)), N2 (29th November 2008, 12:00 – 14:05 h) and N3 (30 November 2008, 14:30 – 16:50 h) with changed satellite configurations to ensure the independence of the results. The satellite visibility was 8-11 satellites in the open areas and the recorded PDOP average values were between 1.2 and 2.4. A total of 876 point observations for the 292 test points were obtained over the three days. In the analysis step, the differences of the coordinates of the 292 test points obtained from N1, N2 and N3 were calculated, such as N1 - N2, N1 - N3 and N2 - N3, respectively. Figure 4 shows the differences and their means and standard deviations for the 292 points. The analysis of the three tests for the RTK results shows that the discrepancies of the horizontal coordinates are a few mm to 1 cm. The discrepancies of the height coordinates were a few mm to about 1-2 cm (Figure 4). As explained above, the nine points in the project area have poor lines of sight to the GPS satellites because of the tree areas, see Figure 2. However, the results for the nine points by using RTK GPS/GLONASS in the project area were not degraded by the tree canopies. Seven to eight (GPS/GLONASS) satellites were visible for these nine points in this period of the three days. The PDOP values were between 2.8 and 3.6 for all three tests. Due to the above mentioned reasons, the RTK GPS/GLONASS measurements on these nine points did not take a very long time on three days. The ambiguity resolution time was approximately 30-40 minutes for these nine points. An analysis of the first, second and third day measurements at the project area resulted in differences which are larger(˜ 2-3 cm) for the vertical coordinates for these nine points, see Figure 4. For the other points, the height differences were at the level of a few centimetres, see Figure 4. All 292 points are also used for technical tasks, which often require a high accuracy of the H (orthometricheight) coordinate. An analysis of the first, second and third day measurements at the project area resulted in differences of about ˜ ± 1-3cm for the vertical coordinates for the 292 points, see Figure 4.

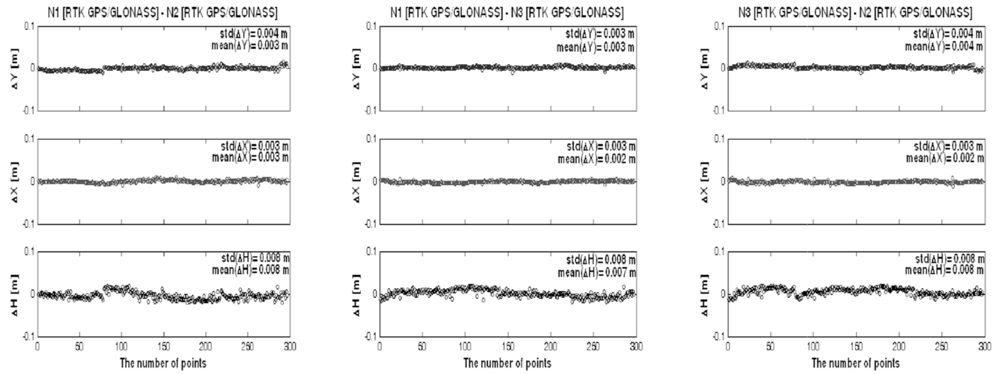


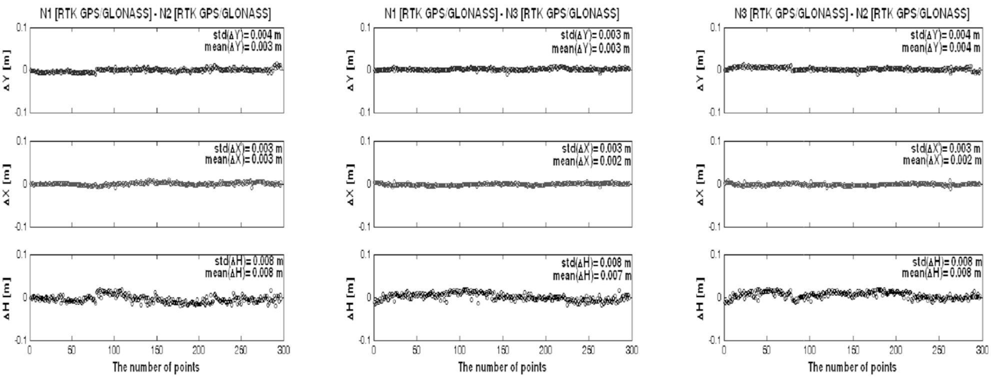
Figure 4: Comparison of the coordinates of the test points using N1, N2 and N3 as reference points (using RTK GPS/GLONASS).

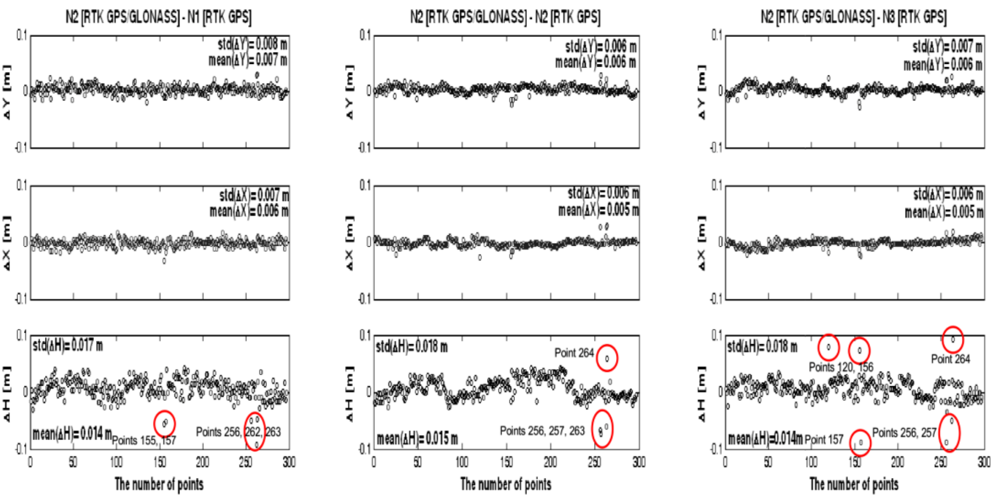
3.2.3 Comparison of RTK GPS and GPS/GLONASS Measurements

In this study we compared the results of Topcon with GPS/GLONASS with Ashtech with GPS only. Figure 5 shows the differences and their means and standard deviations for the 292 points by using three reference points (compare the RTK GPS results with the RTK GPS/GLONASS results on three days). The results for those nine points in Figure 5 (the marked points) show that the RTK GPS positioning was degraded by the tree canopies as they frequently blocked the signals of the low-medium satellites and affected the signals. Therefore, the differences for the horizontal and vertical coordinates of these nine points for the RTK GPS measurements of the first, second and third day differs from the differences for the horizontal and vertical coordinates of these nine points for the RTK GPS /GLONASS measurements, see Figure 5.

Thus the accuracy of the RTK results is presented as derived from the estimation process. Figure 4 shows the average standard deviations for the three tests, in the Easting (Y), Northing (X), and orthometric height (H) coordinate directions. Because orthometric heights are used in geodetic applications in Turkey,the coordinates (Easting, Northing) of all the points were good in general with standard deviation less than 1 cm on average. As expected, the height accuracy was less than that, as its average standard deviation reached 2 cm. The height component was less consistent, and sometimes differed up to 10 cm (Figure 5) at the same point between the RTK GPS tests based on N1, N2 and N3 reference points. Considering the dynamics involved in this test, and the changing geometry of satellites near the tree environment, the results clearly show that the RTK GPS technique is a stable system, and the cm level of accuracy is usually obtainable under various operational conditions except when the points are near the tree environments (Figure 5).

When comparing the RTK GPS/GLONASS results of all the tests, the horizontal coordinates of the test points which were very close to the forest, as separately determined by these tests seems very consistent, with the changes ranging between a few millimetres up to 1 cm. This is shown in Figure 4, which gives the average differences, for all the points. The height component was less consistent, and sometimes differed up to 3 cm at the same point between the RTK GPS/GLONASS sessions. For other points, height differences were as little as a few millimetres to centimetres.





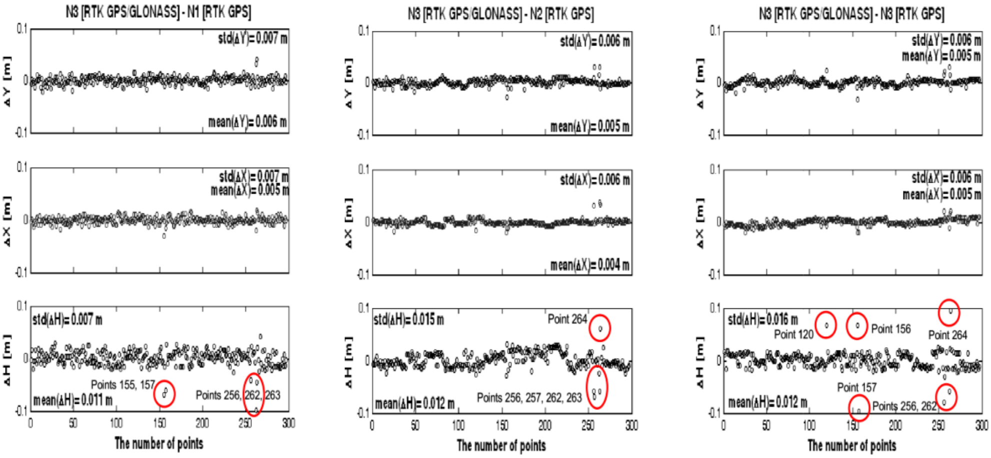


Figure 5: Comparison of the coordinates of the test points using N1, N2 and N3 as reference points (using RTK GPS and RTK GPS/GLONASS).

To evaluate the RTK accuracy, a high (30 cm) resolution aerial photo, a high (5 m) resolution 3D digital terrain elevation model and the RTK measurements of the project area were integrated in Autodesk LandXplorer Studio ProfessionalTM (Figure 6). The aerial photo had quite a good match with the map created through the RTK measurements. 3D digital elevation model increase the users' perception of the data. The model shows that the area where the precision of the measurements decreases owing to the trees. For obtaining better results, it should be far from the trees, especially the higher trees.

Those experiments demonstrate the advantages of RTK GPS/GLONASS in terms of functionality, versatility and ability to operate in the areas subject to high levels of disturbance. Particularly where a centimetre horizontal accuracy is required in the obstructed area, the RTK GPS/GLONASS method is problem free. This study shows that the RTK GPS/GLONASS method can replace other survey methods in surveying applications which require the above mentioned accuracy.

Figure 6:The combination of the aerial photo and RTK GPS/GLONASS measurements in the project area (3D digital terrain model of the project area), (a) is north-south direction, (b) is south-north direction

4 CONSISTENCY OF THE RTK GPS AND RTK GPS/GLONASS RESULTS

To check the compatibility of the RTK GPS technique with the RTK GPS/GLONASS technique, the three dimensional (3D) misclosure vectors were computed as follows (Veersema, 2004):

$$m_n = \sqrt{(Y_{RTKGNSSn} - Y_{RTKGPSn})^2 + (X_{RTKGNSSn} - X_{RTKGPSn})^2 + (H_{RTKGNSSn} - H_{RTKGPSn})^2} \quad (1)$$

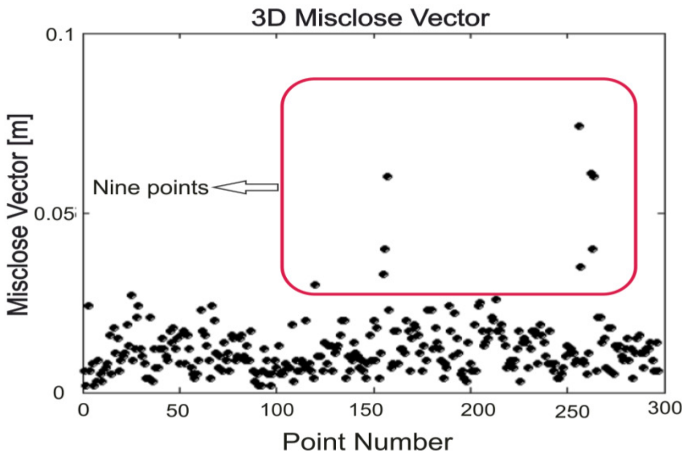


Figure 7: 3D misclosure vectors for all 292 points in the project area.

where n is the point number (1 to 292), m is the misclosure vector (in metres) for the nth point, Orthometric heights, were calculated with ± 12 cm accuracy TG99A (Turkey National Geoid Model 1999) geoid model by using the ellipsoidal heights derived from GNSS (URL 4).$Y_{RTKGNSSn}$, $X_{RTKGNSSn}$ and $H_{RTKGNSSn}$ are the easting (Y), northing (X) ED50 and orthometric height (H) coordinates (in metres) of the nth point from mean RTK GPS/GLONASS coordinates, $Y_{RTKGPSn}$, $X_{RTKGPSn}$ and $H_{RTKGPSn}$ are the easting and northing and orthometric height coordinates of the nth point from mean RTK GPS coordinates (Wolf and Ghilani, 2002). Figure 7 shows the 3Dmisclosure vectors for the two tests. The plane coordinates (Easting and Northing) were generally consistent with a standard deviation of less than 1 cm on the average. The 3D miscloses between the RTK GNSS and the RTK GPS surveys range from 2 mm to 80 mm, with an average misclose of 12 mm and a standard deviation of 9 mm. Results also show that tree canopies were harmful to RTK GPS positioning, as they frequently blocked the signals. Thus, even with the presence of good GNSS satellite visibility, signal blockage due to tree canopies could be considered as the main problem affecting use of GPS in tree environments. However, when supplemented by GLONASS satellites, the PDOP dropped, allowing accurate positioning to resume. There are accuracy improvements associated with enhancing GPS/GLONASS; by far the greatest benefit is improved visibility of satellites. A combined GPS/GLONASS system will often have enough satellites in view to obtain high accuracy position when GPS-alone simply will not work. The availability on the market of GPS/GLONASS receivers on the L1-L2 frequency has led to appreciable advantages in practical geodesy. In this paper, we have demonstrated the advantages in surveys of practical interest to survey engineering based on the use of RTK technique in obstructed and unobstructed sites.

5 CONCLUSIONS

Field tests in operating environments indicate that the addition of GLONASS significantly improves accuracy and availability. In the unobstructed environment, GPS/GLONASS solution provides a horizontal accuracy of about 1 cm, which is at least 3 cm better than any GPS-only dual frequency solution in this study. Our results are consistent with those of many other groups that made similar tests (Al-Shaery, 2011), (El-Mowafy, 2000), (Lemmonand Gerdan, 1999), (Lin, 2003), (Zhang, 2011). In the obstructed areatested with heavy overhead foliageposed the greatest challenge to RTK GPS as ambiguity resolution was nearly impossible.

The current GPS and GLONASS constellations available show a clear advantage when using GPS and GLONASS together for high precision positioning in mobile applications where there are obstructions to the sky. The GPS and GLONASS receivers are able to maintain RTK Integer at times when GPS-only receivers cannot. The dual-frequency GPS and GLONASS receivers are able to resolve ambiguities faster. GLONASS is now a viable solution throughout the world and the number of occasions where it is not useful is now very limited.

The main benefits of next generation GPS/GLONASS are its rich space infrastructure, rich signal, and better geometry which can significantly reduce the positional dilution of precision (PDOP) factor and provide additional systems for cross check. The most valuable benefit is the enhanced resolution of the integer ambiguities encountered in carrier phase tracking as the receiver attempts to determine the unknown number of full cycles between the carrier wave received and the one generated locally.

RTK GPS/GLONASS surveying provides many advantages over other traditional methods, including with respect to speed, accuracy and operational capability by day or night and in any weather. For these reasons and others, RTK GPS/GLONASS should be used increasingly in the future for all type of surveys.

GLONASS is also more resistant to interference and jamming. Future European Galileo system, which is being developed, has to provide further advantages. Galileo is in a more advantageous position with respect to GPS/GLONASS in the sense that many issues related to interoperability with existing navigation systems have been taken into consideration in the initial design of Galileo. Future GPS/GLONASS/Galileo receivers have to become a standard for high-precision positioning. GLONASS is a reliable system that provides superior performances of GNSS receivers, especially in RTK mode under environments with limited visibility of satellites (urban or canopy areas, sites located near trees, buildings etc.). In the future we will perform and evaluate RTK GPS/GLONASS/GALILEO usagein obstructed environments.

Literatura in viri:

Al-Shaery, A., Lim S., Rizos C. (2011).Assessment of network-based positioning performance using GPS alone versus GPS and GLONASS Combined, 24rd International Technical Meeting of The Satellite Division of the Institute of Navigation, Portland, Oregon, USA, 19-23 September, 2341-2349.

Bilker, M., Kaartinen, H. (2001).The Quality of Real Time Kinematic GPS Positioning.Reports of the Finnish Geodetic Institute, No.1, Kirkonummi.

Borjesson, J., Johansson, J., Darin, F. (1999). GLONASS: Experiences from the First Global Campaign. Radio Vetenskappch Kommunikation 99 (RVK99), Karlskrona, Sweden, June 14-17.

El-Mowafy, A. (2000).Performance Analysis of the RTK Technique in an Urban Environment. The Australian Surveyor, 45 (1), 47-54.

El-Mowafy, A., El-Maghraby, M., Issa, M. (1997).Using Semi-Kinematic GPS Techniques for Establishing and Densifying Horizontal Control Networks in Egypt. Proceedings of International Symposium on Kinematic Systems in Geodesy, Geomatics and Navigation (KIS), Banff, Canada, June 3-6.

El-Rabbany, A. (2006). Introduction to GPS: The Global Positioning System, Second Edition, Artech House, 159-160.

Fuhlbrügge, J.H. (2004). Untersuchungen zur Prüfung von GPS-Echzeitsystemen als Beitrag zur Qualitätssicherung im Vermessungwesen, Inaugural-Dissertation zur Erlangung des akademischen Grades Doktor-Ingenieur, Nr. 91, Bonn.

Hoffmann-Wellenhof, B., Litchtenegger H. &Wasle E. (2008).GNSS - Global Navigation Satellite Systems: GPS, GLONASS, Galileo and More, Vienna: Springer-Verlag.

Langley, R. (1998). RTK GPS, GPS World, 9(9), 70-76.

Leick, A., Beser, J., Rosenboom, P., Wiley, B. (1998).Assessing GLONASS Observations, Proceedings of the Satellite Division of the Institute of Navigation 11th International Technical Meeting, ION GPS-98, Nashville, September 15-19.

Lemmon, T.R., Gerdan, G.P. (1999). The Influence of the Number of Satellites on the Accuracy of RTK GPS Positions, The Australian Surveyor, 44 (1), 64-70.

Lin, L.S. (2003).Integrating of GPS RTK and Total Station for Land Surveying of Urban Region. 1st Taipei International Conference on Digital Earth, Chfinese Cultural University, Taipei, Taiwan, November 18-19, No. C1-12, 1-10.

Martin, W., Ladd, J. (1997). GPS+GLONASS Surveying: Post Processed and Real-Time Results. Proceedings of the Satellite Division of the Institute of Navigation 10th International Technical Meeting, ION GPS-97, Kansas City, September 16-19.

Parkinson, B.W., Spilker, J.J. (1996).Global Positioning System, Theory and Applications. Volume 1, Chapter 15, Foliage Attenuation for Land Mobile Users, Stanford University and Telecom, Stanford, California, 569-583.

Schofield, W. (2001).Engineering Surveying: Theory and examination problems for students. 5th Edition, Oxford: Butterworth-Heinemann.

Subari, M.D., Anuar, K. (2004).Experiencing the Use of GPS-RTK for Cadastre Surveys in Malaysia, 3rd FIG Regional Conference TS 14 – Positioning and Measurement – GNSS Applications, Jakarta, Indonesia, October 3-7.

Van Diggelen, F. (1997).GPS and GPS+GLONASS RTK. Proceedings of the Satellite Division of the Institute of Navigation 10th International Technical Meeting, ION GPS-97, Kansas City, September 16-19.

Veersema, A. (2004).RTK GPS for Cadastral Boundary Surveying in New South Wales. Final year thesis project, School of Surveying and Spatial Information Systems, University of New South Wales (http://www.gmat.unsw.edu.au/currentstudents/ug/projects/Veersema, Date of viewing: 16.04.2006).

Wolf, P.R., Ghilani, C.D. (2002). Elementary Surveying, an Introduction to Geomatics. 10th Edition, Prentice Hall Upper Saddle River, New Jersey, Prentice Hall.

Yamada, H.,.Takasu T, Kubo N. & Yasuda A. (2010) Evaluation and calibration of receiver interchannel biases for RTK-GPS/GLONASS, 23rd International Technical Meeting of The Satellite Division of the Institute of Navigation, Portland, Oregon, USA, 21-24 September, 1580-1587.

Zhang, S., Zhang K., S. Li Wu & B. (2011) Network based RTK positioning using integrated GPS and GLONASS observations, International Global Navigation Satellite Systems Society Symposium-IGNSS, Sydney, Australia, 15-17 November.

URL1: http://www.topcon.com.sg/survey/hiperpro.html

URL2: http://www.cmtinc.com/gpsbook/

URL3: ftp://ftp.trimble.com/pub/to_sg/SC%20V10.80/Documentation/English/Help/Eng_SCInitialisation.htm

URL 4: http://www.hgk.msb.gov.tr/haritalar_projeler/bildiriler/jeodezi/makale(pdf)/jeo_tek_bil3.pdf

Received for publication: 6. March 2013
Received by: 25. July 2013

Associate Prof. Dr. Atınç Pirti
Yildiz Technical University, Civil Engineering Faculty, Geomatic Engineering Department,
Surveying Division, Davutpasa Street, Esenler, 34210, Istanbul - Turkey
e-mail: atinc@yildiz.edu.tr

Assistant Prof. Dr. Mehmet Ali Yucel
CanakkaleOnsekiz Mart University,Department of Geomatic Engineering,
Terzioglu Campus, 17100 Canakkale, Turkey
e-mail: ali@comu.edu.tr

Research Assistant Kutalmis Gumus
NiğdeUniversity, Engineering Faculty, Geomatic Engineering Department,
51245, Niğde - Turkey
e-mail: kgumus@yildiz.edu.tr