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MILLIMETER LEVEL ACCURACY POINT POSITIONING IN WOODLAND AREA BY USING HYBRID METHOD

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Abstract

The hybrid techniques (rapid static/total station) can be very helpful technology for centimetre and millimetre level positioning in the woodland. Point Positioning with CORS GNSS (Continuously Operating Reference Stations Global Navigation Satellite System) in the woodland is a significant challenge in terms of time saving to obtain high accurate coordinates of the points. The time for integer carrier-phase ambiguity solution takes approximately one-hour or more time for point positioning under the woodland with GNSS surveys. In this study, hybrid techniques for estimating point coordinates under woodland has been performed, which gives the positioning results with millimetre and centimetre level accuracy and nearly 30 minutes are required to provide the new point location in the woodland. The proposed method may also have practical usage for forest-woodland areas applications with desired accuracy at mm level, which is reached in a short observation time. A fieldwork has been performed to obtain coordinates of the point (K) in woodland with CORS GNSS system and supplementary measurements by establishing two control points (T_1, T_2) observed by rapid static method located at the border of the woodland. On the other hand, the coordinates of point (K) have been also gained by using a static method (3 hours observation). The coordinate differences (static-hybrid) show that a satisfactory solution for woodland is reached at mm level in a short observation time.

Key words: forest, Global Navigation Satellite System, surveying, Virtual Reference Station.

Introduction

Forest canopy is one of the most significant restricting components in utilizing the *Global Navigation Satellite System* (GNSS) for positioning and mapping. However, forestry and natural resources applications are also among the largest users of GNSS technology. The use of GNSS in forestry has become increasingly established particularly in the field of logistics, inventories for surveying. However, the uninitiated forest user takes it for granted that GNSS will always work to the same level of accuracy in any location, while the more critical foresters assume on the other hand, that GNSS cannot possibly function properly anywhere under the canopy of forest trees and reject it for this reason. The impacts of forest can essentially debase the precision and, accuracy of GNSS positions. The GNSS signals are influenced by the canopy and this obviously influences the nature of the processed position. Forest canopy effects on the GNSS signal include obstruction, attenuation and reflection. The signal attenuation can make it very difficult for a GNSS receiver to track the signals. At some points, the receiver will not be able to track the signal at all and the effect will be the same as if the signal has been obstructed. Even if the signal can be tracked, some receivers will have difficulty for accurately measuring pseudo ranges. There are a lot of factors caused by forest conditions which can influence positioning accuracy. Forests are a barrier for signal propagation so the final radio wave is weak and the reflection causes an elevated signal-to-noise ratio, which is caused by the so called multipath effect. The base idea of multipath is strictly connected to signal reflections from objects located near the receiver, which ultimately causes an error in distance measurements. There are many software and hardware solutions to weaken this effect, however it still does not solve the strong forest influence. Additionally, the multipath effect is multiplied by high moisture and the presence of leaves. The forested environment create many obstructions that produce cycle slips in the satellite signals for each observation for the stations. High density sites, tree species, satellite constellation and observation times, are important factors for accurate positioning. When compared to open sky conditions, leaves decrease a number of visible satellites, and hence geometry (PDOP value) is deteriorating. PDOP predicts the accuracy of positions relative to satellite geometry. A low PDOP indicates a higher probability of position accuracy. A high PDOP indicates a lower probability of accuracy. In dense forest where PDOP is relatively low (around 2) the accuracy is really low. It is generally caused by multipath effect signal loses-not PDOP value. The short observation times (RTK and CORS) may not have provided enough time in the forested environment to determine a fixed ambiguity resolution. There are numerous studies concentrating on positioning under forest canopies utilizing different GNSS devices and processing techniques, and the results show that a dense forest canopy can lessen the accuracy of the GNSS instruments. In these situations, the surveys were gained during static sessions of varying length, and the positioning accuracy fluctuated from a few centimetres to several meters, depending on the instrumentation, length of data observation period, and processing (Kaartinen et al. 2015, El-Rabbany 2006, Hoffmann-Wellenhof et al. 2008, Wright et al. 2017, Brach and Zasada 2014).

Fast static, also known as rapid static has similar concept with traditional static surveys. The difference is the time durations of the GNSS observations. Rapid static observations range from 8–30 minutes. The observation times will be based on the site conditions and satellite signals. Rapid static surveying is ideal for many engineering surveys and is halfway between static and kinematic procedures. This method is accurate and economic even there are many points to be surveyed. It is ideally suited for short baselines where systematic errors such as atmospheric, orbital, etc. may be regarded as equal at all points and so differenced out. It can be used on large lines but may require longer observation periods due to the erratic behaviour of the ionosphere. If the observations are carried out at night when the ionosphere has more stable times that may be reduced. This procedure is similar to static surveying, except that one receiver always remains on a control station while the other(s) are moved progressively from one unknown point to the next. An observation session is conducted for each point, but the sessions are shorter than for the static method. The rapid static procedure is suitable for observation baselines up to

20 km in length and at good observation conditions. Rapid static positioning can also yield accuracies approximately ± (3 to 5 mm +1 ppm). GNSS receivers reduce the time required at each station in a rapid static survey due to the increased number of visible satellites and improved satellite geometry. If during the observations the surveyor notices high RMS or other problems, then the surveyor should make and record additional measurements. These additional measurements allow bad measurements to be discarded during the network analysis. Additional measurements at a different time with a different satellite constellation may be necessary (El-Rabbany 2006, Hoffmann-Wellenhof et al. 2008, Pirti et al. 2010, Ghilani and Wolf 2012, Bakula 2013, Pirti et al. 2016).

Total Station is the term applied to modern surveying instruments that incorporate an Electronic Distance Measurement (EDM), a digital theodolite and a microprocessor. This combination of components provides the capability of electronically making simultaneous slope distance and horizontal and vertical angle measurements. Total stations measure very rapidly and display the data automatically in digital format. The microprocessors within the total station display the horizontal and vertical components of sloping lines in real time. Total stations can also be connected to data collectors that enable the automatic recording of field measurements for further processing and plotting capabilities. Robotic total stations (Reflectorless) allow the operator to control the instrument from a distance via remote control and surveys the data by reflectorless mode. This eliminates the need for an assistant staff member as the operator holds the reflector and controls the total station from the observed point (Ghilani and Wolf 2012).

This study investigates the hybrid (rapid static/total station) method achievable accuracy in forest area. The aim of this study is to examine the applicability of hybrid system (GNSS (especially for rapid static method) and total station) for computing the position of a point (*K*) placed under the forested area, according to short observation duration (approximately 30 minutes) and the required horizontal accuracies (±1 cm and below). Two observation stages were performed at the same time: 1) GNSS observations rapid static (about 20 min), and 2) total station surveys (Topcon OS Total Station). This study also intends to supply an economical and practical measurement method to gain accurate point positioning under the forest environments for forestry applications. In this study, it is emphasized how long the solution time of the integer ambiguity and its validity can be camouflaged among the difficulties encountered in determining the location in forest and wooded regions. In this, the hybrid method (Fast Static + Robotic Total Station) which I suggested as an alternative technique is explained. In previous studies, both static and kinematic methods have been tried to determine the position with GPS, GPS + GLONASS and the obtained position accuracy has been in the range of ± (2–15) cm. In addition, in order to achieve this location accuracy (fixing Integer ambiguity), it has to be waited between 1–3 hours in the forest and wooded regions. With this proposed hybrid method, an accuracy of between centimeters and millimeters can be easily reached in the range of about 20 to 30 minutes. This hybrid method provides a great advantage in both economy and time saving in terms of engineering applications; it is presented as an alternative technique to the world of science (Parkinson and Spilker 1996, El-Rabbany 2006, Hoffmann-Wellenhof et al. 2008, Pirti et al. 2010, Ghilani and Wolf 2012, Brach and Zasada 2014, Pirti et al. 2016).

Materials and Methods

Four temporary test points (T_1, T_2, T_3, and T_4) were established to calculate the coordinates of the point (K) under the woodland, located at the Yildiz Technical University, Campus of Davutpaşa, Istanbul, Turkey. The specification of the project area of interest is that it is located at the border of the forested environment and open sky. To eliminate the negative effects (signal attenuation, diffraction, multipath and signal losses), rapid static GNSS surveys (Topcon Hiper SR receivers) have been performed at the open area side of the border aiming at providing observations accurately to enhance the communications of the GNSS receiver with satellites from two points. Besides, terrestrial measurements have been performed simultaneously by using the other two points (T_3 and T_4). The point (K), which coordinates are being computed was located in the woodland, and terrestrial measurements and static GNSS surveys were also performed (3 hours). The project area selected in the woodland is illustrated in Figure 1 (Pirti et al. 2016).

In this project, static and rapid-static GNSS observations were processed with post-processing computation based on

Fig. 1. Network of reference stations with study area.

İSKİ-CORS network, which covers the project area. İSKİ-CORS Network, which coverage area is Istanbul, was established by Istanbul Water and Sewerage Administration (İSKİ) and involves 10 permanent stations. The İSKİ-CORS Network is an active GNSS Network and transmits the correction data to all users completely real-time via the data links and communication systems. The system consists of a number of automated GNSS tracking stations, which continuously record carrier phase and pseudo range measurements for all GNSS satellites in view. Figure 1 shows the coverage area of İSKİ-CORS network, which contains the boundary of the province of Istanbul. İSKİ-CORS network can also supply VRS, FKP and MAC corrections (Pirti et al. 2016).

Four points in all were located around the woodland, namely T_1, T_2, T_3 and T_4 (Fig. 2 and Fig. 3a). Simultaneous surveys were performed from the field site to shorten the measurement time, and then, within about 30 minutes the GNSS (rapid-static/20 minutes) and total station measurements (10 min) finished. To calculate the coordinates of *K*, placed under the woodland, coordinates of T_1 and T_2 were determined by rapid-static GNSS surveys. The measurements on the two points (T_1 and T_2) were performed in the rapid-static mode with at least 20 min of observation time (total 6 hours). The minimum elevation cut-off angle and record interval were 10° and 30 seconds, respectively. All of the GNSS data processing and network adjustments were conducted using Topcon MAGNET Tools Software. In the adjustment procedure,

Fig. 2. Points in the project area: a) Point T_1, T_2, T_3 and T_4; b) Point K in the study area; c) Sky visibility from point *K*.

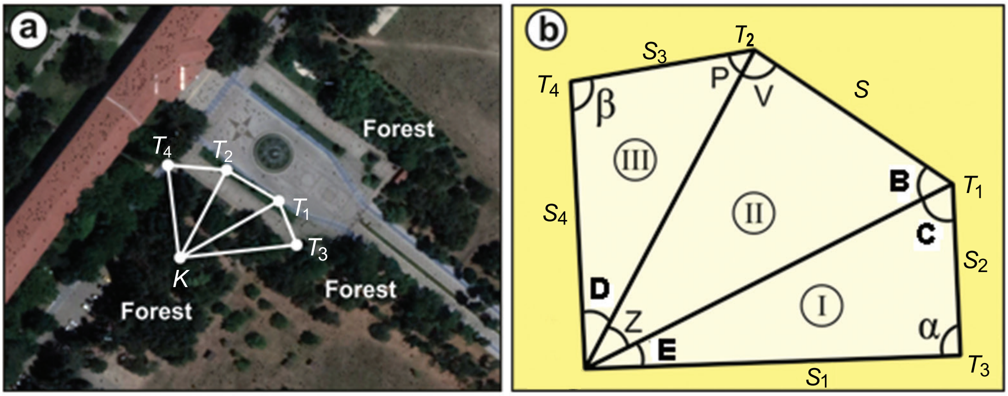

Fig. 3. Four points located near the woodland (a) and calculation design (b).

the ITRF 2008 coordinates of the points KCEK and PALA; İSKİ-CORS reference stations, (approximately 10 km far away from the project area) were taken fixed (Table 1). To check the coordinates of *K*, static GNSS observation was performed during 3-hour observation time. A three hour-static GNSS survey at point *K* (under the forested area, see Fig. 3) was computed by using PALA and KCEK) with commercial post-processing GNSS software, Topcon MAGNET Tools, see Table 1. Coordinates of T_3 and T_4 were computed using terrestrial surveys from two triangles (Triangle I and III, see Fig. 3b).

Table 1. Coordinates and their standard deviations of the three points (3 hours static GNSS surveys).

Point No	X, m	Std., mm	Y, m	Std., mm	h, m	Std.,mm
PALA	4,550,678.133	Fixed	412,882.267	Fixed	170.543	Fixed
KCEK	4,541,595.806	Fixed	397,337.575	Fixed	122.893	Fixed
T_1	4,543,944.263	4	406,700.460	3	113.434	8
T_2	4,543,955.951	4	406,685.336	3	113.892	8
T_3	4,543,928.027	4	406,702.052	3	113.752	8
T_4	4,543,949.683	4	406,663.259	3	113.548	8
K	4,543,920.870	5	406,663.963	4	112.860	10

Note: *h* is ellipsoidal height.

Figure 3b also shows the survey sketch. Even though one triangle is enough to compute the point coordinates, namely *K*, placed under the woodland, the model is built for solving the problem using three triangles, not only to control the measurements surveyed at field site but also to control the coordinates of the points, namely T_3, T_4 and *K* which angles (directions) or distances are measured. The above-mentioned angular variables seen in Figure 4b were computed for each triangle using equations (1) and (2). The equations were generated according to Triangle I (Pirti et al. 2016).

$$\alpha = \arccos\left(\frac{S_1^2 + S_2^2 - S_3^2}{2 \cdot S_1 \cdot S_2}\right), \qquad (1)$$

$$t = \arctan\left(\frac{dy}{dx}\right), \qquad (2)$$

where: α is one of the interior angles of Triangle-I and β is one of the interior angles of Triangle-III were measured. S_1, S_2 and S_3, S_4 indicate measured horizontal distance of the Triangle-I and II, respectively. t is the azimuth angle. dy and dx are departure and latitude values, which are y and x components of a line in a rectangular grid system, respectively.

Equation (1) is the cosine rule for finding angles and Equation (2) is the formula of finding the azimuth, which is defined as a horizontal angle measured clockwise from the north. Table 2 illustrates the coordinate's computation procedure of point *K*. The formulation has been given for Triangle I and III (Pirti et al. 2016).

Table 2. Formulas for computing *K* coordinates.

Parameters	T_3	*K* from Triangle I
Azimuth	$t_{T_1T_3}=t_{T_1T_2}-X$	$t_{T_3K}=t_{T_1T_2}-\alpha$
Coordinates	$Y_{T_3}=Y_{T_1}+S_{T_1T_3}\cdot\sin t_{T_1T_3}$ $X_{T_3}=X_{T_1}+S_{T_1T_3}\cdot\cos t_{T_1T_3}$	$Y_K=Y_{T_3}+S_{KT_3}\cdot\sin t_{T_3K}$ $X_K=X_{T_3}+S_{KT_3}\cdot\cos t_{T_3K}$
	T_4	*K* from Triangle III
Azimuth	$t_{T_2T_4}=t_{T_2T_1}+V+P$	$t_{T_4K}=t_{T_4T_2}+\beta$
Coordinates	$Y_{T_4}=Y_{T_2}+S_{T_2T_4}\cdot\sin t_{T_2T_4}$ $X_{T_4}=X_{T_2}+S_{T_2T_4}\cdot\cos t_{T_2T_4}$	$Y_K=Y_{T_4}+S_{KT_4}\cdot\sin t_{T_4K}$ $X_K=X_{T_4}+S_{KT_4}\cdot\cos t_{T_4K}$

Table 2 shows *X* and *Y* horizontal coordinates, *S* horizontal distance, *V* interior horizontal angle in triangle II, α interior horizontal angle in Triangle I, *P* interior horizontal angle and β interior horizontal angle in Triangle III. Equation (1) and Equation (2) were used to calculate the interior angles of generated triangles and the azimuth of related line (T_1 T_2). All the others were computed in the same way.

Results

To supply the available condition in this computation strategy, visibility between points $T_3 - T_1$, $T_3 - K$ and $T_4 - T_2$, $T_4 - K$ should be provided.

The terrestrial surveys performed with robotic total station presented in Table 3 were performed to obtain the horizontal directions, vertical directions and horizon-

Table 3. Total station surveys to compute the coordinates of point *K*.

Station No	Target No	Horizontal angle, grad	Vertical angle, grad	Horizontal length, m	Explanation
T_3	K	0.0000	100.5408	38.751	t_K=1.485 m
i=1.551 m	T_1	105.6120	98.8956	16.314	t_{T_1}=1.508 m
T_4	T_2	0.0000	100.6872	22.950	t_{T_2}=1.560 m
i=1.460 m	K	116.0430	103.0050	28.827	t_K=1.485 m

Note: *i* – instrument heights, *t* – target heights.

tal lengths. And then the three triangles were checked by using the sum of the angles, see Table 4.

Table 4. Angle computations to check the triangles (Fig. 4).

Triangle		
I	II	III
α=105.6124 grad	Z=28.8784 grad	D=36.3917 grad
E=24.4637 grad	V=92.9377 grad	P=47.5651 grad
C=69.9239 grad	B=78.1839 grad	β=116.0432 grad
α+E+C = 200 grad	Z+V+B = 200 grad	D+P+β = 200 grad

GNSS rapid-static surveys were conducted at T_1 and T_2 simultaneously. Points T_1 and T_2 were surveyed by rapid-static method by using İSKİ-CORS network (Fig. 2), and then the coordinates of these points were determined. The Position dilution of precision (PDOP) values for T_1 and T_2 were between 1.8 and 3.8, see figures 4 and 5. The elevation mask is 10 degree, and record interval is 30 seconds.

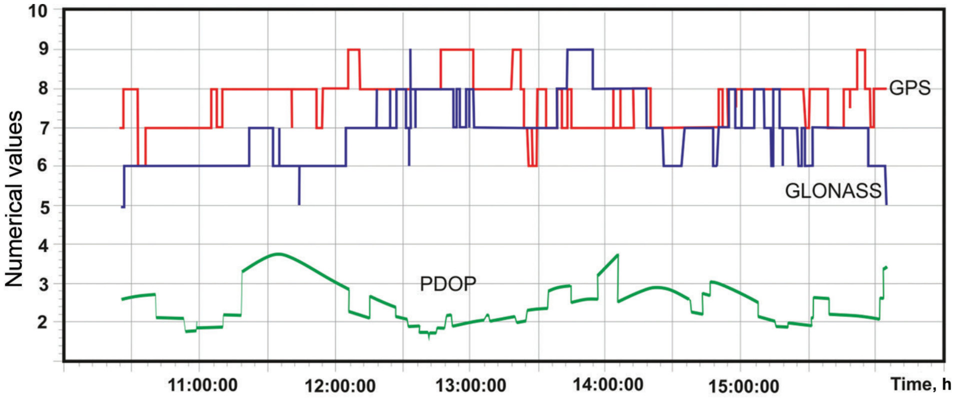

Fig. 4. PDOP and number of satellites for point T_1.

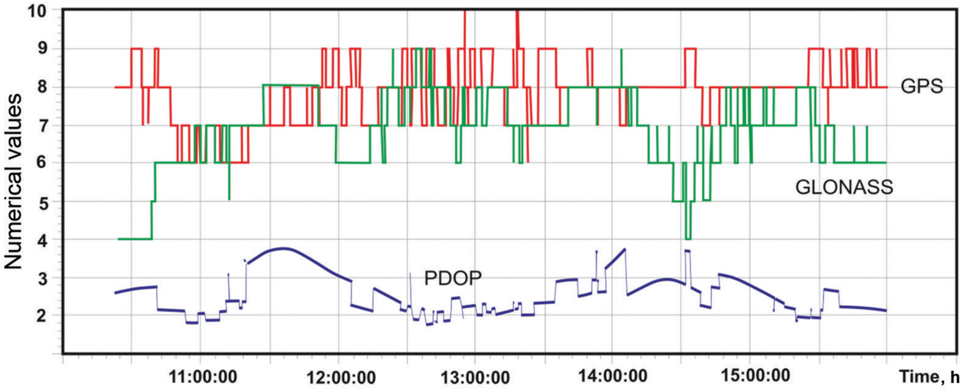

Fig. 5. PDOP and number of satellites for point T_2.

The visible satellite numbers for T_1 and T_2 were between 13 with 9 GPS+4 GLONASS and 16 with 10 GPS+6 GLONASS; between 13 with 5 GPS+8 GLONASS and 17 with 9 GPS+8 GLONASS respectively (figs 5 and 6). There are accuracy improvements associated with enhancing GNSS; by far the greatest benefit is improved visibility of satellites. The provided coordinates depending on these survey situations were computed as shown in figures 6 and 7.

Figures 6 and 7 show the comparison of static with rapid static results for point T_1 and T_2. The standard deviation values of the differences (T_1 and T_2 horizontal coordinates) were also less than 5 mm in general for X and Y coordinates. The mean values of the differences were also less than 6 mm for X and Y coordinates.

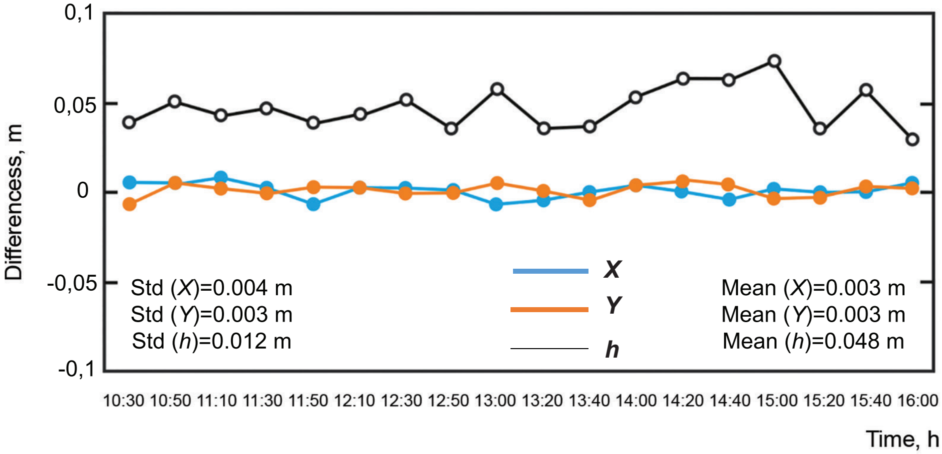

Fig. 6. Compare static results with rapid static results (20 minutes) for point T_1.

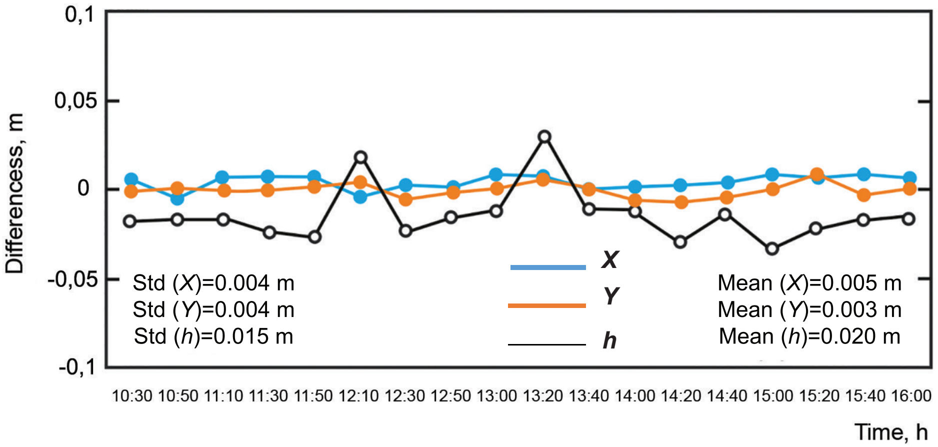

Fig. 7. Compare static results with rapid static results (20 minutes) for point T_2.

The height component was however less consistent with changes ranging between about 10 mm up to 75 mm.

Table 5 shows the computation of the coordinate results for point *K* using hybrid method (rapid static and total station techniques). Triangle I, triangle II, triangle III were used for these computations. T_1, T_2, T_3 and T_4 could be used to help solve these problems.

Table 5. Computation results of coordinates.

Parameters	T_1	*K* from Triangle II
Azimuth	$t_{T_1T_2}=341^g.8858437$ $S_{T_1T_2}=19.114$ m	$t_{T_1K}=263^g.7019437$ $S_{T_1K}=43.350$ m
Coordinates	$Y_{T_1}=406700.460$ $X_{T_1}=4543944.263$	$Y_\mathrm{K}=406663.968$ $X_\mathrm{K}=4543920.864$
	T_2	*K* from Triangle II
Azimuth	$t_{T_2T_1}=141^g.8858437$ $S_{T_1T_2}=19.114$ m	$t_{T_2K}=234^g.8236437$ $S_{T_2K}=41.079$ m
Coordinates	$Y_{T_2}=406685.336$ $X_{T_2}=4543955.951$	$Y_\mathrm{K}=406663.968$ $X_\mathrm{K}=4543920.864$
	T_3	*K* from Triangle I
Azimuth	$t_{T_1T_3}=193^g.7780437$ $S_{T_1T_3}=16.314$ m	$t_{T_3K}=288^g.1656437$ $S_{T_3K}=38.751$ m
Coordinates	$Y_{T_3}=406702.0519$ $X_{T_3}=4543928.027$	$Y_\mathrm{K}=406663.968$ $X_\mathrm{K}=4543920.865$
	T_4	*K* from Triangle III
Azimuth	$t_{T_2T_4}=282^g.3887294$ $S_{T_2T_4}=22.950$ m	$t_{T_4K}=198^g.4319294$ $S_{T_4K}=28.827$ m
Coordinates	$Y_{T_4}=406663.2586$ $X_{T_4}=4543949.683$	$Y_\mathrm{K}=406663.969$ $X_\mathrm{K}=4543920.865$

When the accuracies were compared with static GNSS surveys in both coordinate components, computation showed differences in *Y* and *X* coordinates up to 0.273 and 0.170 m, respectively. They indicated that there were significant differences in the horizontal and vertical coordinates at difficult points. The results derived from this study show that with an integrated (hybrid) survey methodology within quite short duration of the survey (about 30 min), measurements within ±1 cm can be guaranteed, see tables 6 and 7. Figures 8, 9 and 10 show the comparison of static with hybrid (rapid static/total station) results. The standard deviation values of the differences (*K* horizontal coordinates) were also less than 5 mm in general for *X* and *Y* coordinate components. The mean values of the differences were also less than 6 mm for *X* and *Y* coordinates.

Table 6. The obtained point K coordinate results by using three different methods.

	K		
Surveys	***Y, m***	***X, m***	***h, m***
Post Processing Static GNSS (PPSGNSS)	406663.963	4543920.870	112,86
Hybrid method (Total Station+Rapid Static)	406663.968	4543920.865	112.877
CORS VRS	406663.695	4543920.700	112.809

Table 7. Comparison of the obtained coordinate results for point *K*.

Methods	**∆*Y*, m**	**∆*X*, m**	**∆*h*, m**
PPSGNSS-Hybrid Method	0.005	0.005	0.017
PPSGNSS-CORS VRS	0.268	0.170	0.051
Hybrid Method-CORS VRS	0.273	0.165	0.068

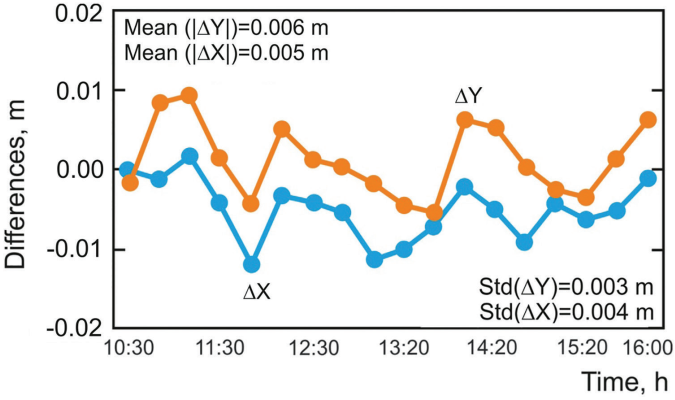

Fig. 8. Comparison of static with hybrid method results (X and Y coordinate differences of point *K*) by using point T_1.

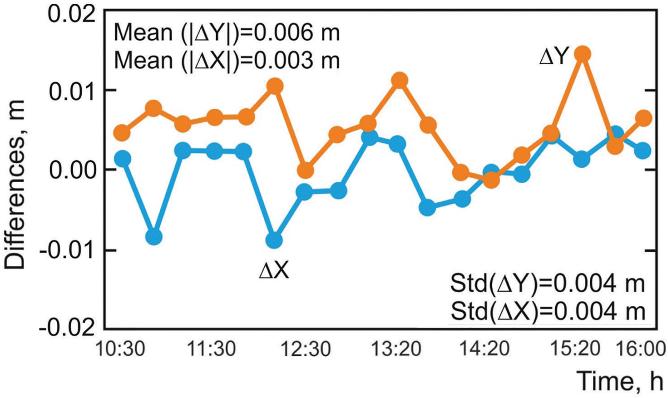

Fig. 9. Comparison of static with hybrid method results (X and Y coordinate differences of point *K*) by using point T_2.

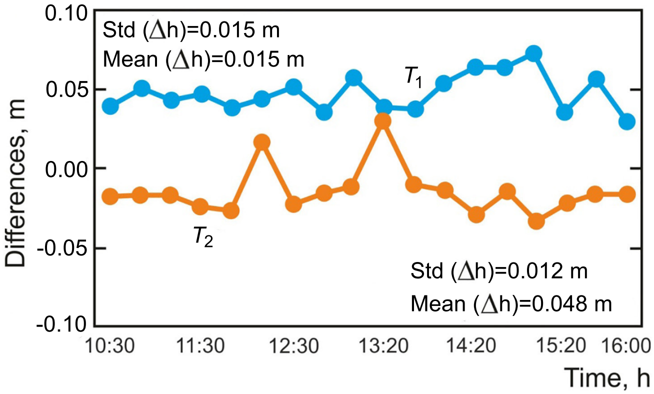

Fig. 10. Comparison of static with hybrid method results (h coordinate differences of point *K*) by using points T_1 and T_2.

The hybrid method derived horizontal coordinates were very consistent, with changes ranging between a few millimetres up to 14 mm (figs 8 and 9). The height component was however less consistent with changes ranging between 40 mm up to 75 mm (Fig. 10).

Conclusion

The points, which are located under trees, are blocked from good satellite observations. The GNSS points, which are located in more open areas, where good measurements to unobstructed satellites can be made. This method is also effective when satellite signals are poor or unavailable because of canyons, steep north slopes, tunnels, dense tree canopy or stems, and similar situations. This paper shows that rapid-static survey can be used for woodland or forest surveys (obtaining accuracy mm level), although a common obstacle, sky blockage, hinders its full effectiveness. However, this problem can be overcome if supplemented by conventional survey techniques. In this study, the CORS-RTK (VRS/FKP) required approximately 60 minutes to survey a point (*K*). The hybrid (integrated) methodology provides accurate coordinate solutions by resection computation method to obtain the coordinates of point (*K*). The hybrid method of surveying a point took approximately 30 minutes in the field. For a point (*K* under the woodland) the horizontal plane coordinates differed up to ±1 cm. Therefore, it appears that in difficult environments (woodland), measurements with ±1 cm and below can be guaranteed in all situations by using this hybrid method. In the future the best way to improve my research would be measure more points in real forest and check the accuracy of GNSS positioning using CORS VRS.

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