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NETWORK REAL TIME KINEMATIC (CORS-FKP METHOD) ACCURACY IN/UNDER FOREST AREA

SUMMARY

The use of Global navigation satellite system (GNSS), (geolocation and navigation system) in/under forestry is increasingly being established, especially in the areas of logistics, inventory and measurements. However, the uninitialized forest user assumes that GNSS will always work with the same accuracy everywhere, while the more critical foresters assume that GNSS will probably not work properly in/under the forest. A criterion is often used to evaluate the performance of a GNSS receiver in an obstructed environment. Due to tree canopy in a forest, GNSS performance can be limited, disturbed or completely prevented. The Real Time Kinematics (RTK) approach can provide centimetre-level accuracy in a suitable environment. A more accurate and stable positioning technique was first proposed in the mid-1990s by meticulously modelling all fault components based on a known reference network called the Network Based RTK (NRTK) technique. Since then, several methods have been developed and implemented in practice, such as the Virtual Reference Station (VRS), the Flächen Korrektur Parameter (FKP) and the Master-Auxiliary Concept (MAC), which are fundamentally similar approaches. The purpose of all studies for this paper was to evaluate the achievable accuracy of the Continuously Operating Reference Stations (CORS)-FKP in the project area and check the results. The CORS-FKP results show that the solution for the forest area was reached at cm level (±10-15 cm) for horizontal accuracy.

Keywords: Global Navigation Satellite System; gps; real time network; precision; static

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INTRODUCTION

Satellite navigation systems are becoming a significant tool in many professions. Global Navigation Satellite System (GNSS) refers to all available navigation satellite systems, GPS (Global Positioning System) and GLONASS (GLobal NAvigation Satellite System), Galileo and Beidou (Compass). It also includes newer systems such as China's BDS (BeiDou Navigation Satellite System), Japan's QZSS (Quasi-Zenith Satellite System), India's IRNSS (Indian Regional Navigation Satellite System), and Europe's Galileo (ESA 2016), (European GNSS (Galileo) Open Service 2021). (Wolf and Ghilani 2002).These satellite systems are sent into orbit and transmit coded electromagnetic signals back to Earth. A GNSS device can calculate its position in space and time by observing and analyzing signals from many satellites. Although the system has various features, in ecology, GNSS devices are usually used to locate bug traps, plant measurement plots, soil boring test locations, tree ring age measurement locations, and species occurrences (Konnestadt 2018). Because GNSS requires continuous connectivity to navigation satellites, using GNSS in semi-open environments produces unexpected results. Trunks, branches, or tree tops may block, reflect, or otherwise disrupt the GNSS signal, and this problem is predicted to worsen as forest density increases. The usage of GNSS beneath forest canopy is a regular aspect of the mapping workflow in many circumstances. This mapping may fail to provide the correct information for natural resource management if the difficulties with signal degradation in forest areas are not addressed. It may also be difficult to examine these coordinates because they do not give any information on how far it is predicted to be from its genuine position (Konnestad 2018, Kaplan 1996, Bakula *et al*. 2015, Brach and Zasada 2014, Frank *et al*. 2014, Massimiliano 2018, Gilbert 2002, Hofmann-Wellenhof *et al.*, 2001, Cina *et al*. 2015, Koivula *et al*. 2018, Pehlivan *et al*. 2019).

Continuously Operating Reference Stations (CORS) networks have been widely employed for high-precision real-time location. The availability of widely dispersed GNSS CORS networks prompted the implementation of the NRTK approach, which allows stations to overcome distance limitations (Wolf and Ghilani 2002), (Rizos 2002), (Shuanggen 2012). (Prochniewicz *et al*. 2020). The utilization of the GNSS CORS network also enables for more reliable differential corrections across large regions, such as the Virtual Reference Station (VRS) technique (Wanninger, 2003), (Mageed, 2013) the Multi Reference Station (MRS) approach (Fotopoulus *et al.* 2001), the Flächen Korrektur Parameter (FKP) approach or other surface correction approaches (Keenan *et al*., 2002), (Kim *et al*., 2017). Several authors (Prochniewicz *et al*., 2020), (Kim *et al*., 2017), (Dobelis *et al*. 2016) demonstrated that the NRTK technique allows reaching centimeter accuracy, comparable with the accuracy of the static measurements. FKP (area correction parameter) was developed by Geo++ Company, and its detailed information is given by (Wübbena *et al*. 2001, Wübbena and Bagge 2002, Cina *et al*. 2015). The correction parameters are calculated based on the number of surfaces estimated for each CORS station and the calculation of the correction parameters; the changes in the north-south and east-west directions are defined. For each reference station, a unique FKP surface is estimated. This data will allow it to converge quickly and accurately. The biggest problems in working with GNSS in the forest and wooded areas are the inability to see enough satellites and the decreases in the strength of the signals received from the satellites seen. As a result of the decrease in the signals of the satellites, the distance between the satellite and the receiver cannot be measured accurately. This causes problems in terms of accuracy in calculating point coordinates (Hofmann-Wellenhof *et al.*, 2001, Koivula *et al*. 2018).

The aim of this study is to evaluate the FKP method's performance in/under the forest environment. The purpose of all experiments in this paper was to investigate the achievable accuracy of the CORS-FKP in the project area and check the obtained results.

MATERIAL AND METHODS

Study Area

To investigate these problems; the effects of forest area that are associated with CORS-FKP positioning, three experiments (CORS-FKP, static, total station surveys) were carried out in the Davutpaşa region (Yıldız Technical University Campus), near Istanbul, in Turkey. For this aim, (K5, K6, K7 and K8) stations were marked in the project area (see Figures 1 and 2). K5, K6, K7 points were located under/in the forest area; but K8 point was marked in the unobstructed area (Figures 1 and 2). The area of interest is distinguished by its location on the border of a wooded region and an open sky. Data distortion and signal losses impair GNSS receiver observations in forestry, reducing precision and accuracy. To avoid this, CORS FKP surveys have been done on the open area side of the border with the goal of giving precise observations to improve the GNSS receiver's communications with satellites. The points whose coordinates are being calculated was established at the forested area side, and CORS FKP surveys and static GNSS surveys were also conducted (Pirti 2010). The data collection and processing speed for CORS-FKP surveys was set to 1 second and 5 epochs with a 10 degree elevation mask angle. The integer ambiguity is fixed between 1 minutes and 35 minutes for each point on 30 September 2020 and 1 October 2020 by using Topcon Hiper HR receiver. The first survey was performed on 30 September 2020 by using FKP technique whereas the other survey was performed on the successive day (1 October 2020) by using FKP technique.

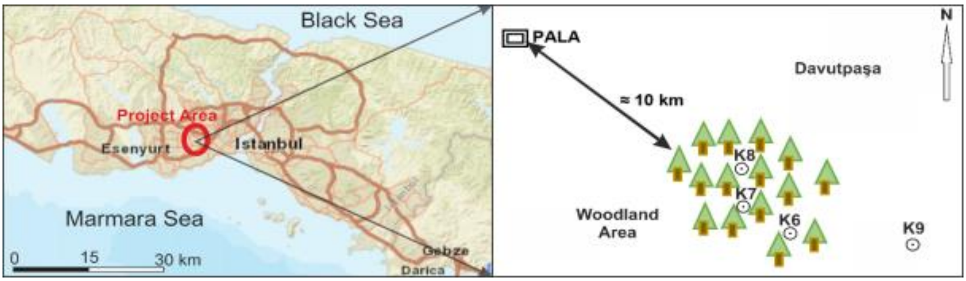

Figure 1. Project area and GNSS network

Figure 2. The four points (K6, K7, and K8 under the forest area and K9 in the unobstructed environment) in the study area

Description of the experiments

On October 2, 2020, static GNSS measurements of these four points were observed for at least 2.5 hours. The data receiving and processing rate is set to 30 seconds, and the cut-off elevation mask angle is set to 10 degrees. By using ISKI-CORS reference station PALA (approximately 10 kilometres away from the project), about 2.5 hours of GNSS static measurement values were calculated at three points (in/below the forest area, see Figure 2 and Figure 3). Area) and commercial post-processing GNSS Software, Topcon magnet tool (version 5.1.1.0). During the adjustment process, the ITRF 2005 coordinates of ISKI CORS/PALA points are fixed (Figure 1, Table 1). Table 1 and Table 2 respectively show the coordinates and standard deviations of the four points, as well as the date and time of observation. The GNSS equipment used for CORS measurement consists of a pair of Topcon Hiper HR receivers (Static (Horizontal =3mm+0.1ppm, Vertical=3.5mm+0.4ppm)), (RTK (Horizontal=5mm+0.5ppm, Vertical=10mm+0.8ppm)), (Topcon Manuals 2020). The two tests by using ISKI-CORS FKP surveys were performed at different times on two days (30 September 2020 and 1 October 2020), see (Table 2). The number and distribution of GNSS satellites tracked were generally "normal", 7 to 13 satellites were observed (Figure 4), and Position Precision Dilution (PDOP) ranged from 1.5 to 3.8, see Fig. Table 2 (Pirti 2010).

Table 1. Standard deviation and coordinate values of the four points by using static surveys

Point	Grid Northing (m)	Grid Easting (m)	Elevation (m)	Std N (mm)	Std E (mm)	Std h (mm)
PALA	4550678.029	412882.003	170.573	0	0	0
K6	4543679.333	406841.909	103.132	3	3	4
K7	4543678.792	406822.821	103.148	5	5	7
K8	4543669.766	406808.598	104.004	4	4	5
K9	4543657.721	406756.410	105.513	3	3	4

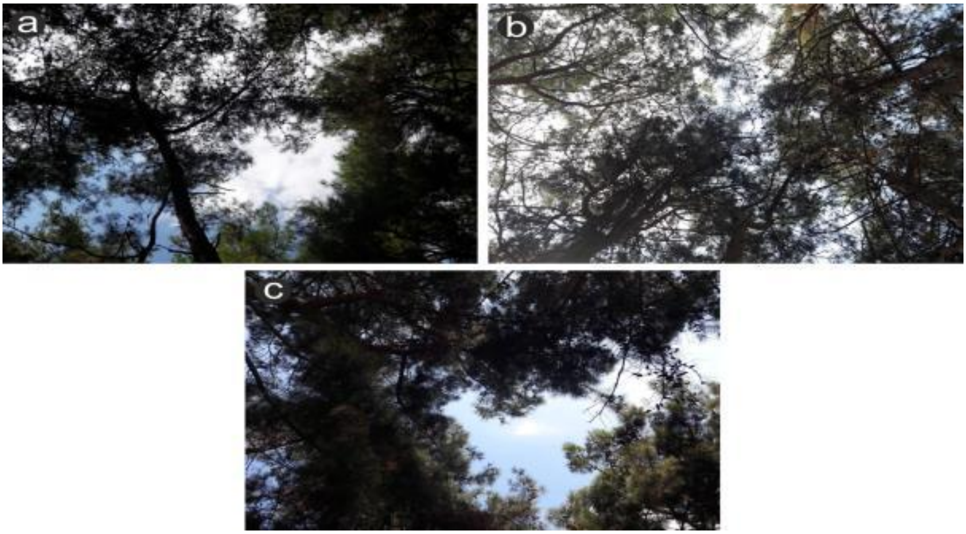

Figure 3. Sky visibility from Points K6, K7 and K8 (a, b, c), respectively

As explained above, GNSS receivers of K6, K7 and K8 were situated under/in the area; see Fig. 3. The problem shown by the sky plot of 9:20-9:39 hours on 30 September 2020 (Fig. 4a) and 10:18-10:26 hours on 1 October 2020 (Fig. 4b) is typical for the whole day; several satellites were shaded by the trees, see Fig. 4. As can be seen from the skyplot (Fig. 4), the receiver tracked satellites, at a high/medium elevation in the obstructed areas of the sky. Nine satellites were shaded in the obstructed area. Strong signal distortion may therefore be expected because these nine satellites have low elevations at this period for K6, K7, and K8 on two days. The signal scatter and signal attenuation is partially due to the low elevation. This effect occurs due to multipath caused by trees environment, see Fig. 3 and Fig. 4.

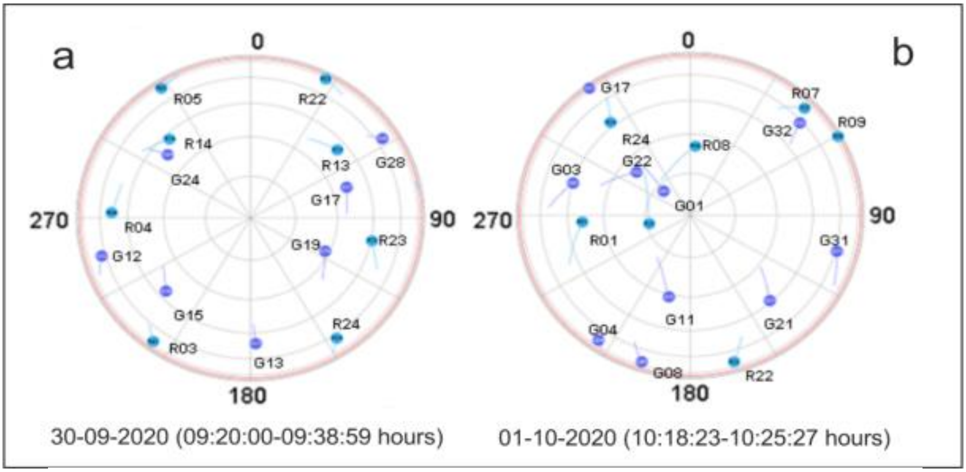

Figure 4. The sky plots in the project area on 30 September 2020 and (a) 1 October 2020 (b)

Table 2. Time schedule of the two FKP measurements for four points by using Topcon Hiper HR receiver

Test 1 Test 1 DateTime Datum	Point Točka	Easting Istočno	CORS-FKP Northing Sjeverno	El.Hgt.	Ep.	Hz	SAT.	hRms	vRms	Pdop	Method	Status
2020-09-30-09:32:03	**K6**	406822.708	4543678.710	102.480	5	1	9	0.006	0.009	3.756	FKP	FIX
2020-09-30-09:36:20	**K7**	406841.916	4543679.295	103.025	5	1	7	0.005	0.006	2.275	FKP	FIX
2020-09-30-09:38:59	**K8**	406756.377	4543657.668	105.567	5	1	13	0.005	0.006	1.706	FKP	FIX
2020-09-30-09:20:00	**K9**	406808.583	4543669.729	103.958	5	1	9	0.004	0.006	3.109	FKP	FIX
Test 2			**CORS-FKP**									
DateTime	**Point**	**Easting**	**Northing**	**El.Hgt.**	**Ep.**	**Hz**	**SAT.**	**hRms**	**vRms**	**Pdop**	**Method**	**Status**
2020-10-01-10:22:16	**K6**	406822.809	4543678.780	103.176	5	1	12	0.004	0.006	1.588	FKP	FIX
2020-10-01-10:23:10	**K7**	406841.800	4543679.397	103.789	5	1	12	0.006	0.008	2.295	FKP	FIX
2020-10-01-10:25:27	**K8**	406756.413	4543657.672	105.507	5	1	13	0.005	0.007	1.564	FKP	FIX
2020-10-01-10:18:23	**K9**	406808.619	4543669.767	103.902	5	1	10	0.004	0.006	2.929	FKP	FIX

RESULTS AND DISCUSSION

Although FKP Technique is less used in the world than VRS Technique today, it is preferred as a result of the developments in real-time-position determination studies. In this study, the accuracy and repeatability analysis of the FKP technique was examined. The performance, accuracy and sensitivity values of the FKP technique in the clear and forested areas were calculated by using the coordinates obtained at different times. While the internal accuracy values of FKP were obtained using measurements made at different times, the external accuracy value was calculated by comparing the values obtained with static measurements. The purpose of the first experiment is to check CORS-FKP and evaluate its performance in forest areas/under forests. The experiment involves a set of four points (K6, K7, K8, and K9) marked on the ground. (Please note that the survey was conducted in different satellite constellations and at different times of the day (see Table 2)). Figure 5 shows the coordinate difference between the FKP measurement results of the four points. Figure 5 also shows the average and standard deviation of the coordinate differences obtained from the first and second CORS-FKP measurements of the four points. Comparing the measurement results, the horizontal coordinates of the points determined by these tests appear to be the same, but there are some changes between a few millimetres and 12 centimetres. However, the consistency of the height component is poor, and sometimes the maximum change amplitude at the same point between two CORS-FKP sessions is 76 cm, as shown in Figure 5. The standard deviation of the horizontal coordinate differences was about 10 cm. The standard deviation of height differences was about 50 cm, see Fig. 5. The mean value of horizontal component is about 6-7 cm and the mean value of height component is about 40 cm (Pirti 2010).

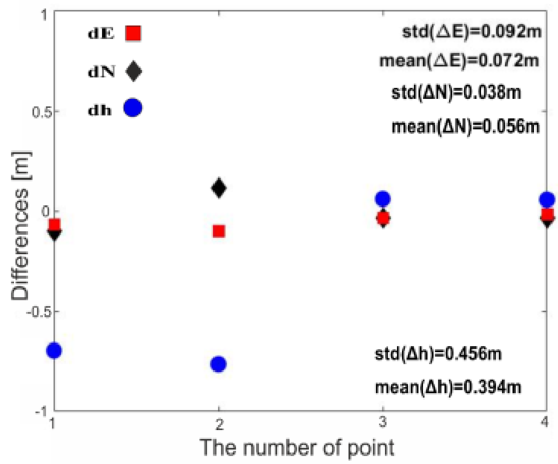

Figure 5. Comparison of the coordinates obtained from FKP surveys for four points on 30 September 2020 and 1 October 2020

The obtained coordinates of the static GNSS survey for four points are compared with the two FKP survey results of four points (on 30 September 2020 and 1 October 2020), see Fig. 6 and Fig. 7, respectively. By September 30, 2020, the coordinates (east and north) of the four points are usually sufficient, the standard deviation value is less than 5 cm, and the average value is less than 6 cm. Between static GNSS measurement and CORS-FKP measurement, the height components at the same height are not consistent, sometimes the difference is about 70 cm. The standard deviation and mean values of height of four points were 30 cm and 22 cm, respectively, see Fig. 6.

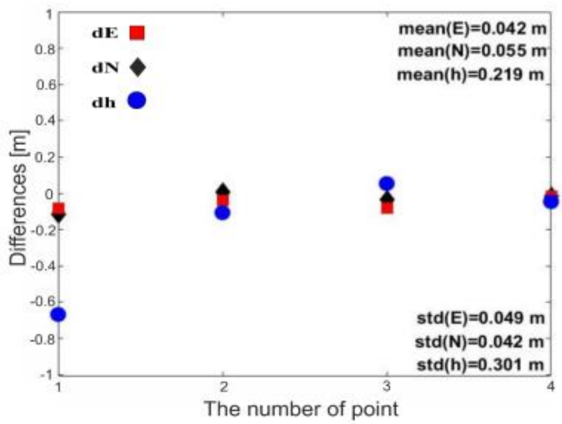

Figure 6. Comparison four points coordinates by using FKP with static coordinates on 30 September 2020

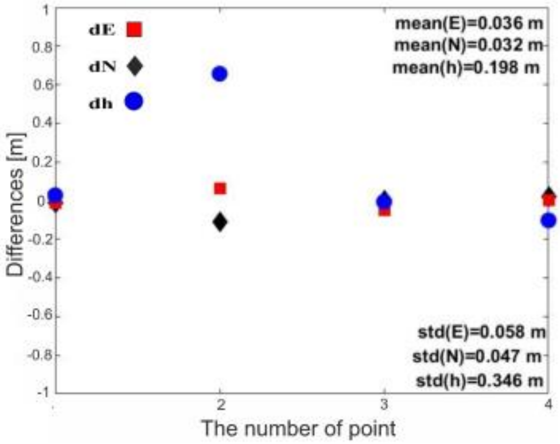

Figure 7. Comparison four points coordinates by using FKP with static coordinates on 1 October 2020

By using CORS-FKP measurement and static GNSS measurement, the coordinate difference (east, north) between the four points by October 1, 2020 is usually large enough, the standard deviation value is less than 6 cm, and the average value is less than 4 cm. Between static GNSS measurement and FKP measurement, the height components at the same height are not consistent, sometimes the difference is about 70 cm. The standard deviation and average height of the four points are 35 cm and 20 cm, respectively, as shown in Figure 7.

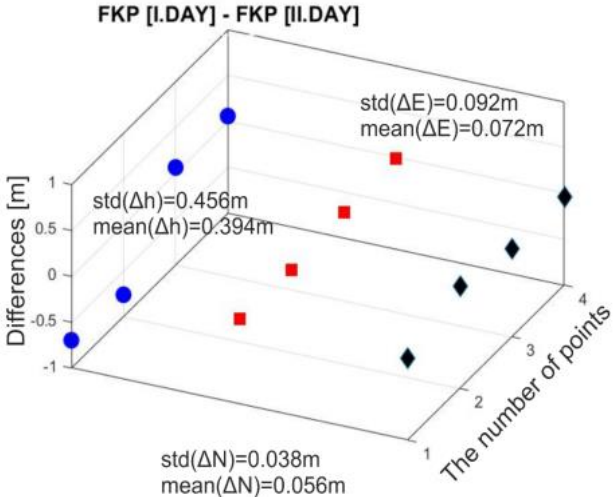

Figure 8. Comparison of the four points coordinates obtained from CORS-FKP surveys on 30 September 2020 (I. Day) and 1 October 2020 (II. Day)

Figure 8 shows two tests (FKP [I.DAY (September 30, 2020)] – FKP [II.DAY (October 1, 2020)] in the east, north, and altitude (Up) coordinate directions. The mean and standard deviation values of coordinates of all points (eastward, northward) are usually very good, and the standard deviation is less than 10 cm; as expected, since the average standard deviation reaches about 50 cm, the height accuracy is less than this value, and the height The weight is smaller at the same time point between two CORS-FKP treatments, sometimes even as long as 76 cm (Figure 8).

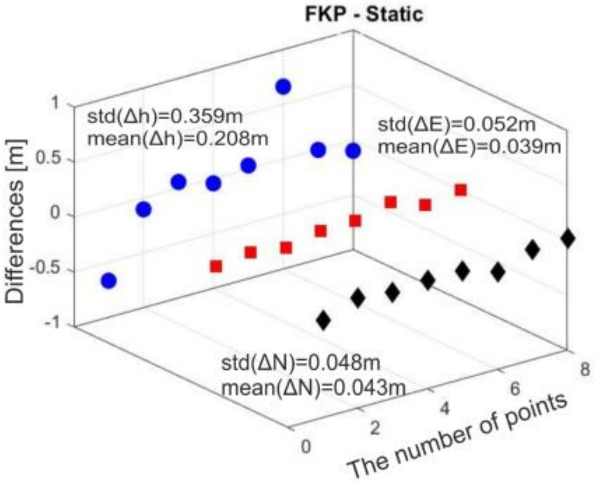

Figure 9. Compare all of the coordinates of the points by using static GNSS method and CORS-FKP method

Figure 9 shows the coordinate difference between CORS-FKP and static GNSS measurement results. Fig. 9 also shows the average value and standard deviation of the coordinate difference. When comparing the results of the two methods, the horizontal coordinates determined using these tests, respectively, appear to be consistent with changes ranging from a few centimetres to 11 centimetres. However, the consistency of the height components is poor, and sometimes the difference between the static GNSS and CORS-FKP heights at the same point is about 70 cm. The horizontal coordinates of the four points (between the CORS-FKP measurement and the static measurement) determined by these tests look very consistent, varying from a few centimetres to 11 centimetres. However, depending on the influence of obstacles in the field in the project area (forest canopy), the consistency of the height component is not very good, and the change is small, sometimes up to 70 cm. All results also show that forest canopy impair the positioning of CORS-FKP. Therefore, even with good satellite windows, signal blockage from forest canopy can be seen as the main problem when using CORS-FKP in the blocked area.

The points in the forest are obscured from decent satellite views. The FKP approach is also ineffective when satellite signals are low or absent due to extensive tree canopy or stems, among other things. This research demonstrates that the FKP survey may be utilized for woodland or forest surveys (obtaining precision to the cm-dm level), despite a common impediment, sky blocking, limiting its full usefulness. However, if traditional survey methodologies are used in addition, this difficulty can be solved. The CORS-RTK (FKP) took around 30 minutes to survey a site in this investigation. The horizontal plane coordinates of the sites (beneath the trees) varied by up to 10-15 cm. As a result, it appears that in tough conditions (forest), readings of 1 cm or less cannot be assured in all cases when employing the FKP technique. In the future, I would want to measure additional locations in the forest and test the accuracy of GNSS (GPS/GLONASS/Galileo/BeiDou) positioning utilizing CORS FKP/VRS techniques. The obtained results in this study are consistent with those of many other groups that made similar tests. The horizontal and vertical accuracy in obstructed areas discussed in this paper are in agreement with those of the other authors (Andersen *et al.* 2009, Bakula *et al.* 2015, Brach and Zasada 2014, Dobelis and Zvirgzds 2016, Frank and Wing 2014, Wing and Eklund 2007, Kaartinen *et al.* 2015, Keenan *et al*. 2002, Kim *et al.* 2017, Mageed 2013, Massimiliano 2018, Naesset and Gievestad 2008).

CONCLUSIONS

As a result of the measurements performed with FKP, the values of the horizontal coordinate differences obtained in terms of repeatability and accuracy remained in the range of 10-15 centimetres. However, the coordinate differences in height values are calculated in the range of 40-50 centimetres. The horizontal coordinate differences between the two-day FKP measurements and the static measurements were found in the range of 3-6 centimetres. Coordinate differences in height values were obtained in the range of 20-35 centimetres. FKP method, this modelling it is limited, the rover can only use data from two stations to compute the atmospheric model.

Forest cover has some negative effects on GNSS signals, such as blocking, attenuation and reflection. The results of this study show that CORS-FKP can achieve a horizontal accuracy of 10-15 cm and a vertical accuracy of 75 cm in forest areas (points K6, K7, and K8). These results show that CORS-FKP is suitable for positioning and other applications that will not cause adverse conditions in blocked areas. However, CORS-FKP can obtain a horizontal accuracy of 1-4 cm and a vertical accuracy of 5-10 cm in an unobstructed area (Point K9). Due to the low accuracy of FKP correction in large-area modelling deviation, it is not suitable for positioning even in a medium-scale network. However, when analysing the 2D and 3D components together, the static technique shows better results than the FKP technique. Particularly where the centimeter level horizontal and vertical accuracy is required, the CORS RTK method is problem free. This study shows that the CORS FKP method can replace other survey methods in the forest applications which require the above mentioned accuracy.

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