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ROLE OF CORS RTK (NETWORK RTK) MODE MEASUREMENTS IN DETERMINATION OF THE FOREST BOUNDARY: A CASE STUDY OF ISKI-CORS

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Abstract

Network Real-time kinematic mode survey technology shows really an efficient and fast improvement within today's technological developments. Permanent reference stations for Global Navigation Satellite System (GNSS) have for a long time been used for positioning of rovers in RTK (Real-Time Kinematic) mode. In this article, we examine the performance and use of Continuously Operating Reference Station (CORS-Network RTK) as an extension of RTK technology-based data acquisition systems near/under tree canopy. As a general rule, a clear view of the sky is preferred when using RTK for determining location. Eight permanent reference stations belonging to the ISKI (Istanbul Water and Sewerage Administration) in Istanbul, Turkey were used for the test measurements. This paper presents the results of İSKİ (Istanbul Water and Sewerage Administration) CORS satellite measurements made using Networked Transport of Radio Technical Commission for Maritime Services via Internet Protocol (NTRIP) data transmission. As a result of measurements taken at 17 measurement points in the obstructed and unobstructed environments, the accuracies obtained at the points with numerous covers in the form of tree branches and leaves ranged from several centimetres which is characteristic for GPS/GLONASS measurements taken under conditions of limited availability of satellites.

Key words: accuracy, Global Navigation Satellite System (GNSS), location, measurement point, reference station, satellite measurements.

Introduction

When defining forest, one must also define where forest ends; forest edge or forest boundary is the imagined line that separates forest and non-forest. The question of a clear definition of the forest boundary is particularly difficult in transition areas between forest and non-forest where a dense forest is gradually opening up to tree-free land, as for example at the timber line or at the boundary of deserts RTK stands for Real Time Kinematic, which is a GPS positioning technology better than *Differential Global Positioning System* (DGPS) in term of accuracy and its capability to keep the accuracy when moving. RTK provides cm grade accuracy while DGPS can provide sub-meter accuracy. To enjoy RTK, the GPS receiver shall support dual frequency L1 and L2. DGPS requires single frequency only. In addition, you need a reference station with known position and a Radio Technical Commission for Maritime Services (RTCM) antenna to broadcast correction to rover. What we know is that phase of carrier and other correction information (such as orbital correction, ionospheric correction and geometric correction) would be transferred from the base station to the rover. At rover, it will compare its phase received with the phase sent by base station to attain a relative position at millimetre level, and this is accurate baseline to provide good measurement. Of course, accuracy of the rover cannot exceed that of base station (Lachapelle et al. 2001, Pirti 2008, Parti et al. 2009). Network RTK is not a latest technology in fact. It was developed in 90s and it has been established in many countries in Europe and States, even China and Hong Kong have established reference station network, which is termed Continuously Operating Reference Station (CORS). CORS is an extension of RTK technology; it is composed of a network of reference stations and a central data processing centre that is a service running 7×24 nonstops. Corrections would be transferred to rover using GSM or wireless network with a standard protocol called Networked Transport of Radio Technical Commission for Maritime Services via Internet Protocol (NTRIP), i.e. RTCM over IP Network Transport of RTCM via Internet Protocol. There are three Network RTK technologies being available in the market including VRS, FKP and IMAX (Vollath et al. 2000, Wübbena et al. 2001, Landau et al. 2002, Vollath et al. 2002, Landau et al. 2003, Kaartinen et al. 2015, Wright et al. 2017).

Virtual Reference Station (VRS) is developed by Trimble; it requires a bi-directional communication between a data processing centre and rover. To start measurement, rover needs to provide an approximate position to the centre and it will select relevant reference station within the proximity to calculate corrections (satellite orbit and clock errors, reference station receiver clock errors, multipath and particularly ionospheric and tropospheric effects) for the rover. A virtual reference station would be created a few meters near the rover for on-going measurements (Vollath et al. 2000, Wübbena et al. 2001, Landau et al. 2002, Vollath et al. 2002, Landau et al. 2003).

The SAPOS (Satellite Positioning) community in Germany introduced a method for broadcasting network correction streams called ‘FKP’. FKP stands for the German word ‘Flächenkorrekturparameter’ which means area correction parameter. Within SAPOS, the providers standardize RTCM 2.3 with a proprietary extension (a type 59 message). This additional message describes the linear ionospheric and geometric correction around a physical reference station. The linear corrections are derived from a data processing centre using multiple reference stations. This is running in a data broadcasting model different from VRS. However, initial position could be sent from rover to centre for selection of reference station to yield a better FKP (Vollath et al. 2000, Wübbena et al. 2001, Landau et al. 2002, Vollath et al. 2002, Landau et al. 2003).

The last one is IMAX from Leica. IMAX is a variant of Max. Max stands for master-Auxiliary corrections while iMax stands for individualized Master-Auxiliary corrections. The difference between Max and iMax is that Max supports RTCM 3.0 that would be broadcasted to rover, while iMax supports RTCM 2.3 and 3.0 that require bi-directional communication. However, the mechanism is that same those servers at the centre will select closest master reference station and auxiliary reference stations to the rover, estimation to correct ambiguity would be provided. The difference from VRS is that Max uses real reference station but not a virtual reference station. There is Auto-Max in which server would provide optimum master and auxiliary configuration (Vollath et al. 2000, Wübbena et al. 2001, Landau et al. 2002, Vollath et al. 2002, Landau et al. 2003, Kaartinen et al. 2015, Wright et al. 2017).

Continuously operating reference stations (CORS)

Within the past year, a new technological development has emerged that dramatically enhances the utility of RTK GPS positioning. For a number of years, various agencies of the federal government have cooperated in developing a network of continuously operating reference stations (CORS) for GPS. These facilities 1) continuously receive and archive signals from all GPS satellites that are visible to them and 2) broadcast corrections to coarse acquisition (C/A) pseudo ranges to be used for differential positioning by any receiver that can receive them. This form of differential positioning produces accuracies of ±2–5 m and is suitable for applications such as automatic vehicle location, personal navigation, and mapping of natural resources. The more recent development in CORS applies to more accurate RTK surveys that employ carrier phase measurements instead of the coarse acquisition code. Achievable accuracies are at the centimetre level. CORS data can be used for Real-Time Kinematic (RTK) applications, meaning that the station provides continuous correction data to roving GPS receivers with internet accessible capabilities. The GPS correction data is typically transmitted at 1-Hz through the internet. Therefore, a GPS system utilizing a cellular modem can obtain the correction data which in return provides centimetre level position accuracy within a short range of the CORS station (1 to 30 miles depending on terrain and other operating conditions). The raw correction data is also archived and made available via the internet for post-processing of GPS data for static surveying, mapping and remote sensing projects. GPS positions are based on a series of calculations and averages. Applying statistical principles, the more data that is used and the more calculations that are made, the more confidence we can have in the results. Continuously Operating Reference Stations (CORS) are permanently located GPS receivers that operate on a continual basis. They are continuously collecting satellite data and using it to recalculate their positions. CORS generally use higher quality GPS antennas, which allow for even more precise calculations. CORS can be implemented in both post processed and RTK surveying. Many CORS are equipped with one or more communication links. CORS that broadcast over UHF radio are making the corrections available to the general public. Anyone with the right UHF radio link on their receiver and within signal range should be able to use the corrections for RTK surveys. CORS stations that are using other methods for broadcasting the corrections may or may not be available to the general public. In order to access the corrections a user might need to be added to a user list or subscribe to a pay service. The advantage of being able to access a CORS for RTK surveys is that this eliminates the need to set up a reference receiver for each survey. The benefit of a CORS site or network is the ability to provide accurate, repeatable position data free of charge permitting users to return to the exact same locations over time. Data collected from CORS sites has a wide array of uses. For example, CORS data can be used for monitoring coastal subsidence, surveying, determining the amount of perceptible water vapour in the atmosphere, recording and locating utility lines, and machine guidance for construction and precision agriculture. The CORS files have data grouped in both one-hour and one-day intervals. During the day of collection, the data is posted in one-hour intervals starting at midnight, Coordinated Universal Time (UTC). Each file is identified by the station identifier, day of the year, a letter designator indicating the hour, the year, and the type of data contained in the file. There are three types of files available for each hour. These are the navigation file (data on satellite positions), the observation file (observed pseudo range data) and the station file (receiver station data) which are designated by n, o and s, respectively. As mentioned earlier, the data is also stored in one-day intervals. This avoids needing to merge CORS files to process data that spans two or more one-hour intervals. However, these one-day files involve considerable amounts of data to download and process. Thus to avoid file conversions, handling unnecessary data, and to simplify the downloading process, the website also provides a User Friendly Option (UF CORS) (Bock et al. 2002, Rizos 2007, Snay 2008).

Materials and Methods

The work was performed in the Campus of Yıldız Technical University Davutpaşa/Esenler, Istanbul Turkey, and see figures 1 and 2. The 17 points were selected in the project area. Two of them were marked in the unobstructed environment; the others were marked near/in the forest environment (see Fig. 3). Two tests were carried out in order to evaluate the performance and the accuracy of the CORS RTK (VRS) method for the survey projects. Throughout the first test, we measured all 17 points by using static GPS measurements. The static GPS survey was conducted on 25 May 2009 in order to determine the coordinates of these 17 test points. The measurements on these test points were performed with at least 2 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 six Ashtech Z Max GPS receivers and data processing and network adjustments were conducted us-

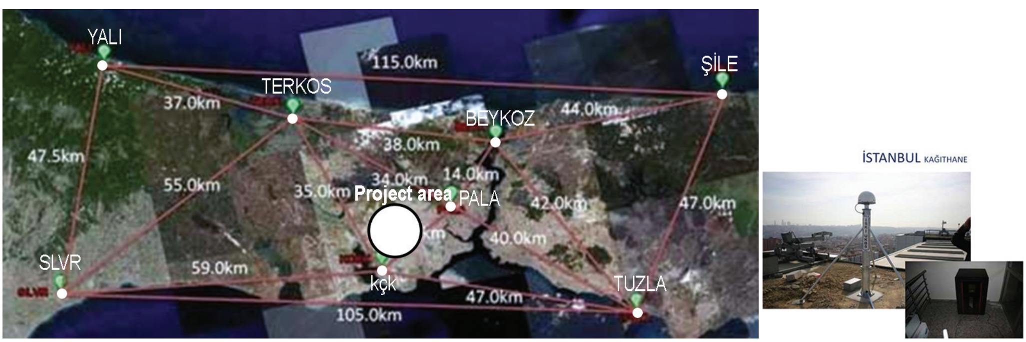

Fig. 1. Istanbul water and sewerage administration (ISKI) CORS GPS network and the project area in Istanbul, Turkey.

Fig. 2. The project area in Davutpaşa, Istanbul, Turkey.

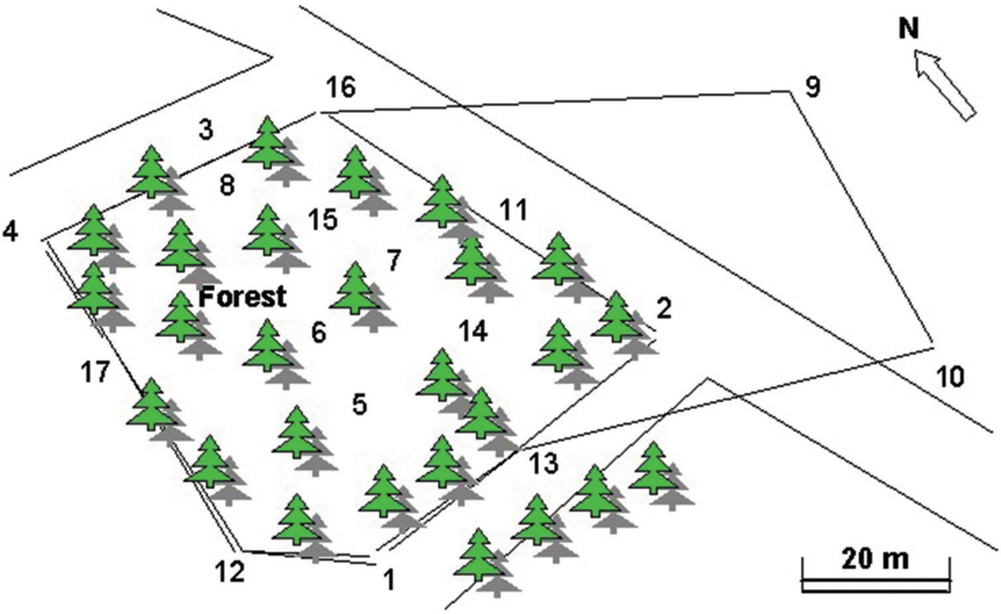

Fig. 3. Distribution of test points in the project area.

ing the Ashtech Solution 2.60 Software. In the adjustment procedure, the ED50 (European Datum 1950) coordinates of N102 (triangulation point in Yildiz Technical University Davutpaşa Campus in Istanbul, Turkey, see Fig. 2) were held fixed (Table 1). Throughout the second test, we performed CORS RTK measurements for 17 test points in the project area by using a Topcon HiperPro RTK (GPS/GLONASS) field unit. For this CORS RTK survey, (Istanbul Water and Sewerage Administration) İSKİ CORS reference points were used in the İstanbul region of Turkey (see Fig. 1). İSKİ CORS system consists of eight stations and one central process-

Table 1. Coordinates and their standard deviations of the test points.

Point No	X, m	Std., mm	Y, m	Std., mm	H, m	Std, mm
102	406,739.361	fixed	4,543,871.860	fixed	71.020	fixed
1	406,725.971	11	4,543,807.512	13	70.791	24
2	406,758.683	19	4,543,840.925	16	69.686	26
3	406,706.434	12	4,543,867.141	18	72.400	20
4	406,686.43	17	4,543,854.375	19	73.349	21
5	406,726.575	29	4,543,833.006	33	71.163	43
6	406,717.805	25	4,543,843.890	27	71.429	34
7	406,725.556	44	4,543,853.778	44	71.605	46
8	406,707.998	30	4,543,859.063	44	72.063	78
9	406,774.905	11	4,543,877.576	16	70.051	21
10	406,791.782	11	4,543,839.573	13	69.320	19
11	406,741.477	15	4,543,855.711	19	71.000	28
12	406,709.896	11	4,543,808.910	11	71.309	21
13	406,743.074	15	4,543,823.778	16	70.531	34
14	406,734.294	24	4,543,841.464	22	71.141	30
15	406,716.893	29	4,543,860.761	73	71.605	92
16	406,719.405	4	4,543,874.624	6	71.887	8
17	406,694.361	4	4,543,838.558	6	71.213	9

ing centre for the processing and distribution of Global Navigation Satellite System (GNSS) data (Fig. 1). These stations are designed to form a precise geodetic network of permanent stations which continuously track the visible GNSS satellites and where satellite receivers are to be installed. The GNSS receivers will telemetry the data to the Central Processing Centre via internet or a GSM media at a measurement interval of 1 second. The objectives of establishing İSKİ CORS network are to increase and to improve the real-time and post processing capabilities of GNSS and their geomatics and engineering applications, monitoring of recent crustal movements and atmospheric and geodynamic studies. In the last test for this study, we performed total station measurements for 17 test points in the project area. The objective of the tests was to assess the CORS RTK (VRS) achievable accuracy by using İSKİ CORS reference points. So, the CORS RTK survey performance (VRS) was evaluated in the unobstructed environment and near/in the obstructed (forest) environment, under varying site conditions and where problems due to signal blockage were expected (see Fig. 3). As explained above, three different survey methods were used to coordinate a group of 17 points, marked on the ground. Figure 3 illustrates the distribution of the test points. The maximum distance between the points in the North-South direction was about 50 m. In the East-West direction the maximum distance was about 50 m.

Results

To evaluate the CORS RTK accuracy, CORS RTK surveys using İSKİ CORS reference points were performed, each time occupying all of the test points. The CORS RTK surveys were performed on 30 May

2009 (9:00 – 19:45 h local time (LT)). The İSKİ CORS reference station PALA was about 10 km away from the CORS RTK measurement site, KÇK about 12 km (see Fig. 2). The satellite visibility was 8–11 (GPS+GLONASS) satellites in open areas (points 9 and 10) and the recorded PDOP average values were between 1.2 and 2.5. A total of 17 point observations for the 17 test points were obtained on 30 May 2009. CORS RTK survey was performed according to no of points. In the analysis step, the accuracy assessment of the CORS RTK survey was conducted by comparing the coordinates of a group of points (17 points) obtained from İSKİ CORS reference points with the coordinates determined by the static GPS measurements from Point No 102. Figure 4 shows the differences and their means and standard deviations for the 17 points. The analysis of the test between the CORS RTK results and static GPS results shows that the discrepancies of the horizontal coordinates are a few mm to 1 cm in the unobstructed environment (points 9 and 10, see Fig. 4, the marked part). The discrepancies of the height coordinates were a few centimetres to about 2 cm in the unobstructed environment (Fig. 4, the marked part). Except for the unobstructed area (Points 9 and 10), the other fifteen points have poor lines of sight to the satellites because of the forested area (see figs 2 and 3). The trees and bushes caused severe obstruction of almost 50–90 % of the sky for these fifteen points in the project area (Fig. 2). Even though several satellites were shaded by the trees and bushes, they can be still tracked by the receiver. Five-six (4 GPS+1–2 GLONASS) satellites were visible in this period. The PDOP value was between 3.4 and 4.2 for this period (Pirti 2005, 2008). Due to the above mentioned reasons, the CORS RTK measurements on fifteen points took a very long time. The ambiguity resolution time was approximately 10 hours 30 minutes for these fifteen points. The differences for the horizontal coordinates of these fifteen points between CORS RTK and static measurements were greater than 2 cm (see Fig. 4).

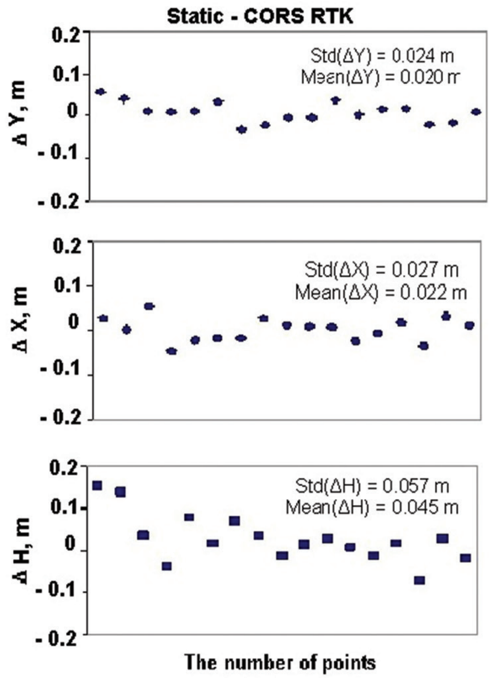

Fig. 4. Comparison of the coordinates of the 17 points in the project area between static GPS and CORS RTK surveys.

Elevation or height differences are necessary measurements for many forest operation activities. Some of the potential and useful GPS applications in forestry include tree location mapping, forest compartment boundary survey, forest road survey, ground truth activities (remote sensing) and resources inventory (Pirti 2005, 2008). An analysis of the measurements at the project area clearly demonstrates that the differences are greater (~5 cm) for the vertical coordinates for the fifteen points (see Fig. 4). For the other two points, the height differences were at the level of a few centimetres (see Fig. 4, the marked part).

The total station survey was carried out to check the performance of the CORS RTK. The 17 point coordinates were established by a total station (Topcon GTS-701 (angle accuracy: ±2", distance measurement accuracy: 2 mm + 2 ppm)). The Point No 101 and Point No 102 triangulation points were fixed for the total station surveys (Fig. 2). The ITRF coordinates of Point No 101 and Point No 102 were determined in static GNSS technique (survey time 60 min) by fixing the IGS reference point ISTA. The sequence of terrestrial measurements was the same with the CORS RTK survey. In order to compute the coordinates of the 17 points, horizontal direction, zenith angle and slope distance were recorded with Topcon GTS-701.

In this test, the accuracy assessment of the CORS RTK survey was performed by comparing the coordinates of a group of points (17 points) gained from ISKI CORS reference points with the coordinates determined by the total station from Point No 102. The term 'geodetic' is used to loosely refer to bearings and coordinates related to the European Datum 1950 (ED50). Figure 5 gives the coordinate differences between the CORS RTK and the traditional survey.

The comparison of the results of the CORS RTK and total station surveys shows that standard deviation of the horizontal coordinate differences was about 1 cm in the unobstructed area. The standard deviation of the height differences was 2 cm in the unobstructed area (see Fig. 5, the marked part). As shown in Figure 5, the mean differences between the RTK survey and the total station survey were less than 1 cm for the horizontal coordinates and less than 2 cm for the vertical coordinates (points 9 and 10). Again, the largest variations in horizontal and vertical components were recorded for the fifteen points (the obstructed area) (see Fig. 5). The variations were about 6 cm in the X-Y coordinates and about 20 cm in the H coordinates in the obstructed environment.

The mean differences between the RTK and traditional survey were less than 1 cm for the horizontal components and less than 2 cm along the vertical components under good conditions. The mean differences between the CORS RTK and traditional surveys were less than 6 cm for the horizontal components, and less than 20 cm along the vertical components in the obstructed areas. Apart from the points which are near/in the forest area,

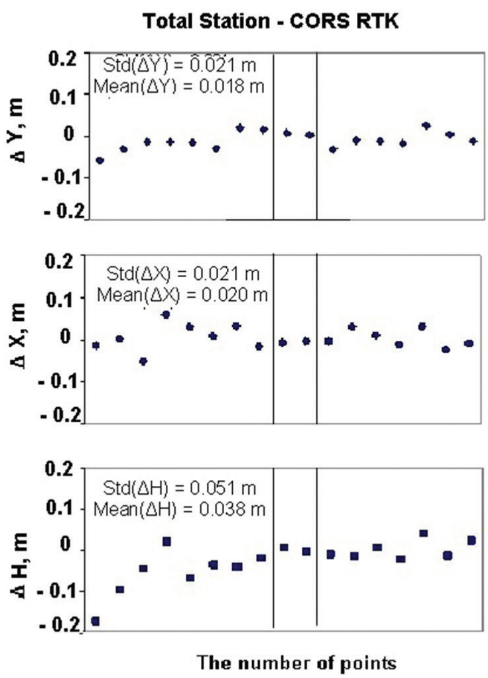

Fig. 5. Comparison of the coordinates of the 17 points in the project area between total station and CORS RTK surveys.

when comparing the CORS RTK, static GPS, total station results of the tests, the horizontal components of the test points as separately determined by these tests seems very consistent, with changes ranging between a few millimetres up to 1 cm. The height value was less consistent, and sometimes differed up to 2 cm at the same point among the CORS RTK, static GPS, and total station sessions. However, the maximum differences of the horizontal and vertical components are about 10–20 cm in the experiment because these fifteen points are near/in the forest area.

The comparison of the results of the static GPS and total station surveys is shown in Figure 6. The standard deviation of the horizontal coordinate differences was about 1 cm for the unobstructed and obstructed areas. The standard deviation of the height differences was about 2 cm for the unobstructed and obstructed areas (see Fig. 6). As shown in Figure 6, the mean differences between the static GPS survey and the total station survey were less than 1 cm for the horizontal components and less than 2 cm for the vertical components.

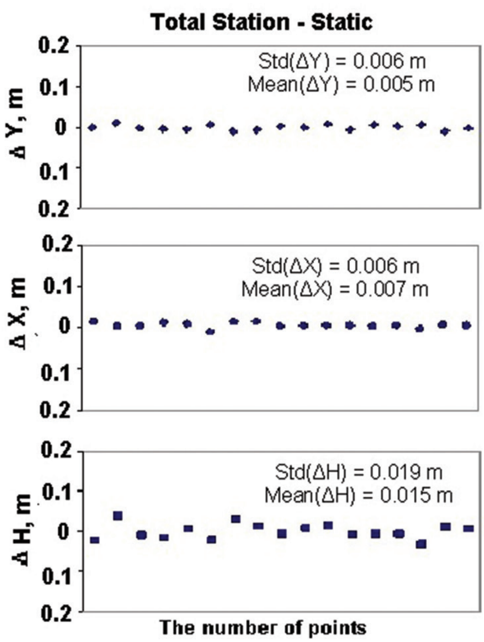

Fig. 6. Comparison of the coordinates of the 17 points in the project area between total station and static GPS surveys.

Conclusions

In this paper, we have shown that CORS RTK can be used for forest boundary surveying, although a common obstacle, the sky blockage, will hinder its full effectiveness. Despite the accuracy problems in forested areas, the CORS RTK method is a very efficient replacement for difficult total station survey situations. Particularly where the centimetre level horizontal accuracy is required, the CORS RTK method is problem free. This study shows that the CORS RTK method can replace other survey methods in the forest applications which require the above mentioned accuracy. But this problem can be overcome supplemented by conventional survey techniques. In this study, CORS RTK method by using only İSKİ CORS reference points took approximately 10 hours 30 minutes to complete 17 points survey in the project area. Total station method took approximately 1 h to survey 17 points in the field. The CORS RTK took about 15 min in the office (Data transfer and processing). Total station took about 10 min in the office (Data transfer and processing).

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