ISSN 1330-3651(Print), ISSN 1848-6339 (Online)
UDC/UDK 528.4.02:629.056.8(560.118)

FINDING AN APPROPRIATE METHOD FOR SMALL-SCALE SURVEYING APPLICATION AMONG REAL TIME SATELLITE-BASED METHODS IN TURKEY

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Original scientific paper
In this paper, for small-scale surveying applications, investigation of appropriate methods among classical RTK, net-RTK which provides Virtual Reference Station (VRS), and Flächen-Korrektur Parameter (FKP) corrections were performed. A test network consisting of 56 stations has been established in Istanbul. Measurements were carried out using the above methods. Five separate tests were applied on the coordinates obtained by the methods. The results showed that the methods from the most accurate to the least accurate one were classical RTK, Net-RTK-VRS and Net-RTK-FKP. In general, horizontal components were found to be two times better than vertical components ranging from 1 mm to approximately 5 cm.

Keywords: *conventional method of position fixing, CORS, GNSS RTK, GNSS STATIC*

Pronalaženje odgovarajuće metode za geodetsko snimanje na maloj površini među metodama na bazi satelita u Turskoj

Izvorni znanstveni rad
U ovom se radu, u svrhu pronalaženja odgovarajuće metode za snimanje malih površina, ispituju klasična RTK, net-RTK koja opskrbljuje Virtual Reference Station (VRS), i Flächen-Korrektur Parameter (FKP) koja vrši korekcije. U Istambulu je postavljena probna mreža koja se sastoji od 56 stanica. Mjerenja su se provodila uporabom spomenutih metoda. Izvršeno je pet odvojenih ispitivanja koordinata dobivenih tim metodama. Rezultati su pokazali da je najtočnija klasična RTK metoda, a zatim slijede Net-RTK-VRS i Net-RTK-FKP. Općenito, pokazalo se da su horizontalne komponente dva puta bolje od vertikalnih u iznosima od 1 mm do približno 5 cm.

Ključne riječi: *konvencionalna metoda za određivanje položaja, CORS, GNSS RTK, GNSS STATIC*

1 Introduction

Global Navigational Satellite Systems (GNSS) is a general name for artificial satellite-based position fixing systems, which include constellations such as Global Positioning System (=GPS owned by DoD, US), GLONASS (Russia), Galileo (EU), Compass (China), QZSS (Japan), etc. These systems require receivers capable of analysing the particular system signal to determine its absolute or relative location. Receivers are ranging from compatible to one system to the combination of two or more. Using one or more of these systems, one can determine its position by either absolute or relative positioning. Absolute positioning requires only one receiver, while relative positioning requires at least two receivers, one for the base station whose coordinates are precisely known and one for the station whose coordinates are in question. Relative positioning is important for precise positioning, which provides atmospheric errors, etc. to be calculated at the base station and then, they are used to correct the simultaneous measurements made at the unknown station. While the former uses the code and broadcast ephemerides to determine its location in real time and the latter uses either code and broadcast ephemerides or phase measurements with precise ephemerides (therefore, post processing required) for precise coordinates. As the technological advancement and alternative methods emerge, modelling the error sources affecting the precision of locations such as atmospheric errors, have provided important developments for real time positioning applications (RTK).

There are a number of studies concerning GNSS applications in the literature. In the last decade, parallel to the technological advancement, applications of RTK occupy an important place. In [1] the authors published important studies on Net-RTK data processing and algorithms. The authors in [2] reviewed and evaluated theoretical and practical developments in RTK and net-RTK up to 2002. The authors of [3] explained the general principles of VRS method. The authors in [4] performed tests on VRS RTK considering starting time and location accuracy and analysed the performance of VRS obtaining 3 cm accuracy in horizontal components and 1 ÷ 5 cm in vertical components. In [5] the authors stated the advantage and disadvantage of VRS and FKP methods with tropospheric models. The authors in [6] compared the VRS, FKP and Nearest Station correction methods and determined the reliability of CORS networks, they established test network where they determined coordinated data from both measurements from CORS network and from post processing and made comparisons with each other. In [7] the authors reviewed the developments in CORS applications. The authors in [8] performed an application in cadastral boundary surveying using RTK GPS. In this application, a comparison to RTK GPS, classical total station and GNSS methods with different days and to different reference points were performed. In [9] the authors presented a methodology suitable for cadastral surveying using RTK GPS. In the study, positions were determined with 11 mm in horizontal and 34 mm in vertical accuracy. The authors in [10] compared the VRS and MAC corrections in terms of both user and network operator's perspective. In Spain, in [11] the authors compared the VRS and Mac Corrections using two active GNSS networks (REGAM and MERISTEMUN). In both methods, they obtained 2,5 cm in horizontal and 5,0 cm accuracy in vertical. Very Large GNSS network assessment was done by [12]. In [13] the authors established the CORS-TR network in Turkey and gave results from their practical experiences. The main aim of a user for small-scale applications is to obtain its location fast and accurate. However, in Turkey, there is insufficient number of studies on assessment of correction methods used in net-RTK (Cors-TR).

The aim of this paper is to evaluate and determine an appropriate method for small-scale surveying applications among satellite based methods, including classical RTK, Cors-Net (in Turkey, Cors-TR) which provides the correction techniques (VRS, FKP).

For this purpose, a test network consisting of 56 stations in Istanbul was established. There are five tests applied, and the results are presented.

2 Materials and methods

A test network consisting of 56 stations in Istanbul was established. The coordinates of these stations were obtained by five positioning methods namely; Static GNSS, classical RTK, conventional method by total station, Cors-TR-VRS, and Cors-TR-FKP, three of which are well known methods; therefore, no further introduction is given here. The rest of them are then described, in particular, Cors-TR VRS and Cors-TR FKP. Then after data description, the procedures that followed are given.

2.1 Continuously Operating Reference Stations (CORS)

Real Time Kinematic Positioning (RTK) is a method for determining positions with cm level accuracy. This method requires at least two GNSS receivers; one for a base station whose coordinates are accurately known and one for a station (rowing receiver) whose coordinates are in question. At the base station, errors are calculated and sent to the rowing receiver for computing its coordinates accurately. However, the accuracy decreases as the baseline between the base station and the rowing receiver increases. This method requires two receivers and simultaneous measurements. It is always not possible to have a station with accurate positions known for a base station. All these drawbacks lead to a relatively new method called Cors-Net.

The Cors network consists of a number of stations whose coordinates are accurately known. These stations are located with an approximately equal distance from each other so that the network covers the whole area where this service is available. On each station, a continuously operating receiver is set up. From all the receivers in the network, measured data is sent to a computing centre for calculating the errors for each station. Then, one can use this network as error calculating station (base station) for eliminating the errors in its location.

There are different error calculation methods namely, Virtual Reference Station (VRS), Flächen-Korrektur Parameter (FKP) etc.

A detailed description of VRS method was given in [14]. VRS is a virtual station assigned by the Cors-net to the approximate coordinates of a receiver whose coordinates are in question (Fig. 1). Errors for this station which serves as a base station in RTK method are calculated by the Cors-net to be sent to the rowing receiver. Then the receiver applies these corrections to calculate its positions in cm level accuracy.

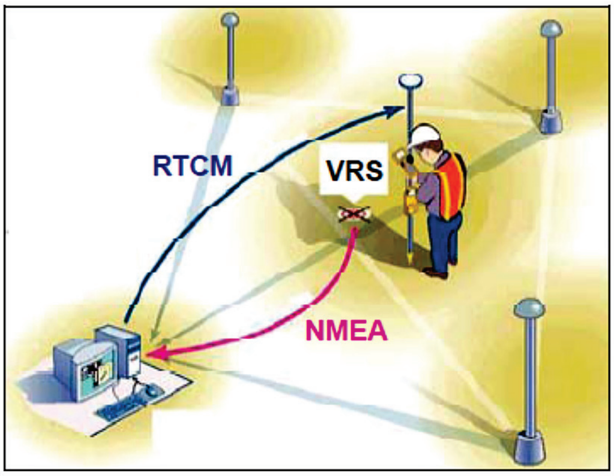

Figure 1 Virtual Reference Station [5]

FKP (area correction parameters) was developed by Geo++ Company, and its details are given by [15]. Correction parameters are calculated based on a number of surfaces estimated for each Cors station and on the calculation of correction parameters; the variations in North-south and East-west directions are defined. For each reference station, a unique FKP surface is estimated (Fig. 2).

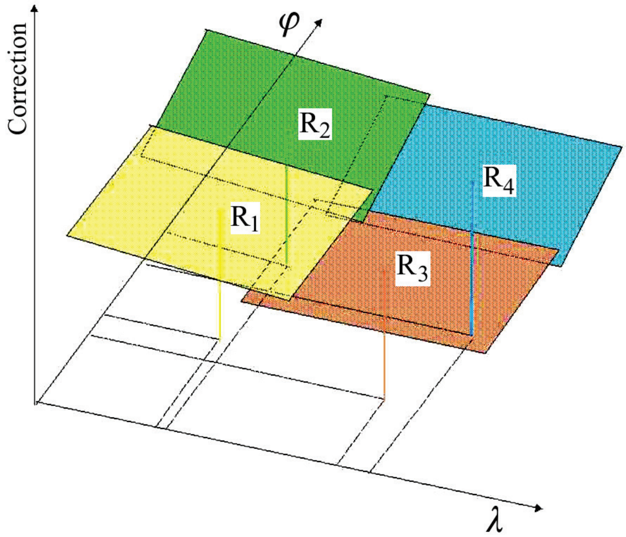

Figure 2 Flächen-Korrektur Parameter surfaces [16]

In this method, for each station in the Cors, atmospheric and phase corrections are calculated. Then these correction parameters are sent to the rowing receiver. The communication between the rowing receiver and computation centres are performed by either one-way or two-ways. In one-way communication, rowing receiver receives the correction from the nearest station in Cors-net. In two-way communication, the station in the Cors-net from which the correction parameters are received is selected by the Cors-net. For every new location of the rowing receiver, new FKP corrections are sent.

2.2 Cors-TR

Turkey has established a Cors network called (Cors-TR) consisting of 147 reference stations country-wide to serve for military, civil and scientific purposes (Fig. 3).

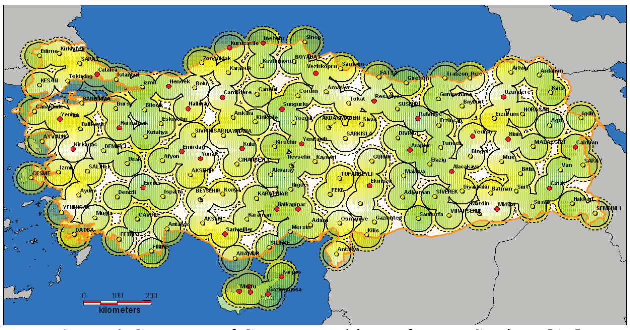

Figure 3 Coverage of Cors TR and its Reference Stations [17]

It is operated with collaboration of Cadestre General Directory and General Mapping Command. There are two computation (control) centres located in Ankara and one in Istanbul in case of failure of one centre [17].

Cors-TR provides 24-hour communication to a rowing receiver via ADSL, GSM/GPRS/EDGE, and Internet (NTRIP) services in Turkey. Control centres send the corrections (VRS, FKP and MAC) with standard formats such as RTCM - V2.1, 2.2, 2.3, 3.0, etc. In addition the rowing receiver sends its approximate location to the control centre via NMEA message. By this process, a single rowing receiver within the coverage area in Turkey can determine its coordinates in real time with a cm level of accuracy.

2.3 Data description

There are five different methods used in obtaining the coordinates of the test network consisting of 56 stations (Fig. 4) the first of which was a static GNSS method. The receivers used in acquiring static GNSS data are ASTECH Z-Max for both base and unknown stations. The base station is UZEL station (ITRF 96, at 2005 reference epoch) located on the Civil Engineering Faculty Building in Yildiz Technical University, Davutpasa Campus, Istanbul. The other receiver is installed on a tribrach for the stations whose coordinates are in question. Measurements are performed simultaneously for four-hour interval with two sessions (with 10-second recording interval and 10° elevation mask) and ASTECH solution 2.6 software is used in post processing.

Second is the classical RTK method. In this method, the station UZEL again served as base station. Topcon Hiper Pro GNSS receivers were used for both the base station and unknown stations. Measurements were performed on 56 stations with five epochs on each station. The third method is the conventional position fixing method by total station. The coordinates of 56 stations in the test network were obtained using total station (Nikon DTM 332 with 3+ 2 ppm precision).

The fourth and fifth methods are Cors-TR with VRS and Cors-TR with FKP corrections respectively. The receiver used in this survey is Topcon Hiper Pro GNSS. In two consecutive days, 10 epochs of measurements on each station were taken on 56 stations with the VRS and FKP corrections provided by Cors-TR.

2.4 Test strategy

To asses and determine appropriately the positioning methods used (static GNSS, conventional method by total station, classical RTK, Cors-TR-VRS, and Cors-TR-FKP), a test network consisting of 56 stations was established in Istanbul.

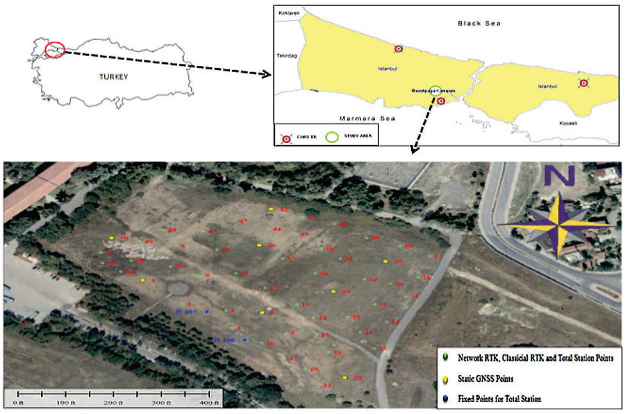

Figure 4 The Test Network in Istanbul

There are five separate tests applied on the network. The first test contained eight stations only in the network due to static GNSS measurements were performed only on eight stations whose coordinates were obtained by network adjustment and whose rms errors were found to be ±2 mm. In this test, the coordinates by static GNSS were assumed to be true due to its being the most accurate method of position fixing. The second test contained 56 stations in the network. In this test, the coordinates by total stations were assumed to be true. The reason for the assumption is that the stations in the test network were close to each other at typically furthest distance of approximately 300 m and total station provided the coordinate with a few mm precision. Considering all systematic error sources and applying them to the measurements, these precisions could represent the accuracy provided that no blunder was contained in the measurements.

The third test was intended to see the differences between coordinates by classical RTK and the ones by both Cors-TR VRS and Cors-TR FKP.

The fourth test concerned repeatability of coordinates of two different days of measurements by Cors-TR VRS and Cors-TR FKP tests.

Finally, cross comparison of VRS and FKP of the first day (VRS1 to FKP1), of the first and second day (VRS1 to FKP2, FKP1-VRS2) and of the second day (VRS2-FKP2) was performed.

3 Results

As described in the test strategy section, the first test was performed only on eight stations in the network. The coordinates by static GNSS were determined with rms 1 mm in horizontal and 2 mm in vertical components. The comparison of rms of other methods with static GNSS is given in Fig. 5.

It is clear that the closest results to the static GNSS are the coordinates by total station followed by classic RTK, Cors-TR VRS and Cors-TR FKP. A general pattern for accuracy obtained is approximately vertical component being two times bigger than horizontal components. For first day of Cors-TR FKP, this rate decreased. In comparing the Cors-TR VRS to FKP, the coordinates by Cors-TR VRS gave better results than Cors-TR FKP in both first and second day. The horizontal components by FKP for the first day were worse than for the second day. One of the possible reasons for this might be time delay in getting the corrections from the computing centre as it changes within the range of seconds.

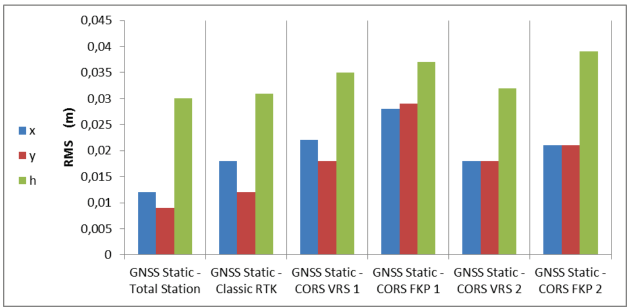

Figure 5 RMS of the coordinate differences between static GPS and the other methods for eight stations

Tab. 1 shows statistical values of the coordinate differences with respect to static GNSS coordinates.

Table 1 Statistics of the coordinate differences between Static GNSS and the other methods

	Compared Methods	Min (m)	Max (m)	Mean (m)
x	GNSS Static - Total Station	-0,024	0,013	-0,005
	GNSS Static - Classic RTK	-0,056	0,013	-0,013
	GNSS Static - CORS VRS 1	-0,052	0,013	-0,018
	GNSS Static - CORS FKP 1	-0,058	0,030	-0,010
	GNSS Static - CORS VRS 2	-0,037	0,024	-0,005
	GNSS Static - CORS FKP 2	-0,033	0,020	-0,008
y	GNSS Static - Total Station	0,000	0,022	0,010
	GNSS Static - Classic RTK	-0,029	0,007	-0,007
	GNSS Static - CORS VRS 1	0,010	0,066	0,032
	GNSS Static - CORS FKP 1	-0,012	0,056	0,026
	GNSS Static - CORS VRS 2	-0,001	0,061	0,038
	GNSS Static - CORS FKP 2	-0,032	0,034	0,004
h	GNSS Static - Total Station	-0,033	0,058	0,017
	GNSS Static - Classic RTK	-0,188	-0,071	-0,096
	GNSS Static - CORS VRS 1	-0,154	-0,033	-0,079
	GNSS Static - CORS FKP 1	-0,142	-0,026	-0,056
	GNSS Static - CORS VRS 2	-0,100	-0,002	-0,033
	GNSS Static - CORS FKP 2	-0,144	-0,010	-0,057

Table 2 Statistics of the coordinate differences between Total Station and the other methods

	Compared Methods	Min (m)	Max (m)	Mean (m)
x	Total Station - Classic RTK	-0,033	0,017	-0,009
	Total Station - CORS VRS 1	-0,034	0,016	-0,003
	Total Station - CORS FKP 1	-0,058	0,031	-0,004
	Total Station - CORS VRS 2	-0,035	0,036	-0,002
	Total Station - CORS FKP 2	-0,026	0,029	0,000
y	Total Station - Classic RTK	-0,040	0,025	-0,009
	Total Station - CORS VRS 1	-0,015	0,064	0,023
	Total Station - CORS FKP 1	-0,060	0,060	0,019
	Total Station - CORS VRS 2	-0,040	0,046	0,009
	Total Station - CORS FKP 2	-0,048	0,076	0,023
h	Total Station - Classic RTK	-0,282	-0,075	-0,154
	Total Station - CORS VRS 1	-0,295	-0,046	-0,133
	Total Station - CORS FKP 1	-0,247	-0,038	-0,117
	Total Station - CORS VRS 2	-0,243	-0,016	-0,113
	Total Station - CORS FKP 2	-0,240	0,104	-0,084

The second test aimed at comparison of 56 station coordinates with respect to total station to find out if the accuracy obtained by the eight station test is compatible with the whole network or not. Fig. 6 shows rms of the coordinate differences between total station and the other methods and Tab. 2 tabulates the statistical values corresponding to them. From Fig. 6, clearly, the values of rms of horizontal components range from 1,1 cm to 2,7 cm and those of vertical components from 5,4 cm to 6,4 cm. The results obtained by this comparison are compatible with the eight stations comparison. These results are compatible with the study done by [4] and [8].

From Tab. 2, one can see the coordinates by classical RTK results were better than Cors-TR VRS and FKP results. It is understood that second days of Cors-TR VRS and FKP were better than the first day.

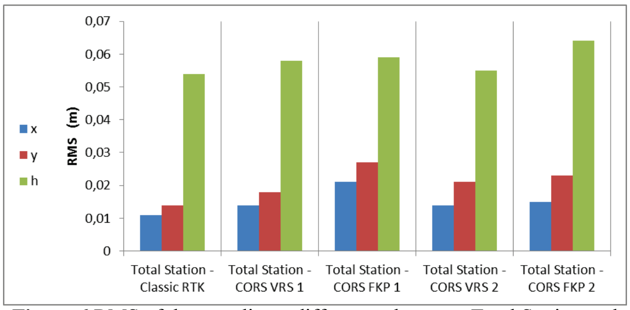

Figure 6 RMS of the coordinate differences between Total Station and the other methods for 56 stations

The third test was concerned with comparison of classical RTK results to Cors-TR VRS and FKP results.

This test is important for those who want to know which method should be taken when they have small-scale surveying application by using satellite-based real time applications. Fig. 7 shows coordinate differences of Cors-TR VRS and FKP of both first and second day measurements to those of classical RTK and Tab. 3. tabulates statistics of them.

From Fig. 7 it can be seen that horizontal components ranged from 1 cm to 3,2 cm and vertical components from 1,2 cm to 1,8 cm. The results in comparison to the results done by [9] present better accuracy in vertical components while horizontal components are compatible. It is interesting to see that rms values of vertical components are smaller than the earlier results. One possible reason for this may be similar error sources existing in the measurement process.

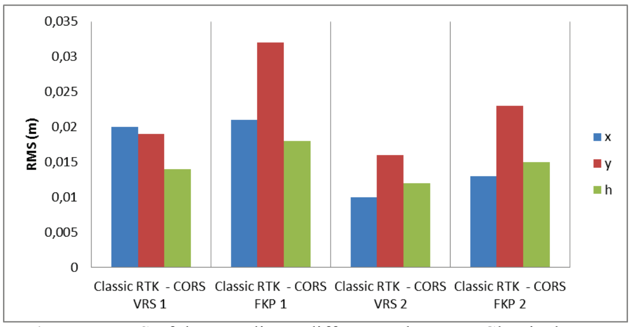

Figure 7 RMS of the coordinate differences between Classical RTK and Cors-TR VRS and FKPS based on both first and second day measurements for 56 stations

The fourth test was carried out on repeatability of Cors-TR VRS, and FKS results for the first and second day. Fig. 8 represents the repeatability and their statistics between Cors-TR VRS of the first day (Cors-TR VRS1) and Cors-TR VRS of the second day (Cors-TR VRS2) and Fig. 10 for FKP1 and FKP2. From Fig. 8, one can see that rms of the repeatability of VRS ranges from 2,0 cm to 2,1 cm for horizontal components and 1,7 cm for vertical components. From Fig. 9, rms of the repeatability of FKP ranges from 2,5 cm to 4,1 cm for horizontal components and 5,6 cm for vertical component. These differences may be measurements taken at different times of the day of the first and second day due to different satellite configuration or possible time delay in getting the correction message from the computing centre.

Table 3 Statistics of the coordinate differences between Classical RTK and the other methods

	Compared Methods	Min (m)	Max (m)	Mean (m)
x	Classic RTK - CORS VRS 1	-0,043	0,046	0,006
	Classic RTK - CORS FKP 1	-0,036	0,047	0,005
	Classic RTK - CORS VRS 2	-0,012	0,034	0,007
	Classic RTK - CORS FKP 2	-0,016	0,036	0,009
y	Classic RTK - CORS VRS 1	0,002	0,070	0,032
	Classic RTK - CORS FKP 1	-0,044	0,075	0,028
	Classic RTK - CORS VRS 2	-0,011	0,051	0,018
	Classic RTK - CORS FKP 2	-0,029	0,083	0,032
h	Classic RTK - CORS VRS 1	-0,013	0,049	0,021
	Classic RTK - CORS FKP 1	-0,040	0,065	0,037
	Classic RTK - CORS VRS 2	0,010	0,064	0,041
	Classic RTK - CORS FKP 2	-0,010	0,077	0,040

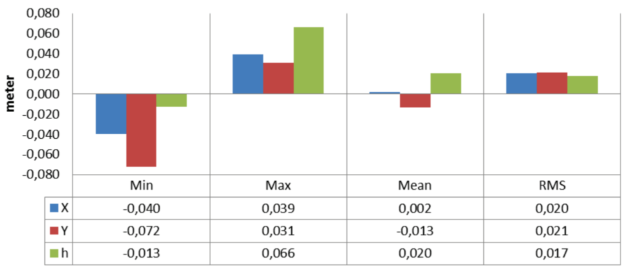

Figure 8 Repeatability and statistics of first and second day results of Cors-TR VRS (VRS1-VRS2)

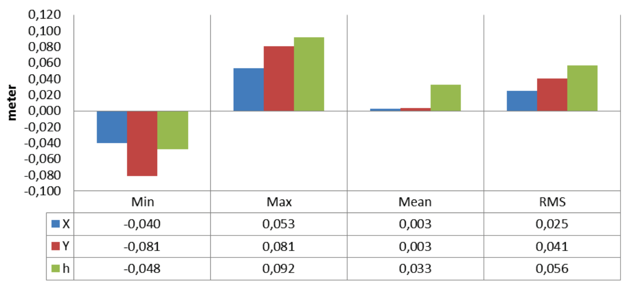

Figure 9 Repeatability and statistics of first and second day results of Cors-TR FKP (FKP1-FKP2)

The final test concerned with the correction methods provided by the Cors-TR. Fig. 10, shows rms of Coordinate differences of VRS1 to FKP1, VRS1 to FKP2, FKP1-VRS2 and VRS2-FKP2 and Tab. 4 tabulates the statistics of them.

It is clear from Fig. 10 that considerable amount of differences in vertical components exists in VRS1-FKP2, FKP2-VRS2 and VRS2-FKP2 while horizontal components stay within approximately 3 cm range. This suggests that FKP method provides large varying vertical components compared to horizontal components.

The results are compatible with the results of study performed by [11].

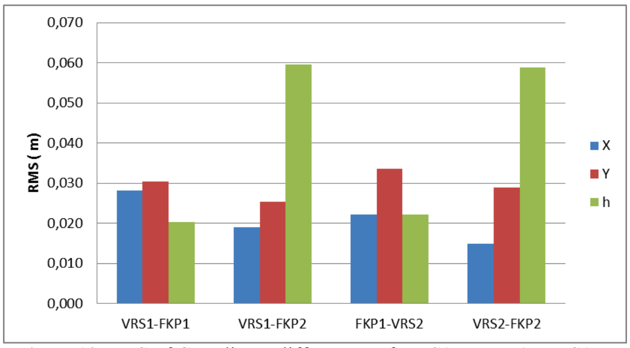

Figure10 RMS of Coordinate differences of VRS1 to FKP1, VRS1 to FKP2, FKP1-VRS2 and VRS2-FKP2 (in meters)

Table 4 Statistics of Coordinate differences of VRS1 to FKP1, VRS1 to FKP2, FKP1-VRS2 and VRS2-FKP2

	Compared methods	Min (m)	Max (m)	Mean (m)
X	VRS1-FKP1	-0,051	0,046	0,000
	VRS1-FKP2	-0,043	0,041	0,003
	FKP1-VRS2	-0,035	0,054	0,001
	VRS2-FKP2	-0,026	0,037	0,002
Y	VRS1-FKP1	-0,054	0,050	-0,003
	VRS1-FKP2	-0,057	0,065	0,000
	FKP1-VRS2	-0,073	0,056	-0,010
	VRS2-FKP2	-0,075	0,063	0,013
h	VRS1-FKP1	-0,074	0,052	0,017
	VRS1-FKP2	-0,030	0,074	0,049
	FKP1-VRS2	-0,029	0,098	0,004
	VRS2-FKP2	-0,071	0,090	0,029

4 Conclusions

A test network with 56 stations was established in Istanbul to asses and determine an appropriate method among real time satellite-based methods including Classical RTK, and Cors-TR VRS and FKP by using five separate tests.

The methods from most to least accurate were found to be classical RTK, Cors-TR VRS and Cors-TR FKP. Comparison with respect to Static GPS and total station to classical RTK, Cors-TR VRS and FKP revealed a general pattern for accuracy showing that approximately vertical components were two times bigger than horizontal components. For the first day of Cors-TR FKP, this rate decreased. In comparing the Cors-TR VRS to FKP, the coordinates by Cors-TR VRS sounded better results than by Cors-TR FKP in both first and second day. The horizontal components by FKP for the first day were worse than for the second day for some reason stated in the results.

From the third test results, one can conclude that for small-scale surveying applications, classical RTK provided better results than Cors-TR VRS and FKP.
The results from the fourth test revealed that repeatability of Cors-TR VRS was approximately two times better than that of Cors-TR FKP in horizontal, but even larger for vertical components.

The fifth test results suggest that FKP method provided large varying vertical components compared to horizontal components.

In general, horizontal components were found to be two times better than vertical components ranging from 1 mm to approximately 5 cm.

Classical RTK method is recommended for small-scale surveying application. However, this method requires two receivers, two persons and a known station. If one receiver is to be used Cors-TR VRS provides better results than Cors-TR FKP.

Acknowledgments

We would like to thank the Land Registry and Cadastre General Directorate for TUSAGA AKTİF (CORS TR) data.

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