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

Kutalmış Gümüş, Cahit Tağı Çelik, İbrahim Koç

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

1 Introduction

Global Navigation 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

ISSN 1330-3651(Print), ISSN 1848-6339 (Online)
UDCUDK 528.4.02-629.058.8(560.118)
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.

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).

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).
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.

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.

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.

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 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.

The fourth test was carried out on repeatability of Cors-TR VRS, and FKPS based on both first and second day measurements for 56 stations.

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.
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

<table>
<thead>
<tr>
<th>Compared Methods</th>
<th>Min (m)</th>
<th>Max (m)</th>
<th>Mean (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classic RTK - CORS VRS 1</td>
<td>-0.041</td>
<td>0.046</td>
<td>0.006</td>
</tr>
<tr>
<td>Classic RTK - CORS FKP 1</td>
<td>-0.036</td>
<td>0.047</td>
<td>0.009</td>
</tr>
<tr>
<td>Classic RTK - CORS VRS 2</td>
<td>-0.012</td>
<td>0.034</td>
<td>0.007</td>
</tr>
<tr>
<td>Classic RTK - CORS FKP 2</td>
<td>-0.016</td>
<td>0.036</td>
<td>0.009</td>
</tr>
</tbody>
</table>

Table 4 Statistics of Coordinate differences of VRS1 to FKP1, VRS1 to FKP2, FKP1-VRS2 and VRS2-FKP2 (in meters)

<table>
<thead>
<tr>
<th>Compared methods</th>
<th>Min (m)</th>
<th>Max (m)</th>
<th>Mean (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VRS1-FKP1</td>
<td>-0.051</td>
<td>0.046</td>
<td>0.000</td>
</tr>
<tr>
<td>VRS1-FKP2</td>
<td>-0.043</td>
<td>0.041</td>
<td>0.003</td>
</tr>
<tr>
<td>FKP1-VRS2</td>
<td>-0.013</td>
<td>0.034</td>
<td>0.001</td>
</tr>
<tr>
<td>VRS2-FKP1</td>
<td>-0.026</td>
<td>0.037</td>
<td>0.002</td>
</tr>
<tr>
<td>VRS2-FKP2</td>
<td>-0.045</td>
<td>0.050</td>
<td>-0.003</td>
</tr>
<tr>
<td>FKP1-VRS2</td>
<td>-0.057</td>
<td>0.065</td>
<td>0.000</td>
</tr>
<tr>
<td>VRS2-FKP1</td>
<td>-0.073</td>
<td>0.056</td>
<td>-0.010</td>
</tr>
<tr>
<td>VRS2-FKP2</td>
<td>-0.075</td>
<td>0.063</td>
<td>0.013</td>
</tr>
</tbody>
</table>

4 Conclusions

A test network with 56 stations was established in Istanbul to assess 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.

5 References


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