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Original scientific paper

A Comparison of the Accuracy of VRS and Static GPS Measurement Results for Production of Topographic Map and Spatial Data: A Case Study on CORS-TR

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Abstract: The on-going developments in Global Navigation Satellite Systems (GNSS) technology affect techniques in geographic information and associated documents. The national Continuously Operating Reference Station (CORS) networks, which operate on the Real Time Kinematic (RTK) principle, are multi-purpose geodetic networks and offer services to a large portion of society including all the public institutions and other organizations, military and civilian users and to scientific researchers. It is possible to utilize these networks both in real time positioning applications using the Network Real Time Kinematic (NRTK) method and in static applications using the Receiver Independent EXchange (RINEX) format data from reference stations. In this study, Virtual Reference Station (VRS) and static GNSS measurements were undertaken based on a Continuously Operating Reference Station-Turkey (CORS-TR) network in a test network established in Turkey. As a result of the measurements, repeatability attained using the VRS method was examined. Moreover, the coordinates obtained from VRS measurements based on CORS-TR network were compared with the coordinates calculated as a result of static observations. From the accuracies and repeatability, an investigation was implemented to determine the extent to which NRTK applications in real-time GNSS networks can be used to produce spatial data and create topographic maps.

Keywords: CORS; GNSS; NRTK; spatial data; VRS; topographic map production

1 INTRODUCTION

In all organized societies geographic data has an extremely crucial role in all kinds of spatial design, planning and applications, hand in hand with the efficient usage of resources. Cadastre and mapping works necessitate the use of up-to-date geographic bases in order to manage and conduct all kinds of spatial works including structural and infrastructural ones [1]. Rapid developments in space and satellite techniques, digital techniques and computers are manifested in the production of geographic information and associated documents. There have also been changes in the methods of producing geographical information and documents and the expected accuracy of the data. Reference [2] cites the fundamental problems in the combination of various types of geospatial data in terms of the production, storage and later use of maps and cartographic information as:

- Unknown horizontal and vertical datum,
- Unknown projection,
- Unknown accuracy.

Both Geographic Information Systems (GIS) and spatial data, which constitute the basis of large-scale map production that serves as a basis for projects applications, need to be determined accurately and reliably. Moreover, this information must be obtained from Global or National Basic Geodetic Networks.

Today's satellite techniques focusing on positioning, i.e. Global Navigation Satellite Systems (GNSS), have exceeded their initial targets, which were limited to military goals, and have entered all aspects of life and have replaced classical measurement techniques in many areas. The establishment of traditional GNSS networks and Real Time Kinematic Continuously Operating Reference Station (RTK CORS) networks in parallel to the developments in GNSS technology have ushered in a new era [3, 4, 5].

In this study, the accuracy and usability of classical Global Positioning System (GPS) techniques and NRTK techniques was investigated. To this end, a geodetic network was established and static GPS observations were conducted in the points of this network. Also, NTRK observations were performed twice in these points using the VRS techniques based on CORS-TR network. As a result of the calculations made, repeatibilities in NRTK methods were examined. Morever, values obtained from NRTK and static GPS observations were compared. Accuracies that were obtained were analyzed for topographic map production and spatial data.

2 REAL TIME GNSS NETWORKS

The GPS users can now determine the three dimensional coordinates of a new point with centimeter level accuracy relative to a control point located several hundred kilometers away. That control point, moreover, may already be associated with a GPS receiver that is being continuously operated by an institution for any of several diverse applications [6]. Classical differential GPS consists of at least one reference station with known coordinates with high level accuracy, and rover receivers which are at distances that will allow them to undertake observations at this station. The data collected in these receivers (phase and code measurements) are brought together and evaluated in the work place, and then the sensitive coordinates of the mobile receivers are determined. The operation in question can also be performed by conveying the reference station data and/or the calculated corrections using any means of communication (such as: GPRS General Packet Radio Service, satellite, internet, mobile phone) to mobile receivers in real-time. The method implemented in this way is called real-time kinematic (RTK) global navigation satellite systems (GNSS). However, the accuracy obtained using this method is limited by systematic impacts that increase on the basis of the distance from the reference station. In order to avoid these limitations, it was proposed that more than one reference station be established [7, 8].

The concept of real time GPS/GNSS networks (Net-RTK) emerged as a result of the application of this idea and utilization of the experience gained. In the Net-RTK system, the dependence on a single reference station disappeared and it also became possible to undertake atmospheric modelling belonging to a specific area by making use of data from various reference stations. As a consequence of this modelling, ionosphere and troposphere errors, which are among the most prominent sources of error that affect GPS/GNSS measurements, are reduced to a minimum in positioning applications [9]. The benefits of these networks are as follows [10]:

a) There is no need to keep tools and personnel at reference stations during GPS measurements.
b) The measurements made and results obtained are directly within the national reference systems.
c) There is no need to waste personnel time and money on investigating points with known coordinates before the implementation of field work.
d) Three-dimensional real-time sensitive coordinates are obtained in the desired datum.
e) Point coordinates are continuously monitored and can be updated in the event of any deformation.

For example, the RTK network allows the majority of topographic-geodetic applications to achieve a higher productivity and makes the undertaking of numerous scientific studies easier. This increased positioning accuracy also has a beneficial effect on other applications, such as freight management and vehicle location, which is why numerous countries and regions currently rely on GNSS networks for accurate real-time positioning [11].

In GNSS measurements, as the base length increases, so do the observation periods and accuracy decrease. Therefore, real-time GNSS networks (CORS) have been developed in many countries in order to obtain ITRF datum positioning data in nearer and shorter distances. Tab. 1 presents examples of CORS systems used across the world.

Table 1 CORS systems used in different countries

Country	System Name
Japan	GEONET
USA	NGS CORS
Germany	SAPOS
Switzerland	AGNES
Holland	NETPOS
Saudi Arabia	KSACON
Turkey	CORS-TR

2.1 CORS-TR

In parallel to the developments in the GNSS world, the efforts to establish the CORS-TR networks began on 1 May 2006 and were completed in December 2008 [1]. The fundamental goals of this project, sponsored by the Turkish Scientific and Technical Research Agency (TUBITAK), were to:

- establish network-based CORS-TR stations functioning 24/7 with RTK capabilities,
- model the atmosphere (troposphere and ionosphere over Turkey contributing to atmospheric studies and weather predictions [12], with an extension to signal and communication studies,
- provide millimeter-level accuracy to monitor plate tectonics, measuring deformations, and contributing to earthquake prediction and early warning systems [13],
- determine the datum transformation parameters between the old European Datum of 1950 (ED50) and the international terrestrial reference frame (ITRFxx) [14].

This CORS-TR Project, consists of the following components [1, 15, 16]:

▪ **Reference GNSS stations:** there are about 146 stations, 142 in Turkey and 4 in the Turkish Republic of Northern Cyprus at intervals of 80-100 km on average, using dual-frequency (GPS, GLONASS and GALILEO) Trimble NetR5 geodetic GNSS CORS receivers (Figure 1). The data collected at the reference stations is conveyed to the control center using the data communication substructure (ADSL, GPRS/EDGE).

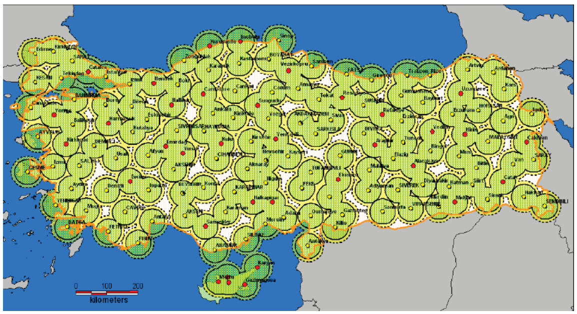

Figure 1 CORS-TR stations [1, 16]

▪ **Control center:** the Control Centers (CC) are the heart of CORS, collecting observations from CORS every second, determining instant coordinates, making corrections throughout the entire country and broadcasting these corrections. The Trimble CC package is able to compute ionospheric, tropospheric and multipath corrections and broadcast them using VRS, Flaechen-Korrektur-Parameter (FKP) and Master-Auxiliary Concept (MAC) techniques. Corrections are transmitted to rovers via Radio Technical Commission for Maritime Services (RTCM) 3.0 or higher using Network Transport of RTCM via Internet Protocol (NTRIP) principles.

▪ **Users:** The project makes extremely important scientific and technological contributions that include: geodetic measurements, cartographic measurements and GIS applications, planning and circumference measurements, identification and monitoring of deformations in large engineering structures, monitoring of sensitive navigation and other kinds of devices, substructure measurements, all types of engineering measurements, e-state, e-municipality and e-trade.

A user can make use of the system through the static and Net-RTK methods. In the static method, the GNSS data belonging to the reference stations can be obtained using the RINEX format. In the Net-RTK method, the user can benefit from the real-time positioning service using one of the FKP, VRS and MAC methods being broadcast by the control center.

3 USE OF CORS NETWORKS IN THE PRODUCTION OF SPATIAL DATA AND TOPOGRAPHIC MAPS

Control points are needed for positioning in forming GIS databases, producing topographic maps and many geodetic applications whereas points with known positions are required for a digital terrain modelling. In these cases, there are two ways to use CORS, namely the static and kinematic methods.

3.1 Static GNSS Applications in CORS Networks

Reference points with known coordinates are required particularly for the measurement and calculation of ground control points. In the traditional network methods, new ground points are calculated by making measurements at these points with known coordinates. Therefore, the time and energy spent on land increase and as a result the cost of producing points also increases. On the other hand, in the CORS networks, the coordinate of each point is known and also there are GNSS receivers at every point that make observations continuously. Making GNSS observations at the newly established points alone will be sufficient to produce ground control points. The RINEX observation files of CORS points can be added to the control network later by downloading them via the internet. By performing base solutions and balancing procedures according to these CORS points with known coordinates, coordinates are calculated in the datum of CORS network at points that will be produced.

Likewise, it is also possible to perform not only post-processes but also online processes in some CORS networks. In this method, users download the observation file and information on the system via the internet, determine the CORS points to be used as reference points and the results of the analysis are sent to them via e-mail. Detailed information about this issue can be accessed through the links given below [17].

- Auto Gipsy (JPL) - provided by JPL
  http://milhouse.jpl.nasa.gov/ag/
- AUSPOS (Geoscience Australia) - provided by Geoscience Australia
  http://www.ga.gov.au/geodesy/sgc/wwwgps/
- OPUS - provided by NGS, USA
  http://www.ngs.noaa.gov/OPUS/
- SCOUT (SOPAC) - provided by SOPAC, USA
  http://sopac.ucsd.edu/cgibin/SCOUT.cgi
- CSRS-PPP (NRCAN GSD) - provided by Natural Resources, Canada
  http://www.geod.nrcan.gc.ca/ppp_e.php

3.2 Network-RTK GNSS Application in CORS Networks

The use of multiple reference station networks with real time kinematic (RTK) positioning provides a high precision, centimeter level, satellite positioning service that is extremely reliable and accessible [18, 19]. RTK network, for example, allows the majority of topographic-geodetic applications to achieve a higher productivity and makes the undertaking of numerous scientific studies easier. This increased positioning accuracy also has a beneficial effect on many applications, such as geodetic, engineering, earthmoving and public works freight management and vehicle location, which is why numerous countries and regions currently rely on GNSS networks for accurate real-time positioning [11, 20]. In this method, the user conducts observations on land using a rover GNSS receiver and can determine the position at cm. level precision instantaneously using the correction data received from the control center. Data communication and correction methods may exhibit similarity or variation in each CORS network. In general, one or more of the different correction methods such as VRS, FKP, MAC, MAX and I-MAX can be used for correction.

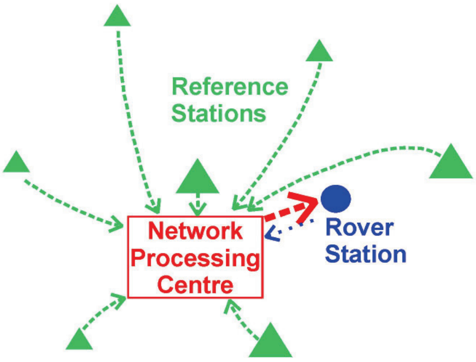

Figure 2 Network processing center and data flow [21]

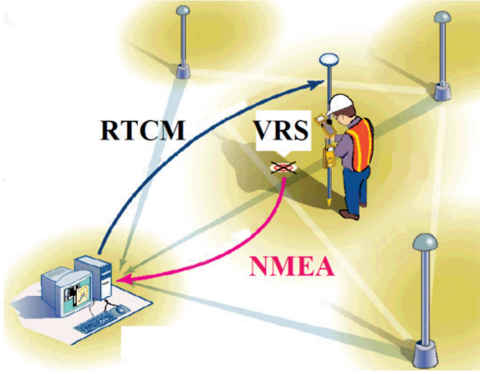

Figure 3 The network server transmits the RTCM correction stream for VRS position [8]

Recently, the use of Virtual Reference Station (VRS) concept has been proposed by many research groups as a more feasible approach for relaying network correction information to the network RTK users (see, [22, 23, 24, 25, 26, 27]). VRS method is a RTK technique that is based on multiple reference stations (Fig. 2). VRS concept is a virtual station on which no devices have been installed and is a few meters away from the roving receiver. In this technique, at least three reference stations with known sensitive coordinates are needed. These reference stations constantly perform GNSS observations and from these observations, corrections are made for the virtual reference station which is in the vicinity of the rover receiver. Thus, some systematic and non-systematic effects, the dispersive and non-dispersive biases of the rover receiver on RTK measurements are reduced to a minimum [28]. This, unlike the conventional RTK system, increases the reliability of the distance between the rover receiver and reference stations, and the system. In this system, even if there is a problem with the functioning of any reference station in the network, the required GNSS corrections can be calculated from the data of the other stations [9]. This technique of creating raw reference station data for a new, invisible, unoccupied station gives the concept the name, 'Virtual Reference Station Concept' [24, 29]. Using this technique, it is possible to perform highly improved RTK positioning within the entire station network [8].

4 APPLICATION

This study used 22 test points at intervals ~2.5 km established in Turkey between Nurdag and Gaziantep over a 52 km line located between the latitudes of 37°10′N and 37°10′N and between the longitudes of 36°44′E and 37°20′E (Fig. 4). Fig. 4 has been drawn using Netcad and Google Earth. The geodetic network that these points formed are based on 5 stations belonging to the CORS-TR network, namely ANTE, KLIS, ONIY, TUFA and EKIZ. The distances between the CORS-TR stations vary between 45 km and 190 km. On the other hand, distances from CORS-TR stations to the points forming the test network vary between 12 and 156 km.

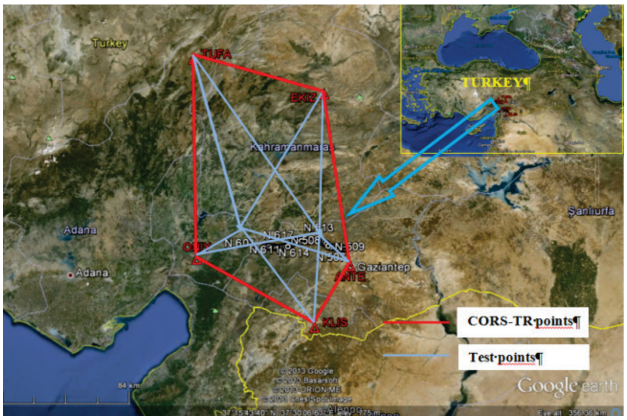

Figure 4 Test network; distribution of the CORS-TR stations and test points

At least four hours of static GPS observations were performed at each point in order to calculate the coordinates of the test points using the static positioning method. The RINEX data and coordinates of the 5 stations belonging to the CORS-TR network, which covered the project area, were downloaded via the internet. The precise ephemeris files in Standard Product 3 (SP3) orbit format, which belong to the days of measurement, were downloaded from the web page of the International GNSS Service (IGS) and used in the baseline analyses. All coordinate calculations were performed within the International Terrestrial Reference Frame 1996 (ITRF96) datum 2005.0 epoch, which is taken as a reference epoch for CORS-TR. A Trimble 5700 double-frequency GPS receiver was used in GNSS observations and Leica Geo Office Combined (LGO) software was used in the evaluation procedures. The RINEX static GNSS observation files belonging to 5 CORS-TR stations and the 22 test points were combined using the LGO software. A 15° elevation mask and precise ephemeris were used as process parameters and iono-free fixed and Hopfield standard troposphere model was used for ambiguity. First, the base analyses from 5 CORS-TR stations to the newly-established points were performed and thus, the baseline components of the test points from the CORS-TR stations were obtained. Then, constrained adjustment was performed by taking ITRF96 datum 2005.0 epoch coordinates of the CORS-TR stations as the reference and the coordinates belonging to the test points were calculated using the static network system (Fig. 5).

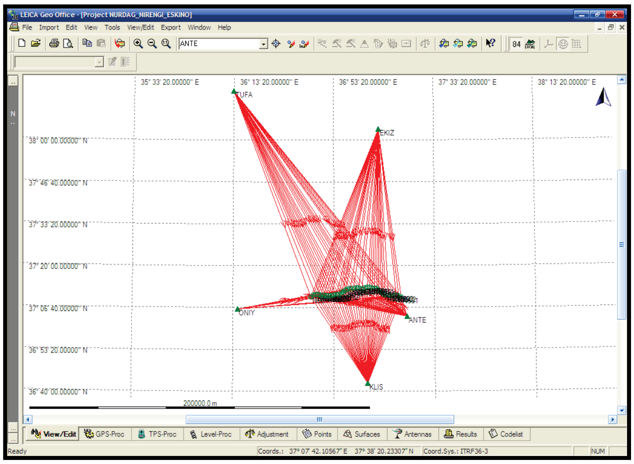

Figure 5 Calculation of the coordinates of the test points with references from the CORS-TR stations

5 RESULTS AND DISCUSSION

Measurements were taken at each point using the VRS method based on the CORS network in order to obtain the coordinates of ITRF96 datum 2005.0 epoch belonging to the 22 newly formed points from instantaneous data (~10 sec.) with the network-RTK principle. A Trimble R4 GNSS receiver was used in the measurements which were taken twice at each point at different times using the VRS technique to test the repeatability. Information about the differences in the coordinates obtained as a result of two measurements taken at two different times using the VRS method are given in Tab. 2. These differences in coordinates were calculated in meters as Easting, Northing at the horizontal and ellipsoid elevation at the vertical. The results showed that the greatest difference between the measurements taken twice using the VRS technique was −0.055 m at Easting, +0.047 m at Northing, and −0.063 m at the ellipsoid elevation.

Table 2 The coordinate differences from two VRS surveys

	ΔEast (m)	ΔNorth (m)	Δh (m)
Min.	−0.055	−0.032	−0.063
Max.	0.047	0.047	0.025
Median	0.000	0.002	−0.012
Mean	0.000	0.004	−0.014
Std. dev.	0.030	0.023	0.027

A single coordinate was calculated for each point for the VRS method, using the mean of the coordinates obtained from the measurements taken twice with the VRS method. Information about the coordinates differences between the coordinates obtained as a result of static observations and the mean coordinates obtained using the VRS method are given in Tab. 3. According to these results, the greatest difference between the measurements taken using the static observation and VRS technique was −0.041 m at Easting, +0.048 m at Northing, and −0.088 m at the ellipsoid elevation.

Table 3 Coordinate differences from static and VRS surveys

	ΔEast (m)	ΔNorth (m)	Δh (m)
Min.	−0.041	−0.033	−0.088
Max.	0.031	0.048	0.007
Median	0.001	0.008	−0.022
Mean	0.002	0.007	−0.027
Std. dev.	0.019	0.023	0.023

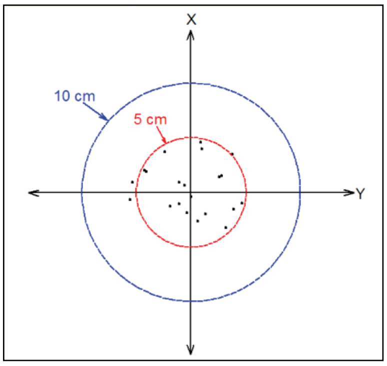

Figure 6 Planimetric repeatability with the VRS method

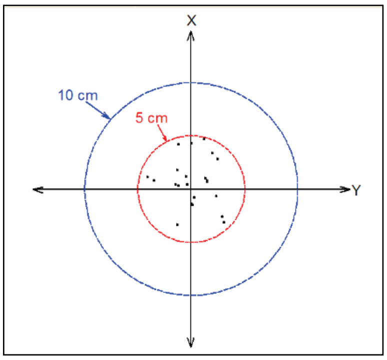

Figure 7 Planimetric differences between the VRS and static methods

In terms of some of the evaluations on networks operating on the NRTK principle, according to reference [30] it is stated that in a network where the distances between stations are less than 50 km, the best performance can be obtained with 2 cm planimetric error and 3 cm elevation. It is stated that these errors may reach up to 4-10 cm planimetrically and 8-15 cm at elevation in medium-size or larger reference lengths. In reference [11] it is stated that in the test measurements undertaken in Spain using the VRS and MAC methods, accuracy values better than 2.5 cm at the horizontal and 5 cm at the vertical were obtained and it was possible to obtain cm level accuracy using the NRTK method. On the other hand reference [31] stated that as a result of the measurements made in Romania using the CORS network RPMPOS, 2-3 cm precision was obtained at the horizontal whereas at the vertical 2.5 cm precision was obtained depending on a quasi-geoid.

6 CONCLUSIONS

GNSS measurements occupy a significant place in the production of large scale maps that are used in all kinds of infrastructure work, in obtaining spatial data, which is the most important component of GIS, and in the implementation of many geodetic applications. CORS systems, by virtue of their nature, allow the use of both static and kinematic methods. In static methods, the CORS networks assume the role of basic geodetic network for micro geodetic networks and points that will be newly established using the post process and online process evaluation methods. In this way, users gain time and speed in projects as their needs for reference points on the ground and for observations are met, and they can determine positions with high precision.

In kinematic applications, on the other hand, CORS networks appear as NRTK, which means users no longer have to find points with known coordinates on land. Moreover, the problem of taking measurements close to the reference point (<10 km) in RTK measurements has been overcome. Since the current work is based on the network principle, higher precisions have been achieved especially in the horizontal coordinates in comparison with classical RTK.

According to the findings obtained in this study, better results were gained than 5 cm for planimetric accuracies and than 10 cm for ellipsoid height accuracies using NRTK techniques. It is seen that these results provide the accuracies required for the classical GPS techniques in topographic map production. Therefore, it can be said that preferring NRTK techniques with short observation times is more economic than classical long time static GPS observations and they provide sufficient accuracies.

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