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Performance of CORS techniques (VRS and FKP) method in Istanbul Metropolitan City

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Abstract: Continuously Operating Reference Stations (CORS) surveys have been utilized for a variety of different surveying applications. A case study was performed to investigate the use of the CORS surveys. Surveys were conducted in the city of İstanbul (Yıldız Technical University Davutpaşa Campus), Turkey on 30 April and 1, 2, 3 May 2011. One hundred and eight points were selected in the project area. The analyses were made in fifth steps. In fifth steps, the CORS (Virtual Reference Station (VRS) – Flächen- Korrektur-Parameter Spatial Correction Parameter (FKP)) results gained on different days were compared with each other. The results showed differences from 0 to ±0.20 metres between the coordinates obtained from the VRS-FKP techniques in the project area. The results from all the tests have proved that this modern technique is very suitable for data acquisition and is efficient and economical. It concludes that the CORS technique competes well with the traditional surveys techniques in terms of accuracy in project area.

Keywords: CORS, Accuracy, Virtual Reference Station, Spatial Correction Parameter

1. Introduction

Relative positioning provides a higher accuracy than that of autonomous positioning. Depending on whether the pseudo range or carrier-phase measurements are used in relative positioning, an accuracy level of a few meters to millimetres, respectively, can be obtained. This is mainly because the measurements of two (or more) receivers simultaneously tracking a particular satellite contain more or less the same errors and biases. Therefore, if we take the difference between the measurements of the two receivers, common errors will be removed and those that are spatially correlated will be reduced depending on the distance between the reference receiver and the rover (Baseline). In surveying tasks where the high accuracy is required, a relative kinematic solution using GPS/GLONASS phase observations can be used to quickly obtain the data. In relative surveys, the accuracy of the position degrades as the rover moves away from the base station (Lachapelle et al., 2001; Vollath et al., 2002; Wolf and Ghilani, 2008; Bock et al., 2002; Landau et al., 2003; Vollath et al., 2000; Vollath, et al., 2001; Wübbena et al., 2001; Talbot et al., 2002; Dai et al., 2003; Bae et al., 2015; Bisnath et al, 2013; Hoffmann et al, 2008; Alves et al., 2011; Ma et al., 2011; Berber and Arslan, 2013).

This paper investigates the accuracy capabilities and performance of the CORS (VRS/FKP) for the Istanbul Metropolitan area. In this article, the feasibility and reproducibility of the CORS for different satellite configurations were investigated in the applications. The results obtained by CORS on three different days were compared with each other.

2. Materials and Methods

2.1. Virtual Reference Station (VRS)

VRS is a Trimble developed system to support high accuracy RTK GNSS positioning. The VRS algorithms simulate the existence of a reference station located at the rover's approximate location. This approach requires: (i) the availability of multiple Reference Stations in the rover's neighbourhood; (ii) to know the approximate location of each rover throughout the entire operation; and (iii) to know the exact coordinates of the Reference Station locations. As a result, the VRS approach requires the establishment of a bi-directional data link between the VRS module and each client rover. It is through this connection that the rover conveys its whereabouts and the system communicates the customized pseudo range corrections. These customized correction messages are generated as if by a reference station located at the rover's approximate location. Thus, the position-dependent errors are better modelled than when using a distant reference station. Through a two-way communication, the central processing server will get the rovers navigation solution in the NMEA format (National Marine Electronics Association). Once it receives this location, it selects the nearest three reference stations to calculate the corrections for the rover. It creates a VRS in close proximity to the rover. Thus in the end the rover will receive a single baseline solution with a much shorter baseline length. Nowadays, this is the most widely used method for CORS positioning because there is no need to upgrade the user equipment software. But this method does have the drawback that there is no information about the quality of the interpolation process and thus on the quality of the VRS reference observations. VRS locates a virtual reference station as close as the rover receiver which requests correction calculated with integer ambiguity fixed by using all the CORS stations data in the network. Then the corrections are sent via the VRS to the user. When the rover moves too far away from the calculated VRS, the rover is forced to reinitialize its position fix and a new VRS needs to be calculated, therefore the efficiency of this approach is reduced (Landau et al., 2003; Vollath et al., 2000; Dai et al., 2003; Edwards et al., 2010; Ma et al., 2011; Berber and Arslan, 2013).

2.2. Spatial Correction Parameter (FKP)

The Flächen- Korrektur-Parameter (FKP) technique is another way that delivers the information from a base station network to the rover. No precise knowledge of the rover's position is required for providing the correct information. The corrections are deployed as gradients to be used for interpolating to the rover's actual position. FKP is the preferred method of Geo++ for disseminating network RTK information. In principle, any format capable of transporting base station raw observations can be used together with a message to transport the FKP coefficients. Geo++ combines the FKP information with RTCM version 2.3, RTCM2021 messages which has been adopted as the standard for SAPOS. For the FKP information, no standard has been adopted yet but some users and providers argue that there is a standard because the information is being transmitted in an RTCM59 message. The layout of the message is described in RTCM Message Type 59-FKP for transmission of FKP. The FKP approach involves simply a one-way communication from the server to the rover. FKP was introduced in Germany as its standard technique to provide network information to an RTK rover. FKP increases the RTK performance by using area correction parameters information from reference station networks. FKP supplies information about the distant dependent error components. The parameters are given in the RTCM 2.3 message 59 (Landau et al., 2003; Bock et al., 2002; Edwards et al., 2010; Ma et al., 2011; Berber and Arslan, 2013).

3. Results

To test the performance of the CORS, two different test configurations (VRS/FKP technique) were considered within the boundaries of the Istanbul City (Davutpasa Campus of Yildiz Technical University). The stations of the ISKI CORS (ISKI is short for İstanbul Metropolitan City Irrigation and Drainage Administration, CORS) were used in this study, which is depicted in figure 1 (Gumus, 2016). This network consists of eight stations distributed in Istanbul city boundary. The network can also provide VRS, FKP and Master Auxiliary Concept (MAC) corrections. These corrections are calculated by Topcon Geo+ Software. First of all ISKI-CORS (VRS-FKP) measurements were performed on consecutive days and at different times of the day (VRS1 (30 April 2011, 9:00 – 11:20 h local time (LT)), FKP1 (30 April 2011, 12:00 – 14:20 h local time (LT))), (VRS (1 May 2011, 10:00 – 12:20 h local time (LT)), FKP2 (1 May 2011, 13:00 – 15:20 h local time (LT))), (VRS3 (2 May 2011, 11:00 – 13:20 h local time (LT)), FKP3 (3 May 2011, 14:00 – 16:20 h local time (LT))) with changed satellite configurations to ensure the independence of the results. ISKI-CORS solution for this study used in surveying is 5s at each point with 1s registration interval with a cut-off elevation mask angle of 10 degrees.

In all cases, all CORS measurements are made using Topcon HiperPro dual frequency GNSS receivers (Horizontal Accuracy: 10mm+1.0ppm; Vertical Accuracy: 15mm+1.0ppm) with standard hardware and software and observations from 6-12 (GPS / GLONASS) satellites and observations of 1.2-4.8 PDOP values during all sessions (Figure 2). Thus, all these 108 object points are positioned with VRS-FKP techniques in ITRF 2000 datum (ITRF (International Terrestrial Reference Frame) which is a physical realization of ITRS (International Terrestrial Reference System)).

To evaluate the ISKI-CORS repeatability in Istanbul, six independent CORS surveys ((VRS1 (30 April 2011, 9:00 – 11:20 h local time (LT)), FKP1 (30 April 2011, 12:00 – 14:20 h local time (LT))), (VRS (1 May 2011, 10:00 – 12:20 h local time (LT)), FKP2 (1 May 2011, 13:00 – 15:20 h local time (LT))), (VRS3 (2 May 2011, 11:00 – 13:20 h local time (LT)), FKP3 (3 May 2011, 14:00 – 16:20 h local time (LT))) solutions) by using ISKI CORS reference points were conducted. A total of 648 point observations for the 108 test points were obtained. In the first analysis step, the differences of the coordinates of the 108 test points obtained from VRS1, VRS2 and VRS3 were calculated, such as VRS1 - VRS2, VRS1 - VRS3 and VRS2 - VRS3, respectively. Figure 3 shows the coordinate differences, mean and standard deviation values for 108 points. The standard deviation values between ±0.03 and ±0.05 m; the mean values (abs (ΔX), abs (ΔY), and abs (ΔH)) between 0.03 m and 0.04 m are obtained for the X and Y coordinate components: The coordinate differences in the H direction are about 0.02-0.03 m; the standard deviation value is ±0.028 m and the mean value is 0.021 m. The VRS results show that the horizontal coordinate differences are between ±0.01 m and ±0.15 m. The differences in height coordinates at some points are about ±0.18 metres (Figure 3).

3.1 Horizontal and Vertical Accuracy of FKP Technique

In the second phase, the coordinate differences of 108 points obtained from FKP1 (30 April 2011, 12:00 – 14:20 h local time (LT)), FKP2 (1 May 2011, 13:00 – 15:20 h local time (LT)) and FKP3 (3 May 2011, 14:00 – 16:20 h local time (LT)), such as FKP1 - FKP2, FKP1 - FKP3 and FKP2 - FKP3 were calculated respectively. In this study, CORS surveys are affected by an obstacle (i.e. the nearby building north-south of the rover antenna, approximately obstructed 50% of the sky, see figure 2). Figure 4 presents the differences and their mean and standard deviation values for the 108 points. When the coordinate differences in Fig. 4 are examined, it is seen that the standard deviation values are between ±0.03 m and ±0.05 m, the mean values are between ±0.03 m and ±0.10 m for the X and Y coordinate components. The mean difference values in vertical (H) direction are between ±0.02 and ±0.03 m, the standard deviation values are between ±0.02 and ±0.03 m. Analysis of the FKP results show that the horizontal coordinate differences are between ±0.01 m and ±0.20 m. The maximum differences in height coordinates are about ±0.15 metres (Figure 4). Analysis of the first, second and third days of FKP measurements in the project area shows that the differences in horizontal and vertical coordinates are generally approximately between ±0.02 m and ±0.20 m (Figure 4).

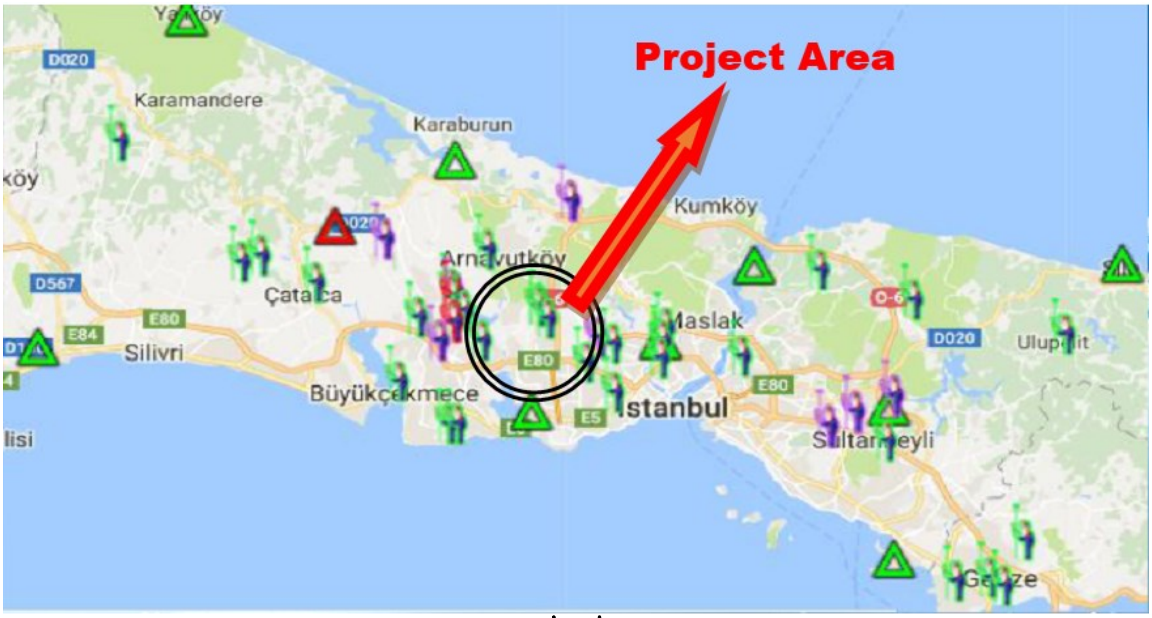

Figure 1: Project area and İSKİ CORS stations in Istanbul

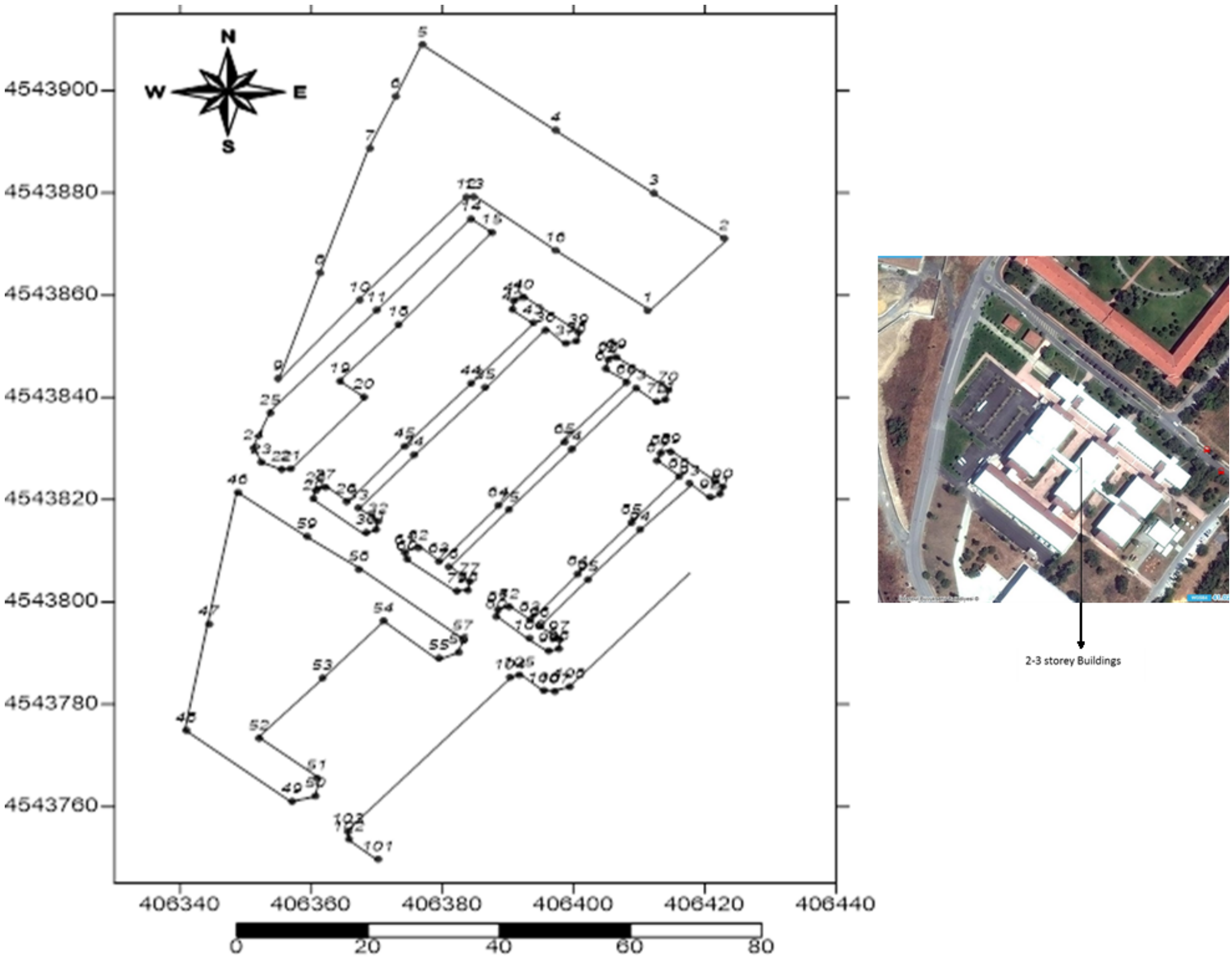

Figure 2: Distribution of test points in the project area

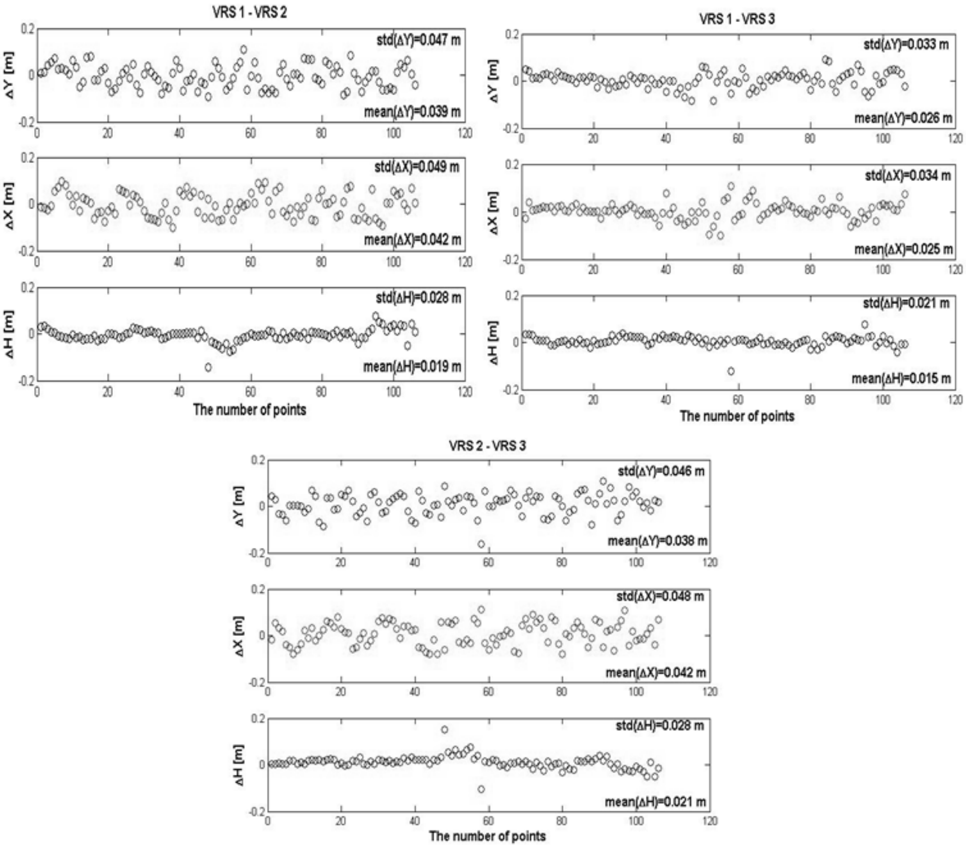

Figure 3: The comparison of the coordinates of the test points using VRS1, VRS2 and VRS3

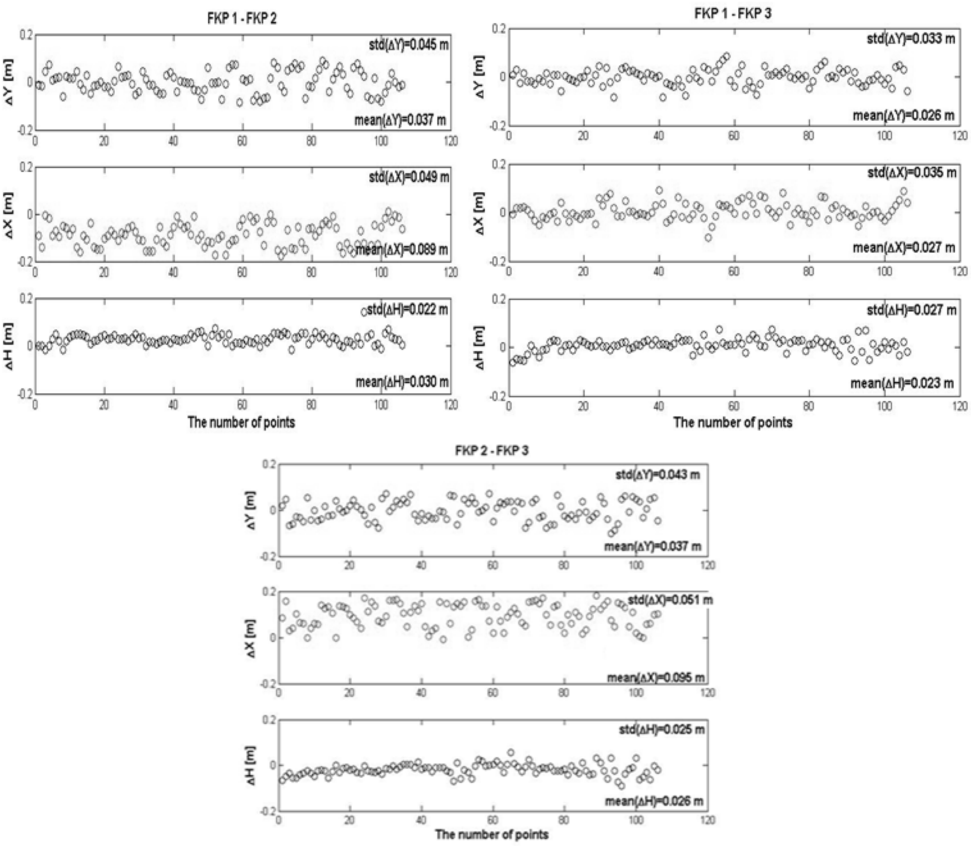

Figure 4: The Comparison of the coordinates of the test points using FKP1, FKP2 and FKP3

The X component was less consistent for FKP 2, and sometimes differed up to ±0.20 m at the same point between the FKP tests (Figure 4). Considering the dynamics involved in this test, and changing geometry of satellites near the building environment, in particular, were harmful to positioning, as they frequently blocked the signals of the low satellites. This is often subject to shadowing, diffraction and scattering of the satellite signal by building environments. Even though several satellites were shaded/blocked by the buildings, they can still be tracked by the receiver. Six-seven satellites (GPS+GLONASS) were visible at this period (FKP2). The PDOP value was between 3.1 and 4.8 at this period. The differences of X components for the CORS (FKP2) measurements are greater than the other two FKP surveys (FKP 1, FKP3).

3.2 Horizontal and Vertical Accuracy between VRS and FKP Techniques

In the third step of analysis, the coordinate differences of 108 points obtained from VRS1, FKP1, FKP2 and FKP3, such as VRS1 - FKP1, VRS1 - FKP2 and VRS1 - FKP3, respectively, were calculated. Figure 5 illustrates the differences and their mean values and standard deviations for 108 points. Examination of the differences in Figure 5 reveals that the standard deviation values are between 0.02 m and 0.05 m, the mean values are between 0.02 m and 0.09 m for the X and Y coordinate components.

However, the standard deviation values in the H direction are between ±0.02 m and ±0.03 m, the mean values are close to ±0.02 m. Analysis of the CORS results show that thee horizontal coordinate differences are between ±0.01 m and ±0.20 m. The differences in height coordinates are about ±0.10 metres (Figure 5). The analysis of the first, second and third days in the project area (VRS1, FKP1, FKP2 and FKP3) clearly shows that the horizontal and vertical coordinate differences are generally approximately ±0.02 m, see Figure 5. The differences of X components for the CORS (between VRS1 and FKP2) surveys are greater than VRS1-FKP1 and VRS1-FKP3 surveys because of the previously mentioned reasons.

In the fourth analysis step, the coordinate differences of 108 test points obtained from VRS2, FKP1, FKP2 and FKP3, such as VRS2 - FKP1, VRS2 - FKP2 and VRS2 - FKP3, respectively, were calculated. Figure 6 illustrates the differences and their means and standard deviations for the 108 points. When the differences in figure 6 are examined, the standard deviation values are between ±0.03 m and ±0.05 m, the mean values are between ±0.03 m and ±0.09 m for the X and Y coordinate components are obtained. However, the mean values in the direction of H are about ±0.02-0.03 m, standard deviation values are approximately ±0.02-0.03 m. Analysis of the techniques of the CORS results show that the horizontal coordinate differences and the height coordinate differences are between a few and ±0.20 m (Figure 6). Analysis of the first, second and third days in the project area (VRS2, FKP1, FKP2 and FKP3) shows that the differences in horizontal and vertical coordinates are generally between 2 cm and 10 cm.

In the fifth analysis step, the coordinate differences of 108 test points are gained from VRS3, FKP1, FKP2 and FKP3 were computed, such as VRS3 – FKP1, VRS3 – FKP2 and VRS3 - FKP3, respectively. Figure 7 indicates the coordinate differences and their mean values and standard deviations for the 108 points. In the examination of the coordinate differences in Fig. 7, the standard deviation values are between ±0.03 m and ±0.05 m, the mean values are between ±0.03 m and ±0.10 m are obtained for the X and Y coordinate components. However, the standard deviation values in the H direction are between ±0.02 m and ±0.03 m, the mean values are about 0.02 m. Analysis of the techniques of the CORS results show that the horizontal coordinate differences are between ±0.01 m and ±0.20 m. The height coordinate differences are between ±0.01 m and ±0.15 metres (Figure 7). Analysis of the first, second and third days in the project area (VRS3, FKP1, FKP2 and FKP3) shows that the differences in horizontal and vertical coordinates are generally between ±0.02 m and ±0.04 m.

In order to compare all of the results obtained from the VRS techniques, Figure 8a is prepared for the minimum and maximum differences in each coordinate component and the mean and standard deviation values calculated from these coordinate differences. To compare all of the results obtained from the FKP techniques, Figure 8b is prepared for the mean and standard deviation values calculated from these coordinate differences with minimum and maximum differences of each coordinate component. In order to compare the results obtained from both techniques (VRS and FKP), figure 9 is prepared for the minimum and maximum differences in each coordinate component and the mean and standard deviation values calculated from these coordinate differences. Thus the accuracy of the CORS results is presented as derived from the estimation process. Figure 9 shows the average standard deviations for all tests, in the Y, X, and H coordinate directions. The horizontal coordinates of all the points were good in general with standard deviation less than ±0.05 m on the average. Considering the dynamics involved in this test, and the changing geometry of satellites, the results clearly show that the CORS technique is a stable system, and the cm level of accuracy is generally obtainable (Figures 8 and 9), (Lachapelle et al., 2001; Landau et al., 2003; Vollath et al., 2000; Vollath et al., 2001; Vollath et al., 2002; Wübbena et al., 2001; Pirti, 2007; Pirti, 2008; Pirti et al., 2009).

The obtained results in this study are consistent with those of many other groups that made similar tests (Berber and Arslan, 2013; Gumus, 2016; Ma et al., 2011; Volker, 2009; Edwards et al., 2010). The accuracy values quoted by other authors for this situations are 1-2 cm in horizontal coordinates and 1.5-3.5 cm in height.

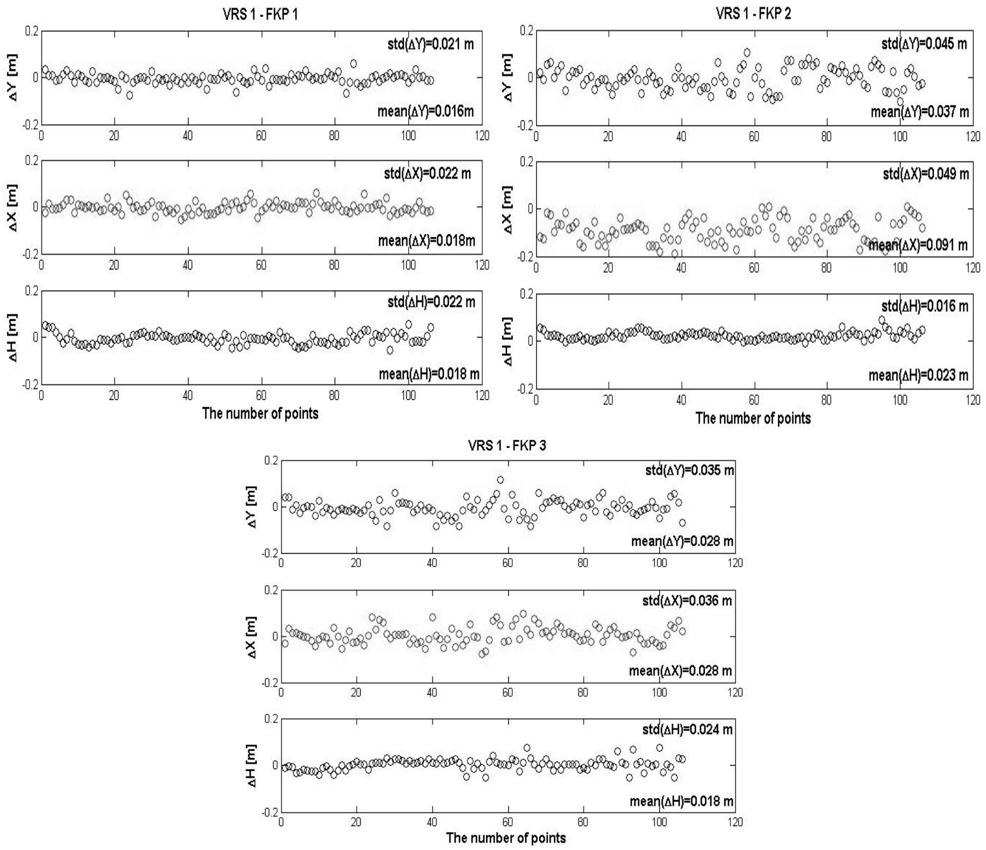

Figure 5: Comparison of the obtained coordinates of the test points by using VRS1 and FKP techniques

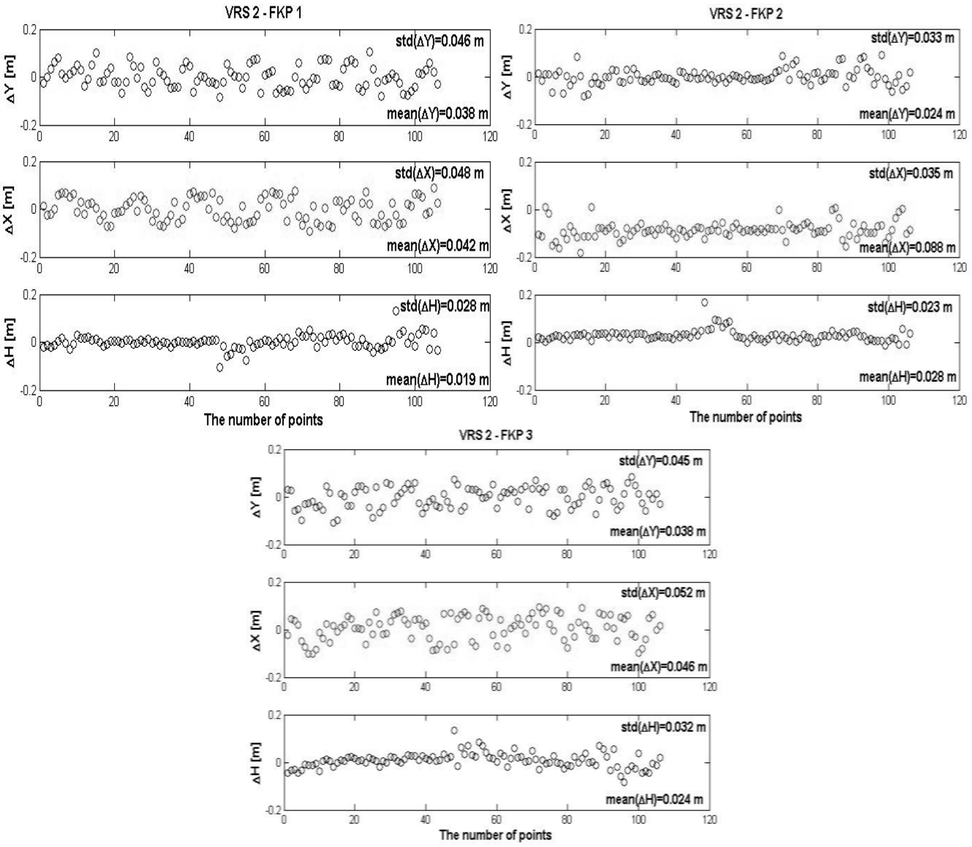

Figure 6: The comparison of the obtained coordinates of the test points using VRS2 and FKP

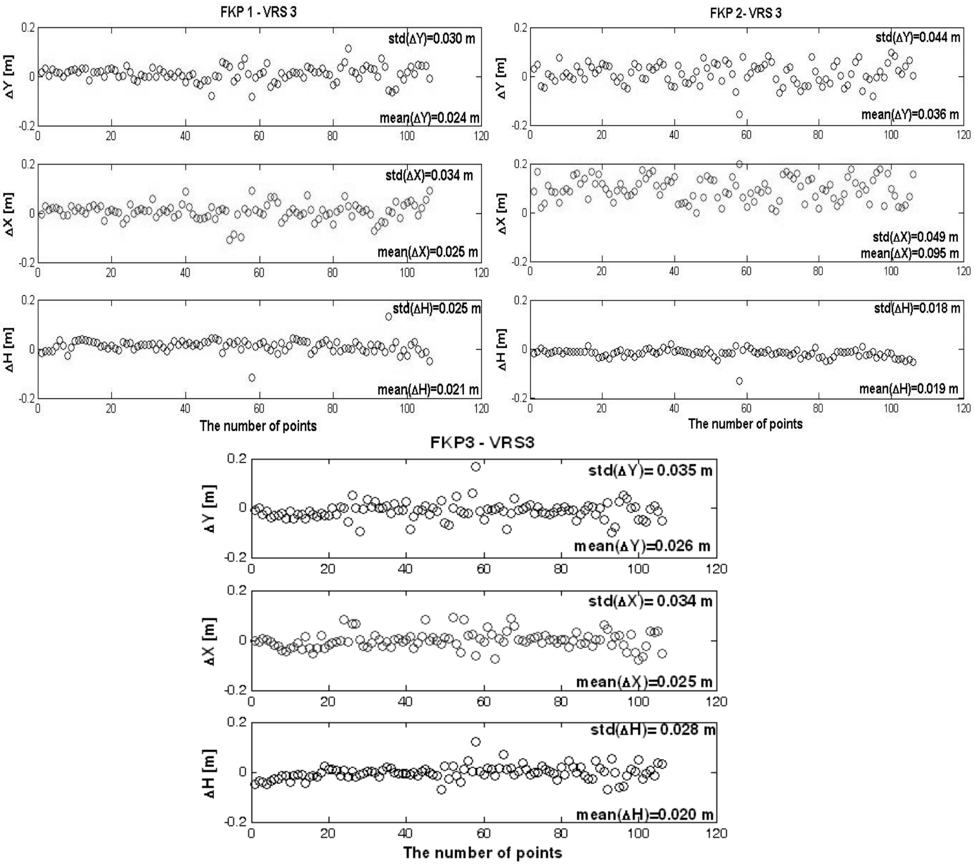

Figure 7: Comparison of the coordinates of the test points using VRS3 and FKP

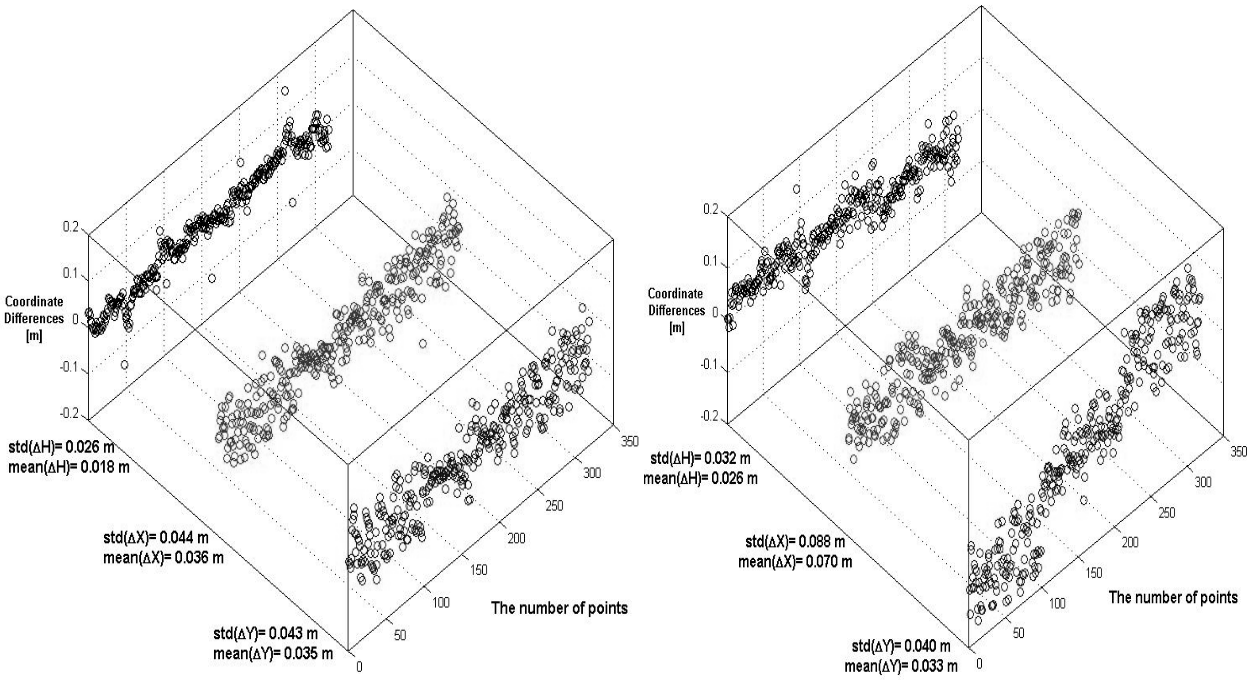

Figure 8: Comparison of the obtained coordinates of the test points by using VRS and FKP

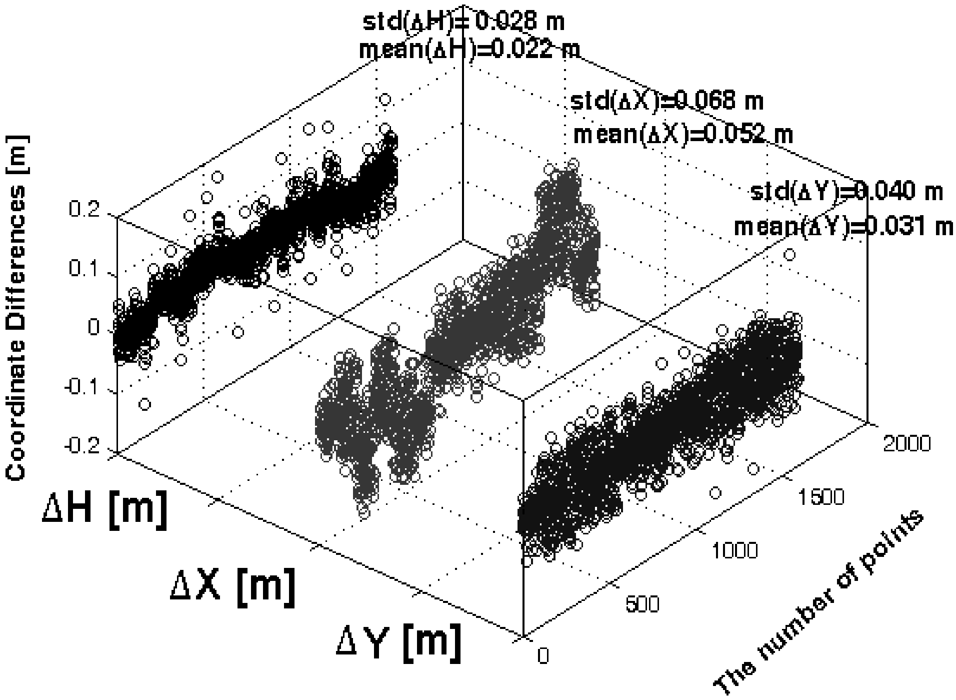

Figure 9: Comparison of the obtained coordinates of the points by using VRS-FKP in three days

4. Conclusions

Advances in communication technology have enabled the development and implementation of precise CORS. Although there are many considerations when implementing CORS, the achievable survey-grade accuracies provide new possibilities to data collection and applications. When comparing the CORS results of all the tests the horizontal and vertical coordinates of the test points as separately determined by these standard deviations and mean values seem generally very consistent, with changes ranging between ±0.01 m and ±0.20 m. It is shown in Figure 9, which gives the mean and the standard deviation values for all the points. In all the tests carried out in this study, reached an achievable and repeatable accuracy of approximately generally between ±0.03 m and ±0.07 m. The results in this study indicate that CORS positioning solutions from both VRS and FKP can achieve between 2 cm and 7 cm accuracy, which is required by the majority of topographic-geodetic applications.

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