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Consistency between CORS and NACN Egyptian Networks in Cairo and Nile Delta

Mohammed El-Tokhey, Tamer F. Fath-Allah, Yasser M. Mogahed and Mohammed Mamdouh
Public Works Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt

Abstract— The Egyptian Survey Authority (ESA) established in 1995 the High Accuracy Reference Network (HARN), which is zero order. In 1997, ESA established the New Agricultural Cadastral Network (NACN), which has been tied to the HARN. From this date till now, ESA has depended on the NACN for GPS surveying, mapping, and positioning activities… etc. On the other hand, and due to the increasing demand for high accuracy relative position using GPS, ESA established the 1st Egyptian Continuously Operating Reference Stations (CORS) network in January, 2012. The established network was processed and adjusted relative to the International Reference Terrestrial Frame (ITRF) 2008 at epoch 23 October, 2011.
3D positional discrepancies are found between both NACN and CORS networks. Such discrepancies are referenced to the difference in fixation of each network. These discrepancies can lead to serious problems in surveying activities in Egypt unless it is considered and accounted for. In this paper, the relation between NACN and CORS networks was studied as well as the possibility of direct transformation between such two networks. To achieve this goal, two GPS campaigns were established, located in Cairo and Nile Delta, to study the discrepancies in the obtained 3D coordinates for each campaign related to NACN and CORS networks. Then, the 3D transformations parameters between the two networks were calculated in two different cases (considering shift only in the first case and seven parameters transformation in the second). Results showed that both networks are different, mainly with significant average shift components of 0.450m in position and slight rotation in the order of 0.2222 arc-second. Also, it was proved that a direct translational transformation can be performed between CORS and NACN networks.

Index Terms: New Agricultural Cadastral Network (NACN), High Accuracy Reference Network (HARN), International Reference Terrestrial Frame (ITRF)

1 Introduction

GPS was becoming an indispensable geodetic tool during the 1980s and early 1990s. Governmental agencies looked for ways to replace traditional geodetic control networks initially with ground marks surveyed using GPS technology [1]. In Egypt, ESA was finished the establishment of the NACN in 1997 with the aid of United States Agency for International Development (USAID). The NACN is order B (1:1,000,000) geodetic network and its ground monuments are distributing all over the country with 30km to 40km intervals, and their final adjusted 3D coordinates were computed related to twelve points from the HARN of Egypt in ITRF 1994 datum at epoch January 01, 1996. After the publication of results of the final adjustment of the new national geodetic network in October 23, 1997, ESA is performing all GPS surveying, mapping, positioning activities… etc., related to this network.

The increasing demand for the Global Navigation Satellite System (GNSS) application has driven GNSS receiver manufacturers to focus on positioning solutions using CORS network, which are even more advantageous than normal GNSS surveying observation techniques [2, 3], thus make that, more and more countries are building networks of CORS. These provide services to the surveyor that can increase the efficiency with which surveys can be undertaken [4].

As GPS CORS networks are an important enhancement to a wide range of GPS surveying, mapping and positioning activities, they can improve the efficiency and accuracy of the activities they support and may result in a host of derived data products that in turn make possible additional GPS applications [3]. ESA completed the establishment of the 1st CORS network in Egypt in January, 2012. This established network was processed relative to the ITRF 2008 at epoch October 23, 2011 and consists of 40 permanent stations (Fig. 1).

Fig. 1. The Egyptian CORS network

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Many countries already have a national network of GNSS CORS. Such networks have been connected to the IGS network and thus the stations will have accurate ITRF coordinates. When establishing a new stand-alone reference station or network of stations, it is preferable to connect the new station or network to the national network [4]. Unfortunately, this concept has not been considered in the establishment of the Egyptian CORS network. So, in this paper, positional discrepancies between the obtained 3D coordinates related to the NACN and CORS networks will be analyzed. Then, transformation parameters using Molodensky transformation model between the two networks will be calculated in two cases of study. In the first case, only shift components between the two networks will be considered, whereas shift, rotation and scale parameters will be considered in the second case.

2 Methodology of Application

To study the positional discrepancies between the obtained 3D coordinates relative to the NACN and CORS networks, two GPS campaigns were established in two different locations in Egypt. Each campaign consists of six unknown points. Then, the collected GPS data at the new established points were post processed twice for each campaign. The 1st post processing relative positioning solution was carried on using the NACN network, while the 2nd solution was based on the CORS network available stations. Then the study of the positional discrepancies will take place using the obtained 3D coordinates for each solution. Finally the classical 3D coordinate transformation between the two Egyptian networks, using Molodensky model, will be calculated twice according to the obtained 3D coordinates of selected 8 points, from the new established 12 points.

After calculating the transformation parameters, the remaining four unused points will be used to validate the obtained parameters. The previous issues will be discussed in details in the next sections.

3 The used data

To achieve the goal of the current research, different types of data were used. These data will be discussed in details in the following sub-sections.

3.1 GPS Campaigns

As mentioned before, two GPS campaigns were established in two different regions in Egypt as seen in figure (2).

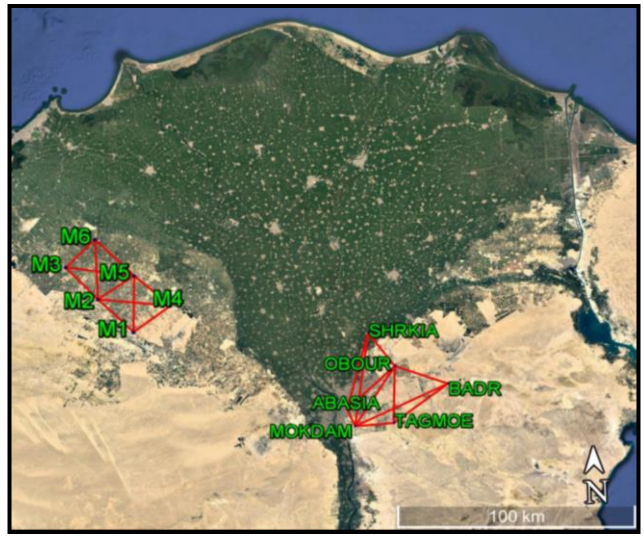

Fig. 2. Locations of the established GPS campaigns

The 1st GPS campaign (Fig. 2), located near Cairo in South East the Nile Delta, contains six points (Abasia, Badr, Mokdam, Obour, Shrkia and Tagmoe), which were fixed on different buildings' tops. The distances between these points vary from 8km to 43km.

The 2nd GPS campaign (Fig. 2), located West of the Nile Delta, contained six points (M1, M2, M3, M4, M5 and M6). The points (M1, M2 and M3) were fixed on Cairo-Alexandria desert road, while the other 3 points were fixed on 3 different minor roads. The distances between the points vary from 17km to 30km.

3.2 The used CORS Stations

Two CORS stations were chosen for each campaign. They were selected as the nearest operated CORS station for the 1st and 2nd campaigns. The two operated CORS stations (CARO and RMDN) were chosen for the 1st campaign, while (BADR and SDAT) stations were assigned for the 2nd campaign.

CORS observation data files consist of GPS code and carrier phase observations, which are provided in the common Receiver INdependent EXchange (RINEX) format [5]. In this research, the used CORS observation data, provided by ESA, are dual frequency 30 seconds sampling rate GPS RINEX format data.

3.3 The used NACN Ground Points

In the current research, points (0Z88, 0Z98) and (0Y11, 0Z92) were selected from the NACN network. The first NACN set was used for the 1st campaign, while the other NACN set was chosen for the 2nd campaign. These two sets were selected as the nearest existing points to the established campaigns. These points will be used as constraint fixed points during the post processing stage of the two established campaigns, and

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their 3D Cartesian coordinates were provided by ESA depending on results of the final adjustment of the new national geodetic network in October 23, 1997.

4 Data Processing

To assess the consistency between CORS and NACN networks, the two established campaigns were processed twice. First time was based on post processing static solution using the nearest existing two NACN points, whereas the second solution was based on the nearest operated two CORS stations. Details of each campaign solution will be discussed in the following two subsections.

4.1 Static Solution Relative to NACN Network

Using the traditional method of establishing a geodetic network by using the GPS dual carrier phase static observations for all points of each campaign and the selected NACN points, the post processing of the recorded observations were made in order to get the adjusted 3D coordinates relative to the NACN network. The recorded GPS observations were 5 seconds epoch interval and 15˚ cutting off angle. The details of processing each campaign will be discussed in the following.

4.1.1 First GPS Campaign

Using the observed GPS data for the 1st campaign points and the two NACN points (0Z88 and 0Z92), a geodetic control network was established. The established network consisted of 15 base lines (Fig. 3); the post processing solution for these base lines was performed by fixing the 3D Cartesian coordinates of the two NACN points (0Z88 and 0Z92) during the processing and adjustment processes.

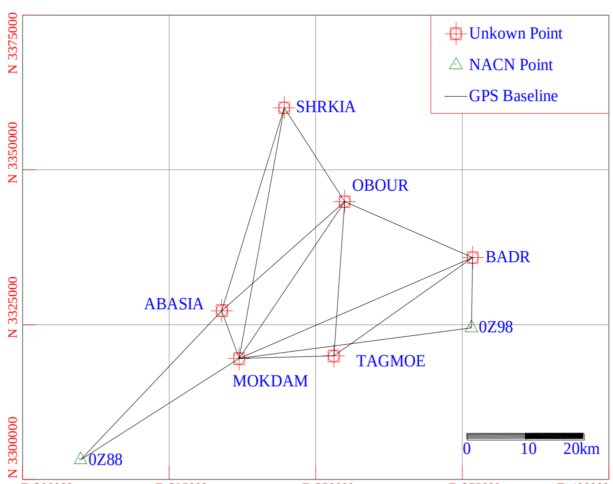

Fig. 3. Static GPS network for the 1st campaign relative to the NACN network

Observations of the established network were carried on using two Trimble R8 GNSS receivers, and the observations were taken during the period of September, 2014 till January, 2015.

4.1.2 Second GPS Campaign

Similar to the described in the previous section, 15 GPS vectors were post processed to establish a geodetic network for the 2nd campaign (Fig. 4). The post processing and adjustment processes were made according to the fixed 3D Cartesian coordinates of the two NACN points (0Y11 and 0Z92).

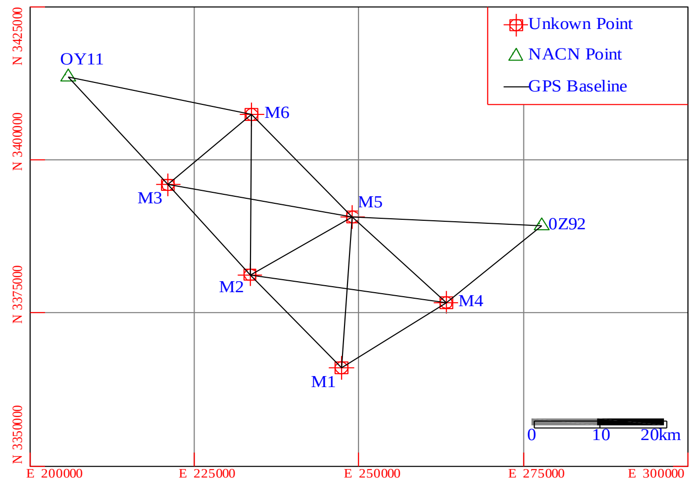

Fig. 4. Static GPS network for the 2nd campaign relative to the NACN network

4.2 Static Solution Relative to the CORS Network

The recently established CORS network provides an even more accurate set of positional coordinates [6] as user could collect data in the field with a single GPS receiver, latter retrieve the data collected during the same time span by a nearby reference station, and combine the two datasets to perform single-handed, post-processed relative positioning [7]. As mentioned before, the same two campaigns will be processed using the CORS stations in order to check its consistency with the NACN network. Details of each campaign solution will be discussed in the following.

4.2.1 First GPS Campaign

Two Trimble R8 GNSS receivers and two South S86 GNSS receivers were used to observe the points of the 1st campaign in static mode for average observation time of 2 hours for each session. The observations were taken during the period of September, 2014 till January, 2015. The two CORS stations (CARO and RMDN) were found to be the nearest operated stations during the observation time of the 1st campaign points. The GPS observed data for these two stations was provided by ESA.

Using the observed GPS data and by fixing the 3D Cartesian coordinates of the used two CORS stations during the post processing and adjustment processes, a two GPS vectors were post processed for each established point in the 1st campaign (Fig. 5) in order to get their adjusted 3D coordinates relative to the CORS network.

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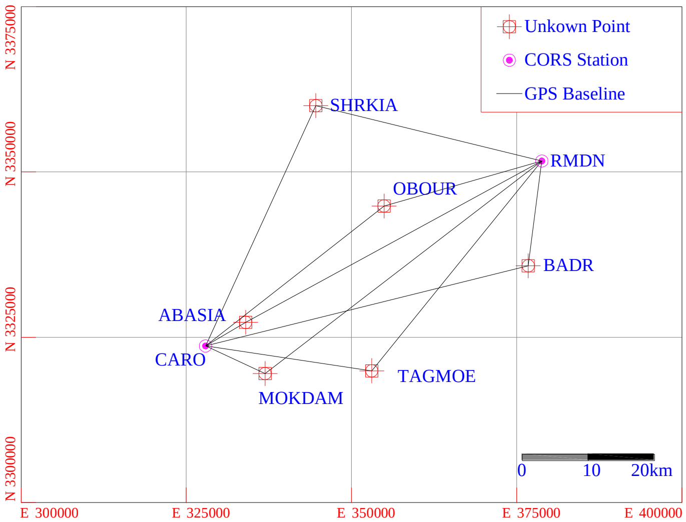

Fig. 5. Static solution for the 1st campaign relative to the CORS stations

4.2.2 Second GPS Campaign

The 3D Cartesian coordinates of the established points for the 2nd campaign were obtained by processing the collected GPS static data, as each point was observed for about 2 hours during the period of October, 2015 till December, 2015. The post processing and adjustment processes were performed similar to the previously mentioned for the 1st campaign, using the provided GPS observations by ESA for (BADR and SDAT) CORS stations. Figure (6) shows the post processed GPS vectors for 2nd campaign.

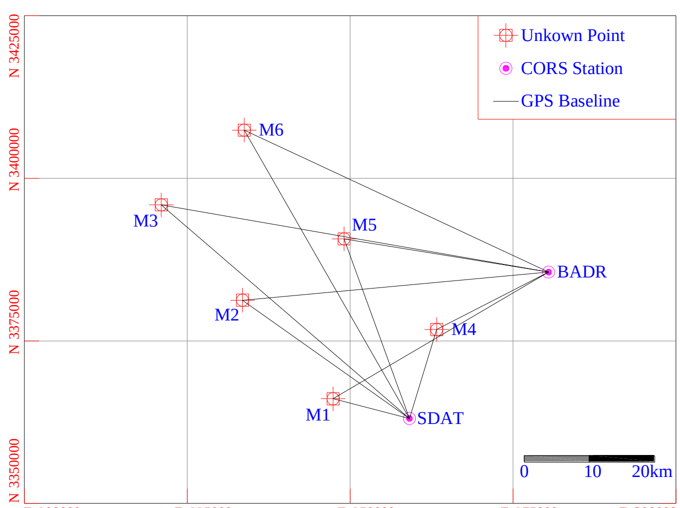

Fig. 6. Static solution for the 2nd campaign relative to the CORS stations

5 Results

By comparing the calculated adjusted 3D coordinates for the two established campaigns' points relative to the NACN and CORS networks, discrepancies in 3D coordinates were found as listed in tables (1) and (2). Also, tables (3) and (4) show the statistics of the computed discrepancies for each campaign.

Table 1
Discrepancies in 3D coordinates of the 1st campaign's points relative to NACN and CORS networks
(NACN minus CORS)

Point	ΔX (m)	ΔY (m)	ΔZ (m)	ΔP (m)
ABASIA	0.321	-0.181	-0.253	0.447
BADR	0.313	-0.184	-0.246	0.439
MOKDAM	0.280	-0.201	-0.268	0.437
OBOUR	0.334	-0.169	-0.232	0.440
SHRKIA	0.370	-0.160	-0.209	0.454
TAGMOE	0.333	-0.168	-0.236	0.441

Table2
Discrepancies in 3D coordinates of the 2nd campaign's points relative to NACN and CORS networks
(NACN minus CORS)

Point	ΔX (m)	ΔY (m)	ΔZ (m)	ΔP (m)
M1	0.302	-0.183	-0.261	0.439
M2	0.351	-0.166	-0.233	0.453
M3	0.389	-0.147	-0.204	0.463
M4	0.370	-0.151	-0.223	0.458
M5	0.367	-0.165	-0.221	0.459
M6	0.409	-0.136	-0.188	0.470

Table 3
Statistics for the computed discrepancies
(1st campaign)

	ΔX (m)	ΔY (m)	ΔZ (m)	ΔP (m)
Min.	0.280	-0.201	-0.268	0.437
Max.	0.370	-0.160	-0.209	0.454
Mean	0.325	-0.177	-0.241	0.443
RMS	0.326	0.178	0.241	0.443

Table4
Statistics for the computed discrepancies
(2nd campaign)

	ΔX (m)	ΔY (m)	ΔZ (m)	ΔP (m)
Min.	0.302	-0.183	-0.261	0.439
Max.	0.409	-0.136	-0.188	0.470
Mean	0.365	-0.158	-0.222	0.457
RMS	0.366	0.159	0.223	0.457

Based on the obtained results it is very clear that the two campaigns exhibited similar results in coordinate discrepancies. This means that it is possible to perform a direct 3D coordinate transformation between the NACN network and CORS network, which will be discussed in the next section.

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6 Transformations between the NACN and CORS networks

According to the obtained results, and in order to get the full benefits of the CORS stations in Egypt, it is of great importance to compute the transformation parameters between the NACN and CORS networks. The used transformation will be based on Molodensky transformation model. This will be tried twice. In the first time concerning shift only between the two systems, while the second trial will be based on the seven transformation parameters (3 shift components, 3 rotation angles and scale factor) as will be discussed in the following subsections.

6.1 Three Shift Parameters Transformation

The three shift transformation parameters were calculated according to the obtained coordinates of eight points (four points from each campaign) using Molodensky model. Table (5) shows the calculated transformation parameters from the CORS network to the NACN network, whereas table (6) shows the statistics of calculated residuals of 3D coordinates of the selected eight points.

Table5
Three transformation parameters from CORS to NACN networks

Parameter	Value	RMS
Shift dX (m)	0.3456	0.010
Shift dY (m)	-0.1671	0.010
Shift dZ (m)	-0.2318	0.010

Table6
Statistics of calculated residuals for 3D coordinates of the selected eight points.

	ΔX (m)	ΔY (m)	ΔZ (m)	ΔP (m)
Min.	-0.063	-0.031	-0.044	0.005
Max.	0.066	0.034	0.036	0.083
Mean	0.000	0.000	0.000	0.036
RMS	0.036	0.018	0.022	0.046

After calculating the three transformations parameters, they were used to transform the obtained coordinates relative to CORS network of the rest four points (BADR, SHRKIA, M1 and M3) to the NACN coordinate system. Table (7) shows the differences in 3D coordinates for transformed points and their processed and adjusted coordinates relative to NACN network.

Table7
Difference in 3D coordinates for the transformed four points (Transformed minus observed coordinates)

Point	dX (m)	dY (m)	dZ (m)	dP (m)
BADR	0.033	0.017	0.014	0.040
SHRKIA	-0.024	-0.007	-0.023	0.034
M1	0.044	0.016	0.029	0.055
M3	-0.043	-0.020	-0.028	0.055

6.2 Seven Parameters Transformation

The seven parameters transformation expresses the relationship between the two datums in terms of a translation, rotation, and scale factor. The translation and rotation are defined for each of the 3 coordinate axes, making a total of 7 parameters [4].

The seven transformation parameters between the CORS and NACN were calculated by using the obtained coordinates of eight points (four points from each campaign). The used transformation model was Molodensky and the rotation origin was the mean value of the used points. Table (8) shows the calculated seven transformation parameters from the CORS network to the NACN network. Table (9) shows statistics of calculated residuals for 3D coordinates of the selected eight points.

Table8
Seven transformation parameters from CORS to NACN networks (Molodensky Model)

Parameter	Value	RMS
Shift dX (m)	0.3456	0.0048
Shift dY (m)	-0.1671	0.0048
Shift dZ (m)	-0.2318	0.0048
Rotation about X (")	0.16253	0.02644
Rotation about Y (")	-0.41053	0.08409
Rotation about Z (")	0.09350	0.04456
Scale (ppm)	0.043700	0.0784

Table9
Statistics of calculated residuals for 3D coordinates of the selected eight points.

	ΔX (m)	ΔY (m)	ΔZ (m)	ΔP (m)
Min.	-0.025	-0.016	-0.017	0.007
Max.	0.021	0.013	0.009	0.034
Mean	0.000	0.000	0.000	0.018
RMS	0.015	0.010	0.009	0.020

After calculating the seven transformation parameters, they were used to transform the obtained coordinates

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relative to CORS network for the rest four points (BADR, SHRKIA, M1 and M3) to the NACN coordinate system. Table (10) shows the differences in 3D coordinates for transformed points and their processed and adjusted coordinates relative to NACN network.

Table10
Difference in 3D coordinates for the transformed four points (Transformed minus observed coordinates)

Point	dX (m)	dY (m)	dZ (m)	∆P (m)
BADR	0.029	0.021	0.019	0.041
SHRKIA	-0.002	0.008	-0.003	0.009
M1	0.037	0.009	0.02	0.043
M3	-0.014	-0.009	-0.013	0.021

6.3 Analysis of the Obtained Results

Referring to table (7), which indicates the difference in 3D coordinates for the transformed four points using the three parameters transformation, it can be seen that the value of position discrepancies are ranging from 0.034m to 0.055m with mean value of 0.046m . Also referring to table (10), which indicates the difference in 3D coordinates for the transformed four points using the seven parameters transformation, it can be seen that the value of position discrepancies are range from 0.009m to 0.043m with mean value of 0.029m. In this context it can be noticed that, the difference between the two solutions is not significant. So the first solution (three transformation parameters), which is more easier than the second solution (seven transformation parameters) can be recommended for transforming the obtained coordinates from the CORS network to the NACN network.

7 Conclusion

Based on the obtained results as well as their analysis, it can be concluded that:

- There are significant differences in coordinate systems between both CORS and NACN networks in Egypt.
- Any GPS derived coordinates processed with respect to CORS stations should be transformed correctly before using it in any further surveying works.
- The RMS of discrepancies from the stand alone solution relative to the two networks, the CORS network and the NACN network, are 0.346m in X direction, 0.169m in Y direction, 0.232m in Z direction, and 0.450m in position.
- The three transformation parameters solution increases the accuracy of discrepancies between the two networks. The RMS of discrepancies between the two networks, the CORS network and the NACN network, are 0.036m in X direction, 0.018m in Y direction, 0.022m in Z direction, and 0.046m in position.
- The seven transformation parameters solution increases the accuracy of discrepancies between the two networks. The RMS of discrepancies between the two networks, the CORS network and the NACN network, are 0.015m in X direction, 0.010m in Y direction, 0.009m in Z direction, and 0.020m in position.
- The first solution (three transformation parameters), which is more easier than the second solution (seven transformation parameters) can be recommended for transforming the obtained coordinates from the CORS network to the NACN network.

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