Enhancing the Integrity of the National Geodetic Data Bases in Egypt

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Key words: GPS, Geodetic control networks, Geoid.

SUMMARY

Egypt has recentely established a new precise geodetic framework based on the global WGS84 datum to furnish a national GPS-based reference system. For agricultural development along the Nile valley, the National Agricultural Cadastral Network (NACN) has been established with a precision of 1 part per million. However, the orthometric heights of the 112-station network have been computed utilizing the OSU91A global geopotential model. Previous studies have shown that the accuracy of this model over Egypt is almost 1.5 meter. Even the new global models, such as EGM96, PGM2000, and UCPH2002, do not represent the gravitational field over Egypt better than 0.80 meter.

Currently, accurate GPS networks are being constructed along the Nile to serve various undergoing surveying and mapping activities. Recent two local geoid models, SRI2001 and NILE2004, have been integrated to generate a new model mainly for the Nile valley. Accordingly, more reliable orthometric heights have been computed for 15 NACN stations. Over 5 known check points, the obtained heights have produced errors in the range between 0.06 meter and 0.42 meter with an average of 0.18 meter, which is seven times more accurate than the heights published by ESA right now. From an economical point of view, the developed approach can be performed as an alternative to the relatively expensive and time-consuming spirit levelling method. Thus, this scheme yields a considerable cost reduction in surveying and mapping applications in Egypt.

ملخص

للدخول في القرن الحادي و العشرين أنشأت مصر هيكل جيوديسي جديد عالي الدقة اعتمادا علي المرجع الجيوديسي العالمي لعام 1984 ليكون النظام المرجعي القومي المبني علي جي بي إس. أقيمت الشبكة القومية للكادستر الزراعي المكونة من 112 محطة جيوديسية بدقة جزء في المليون لخدمة التنمية الزراعية في وادي النيل. إلا أنه لم يتم رصد مناسيب نقاط هذه الشبكة وتم حساب المناسيب باستخدام نموذج الجيويد العالمي لعام 1991. وقد أثبتت دراسات سابقة أن دقة هذا النموذج في مصر تبلغ حوالي 1.5 متر ، وحتى نماذج الجيويد العالمية الأحدث لا تمثل طبيعة مجال الجاذبية الأرضية في مصر بدقة أحسن من 0.8 متر. يتم حاليا إنشاء شبكات جي بي إس دقيقة علي نهر النيل لخدمة العديد من تطبيقات المساحة و الخرائط لأغراض الإدارة المتكاملة للموارد المائية في مصر. وعلي صعيد آخر فقد تم دمج أحدث نموذجي جيويد محليين لإنتاج نموذج جيويد دقيق لمنطقة وادي النيل. ومن ثم فقد أمكن حساب مناسيب أدق لخمسة عشر نقطة من نقاط الشبكة القومية للكادستر الزراعي. وعند اختبار الطريقة الجديدة عند خمسة نقاط معلومة فقد أثبتت النتائج أن الدقة المتوقعة للمناسيب تتراوح بين 0.06 متر و 0.42 متر بمتوسط 0.18 متر مما يعادل سبعة أضعاف دقة المناسيب المستخدمة حاليا. ومن ثم يخلص البحث إلى أن هذا الأسلوب يزيد من دقة و تكامل وتجانس قواعد البيانات الجيوديسية في مصر ، كما أنه من وجهة النظر الاقتصادية يمكن استخدامه كبديل لطريقة الميزانيات الارضية المكلفة مما يساعد في خفض تكلفة مشروعات المساحة و الخرائط في مصر.

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1. INTRODUCTION

At the end of the twentieth century, the necessity to develop new precise geodetic systems has been a crucial demand by the geodetic communities worldwide e.g. Kasser and Breton, (2003) . With the rapid growth of GPS utilization in Egypt since 1985, the WGS84 global geodetic datum has been selected to be the new geodetic framework. In 1995, two national GPS geodetic control networks have been established, by the Egyptian Survey Authority (ESA), to furnish a nationwide GPS skeleton for surveying and mapping applications. The first network is the High Accuracy Reference Network (HARN) that covers the entire Egyptian territories and consists of 30 stations with approximate separation of 200 Km. The relative precision level of HARN is 1:10,000,000. The second network is the National Agricultural Cadastral Network (NACN) that is mainly covers the Nile valley and the Delta. NACN consists of 112 stations, with a station separation of 50 Km approximately, whose relative precision is 1:1,000,000. Both networks are depicted in Figure 1. Other GPS geodetic control networks have been established for some specific projects, but do have neither a national coverage nor such accuracy limits e.g. Saad, (1998) .

A vital drawback for both networks concerns the orthometric heights of almost all stations. Because of the site selection of the stations to be on high places such as the top of buildings, the spirit levelling technique could not be used to observe those orthometric heights. Instead, the OSU91A global geopotential model has been employed to convert the ellipsoidal heights to the orthometric ones. It has been proved that the accuracy of the OSU91A model over Egypt is in the order of 1.5 meter Saad and Dawod, (2002) . Furthermore, new global geoid models, such as the EGM96, PGM2000A, and UCPH2002, do not represent the gravitational field over Egypt better than 0.8 meter Dawod, (2005) . Hence, this paper aims to develop a new efficient scheme to estimate precise orthometric heights of national GPS geodetic control networks in order to increase the integrity and completeness of the national geodetic databases in Egypt.

2. RECENT PRECISE GEOID MODELS IN EGYPT

Saad and Dawod (2002) have developed two precise geoid models for the entire Egyptian territory. The first geoid, called SRI2001A, is a gravimetric geoid model utilizing the most recent and accurate first-order gravity measurements, and is based on the GRS80 reference datum. The EGM96 global geopotential spherical harmonic model is used to provide the long wavelength of the Earth gravitational field, along with a local DEM in the remove-compute-restore FFT processing technique. The obtained geoid undulations range from 5.42 m to 22.40 m with a mean value of 14.54 m and RMS equals 2.96 m. A GPS/Levelling data set of 195 precise stations has been used to generate a geometric-satellite geoid model. A second-order polynomial, as a function of the distance from the network origin, is found to be the best fitting function to integrate gravimetric undulations and GPS/Levelling undulations. Therefore, a combined GPS/Gravity geoid for Egypt, SRI2001B, has been generated. This geoid model, depicted in Figure 2, has a minimum undulation value of 9.437 m and a maximum value of 21.39 m with an average of 13.62 m and RMS of 2.62 m. The values of the estimated undulations from the SRI2001B model have been compared against the pure GPS undulation of some independent GPS/Levelling stations. The differences range between –0.01 m and –0.28 m, with an average equals –0.10 m, and RMS of 0.49 m.

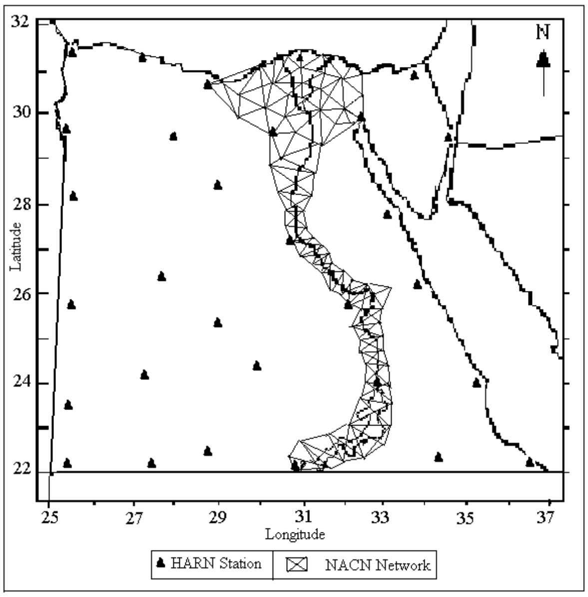

Figure 1: Recent precise GPS geodetic control networks in Egypt

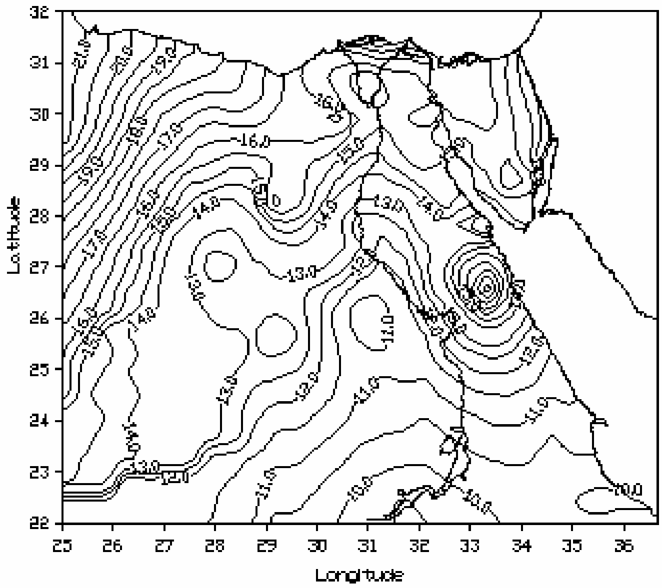

Figure 2: SRI2001 Geoid Model of Egypt

Dawod (2005) has proved that the EGM96 model, compared to other global geoid models, is the optimum global geoid model to deal with in Egypt. Therefore, it has been decided to model the irregularities between its geoid undulations and the observed estimates at GPS/Levelling stations in the study area, that covers 408 km along the Nile from Delta barrage to Assiut barrage. It has been conclueded that a simple polynomial is not able to fit the irregular structure of the undulation differences. Thus, a correction or conversion surface has been developed to fit the undulation differences. The obtained results show that the accuracy of this surface is better than 0.04 m. Hence, a precise geoid model, called NILE2004, has been obtained covering the fourth reach of the River Nile and is applied in the undergoing project of hydrographic surveying.

3. HYDROGRAPHIC SURVEYS ALONG THE NILE

Hydrographic and topographic maps play a crucial role in the management of water resources. Since the Nile constitutes the main source of fresh water in Egypt, its precise maps are a key element in the context of integrated water resources management policy. In order to study the recent morphological and hydrological changes of the Nile, the Nile Research Institute (NRI) has initiated a four-year national project to produce precise digital hydrographic and topographic maps covering the river and its two branches. The main core of this pioneer project is a multi-fold precise geodetic control network utilizing the state-of-the-art GPS instrumentation and techniques. The network consists of approximately 600 control stations spacing 5 km apart on both banks of the Nile, which is almost 1435 km long. Orthometric heights of all control stations will also be determined. It is anticipated that this network will improve the reliability of the national geodetic networks, and have a great economical impact on surveying and mapping activities in Egypt.

4. AVAILABLE DATA AND PROCESSING

A precise GPS control network have been established on both banks along the forth reach of the Nile, that is from Delta barrage to Assiut barrage extending about 408 km. The network, depicted in Figure 3, consists of 168 control points, of them 130 stations have observed orthometric heights, which station separation ranges from 0.2 km to 9.2 km with an average equals 5.7 km. The network has been observed and processed in the optimum way to insure the quality of precise geodetic control networks, i.e., at least 1 ppm level of precision. It has been tied to the HARN and NACN national networks through 20 tie stations. The networks' statistics are summarized in Table 1. The distances from GPS stations to NACN points range from 4.5 km to 34.2 km with an average equals 19.7 km. As previously stated, those stations have no observed orthometric heights.

The issue of obtaining orthometric heights from GPS measurements attains a great deal of research work recently e.g. Hu et al, 2004, Wisloff, 2002, and Martensson, (2002) . The proposed strategy consists of two steps: (a) obtaining a precise estimate of the undulation differences for each observed baselines connecting a NACN station to the GPS network, and (b) combining the attained undulation differences to the ellipsoidal height differences to come up with an accurate orthometric height difference, which added to the observed orthometric height of the GPS station to compute the orthometric height of an NACN point.

Table 1: Statistics of available geodetic data

	GPS Control Network	GPS/Levelling Stations
No. of stations	166	130
Minimum distance (km)	0.2	0.2
Maximum distance (km)	7.3	9.2
Mean distance (km)	4.5	5.7

Since the NILE2004 geoid is restricted to the Nile area with a width of approximately 4 Km only, the first procedure combines the two local geoid models to produce a more-precise one that covers the study area. Next, the kriging statistical method has been utilized to interpolate undulation differences for the observed GPS baselines. Kriging is a geostatistical interpolation technique that gives best-linear unbiased prediction estimates of unknown values of a random function or a random field. Due to its efficiency in modeling the variations of geospatial quantities, this method is widely applied in various geodetic applications in the last few years e.g. Smith et al, 2003, and Wielgoz et al, (2003) . Krigging attempts to express trends suggested in a specific data set by utilizing the spatial and temporal correlation properties of the underlying phenomenon and incorporating the measures of the error and uncertainties when determining the estimates. The mathematical principle underlines krigging is the variogram, which is a measure of how quickly things change on the average, so it is a function of the distance between two locations. For example, a linear weighting kriging scheme is given by Johnston, (2003) :

$$\gamma (h) = (1/2n)\ \Sigma \{ zi - zi\text{-}h\}2 \qquad (1)$$

where,

h is the lag distance (the distance between two points used to calculate the variance), n is the number of observations, γ is the average difference in the interested quantity at a specific lag distance, z is the attribute of interest – in this case geoidal undulation, and i and i-h are index notations denoting the location of z. Applying an ordinary kriging, the geoidal undulation variations have been represented in a two-dimensional manner, that enables precise interpolation of undulations at the required unknown NACN points. Hence,

$$\Delta Ni,j = Nj - Ni \qquad (2)$$

where,

Nj is the known undulation at the GPS point j, and Ni is estimated or interpolated undulation at the NACN point i.

Similarly, the height difference can be written:

$\Delta hi,j = hj - hi$ (3)

where,

hj and hi are the ellipsoidal heights for both the GPS point j, and the NACN point i.

Since,

$Hi = hi - Ni$ (4)

where Hi denotes the orthometric heights of the required point, and the other two quantities are defined above. A similar equation (4) can be written also for station j. So, in a relative sense, it can be written:

$\Delta Hi,j = \Delta hi,j - \Delta Ni,j$ (5)

Having obtaining the orthometric height difference between the GPS and the NACN points, the level of the NACN station can be computed as:

$Hi = Hj + \Delta Hi,j$ (6)

If the NACN point is connected to several GPS stations, a least-squares adjustment is performed to come up with the optimum orthometric height estimate. Applying such a strategy, the orthometric heights of 20 HARN and NACN stations, depicted in Figure 3, have been attained. Finally, in order to judge the achieved results, 5 HARN stations with known observed orthometric heights (T2, E7, M3, F1, and O1) are utilized. The differences, or errors, in orthometric heights at those check points range from 0.06 meter and 0.42 meter with an average of 0.18 meter. Hence, it can be concluded that orthometric heights of 15 NACN national GPS stations, given in Table 2, have been estimated with a mean precision of ± 0.20 m.

Table 2: Computed orthometric heights of NACN stations

Station	Orthometric Height	Station	Orthometric Height
Z64	200.48	Z76	70.72
Z65	93.55	Z78	115.69
Z66	77.44	Z81	156.06
Z67	59.07	Z82	47.83
Z69	133.74	Z87	220.86
Z73	140.61	Z88	122.49
Z74	196.75	Z96	42.24
Z75	54.02		

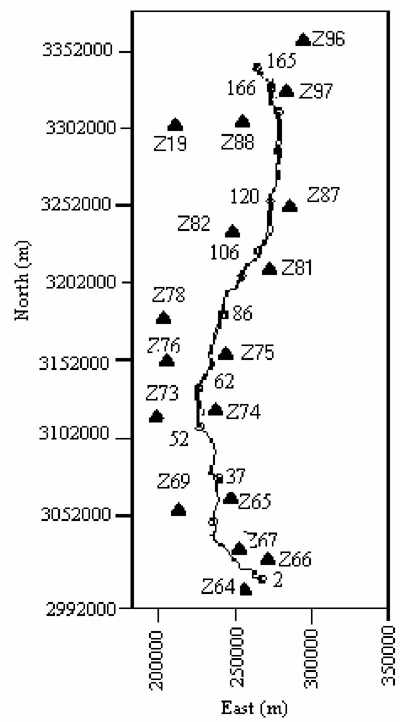

Figure 3: Utilized GPS networks

5. ACCURACY AND ECONOMICAL BENIFITS

From a technical point of view, it can be noticed that the developed procedure produces orthometric heights that are almost seven times more-accurate than the OSU91A-based heights published by ESA right now. Also, the results are even four times the accuracy of the EGM96-based (and those based on new global models such as PGM2000A and UCPH2002) orthometric heights. Recall that the average distance between the GPS and the NACN stations is 20 km, it can be concluded that the computed orthometric heights are within 1 cm/km level of relative precision. As the GPS national project over the Nile River continues, all NACN stations can obtain their precise and reliable orthometric heights utilizing the same procedure.

It is a matter of fact that the spacing between the NACN stations is 50 km in average, while that of the Nile GPS network is only 5 km approximately. Following the developed strategy, all GPS networks along the Nile valley can have an accurate estimate of orthometric heights. Hence, for any new GPS survey connected to an NACN station, orthometric heights can be estimated by converting the ellipsoidal heights. Economically speaking, the developed strategy can be used as an optional manner to get ride of the relatively expensive and time-consuming spirit levelling method. Thus, this scheme yields a considerable cost reduction in surveying and mapping applications in Egypt.

6. CONCLUSIONS

A critical shortcoming for the Egyptian national GPS networks (HARN and NACN) is the lack of observed orthometric heights of almost all stations. ESA has employed the OSU91A global geopotential model to convert the ellipsoidal heights to the orthometric ones. It has been proved that the accuracy of the OSU91A model over Egypt is in the order of 1.5 meter. This paper has developed an efficient scheme to estimate precise orthometric heights of national GPS geodetic control networks based on utilizing the recent national geoid models and the GPS network currently being established along the Nile.

It has been concluded that the accuracy of the estimated orthometric heights ranges from 0.06 meter and 0.42 meter with an average of 0.18 meter, which is seven times more-accurate than the OSU91A-based heights published by ESA right now. In a relative sense, the computed orthometric heights are within the 1 cm/km level. As the GPS national project over the Nile River carries on, all NACN stations can obtain their precise and reliable orthometric heights utilizing the same technique. Consequently, the developed procedure enhances the reliability and integrity of the national geodetic database in Egypt. Moreover, new GPS surveys can gain orthometric heights by converting the ellipsoidal heights. From an economical point of view, the developed approach can be performed as an alternative to the relatively expensive and time-consuming spirit levelling method. Thus, this scheme produces significant cost saving in surveying and mapping applications in Egypt.

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BIOGRAPHICAL NOTES

Gomaa M. Dawod received his Master of Geodetic Science and Surveying from the Ohio State University, Columbus, Ohio, USA in 1991 and his Ph.D. of Surveying Engineering from Shobra Faculty of Engineering, Zagazig University, Egypt in 1998. Since 1987, he is affiliated with the Survey Research Institute (SRI), the National Water Research Center (NWRC), Egypt, mainly in the field of Geodesy. He has participated in several national surveying and mapping projects and has established many geodetic control networks by GPS. He, also, has been fully involved in establishing the Egyptian National Gravity Standardization Network (ENGSN97). From 2002 to 2004, he has moved to the Nile Research Institute (NRI) and participated in the project of updating the hydrographic and topographic maps of the Nile River.

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