ESTABLISHEMENT OF A PRECISE GEODETIC CONTROL NETWORK FOR UPDATING THE RIVER NILE MAPS

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ABSTRACT

Geodetic control networks play the most crucial role in the attainable accuracy and reliability of surveying and mapping applications. Since the mid 1980's, several geodetic control networks have been established for a wide range of mapping projects utilizing the Global Positioning System (GPS) technology. On the other hand, there are no official documented specifications and standards for GPS-based geodetic control networks in Egypt.

The Nile Research Institute (NRI) of the National Water Research Center (NWRC) has initiated a national project to create modern digital topographic and hydrographic maps of the River Nile 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, which enables the creation of a precise geoid model of the Nile valley. This paper presents the characteristics and the designed unique standards and specifications of the geodetic control network. It is anticipated that this network will improve the reliability, availability, and integrity of the national geodetic networks, and have a great economical impact on surveying and mapping activities in Egypt, particularly for water resources management.

KEY WORDS

Geodetic Networks, River Nile Maps, GPS; Specifications.

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INTRODUCTION

Geodetic control networks are mandatory for a wide variety of disciplines such as mapping, urban management, engineering projects, hydrography, aerial photography, astronomy, geophysics, and deformation monitoring. The GPS technology has been considerably employed in Egypt to establish geodetic control networks since 1985. Only one GPS network achieves high degree of accuracy, reliability, and integrity. A main reason behind this fact is the lack of official documented series of GPS standards and specifications to be fulfilled in Egypt.

Currently, a new GPS network is established over the river Nile and its two branches. Previous GPS networks in Egypt have been thoroughly studied to conquer their limitations and defects. Moreover, recent international GPS specifications have been collected and thoroughly analyzed prior to designing the new network. The developed characteristics of this network, in terms of hardware, data capture, data processing and adjustment, have been worked out to ensure acquiring a high-precision GPS network. This research study presents the derived set of standards and specifications being implemented to establish the new national GPS control network.

STATUS OF GPS GEODETIC CONTROL NETWORKS IN EGYPT

GPS has been extensively utilized in Egypt to establish geodetic control networks for a wide range of surveying and mapping applications. However, most of these networks are limited in coverage and availability. The most important GPS network in Egypt is the so-called High Accuracy Reference Network (HARN). The HARN network has been established by the Egyptian Survey Authority (ESA) in the mid 1990s, with the cooperation of some American partners. The HARN network is divided into two sub-networks: HARN order-A, and HARN order-B. The HARN order-A network, Fig. 1, consists of 30 stations covering the Egyptian territory with an average spacing of approximately 200 km. Its relative accuracy estimate is 1:10,000,000 or 10 part per million (ppm). This network has been tied to some International Geodynamic Service (IGS) global precise GPS stations in order to obtain such a high accuracy estimate. Few stations from the old Egyptian first-order triangulation network have been utilized as GPS stations in this network. The HARN order-B network, also called the National Agricultural Cadastral Network (NACN), consists of 140 stations. The NACN covers the Nile valley and Delta with a spacing of approximately 50 km. The relative accuracy estimate of this network is 1:1,000,000 or 1 ppm.

Rather than the HARN network, the remaining GPS networks in Egypt are limited in coverage. The following are few examples of GPS networks in Egypt (Fig. 2):

* A network established in 1980s by ESA and Finnmap Inc. for producing 1:50,000 topographic maps for the Eastern desert. It consists of 31 first-order stations with a mean baseline length equals 112.5 km [3].
* A network established by the Survey Research Institute (SRI) in 1980s for producing 1:50,000 topographic maps for Sinai. It consists of 70 stations with average spacing of 25 km covering north and central Sinai [10].
* A network established by SRI in 1996 for developing the navigational route of Rosetta branch of the Nile. It consists of 44 stations with average spacing of 5 km on both banks of the branch [13].
* A network established by the Nile Research Institute (NRI) in 1995 to support hydrographic and land surveying activities in the Esna – Nag Hammadi reach. It consists of 82 stations, covering a total distance of 203 Km, with average spacing of 5 km on both banks of the Nile [11].
* A network established by SRI in 2000 for developing the navigational route of Dammitta branch of the Nile. It consists of 48 stations with average spacing of 5 km on both banks of the branch [14].
* A network established by SRI in 2000 for several management activities of the Nile. In its first stage, the network consists of 146 stations with average spacing of 2 km on both banks of the Nile from Delta barrage to Bani-Swaif city [15].

A crucial issue, regarding GPS control networks, is that there are no official documented sets of standards and specifications. Although a recent study has proposed a preliminary series, it requires extensive revision and modifications to be officially accepted [2]. Therefore, the integrity and reliability characteristics of control networks in Egypt vary seriously from one network to another. Moreover, many of these networks have not tied to a high-precision GPS datum that can be used to unify them. Usually, the coordinates of at least one station are determined by point positioning for a relatively long session, and then kept fixed for the entire network. Hence, the obtained network coordinates are completely dependant on such station's coordinates, which are implicitly biased by satellites and receiver errors. The same conclusions have been drawn by other investigators [e.g. 12].

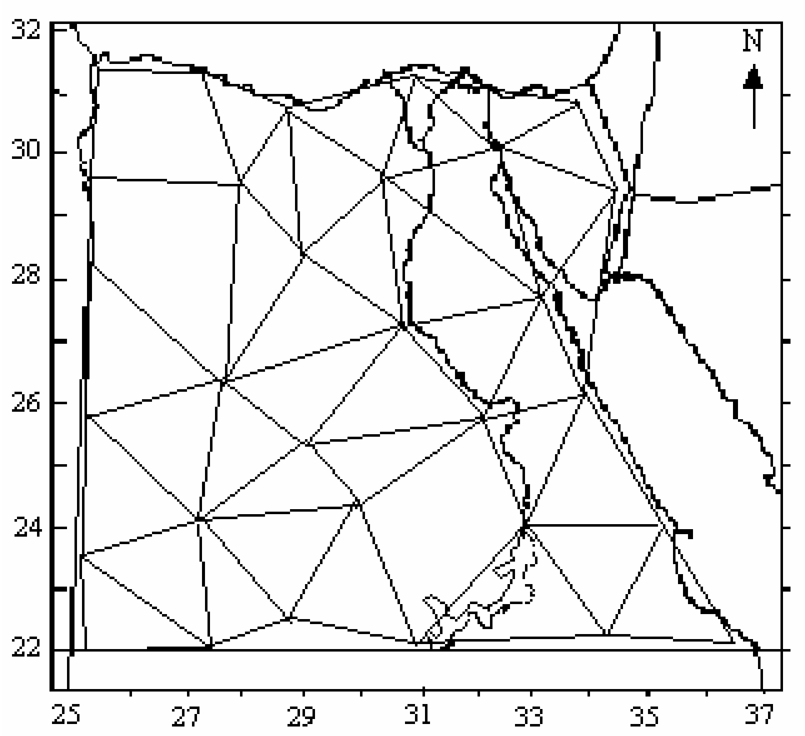
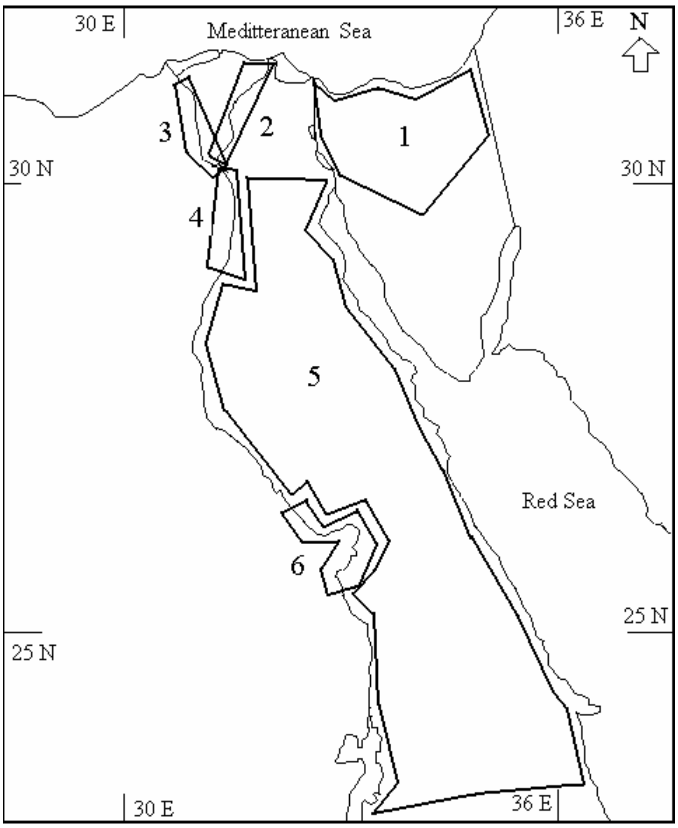


Figure 1: The High Accuracy GPS Reference Network (Order A)



1- SRI: 70 stations. 2- SRI: 44 stations. 3- SRI: 48 stations.
4- SRI: 146 stations. 5- Finnmap: 31 stations. 6- NRI: 82 stations.

Figure 2: Examples of GPS Networks in Egypt

RIVER NILE MAPPING

Hydrographic and topographic maps play a crucial role in the management of water resources in Egypt. 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. The existing complete hydrographic maps of the Nile have been produced by Kenting Earth Science Ltd Co. in 1982. That project has been executed from 1978 to 1982 by NRI, through Canadian funds, resulted in 380 topographic maps of scale 1:10,000. These maps were originally derived from aerial photographs taken in 1978. They cover 2 km beyond either sides of the Nile. Contour lines are also obtained on these maps with a contour interval of 1 m, enhanced with 0.5 m interpolated contours in areas of little relief. Moreover, 249 hydrographic maps with scale 1:5000 have been derived for the Nile and its two branches. They represent the relief of the river bed with the same contour intervals.

Geodetic control networks have been established with a station separation of 5 km on both banks of the Nile and its two branches. Traditional terrestrial surveying techniques have been utilized to determine the coordinates of the networks' stations on the Old Egyptian Datum of 1906. Orthometric heights have been also determined for most stations. Therefore, these geodetic networks have considered the core of the produced Nile maps.

In order to study the recent morphological and hydrological changes of the Nile, NRI has initiated a four-year national project to produce precise digital hydrographic and topographic maps covering the river and its two branches. The project consists of the following components:

- Conducting 1:15,000 aerial photography for the area of study, that is approximately 4,000 square kilometers.
- Production of 1:5,000 digital topographic maps, covering 1 km from each bank of the Nile. The maps show contours with a 0.5 m interval, which implicitly require dense terrestrial levelling measurements.
- Performing precise hydrographic surveys to represent the river relief with the same contour interval.

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, which enables the creation of a precise geoid model of the Nile valley. It should be stated, herein, that the hydrographic surveys do not necessarily require the usage of a first-order control network [1]. However, it is decided, in the current project, to establish a high-precision GPS network that can be utilized in various national surveying and mapping applications and remarkably enhances the geodetic data bases in Egypt. In order to fulfill these objectives, a series of standards and specifications has been planned for the current project. The first fundamental step was to collect and thoroughly analyze recent international GPS specifications [e.g. 5-9].

SPECIFICATIONS OF THE NEW NATIONAL GPS NETWORK

Classifications of geodetic networks depend on the geometric distance accuracy. It is defined as the ratio of the relative positional error of a pair of control points to the separation of these points. Minimum distance accuracy is assigned to each order of geodetic networks. With the development of GPS survey observation systems, a modification to the geometric distance accuracy criterion was proposed by the U.S. Federal Geodetic Control Committee (FGCC) [4]. This revision reflects the performance of systems include a base error, so that the accuracy standard, in the 95% confidence level, is divided into a base error, e.g. a receiver setup error, and a length-dependant part. Based on this scheme, the standards of national GPS networks are shown in Table 1. It has been decided that the GPS network, established for the current project, should fulfill the standards of order B, or better. Based on this criterion, other specifications have been designed as discussed in the next sub-sections.

Table 1: Standards of GPS Geodetic Networks

Category	Order	Base Error (cm)	Length-Dependant Error	
			ppm	1:a
Primary national geodetic network	A	0.5	0.1	1:10,000,000
Secondary national geodetic network	B	0.8	1	1:1,000,000

<u>Station monumentation</u>

Unfortunately, many geodetic control stations are quickly damaged and lost due to the way it was constructed. For example, considerable percentage of the HARN-order B' stations have been constructed in urban areas by just fixing a steel nail on the floor of a bridge or on the top of a building. Such a monumentation style can be easily broken. Hence, the monumentation of the current GPS stations is rigid enough to survive rough circumstances. Each mark consists of a 50x60x100 cm concrete box with half of its height burned under the ground. A 100-cm steel cylinder is fixed in the middle of the concrete box, with an aluminum cover on its top. The project name and the station serial number are engraved on that cover. The location of each station is chosen to be at least 50 meters away from any artificial structures in order to minimize the harmful multipath effects. Site accessibility should also be considered in the reconnaissance stage.

GPS hardware

There are several characteristics to choose ‘good GPS receivers’ from the available wide market. It is a fact of reality that dual-frequency GPS receivers meet the accuracy specifications for precise geodetic networks with no constraints, while the single-frequency receivers may not fulfill these specifications with the presence of significant ionospheric disturbances. The advantage of having dual-frequency data is the capability to develop the so-called ionospheric-free observables’s combination that results in a more precise solution. Moreover, multi-channel receivers are more reliable and have better signal-to-noise ratio, which means they can receive even weaker signals. Additionally, GPS measurements can be significantly corrupted by GPS signals that reflecting off surfaces near (within some 30 meters) the antenna. The sensitivity of multipath corruption depends on the reflectivity of the surfaces in the antenna environment, and on the antenna gain (sensitivity) in the direction of these reflectors. The placement of the antenna and the use of absorption material can significantly reduce the multipath effects.

GPS field work

The most affecting error sources in GPS fieldwork are the antenna setup errors. These errors contain the centering error and the error in measuring the antenna height. Consequently, the following field procedures are considered to minimize antenna setup errors:

- Measure and record antenna height before and after each station occupation.
- GPS operators, if more than one, should verify all measurements.
- Check collimation and levelling of the antenna before and after each station occupation.
- Log antenna serial number as a part of the station record in order to verify, later, that the correct phase center correction is applied.
- Redundant station occupation should be performed as much as possible.

The designed guidelines to be fulfilled regarding the GPS data capture include:

- Number of utilized receivers in a session is more than 4.
- Minimum number of healthy satellites to be tracked by all receivers is 4.
- The session interval is 60 minutes or more.
- The sample rate of observations is 15 seconds.
- Minimum cut-off angle above the horizon is 15^o.
- GDOP value does not exceed 6.
- At least two points are observed commonly between two successive sessions.
- Minimum number of points having redundant occupations is 30%.

Considering tying the Nile GPS network to the HARN network, the following procedures must be satisfied:

- Whenever possible, the new GPS net should be tied to the HARN order-A network. Otherwise, HARN order-B is used to reference the new network.
- The tying observation process should be carried out every 50 km of the longitudinal direction of the net.
- In each tie, a minimum of two HARN stations (one from each side of the Nile) should be utilized.
- The minimum occupation time in the tying is two hours, but it should be proportional to the baselines' length.

<u>GPS data processing</u>

Based on the international GPS specifications of high-precision networks, the following procedures are designed:

<u>(A) For a base line:</u>

- Root Mean Square error (RMS) should fill in the range from 0.01 to 0.2 cycles.
- The ratio test should be greater than 3.
- The iono-free L1/L2 fixed solution must be obtained for the Nile network.
- Ionospheric and tropospheric models should be implemented.
- Percentage of rejected measurements should be less than 10%.
- Maximum standard deviation of a base line is 2 cm.
- Tolerance of base line processing should be better than 2 cm horizontally and 4 cm vertically.
- Precise ephemeredes are preferable to be utilized rather the broadcasted values.

(B) For a session:

- All combination of baselines in a session should be processed.
- Maximum loop closure in vector components is 25 cm.
- Loop closure does not exceed 12.5 ppm.

GPS adjustment

For any GPS network, it is necessary to describe how to position and orient the network on the earth's surface (i.e., datum definition). This can be done, in general, in several ways:

- Holding one point fixed (fixed-point approach).
- Holding one point properly weighted (fiducial-point approach).
- Holding no point fixed (free-net approach).
- Holding several points fixed (over-determined approach).
- Holding several points properly weighted.

The first three approaches use the minimum necessary number of positional constraints, and therefore known as minimally constrained adjustment. It is known that a GPS network has three (out of seven) datum defects since the orientation and scale are implicitly known from the phase observations because the coordinates of the satellites are assumed to be known. A method for overcoming this problem is to use inner constraints to allow the adjustment to proceed by using the centroid of the unadjusted coordinates to control coordinates translation. The last two approaches belong to the so-called over-constrained adjustment. The process of GPS network adjustment is recommended to be performed in the following sequence of procedures to come up with optimum results:

I. Analyze the loops' closure to verify that the closure errors are within the accuracy Specifications required.
II. Perform a free net adjustment (i.e., fix a single, often arbitrary, point) to analyze the internal consistency of the survey data.
III. Use the statistical information of the free net adjustment to detect blunders and residual outliers. Detecting and removing erroneous observations is a must in geodetic networks to improve the network reliability.
IV. Perform a final constrained adjustment (minimal or over-constrained) to fit the GPS survey to existing geodetic frameworks.

The precision of the adjusted control points in a GPS geodetic network is expressed as a ratio by converting its standard errors into a linear distance and dividing this distance by the distance to the nearest control point. These precision ratios of all the network points should meet the geodetic network proposed specifications (shown in Table 1).

GPS/LEVELLING MEASUREMENTS

Another important requirement of the current project is to relate the collected height information to the Mean Sea Level (MSL) datum of Egypt. Hence, orthometric heights of all control stations will also be determined by, at least 2nd order, levelling techniques. This procedure enables the creation of a precise geoid model of the Nile valley, which can be further utilized to transform GPS ellipsoidal heights to orthometric values for any other surveying applications.

CONCLUSIONS

The Nile Research Institute has initiated a project to produce topographic and hydrographic digital maps of the Nile and its two branches. Within the multi-purpose activities of this pioneer national project, a GPS geodetic control network is established with a station separation of 5 km. The network consists of approximately 600 stations to cover both sides of the river in an area extends 1435 km. A set of standards and specifications has been designed and currently being implemented in order to achieve a high-precision national GPS network. This network, along with the HARN GPS network, will furnish a precise national GPS datum in Egypt. It is recommended that the geodetic community in Egypt should collect unify all available geodetic control networks in a unique complete data base for improved management of surveying and mapping activities. Additionally, it is highly recommended that the surveying and mapping community should carry out maximum efforts to formulate a national official series of GPS standards and specifications in Egypt. A preliminary step has been proposed recently, but it requires extensive revision and modifications to be officially accepted.

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