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PROPOSED STANDARDS AND SPECIFICATIONS FOR GPS GEODETIC SURVEYS IN EGYPT

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ABSTRACT

High-precision positioning with the Global Positioning System (GPS) with a precision of a few parts per million has become a routine task worldwide, with Egypt be no exception. Since the mid 1980's, GPS bas been utilized in Egypt for a wide range of applications on a national scale, especially the extensive geodetic employment of this revolutionizing satellite technology in the huge national south valley development project. However, there is no set of Egyptian standards and specifications for applying GPS in geodetic surveys in order to be able to unify different GPS projects and results towards the establishment of nation-wide geodetic data banks.

A series of standards and specifications is designed for Egypt for the first time. This set includes specifications for equipment and software to be used, GPS network design, site selection and monumentation, field procedures, data processing, network adjustment; and GPS final output documentation. This set is just a starting required step. Hence, it is highly recommended that the geodetic community in Egypt should make extended efforts to come up with a final form of specifications for the manipulation of GPS geodetic surveys in Egypt.

1. Introduction

> "Sometimes one hears the opinion that every thing in geodesy can now be done by GPS, and GPS receivers can be operated by technicians without university education, so that geodesists are no longer needed."

The above statement by the sole father of geodesy 'Helmut Moritz', [17], is just an example of how GPS has been spread in the surveying community worldwide. The performance of GPS for precise relative positioning has lead the geodetic community to believe that base lines of a few tens of kilometers in length could be determined in a routine fashion to a relative precision level of a few parts per million. Moreover, some global GPS networks have produced excellent results of one part per billion (i.e., an error of 0.001 mm in a base line of one-kilometer length) for base line lengths up to 4000 kilometers [4].

The rapidly growing use of GPS for geodetic surveys in Egypt, in the last decade, makes it critical to develop a set of acceptable accuracy standards. Specifications reflect the measurement systems, and therefore will be developed and refined as improvements to measurement systems are demonstrated. Standards, on the other hand, must provide the user with a stable, understandable and usable identification scheme for control points. This research study proposes an Egyptian series of standards and specifications that include most of the practical issues in: pre-planning, network design, field procedures, data processing, network adjustment; and presentation of the final results. The current study is restricted, for the time being, to only the first and second order geodetic networks.

2. Specifications of geodetic networks

Classifications of geodetic networks depend on several approaches such as the geometric distance accuracy in USA [13] and the semi-major axis of error ellipse in Canada [8]. It is inferred that the first approach was implemented when the first-order Egyptian geodetic networks were established [5]. The geometric distance accuracy is 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. For the first-order conventional geodetic network in Egypt, the distance accuracy was 1:100,000 where the average side length ranges from 40 to 50 km [ibid.].

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) [10]. 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 recent approach, a proposed classification of GPS geodetic networks in Egypt is shown in table 1.

Table 1: Standards of GPS Geodetic Networks

Category	Order	Base Error (cm)	Length-Dependant Error ppm	Length-Dependant Error 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

3. Specifications for GPS network design and pre-planning

Prior to starting a GPS field campaign, some stereotyped items must be settled for the network design, the selection of GPS hardware to be used, the campaign pre-planning; and the site selection and monumentation for geodetic GPS stations. Each item is further investigated in the next sub-sections.

3.1 GPS network design

Generally, the quality of a geodetic network is characterized by three factors: economy, productions; and reliability. Economy expresses the costs of monumentation, observations, transportation,.. etc. Precision, as expressed by the standard deviation, is the measure of the network's characteristics in propagating random errors. Reliability describes the ability of the network to check model errors. Although the accuracy of GPS techniques is less sensitive than terrestrial techniques to network design geometry, the accuracy can be improved by taken some considerations into account in the network design process. For a GPS network to fulfill its primary role as a strong and reliable reference framework, it must maintain the following basis:

- Homogenous coverage.
- Reasonable redundancies.
- Well-shaped closed individual figures (loops).
- Stations should be as evenly spaced as possible.
- The ratio of the longest to the shortest baseline should never be greater than five and usually be much less.

3.2 Selection of GPS hardware

The GPS hardware market has a wide variety of GPS receivers, which could be classified based on several factors as shown in figure 1. Testing several single and dual-frequency GPS receivers shows that dual-frequency ones 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 [11 and 12]. At a frequency of 1.575 GHZ, ionospheric refraction can delay the transmission of information modulated onto the carrier wave by up to 300 nanoseconds from its free space velocity, which corresponds to a range error of 100 meters [14]. 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. Code GPS receivers, on the contrary to codeless type, can access the information contained in the transmitted navigation message of satellites. Multi-channel receivers are more reliable and have better signal-to-noise ration, which means they can receive even weaker signals. Hence, the specifications of GPS receivers to be used in establishing first and second-order geodetic networks are summarized in table 2.

Table 2: Specifications of Geodetic GPS Receivers

- Static
- Differential positioning
- Dual-frequency
- Code
- Multi-channel with at least 8 independent channels
- Built-in or external memory for at least 6 hours of data collection.
- Internal power sources enough for at least 6 hours of observations.

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. Signal multipath interference could be 4 meters numerical standard deviation [9]. The placement of the antenna and the use of absorption material can significantly reduce the multipath effects. Therefore, a geodetic GPS receiver's antenna should have the characteristics shown in table 3.

Table 3: Characteristics of Geodetic GPS Antennas

- Resistance to multipath effects
- Phase-center determination accuracy
- High sensitivity
- Ease of antenna centering

3.3 Pre-planning

Prior to conducting a GPS project, a certain amount of office planning is essential. The following factors should be carefully checked so that the GPS survey meets the accuracy standards required:
- Maximum number of control points available.
- Maximum and minimum station spacing.
- Location of control points.
- Number of receivers observing simultaneously.
- Session interval.
- Subset of tracked satellites that give good Position Dilution Of Precision (PDOP).
- Independent occupations per stations.
- Repeated baseline measurements.

One of the most important factors in the pre-planning step to be taken into consideration is the PDOP value, which is a measure of the accuracy of pseudorange measurements in three-dimensional positioning. PDOP values in the range 3-5 m/m are considered very good, while values greater than 10 m/m are considered poor [2].

A simulation computer program should be used to estimate several PDOP values to select beforehand the subset of satellites, which should be tracked to give the best station-satellite geometry.

3.4 Selection of GPS stations and monumentation

Selecting sites for GPS stations must fulfill the following criteria:

- Monuments set on stable solid rock.
- Visible sites (placed in areas with clear sky above 15^o elevation).
- No multipath targets nearby.
- Easily accessible.
- Apt to remain intact for a long time.
- Convenient for use.

The proposed Specifications for design GPS geodetic networks are summarized in table 4.

Table 4: GPS Network Design Specifications

Items	1st order net	2nd order net
Maximum station spacing (km)	100	50
Minimum control points	3	3
Bench marks included	minimum 4	optional
Maximum number of lines in a loop	10	10
Maximum loop overall length (km)	100	100
Maximum percentage of stations with 2 or more occupations	50 %	30 %
Minimum degree of freedom	12	9

4. Specifications for 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. The phase measurements made by GPS receivers referee to the antenna phase center, while the station positions and baseline vectors should be referenced to the ground survey marks. Therefore, a correction is needed to tack into account the height difference between the antenna center and survey marks. Some GPS receivers are equipped with a means to measure this vertical height difference directly. Other receivers have a way to measure the diagonal distance between the circular antenna edge and the survey mark, and hence, another correction is required to compute the vertical height difference knowing the radius of the antenna plate. For example, using the non-corrected antenna diagonal heights (0.84 and 1.39) instead of the corrected vertical heights (0.81 and 1.37) results in an error of about 1 cm in each component of a baseline vector of 60,060 meter length, which is a significant error in precise geodetic networks. Consequently, suggested field procedures to minimize antenna setup errors include:

1- Measure and record antenna height, in both meters and inches, before and after each station occupation.

2- GPS operators, if more than one, should verify all measurements.

3- Check collimation and levelling of the antenna before and after each station occupation.

4- Log antenna serial number as a part of the station record in order to verify, later, that the correct phase center correction is applied.
5- Redundant station occupation should be performed as much as possible.
6- Photographs of every station mark are required to allow verification that the mark occupied was in fact the correct one.

Proposed Specifications for GPS field procedures for geodetic surveys are given in table 5.

Table 5: GPS Field Procedures Specifications

Items	1st order net	2nd order net
L1/L2 observations	Yes	optional
Minimum number of receivers	3	3
Minimum number of satellites	4	4
Session interval (minutes)	90-120	45-90
Sample rate of observations (seconds)	15-30	15-30
Minimum mask angle above horizon	15^o	15^o
Minimum antenna height measurements	2	2
Maximum difference in antenna height measurements (cm)	2	2
Photograph required	yes	yes

5. Specifications for GPS data processing

Data processing is the most crucial stage in any GPS project. Computer software are used to process the raw satellite signals, apply required corrections, and solve the normal equation system in a least-square sense to come up with the precise vector components and related results. The data processing criteria to be considered are [18]:

- How the antenna offsets are applied.
- The cut-off angle.
- Ephemeredes source and age.
- Measured data quality.
- Measurements rejection criteria.
- Maximum residuals.
- Baseline or session adjustment specifications.

Important measures for judging the quality of the data are: RDOP, RMS, ratio test; and the solution for phase ambiguities. Relative Dilution Of Precision (RDOP) is a quantity describes the geometry of the satellites and its impact on the precision of the recovery of carrier phase measurements. RDOP values around 0.1 m/cycle are considered acceptable [15]. Root Mean Square (RMS) is a measurement, in unite of cycles, of the quality of the observed data collected during a point of time. Factor ratio is the ration of sum-of-squares of two solutions using different sets of phase ambiguity integers. RMS is considered good in the range from 0.01 to 0.2 cycles, while the ratio test should be greater than 3 to obtain fixed solutions. Careful screening of these quality measures is desired to decide which base line solution to be finally accepted and included in the network adjustment. It worth mentioning that some adjustment software has an “automatic selection” option to figure which solution is the "best". However, some recommendations in this issue are shown in table 6. Still, the substantial question is "which post-processing software to be used?". Table 7 gives some proposed Specifications for GPS processing software for precise geodetic applications, while table 8 presents some Specifications for performing GPS data processing and judging the obtained solutions.

Table 6: Recommended Procedures in GPS Data Processing

RMS	Factor Ratio	Distance	Integer Solution	Recommendations
Small	Large	< 20 km	Yes	Use fixed solution
High	Large	> 20 km	Yes	More inspection, use fixed solution
High	Large	< 20 km	Yes	Re-process fixed solution or repeat measurement
Small	Large	20-65 km	No	Use float solution
High	Large	> 65 km	No	Use triple solution or repeat measurement

Table 7: Specifications for GPS Data Processing Software

- Process pseudoranges and carrier phase observations.
- Support point, baseline; and network modes of positioning.
- Automatically detect and resolve cycle slips.
- Endure single, double; and triple processing modes.
- Accept up to 10 base line, or more, in a single session.
- Provide fixed, float; and triple solutions.
- Output statistical information along with each solution.
- Support several values of processing parameters (e.g. sample rate, tropospheric models, meteorological data, mask angles, … etc.).
- Interactive with users when changes are needed.
- Hold up different antenna types.
- Provide pre-analysis modules (e.g. compute PDOP in advance).
- Accept different sources of satellite ephemeredes (broadcast or precise).
- Support both single and dual-frequency data.
- Sustain manual, interactive; and automatic batch modes.
- Preferable: menu-driven, easy-to-use; and friendly software.

Table 8: Proposed GPS Data Processing Specifications

Items	1st order net	2nd order net
Precise ephemeredes	Recommende	Optional
Maximum loop closure in vector components (cm)	d	30
Maximum loop closure (ppm)	25	25
Maximum percentage of rejected measurements	12.5	10 %
Standard deviation of base line solution (cm)	10 %	1 to 4
	0.1 to 2	

6. Specifications for 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 [18]:

- 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 [6]. 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 factors that may be considered as proposed Specifications for GPS adjustment software are shown in table 9.

Table 9: Specifications for GPS Adjustment Software

Support processed solutions from several GPS manufactures. Sustain minimally and fully constrained adjustments. Support datum definition and transformations. Maintain several map projections. Support pre-analysis modules (e.g. loop misclousure). Allow data editing by the user. Provide statistical information (e.g. RMS, chi-squares, ppm, …etc). Preferable: menu-driven, easy-to-use, friendly, handles big networks, fast; and provides plotting capability.

The process of GPS network adjustment is recommended to be performed in the following sequence of procedures to come up with optimum results:

A. Analyze the loops' closure to verify that the closure errors are within the accuracy Specifications required (refer to table 7).
B. Perform a free net adjustment (i.e., fix a single, often arbitrary, point) to analyze the internal consistency of the survey data.
C. 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 [3].
D. 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).

7. Specifications for GPS final results documentation

Presenting and documenting the final results of a GPS project is an important step to summarize all the procedures of design, fieldwork, data processing; and network adjustment. Unless there are certain Specifications for such a step, the unification of GPS networks in Egypt for the sake of developing geodetic data banks, will not be easily established. Table 10 presents a form of the final documentation of a GPS project.

Table 10: A Form for Final Documentation of GPS Projects

- The project name, location; and objectives.
- Design criteria:
  - Objective and classification of the GPS network.
  - Network design Specifications (table 4).
- Field work procedures:
  - Types and number of receivers and antennas used.
  - Session interval.
  - Redundant station occupations.
  - Meteorological data (if measured).
  - PDOP, RDOP.
  - Field data records of all stations.
- Processing procedures: sample rate, cutoff angles, …etc.
- Types and versions of software used for data processing and adjustment.
- Adjustment Specifications:
  - Adjustment model (minimally or over constrained).
  - Number and names of fixed points.
  - Source and values of fixed points coordinates.
  - Datum on which the adjustment was performed.
  - Statistical information: ppm, RMS, Tau values, ..etc.
- Plots: Network plot, error ellipses; and histogram of residuals.
- Final results:
  - Cartesian and geographic coordinates of all stations along with the corresponding standard deviations.
  - Distances and their relative precision (ppm).

8. Conclusions

The GPS positioning technology has been used for several geodetic projects in Egypt since the mid 1980's. However, there is no set of specifications and standards available. Primary specifications and standards are proposed in this research study for first and second-order geodetic GPS networks in Egypt. The suggested set includes specifications for network design, selection of equipment and software, pre-analysis, station monumentation, field procedures, data processing, network adjustment; and final results documentation. This set provides GPS users in Egypt with standard, understandable; and usable procedures for precise geodetic surveys. The geodetic community in Egypt should make extensive efforts to come up with national final specifications for the use of GPS advanced positioning technology in Egypt.

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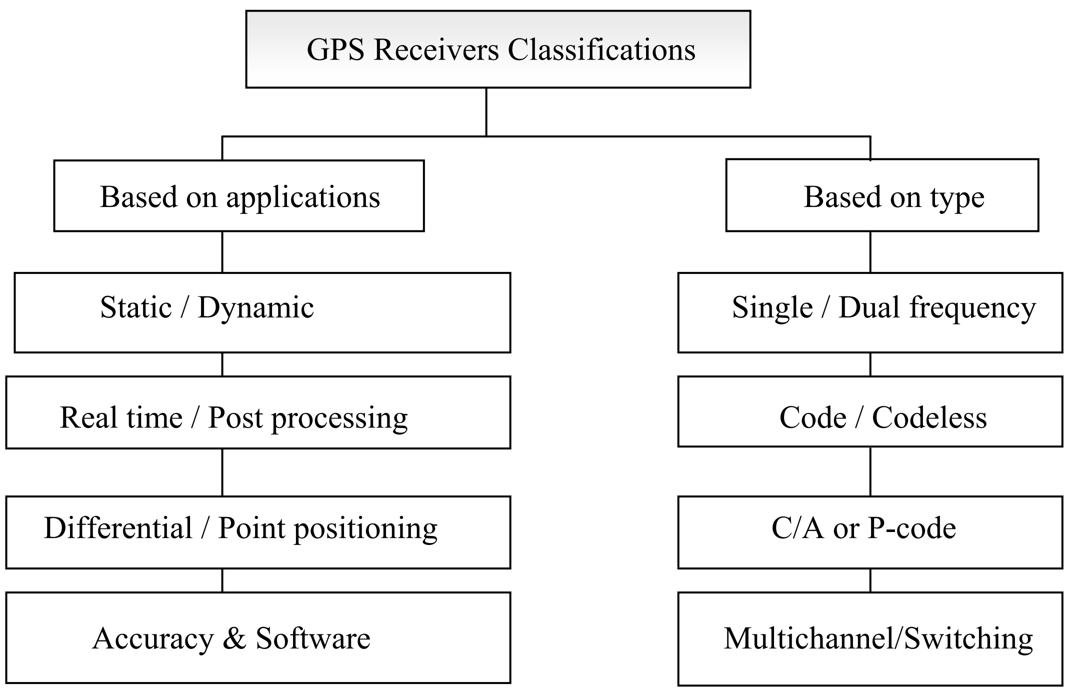

Figure 1: GPS Receivers Classifications