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EFFECIENCY OF GPS TECHNIQUES IN NATIONAL APPLICATIONS

By

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ABSTRACT

The horizontal expansion and land reclamation has been the dream of Egypt's successive generations. The new delta project south of Egypt is a way for recomposing the demographic map by establishing a national integrated development project, which has agricultural, industrial, environmental, and social points of view. The availability of accurate topographic maps is one of the crucial elements in the decision making stage in large engineering projects.

The use of the traditional terrestrial surveying tools for the production of topographic maps is limited in time. On the other hand, maps created from romte-sensing satellite techniques do not fulfill the accuracy requirements for the project detailed planning. The ideal solution inherently combines a new challenge of employing integrated Global Positioning System (GPS) with conventional terrestrial techniques. New GPS surveying methodologies have been applied, for the first time in Egypt at a large scale, to produces topographic maps for an area of 75,000 feddans (315 millions squared meters approximately). This paper describes the formulation and practical application of the new approach of combining GPS and terrestrial surveying observations in a unique framework, including steps for data acquisition, transformation, and map production. It has been found that those techniques result in 50% cost saving and 75% time saving, yet satisfying the national standards and specifications for topographic maps.

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1. Introduction

Precise topographic maps are one of the crucial elements for planning and decision making in large engineering projects. Traditional surveying techniques for the production of topographic maps are limited in productivity since they are time and cost consuming. On the other hand, the Global Positioning System (GPS) has been applied in Egypt since 1985, but only in static mode for establishing geodetic control points. Advances in GPS positioning technologies and instrumentation have led to new surveying approaches that are efficient and productive for topographic mapping. For example, pseudo-kinematic methods, have been exercised worldwide and proposed to be applied in Egypt for huge surveying projects [Dawod, 1992]. However, no attempt has been made to apply these new GPS techniques at a national production level.

The integration of advanced GPS techniques with terrestrial surveying measurements is the optimum approach for topographic mapping in open areas. This study presents the development and application of this modern methodology for surveying an area of 75,000 feddans in the south valley development project (Toshka). Section two presents a brief description of this national development project in Egypt. Basics of kinematic GPS positioning modes are offered in section three, with specific emphasis on the On-The-Fly (OTF) observation mode. Section four introduces the collected field data including the static GPS, kinematic GPS; and levelling measurements. The computational procedures and results of the integration of all data types, coordinates transformation; and map projection are given in section five. The economical aspects and the comparison between the traditional and the new approaches are provided in section six. The conclusions and obtained recommendations are given in section seven.

2. The south valley development project

The south valley development project, known also as Toshka project, is a strategic ambitious national program that embraces a number of development fields covering activities the areas of agriculture, industry, transport, communication and roads, as well as social and environmental aspects. The overall objectives of the projects are:

* Addition of new areas of agricultural land of some two million feddans.
* Establishment of agricultural and industrial communities south of Egypt.
* Recomposing the demographic map of Egypt by establishment of new communities that gradually alleviating the problem of overpopulation in the old Delta.
* Establishment of a network of main and side roads.
* Promotion of touristic activities in these regions rich in ancient monuments.

The project area extends from latitude 22.5^{o}N to 23.5^{o}N, and from longitude 30.5^{o}E to 33^{o}E (Figure 1). The project starts with a giant major pumping station to be set on the left bank of lake Nasser 8 km north of Toshka. The station is designed to have a maximum static lifting of about 52.5 meters to guarantee its operation when the water level in lake Nasser reaches its lowest level of storage, namely 147.5 meters, and the main canal water level is 200 meters. Since the average of the water level in the lake throughout the years is 165 meters, the quantity of the average lifting reaches about 35 meters. Twenty four pumps, each with a discharge of 16.7 m^3/sec, will be housed inside the pumping station. The irrigation system of canals in the project is characterized by a main canal (Shiekh Zaied canal) of a length of 70 km, and four branch canals with a total area served in the first stage of 540,000 feddans of first-degree agriculture lands. The cross section of the main canal was designed to be lined to prevent any water leakage with a bed of 30 meters width and water depth of 6 meters.

The implementation plan of the project anticipates the construction of the main canal to be accomplished by December 2001, while the development of the four branch canals is planned to be finished by December 2000. A primary project budget, including the civil and social structures, starting from fiscal year 1996/1997 to fiscal year 2003/2004 is estimated to equal 6807 million Egyptian pounds [NWRC, 1998].

3. Kinematic GPS techniques

GPS is the most advanced satellite positioning system currently in use for a wide range of civilian and military applications. Compared with traditional terrestrial surveying systems, several advantages of GPS surveying have been accomplished. For example, there are no intervisibility requirements and practically no limit to distance between receivers. Additionally, the obtained coordinates are three dimensional, in a unique coordinate system, with a superior level of accuracy.

The classic GPS observation approach is the static mode in which more than one receiver are kept fixed over ground stations and record satellite signals for more than thirty minutes of observation. Positioning of moving platforms with GPS (the kinematic mode) is the last frontier in GPS surveying. The kinematic applications include surveying on land, aerial photogrammetry without control points, airborne gravimetry; and altimeter profiling on land and sea. Kinematic positioning can be classified into two main groups: absolute kinematic and relative kinematic [Nassar, 1994]. The absolute kinematic deals with positioning of a moving antenna with respect to an implied coordinate system. On the other hand, relative kinematic positioning is performed relative to one or more receivers at known stations. Relative kinematic GPS surveying starts with two receivers being located initially at two stations of known relative position. One of the stations is called the fixed (or base) site, where the antenna remains stationary at this point. The antenna of the other station, called the roving antenna, moves to points whose positions to be located. There are several modes of relative kinematic GPS surveying based on the way of the receivers capabilities, data processing; and field observation procedures. Some of these modes are: pseudo-kinematic, rapid static, stop and go, antenna swap; and On-The-Fly (OTF). Details concerning those kinematic techniques are found in a lot of surveying literature [e.g. Sickle, 1996].

One of the main aspects of data processing in GPS positioning is the so-called ambiguity resolution. It is known that GPS receivers measure the accumulating phase over time, but do not have knowledge about the integer number of full cycles of phase that occur from the first moment of the lock on a satellite. The number of full cycles of phase, which does not change unless that lock is lost, is known as the integer ambiguity or phase ambiguity and could be solved for easily in the static GPS positioning, since the receivers collect data from the same satellites for a period of time. However, this requires specific field procedures in the relative kinematic positioning modes. Actually, the resolution of the integer ambiguity is the main point leaded to the development of several relative kinematic positioning techniques. Relative kinematic observation modes try to resolve the phase ambiguity before the survey starts, in a process called initialization that requires some sort of static positioning for a specific period of time.

On The Fly (OTF) relative kinematic approach is the most advanced technique for resolving the phase ambiguity while the receiver is actually in motion. This implies that unlike all other relative kinematic GPS techniques, the initialization process tack place with no delay. OTF has been used recently in various applications for precise GPS coordinates determination [e.g. Chen et al, 1999]. The mathematical model behind OTF technique is called wide-lane observable, which is based on the linear combination of the measured phases from both GPS frequencies, L1 and L2. The strategy starts by solving for the phase ambiguity on the fictional wide-lane observable, which is then used to resolve the phase unknowns on both L1 and L2 frequencies, as follows [Mervart et al, 1994]:

$$L^i_{1k} = \rho^i_k - I^i_k * (f^2_2 / (f^2_1 - f^2_2)) + \lambda_1 b^i_{1k} \quad (1)$$
$$L^i_{2k} = \rho^i_k - I^i_k * (f^2_1 / (f^2_1 - f^2_2)) + \lambda_2 b^i_{2k} - \Delta\rho^i_k \quad (2)$$
$$L^i_{3k} = (1/(f_1 - f_2)) * (f_1 L^i_{1k} - f_2 L^i_{2k}) \quad (3)$$
$$= \rho^i_k + I^i_k * (f_1 f_2 / (f^2_1 - f^2_2)) + \Delta\rho^i_k (f_2 / (f_1 - f_2)) + \lambda_3 b^i_{5k} \quad (4)$$
$$b^i_{1k} = N^i_{1k} + \delta\Phi_{1k} - \delta\Phi^i_1 \quad (5)$$
$$b^i_{2k} = N^i_{2k} + \delta\Phi_{2k} - \delta\Phi^i_2 \quad (6)$$
$$b^i_{3k} = b^i_{1k} - b^i_{2k} \quad (7)$$
$$\lambda_3 = c / (f_1 - f_2) \quad (8)$$

where:

k is the receiver index,
i is the satellite index,
L^i_{1k}, L^i_{2k} are the carrier-phase pseudoranges,
ρ^i_k is the non-dispersive delay, lumping together the effects of geometric delay, ionospheric delay, tropospheric delay, clock signatures, and any other delays which affect the observables,
$\Delta\rho^i_k$ is the differential delay between the L1 and L2 antenna phase centers,
I^i_k is the difference in ionospheric delay between the L1 and L2 carriers,
f_1, f_2 are the frequencies of the L1 and L2 carriers, which equal1575.42 MHz and 1227.60 MHz respectively,
λ_1, λ_1 are the wavelengths of the L1 and L2 carriers, which equal 19.0 and 24.4 cm respectively,
λ_3 is the wavelength of the wide-lane observable, which equals 86.2 cm.
b^i_{1k}, b^i_{2k} are the phase biases on the L1 and L2 carriers,
b^i_{3k} is the wide-lane phase ambiguity to be estimated,
N^i_{1k}, N^i_{2k} are the initial phase ambiguities,
$\delta\Phi_{1k}$, $\delta\Phi_{2k}$ are un-calibrated components of phase delay originating from the receivers (assumed to be common for all satellite channels),
$\delta\Phi^i_1$, $\delta\Phi^i_2$ are un-calibrated components of phase delay originating from the satellites (assumed to be common for all receivers),

4. Data and practical field procedures

The objective of the mission carried out by the Survey Research Institute (SRI) was the development of topographic maps for an area of 75,000 feddans (approximately 315 million squared meters) in the south valley development project. This comprises the production of 50 topographic maps of scale 1:5,000 with a contour interval of 1 meter. Each map covers a 3x2 km piece of land whose area is 1500 feddans. The required maps are required to be referenced to the Helmert 1906 ellipsoid and projected using the Transverse Merecator map projection in order to fit the Egyptian national horizontal mapping system, and the heights must be referred to the Mean Sea Level (MSL). Therefore, 75 GPS stations have been established as the corners of the individual areas (Figure 2). The field data campaigns consists of three types of geodetic observations, namely static GPS, OTF relative kinematic GPS; and levelling.

4.1 Static GPS observations

Six dual-frequency geodetic GPS receivers have been used to obtain accurate coordinates for the 75 established control stations. These receivers contain two Trimble 4000SST, two Trimble 4000SSI; and two Leica 300 receivers. Ten observation sessions have been performed whose time period varied from 1 to 3 hours of observations based on the baseline length. Eight local GPS control points established by the Egyptian Survey Authority (ESA) have been included in order to work in the same unique coordinate framework of the Toshka project. Both Trimble GPSURVEY and Leica SKI processing software have been employed to process the GPS data separately so that the results comes from two independent sources. Of course, the Receiver INdependent EXchange (RINEX) data format have been used to transfer the collected observations between both software. The GEOLAB software is utilized in the GPS adjustment process because of its flexibility and richness of statistical tools that are useful in increasing the reliability of the final adjusted coordinates. Table 1 summarizes the results of the final adjusted coordinates of static GPS networks.

Table 1
Summary of Static GPS Networks

No of stations	89
No. of baselines	164
No. of observations	492
No. of unknowns	243
Degrees of freedom	249
Minimum residual	0.02 m
Maximum residual	0.13 m
Minimum standard deviation	0.01 m
Maximum standard deviation	0.09 m

4.2 OTF relative kinematic GPS observations

Four of the available GPS receivers are equipped with the OTF option, namely the Trimble 4000SSI and Leica 300 brands. The remaining two receivers, the Trimble 4000SST models, are reserved to occupy two stationary base stations in each session. As mentioned previously, no static initialization is required since the OTF technique is utilized (Figure 3). In order to achieve a high accuracy level, a set of configuration have been predetermined for the surveys. It includes:

* A minimum of 5 tracked satellites is a must from the first epoch forward.
* A sample observation rate of 5 seconds is unified in all receivers' configurations.
* The raw observations are recorded in the compact format.
* No loss of lock on satellites in the first 200 epochs.
* Good satellite-receiver geometry (low GDOP).
* Vehicles speed do not exceed 30 km/h.
* Distance between two adjacent car trajectory is in the order of 100 m.
* Two stationary base receivers are used for obtaining more robustness in the OTF solution.

4.3 Levelling observations

GPS positioning produces three-dimensional coordinates (latitude φ, longitude λ; and ellipsoidal height h) relative to a global geocentric ellipsoid called the World Geodetic System 1984 (WGS84). However, topographic maps are usually based on orthometric heights (H) relative to the geoid that coincides with the Mean Sea Level. The difference between ellipsoidal and orthometric heights is known as geoid undulation or geoidal height (N):

$$N = h - H \qquad (9)$$

Orthometric heights of 20 established GPS control stations have been determined by running levelling routes from the available bench marks in the region (Figure 2). The determined orthometric heights are utilized to model the local geoid surface in the area.

5. Data processing and results of the new integrated approach

There are several data processing aspects of integrating OTF kinematic GPS and terrestrial measurements, for topographic map production, to be taken into account. They include: geoid determination, geodetic datum transformation; and map projection.

5.1 Geoid determination

Geoid undulations are required to convert the GPS ellipsoidal heights to orthometric heights to produce meaningful topographic maps. There are several terrestrial and satellite measurements utilized for geoid determination, such as gravimetric, astronomical, altimetric data types. A combination of gravity, GPS, and levelling data is one of the most precise geoid determination techniques used world-wide and in Egypt. Although global geoid models exist and usually integrated in commercial GPS software(e.g. OSU91A and EGM96 models), their accuracy is in the order of few meters [Dawod, 1998]. An optimum solution is the integration of global geoid models with terrestrial local measurements.

Geoid undulations from the OSU91A geoid model have been interpolated for the twenty established control points whose orthometric heights are determined. The differences between the model geoid undulations and the computed corresponding values have been determined:

$$\Delta N = N_{OSU91A} - N_{(h-H)} \tag{10}$$

The obtained geoid undulation differences range from 1.8 to 2.9 meters. These differences have been modeled over the area under study. Consequently, refined geoid undulations (N') are determined for all static and kinematic GPS measured points, and their orthometric heights are determined:

$$H = h - N' \tag{11}$$

5.2 Datum transformation

The issue of datum transformation determination has been one of the crucial elements of GPS applications in Egypt in the last decade [Alnaggar, 1990]. The Egyptian geodetic coordinate system is based on the Helmert 1906 ellipsoid as the figure of the Earth. However, GPS produces coordinates relative to the global WGS84 ellipsoid. Therefore, a datum transformation procedure is a must in any precise GPS surveys in Egypt. This step basically utilizes known values for seven parameters that describe the mathematical relationship between the two ellipsoids. These parameters include three translation unknowns (ΔX, ΔY, and ΔZ), which describe the 3D shift of the origin of one ellipsoid relative to the origin of the second ellipsoid), three rotation parameters (ω_x, ω_y, and ω_z) that describe the angular relationship between the axes of both system in the Euclidean space; and a scale factor (s) describes the size differences between both ellipsoids. The Bursa-Wolf datum transformation model is given by:

$$\begin{bmatrix} X_{Helmert1906} \\ Y_{Helmert1906} \\ Z_{Helmert1906} \end{bmatrix} = \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix} + s \begin{bmatrix} 1 & \omega_z & -\omega_y \\ -\omega_z & 1 & \omega_x \\ \omega_y & -\omega_x & 1 \end{bmatrix} \begin{bmatrix} X_{WGS84} \\ Y_{WGS84} \\ Z_{WGS84} \end{bmatrix} \tag{12}$$

In order to cup with the same coordinate system for the south valley development project, the transformation parameters determined by ESA are applied to transform the 3D Cartesian coordinates from the WGS84 to the Helmert 1906 ellipsoid. Table 2 gives the values of these parameters.

Table 2
Transformation Parameter From WGS84 to Helmert 1906 Ellipsoids

Translation Unknowns	ΔX (m) ΔY (m) ΔZ (m)	121.8 -98.1 10.7
Rotation Unknowns	ω_x (seconds) ω_y (seconds) ω_z (seconds)	0.0 0.0 -0.02
Scale Factor	S (part per million: ppm)	0.226

5.3 Map projection

For the production of maps, the cartesian three-dimensional coordinates are projected into a two-dimensional coordinate system. The Egyptian mapping system is based on the Transverse Merecator map projection model, which uses a projection cylinder whose axes is imagined to be parallel to the earth's equator and perpendicular to its axes of rotation. In order to minimize the projection distortions, the local mapping system is divided into three belts or zones. The area under study is located in the Red Belt, whose defining parameters are given in table 3. It worth mentioning that the false northing value has been set as 1,000,000 m in order to ensure positive northing coordinates for the so-called negative strip close to the Egyptian-Sudan borders, neglecting the originally defined false northing value of 816,000 m.

Table 3
Parameters of the Red Belt Zone of the Egyptian Mapping System

Latitude Origin Central Meridian Zone Width	30^o 31^o 4^o
False Easting False Northing	615,000 m 1,000,000 m
Scale Factor	1.0

Those parameters have been applied to obtain the horizontal easting and northing coordinates of all measured points, whose orthometric heights are computed. Then, a contouring software was utilized to create 50 topographic maps of scale 1:5,000 with a contour interval of 1 meter. A final topographic map for the entire area has been developed with a scale 1:50,000 (Figure 4). Table 4 summarizes the essential information about the surveyed area. From these figure and table, it can be seen that the orthometric heights of the area range from 186 m to 254 m, with an average of 222 m.

Table 4
Essential Data of The Surveyed Area

Item	Minimum	Maximum	Average
Latitude φ (degree) Longitude λ (degree)	22.923 31.495	23.213 31.761	23.068 31.628
Northing (m) Easting (m)	27992 665823	58194 692832	43093 679328
Orthometric Height (m)	**186**	**254**	**222**

6. Economical aspects of the new integrated approach

A comparison is performed between the traditional surveying system, using total stations and levels, with the newly practiced approach of integrating kinematic GPS and terrestrial measurements. The only disadvantage of the new technique, from the authors' point of view, is its requirement of advanced theoretical background of modern geodesy. A detail understanding of the concepts underlying the satellite positioning techniques, coordinate systems; and the role of geoid is a must in order to be able to precisely integrate satellite and terrestrial measurements. On the other hand, the integrated approach has many benefits over the traditional methods. The ease of use of GPS instrumentation, the capability of collecting data over 24 hours under any weather conditions; and the achieved high accuracy level are some examples of these merits.

The cost-benefit comparison between the new and conventional surveying approaches is shown in table 5. Regarding the traditional terrestrial surveying methods, it has been found that field and office stages of this job is expected to be done by means of 40~60 persons in 36~48 weeks, so that the cost estimate would be 12 L.E. per feddan approximately. Applying the new integrated approach, the job has been completed by 10~15 persons in 9~12 weeks resulting in actual cost of 6 L.E. per feddan approximately. Therefore, the new integrated approach wins time shortcut of 75% and cost-effectiveness of 50%.

Table 5
An Economical Comparison Between
Traditional and New Approaches

	Traditional Surveying	Integrated Surveying
Time needed (weeks) Persons Needed	36 ~ 48 40 ~ 60	9 ~ 12 10 ~ 15
Cost per feddan	≈ 12 L.E.	≈ 6 L.E.
Time saving Cost saving	- -	75 % 50 %

7. Conclusion

For the first time in Egypt, an integrated approach of combining GPS positioning and terrestrial surveying techniques has been developed and utilized for the production of topographic maps at a large scale. The new approach has several merits over other traditional surveying methods in terms of accuracy, productivity, time and cost savings. This advanced approach has been utilized for the production of topographic maps cover an area of 75,000 feddan (approximately 315 million square meters) in the south valley (Toshka) development project. Results have shown that this advanced technique reduces the needed time by 75% and results in 50% saving of the costs of applying traditional surveying methods. Furthermore, the new approach yet satisfies the national standards and specifications for topographic maps. Hence, it is recommended to utilize this modern methodology for the production of topographic maps at the national scale in Egypt.

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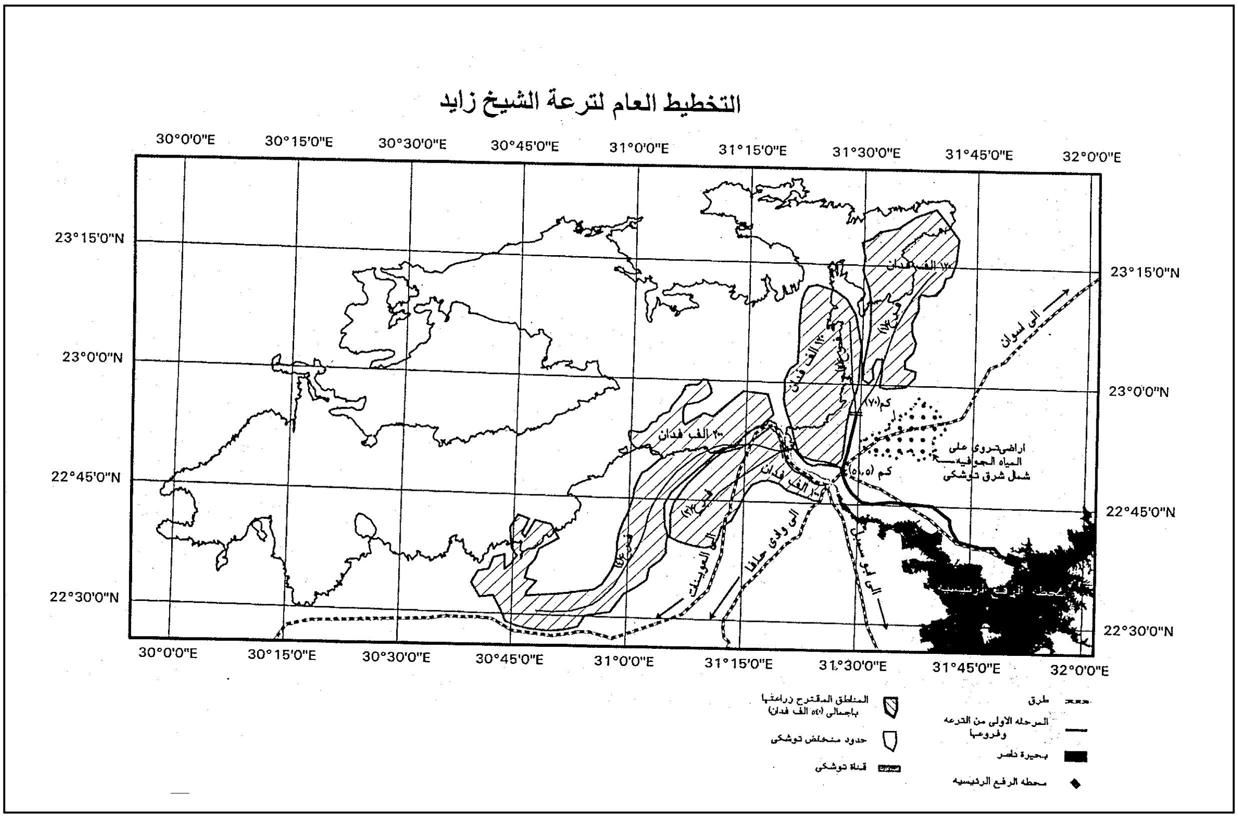

Figure 1
The South Valley (Toshka) Development Project Layout

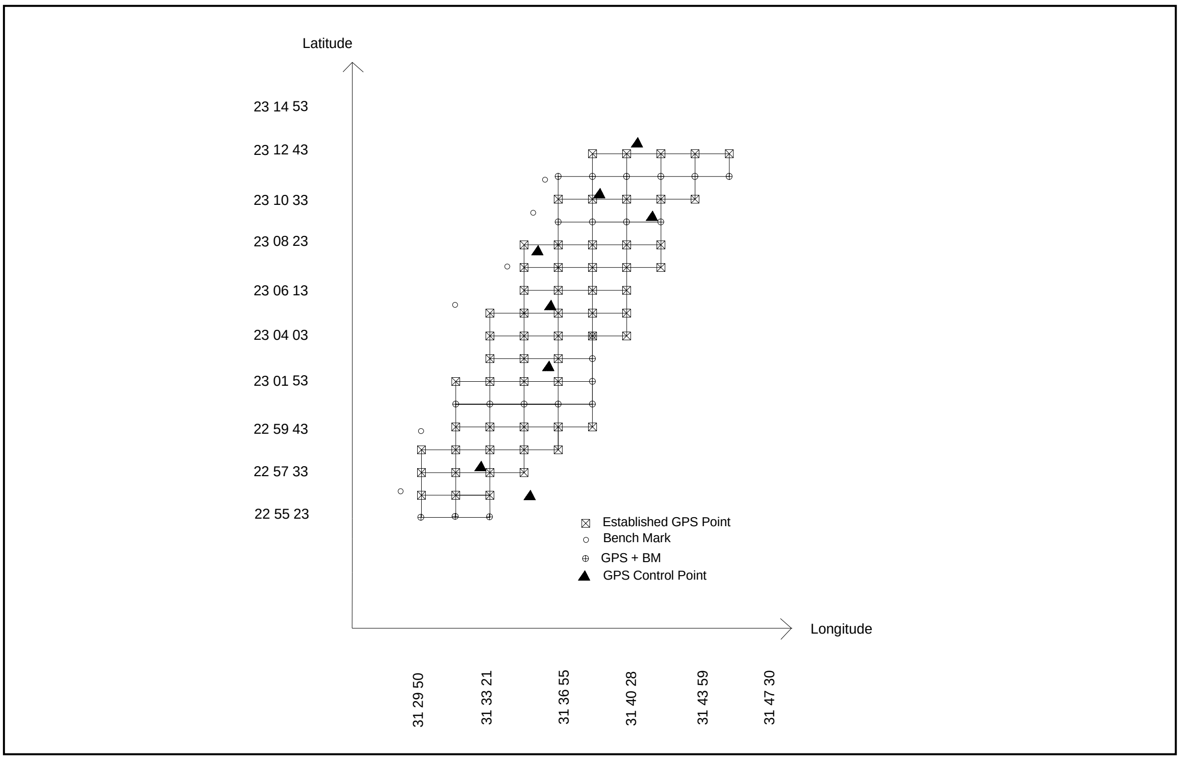

Figure 2
The Established GPS Control Network

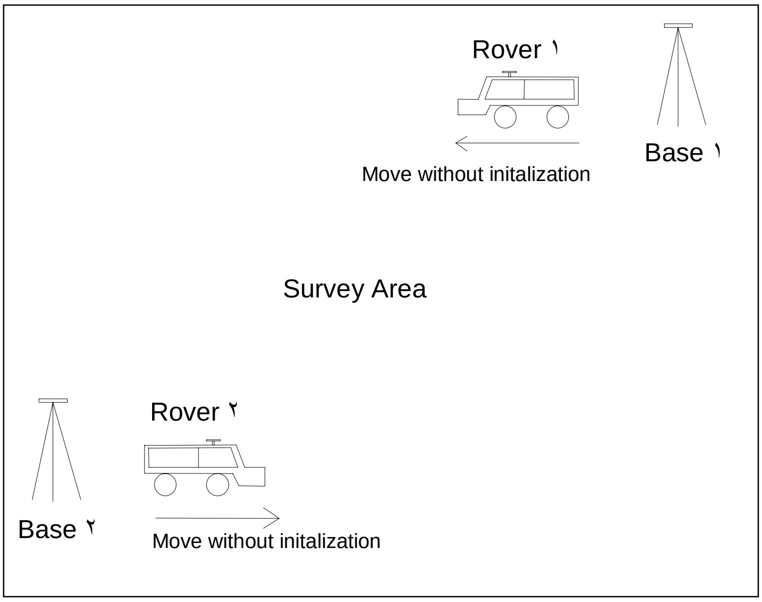

Figure 3
The OTF Relative Kinematic GPS Technique

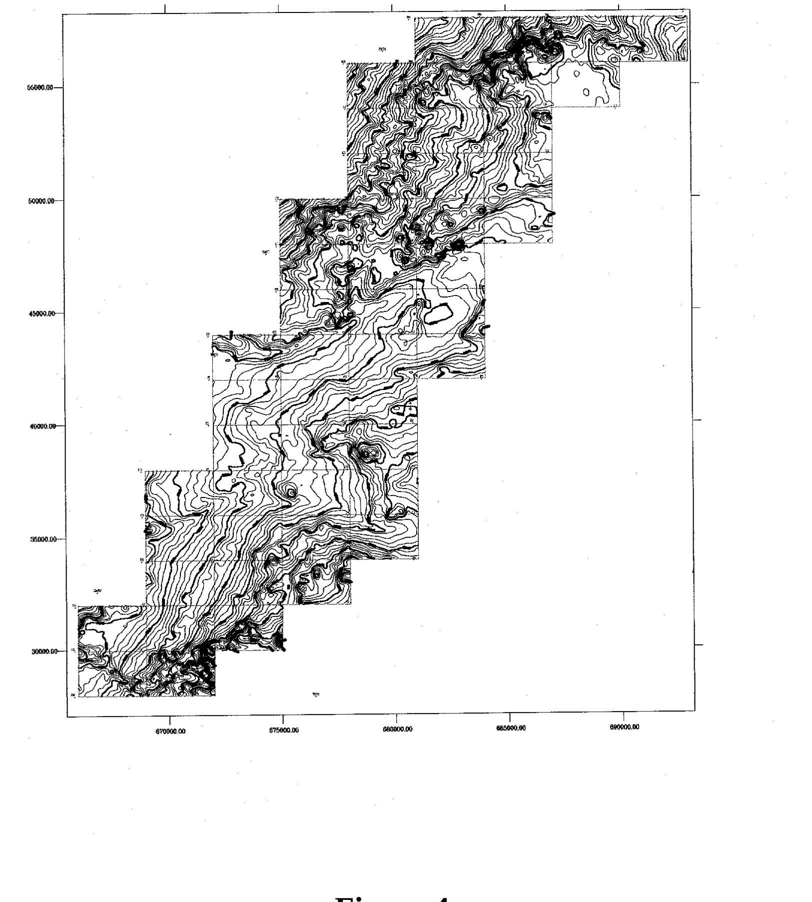

Figure 4
The Developed Topographic Map