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# ENHANCEMENT THE QUALITY OF THE EGYPTIAN FIRST ORDER GEODETIC NETWORK USING GPS DATA.

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## ABSTRACT

Extension of existing geodetic control using traditional terrestrial techniques has become impractical nowadays as far as the time and the cost are concerned. And with the wide spread use of GPS in geodesy the combination of GPS data with the existing terrestrial data is essential to improve and enhance the quality of terrestrial geodetic control networks. This research paper presents a methodology for combination of the Egyptian first order terrestrial geodetic control network with GPS points. The standard deviations will be used as a precision criteria. A numerical example is presented.

تعتبر شبكات التحكم الجيوديسية هى الأكثر انتشاراً وهى الهيكل الأساسى لجميع الأعمال المساحية والخرائط لأى دولة مثل مصر ولذلك لابد من أن تكون دقيقة لتفى بمتطلبات مقاييس الدقة وتطبيقات الشبكات الجيوديسية ، حيث يتم تحسين معايير هذه الشبكات عن طريق اضافة بعض النقاط الجديدة باستخدام الأقمار الصناعية GPS فى بعض أماكن هذه الشبكة. ويعتبر نظام GPS هو من أفضل الطرق فى تحسين الشبكات التقليدية حيث يمكن استخدامه فى جميع الظروف الجوية المختلفة ولا يحتاج إلى تبادل الرؤية بين النقاط المرصودة ويعطى دقة عالية تفوق مثيلتها من الطرق المساحية الأخرى مع سرعة انجاز العمل. وقد اهتم هذا البحث بدراسة جزء من شبكة مثلثات جمهورية مصر العربية من الدرجة الأولى ودراسة دقة هذا الجزء من الشبكة قبل وبعد اضافة النقاط الجديدة باستخدام GPS والمقارنة بينهما.

## 1. INTRODUCTION

For any extended engineering project, it is necessary to establish a control network consisting of a sufficient number of points to satisfy the quality standard of the surveying work. The most famous control network for such engineering projects is the closed and/or the connected traverse as well as a micro network.

For such types of control networks, the traditional ground surveying technique are time consuming, on the other hand the adopted control network should be established in a short time, since other engineering activities cann't be started before observing and adjusting it. The most effective tool to shorten time and minimizing the cost of establishing the control network is the use of Global Positioning System (GPS). [ El Tokhey and El Maghraby, 2002 ].

GPS has revolutionized the navigation and positioning application because it is all-weather, world wide, very accurate navigation and positioning system. It provides three-dimensional positions and velocities on a 24 hour a day. [ Adnan, 1995 ].

## 2. TERRESTRIAL GEODETIC NETWORK

Terrestrial geodetic network can be defined as a geometric frame which consists of ground control points. Each of them is uniquely defined by its coordinates relative to a specific coordinate system. The coordinates are not directly observed but they are derived via some observables amongst various network points. Using appropriate functional relationships, the observables are used to compute a homogeneous set of coordinates of the network points.

The precision of the network point coordinates depends on the observations, the adopted mathematical models and the accumulation of the unaccounted systematic errors. [ Fayad, 1996 ].

Network which are composed of one type of measurements only are called particular nets such as triangulation, trilateration, gravity, satellite or leveling nets [ Wolf, 1982 ].

Geodetic networks may be one of three categories depending on how the positions of the points are defined. A network of points positioned by three coordinates are referred to as a three-dimensional network. A network of points with known horizontal positions, say latitude and longitude ( $\varnothing$, $\lambda$ ), is called two-dimensional geodetic network. Finally, the network of points defined by one coordinate, which is the height above a certain datum, is called height network and sometimes referred to as one-dimensional network. [Vaniček and Krakiwsky, 1982].

The performance of any geodetic surveying project, requires testing for the efficiency of the work done according to some limitations or accuracy standards and specifications based on the purpose of such project, or in other words, the order and class of accuracy upon which such work will be executed within. Survey standards are defined as minimum accuracies that are necessary to meet specific objectives, while specifications are defined as field methods and procedures required to meet a particular survey standard.

The standard for horizontal control networks, with different order or class, is obtained, as a distance accuracy, which represents the ratio between the relative positional accuracy of two control points (standard deviation of the distance between them) and the horizontal separation of those points. Table (1) represents the distance accuracy standards for terrestrial horizontal geodetic control networks of different order and class.

Furthermore, the accuracy standards for vertical geodetic control networks can be obtained as elevation difference accuracy, which represents the relative elevation error between two network points (standard deviation of elevation difference). Table (2) represents the elevation difference accuracy standards for terrestrial vertical geodetic control networks of different order and class. [ Hafez, 2003].

**Table (1)** Horizontal Geodetic Control Networks

| **Classification** | **Minimum Distance Accuracy** |
|---|---|
| First Order | 1:100 000 |
| Second Order, Class I | 1:50 000 |
| Second Order, Class I I | 1:20 000 |
| Third Order, Class I | 1:10 000 |
| Third Order, Class I I | 1:5000 |
| Fourth Order, Traverse | 1:2500 |

**Table (2)** Vertical Geodetic Control Networks

| **Classification** | **Minimum Elevation Difference Accuracy** $(mm/\sqrt{km})$ |
|---|---|
| First Order, Class I | 0.5 |
| First Order, Class I I. | 0.7 |
| Second Order, Class I | 1.0 |
| Second Order, Class I I | 1.3 |
| Third Order | 2.0 |

## 3. GLOBAL POSITIONING SYSTEM

Due to the necessity of inter-visibility between stations and other reasons related to the field difficulties, the use of terrestrial triangulation, trilateration and traversing in the establishment of the geodetic networks was limited to local and regional networks.

For continental and global networks, another approach of positioning has been adopted by the surveyors. Artificial satellites have been used to determine the position and the velocity of targets on the earth's surface. [ Fayad, 1996 ].

There are many extra-terrestrial positioning systems for determining the positions. The most important method is GPS which has been developed and tested by military agencies in the U.S.Department of Defense (DOD). [Kebbich, 1995].

The final accuracy obtainable with GPS depends on the following factors :

1- The precision of the measurements.
2- The measurements processing technique.
3- The receiver-satellite geometry.
4- The accuracy of the satellite ephemeris and
5- The accuracy which atmospheric effects can be modeled. [ Adnan, 1995 ].

The mathematical model of the GPS measurements is linear. The standard equation of least – squares adjustment involving observations and conditions is :

$$A_{c,n}v_{n,1} + x_{u,1} = f_{c,1} \qquad (1)$$

And,

$$Q_{n,n} = W^{-1}{}_{n,n} \qquad (2)$$

Where :

v is the vector of residuals
Q is the covariance matrix of observations
x is the vector of unknowns
f is the vector of right-hand sides
W is the weight matrix, representing the differences and
A is the design matrix, which will be given as : [ Rahil, 2008 ]

$$A = \begin{bmatrix} 1 & 0 & 0 & \dots & 1 & 0 & 0 \\ 0 & 1 & 0 & \dots & 0 & 1 & 0 \\ 0 & 0 & 1 & \dots & 0 & 0 & 1 \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ 1 & 0 & 0 & \dots & 1 & 0 & 0 \\ 0 & 1 & 0 & \dots & 0 & 1 & 0 \\ 0 & 0 & 1 & \dots & 0 & 0 & 1 \end{bmatrix} \qquad (3)$$

The dimensions are given by :

n = ( number of observed lines ) × 3
r = ( number of new points ) × 3
c = n – r = number of conditions

u = number of parameters ( unknowns )

And the normal matrix (N) will be given as :

$$N = \begin{bmatrix} \sum P_{\Delta n} & 0 & 0 \\ 0 & \sum P_{\Delta e} & 0 \\ 0 & 0 & \sum P_{\Delta u} \end{bmatrix} \quad (4)$$

Where Δn and Δe are the accuracies of the horizontal components of the measurements vectors, Δu is the accuracy of the vertical component.

The accuracy of a measured GPS vector depends in general on its length. We can adopt the following weights : $P_{\Delta n} = P_{\Delta e} =$ and $P_{\Delta u}$=1/4

The resulting normal matrix and its inverse are respectively :[ Even – Tzur, 1996 ]

$$N = \begin{bmatrix} 4 & 0 & 0 \\ 0 & 4 & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (5)$$

$$N^{-1} = \frac{1}{4}\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 4 \end{bmatrix} \quad (6)$$

## 4. EGYPTIAN FIRST ORDER GOEDETIC NETWORK

The Egyptian first order geodetic network is considered to be the first national network to be established in Africa. It consists of two main parts, namely: network 1 and network 2, the execution of network 1 has been started in 1907 and was completed in 1944. It was carried out by means of chains of quadrilaterals with all horizontal angles observed. In several cases, the chain has been strengthened by intrlinking the quadrilaterals. Network 1, consisting of ten section each section was adjusted separately, covers the cultivated area of the nile valley to the sudanese border in the North – South direction, while covering the northern coast from Al-Arish to Al-Saloum in the East – West direction. This network was extended in order to cover the area of Sinai and some parts of the Eastern and Western deserts. This extension was connected to network 1 through 15 common stations and was called network 2, consisting of eleven stations. This network was executed from the year 1955 until the year 1968. [ Hafez, 2003 ].

## 5. COMBINATION OF TERRESTRIAL AND GPS NETWORK

With the wide spread use of GPS in geodesy, it is convenient to combine GPS data with the existing terrestrial data in the network computations, especially after GPS has been used in Egypt.

Such a combination is expected to enhance the quality of the Egyptian terrestrial network, such that it can suffies the recent precise measurements, as well as other geodynamical applications, and extend to precise mapping for oil exploration and other important national resources management and control, among several respective authorities.

There are many advantages of using GPS observations in the establishment of the geodetic networks. The capability of measuring long baseline with high accuracy and without intervisibility conditions makes the use of GPS in combination with the terrestrial data an advantage in case of geodetic network. [ Adnan, 1995 ].

## 6. APPLIED STUDY AND RESULTS

In this paper, applications of the presnted combination of terrestrial and GPS networks, given in section ( 5 ) are performed using actual terrestrial data.

first, the software used in this study is explained then, a description of the data used finally, the obtained results of computations will be discussed and analysed.

### 6.1. THE SOFTWARE

To perform the computations of the combination between terrestrial data and GPS data and to compute the result of these combination, a computer program using the PC – Matlab version is used . This computer program is designed to compute the final criteria of the final geodetic control, after adding GPS informations, to compare it with the criteria of the used terrestrial data.

### 6.2. INPUT DATA

The used data is a part of Egyptian first order horizontal terrestrial geodetic network, which has been presented in section ( 4 ). The data consists of ten points, contains two fixed points (over-constrained network ) [ Doma, 2008 ].

These points are well distributed over the Egyptian territory. These points ( 2 – D ) cartesian coordinates defined relative to WGS 84 ( World Geodetic System 1984 ) datum. The locations of these points are given in Figure ( 1 ).These points data has been collected from El Habiby. [El Habiby, 2002].

### 6.3. APPLICATION OF THE PROPOSED ALGORITHM

Let us assume that, the Egyptian trilateration geodetic network, with a layout as shown in Figure (2), has been measured using EDM instrument with achievable accuracy $\sigma_s^2 = (0.5\ ppm.S)^2$ ( 7 )

where S is the distance computed from the approximate coordinates. After this trilateration network observed, we want to combine it with GPS points as shown in Figure (3). Suppose that the selected GPS receivers can allow for a baseline to be determined with the following precision:

$$\sigma_S^2 = (1mm + 1\,ppm\,.S)^2 \qquad (8)$$

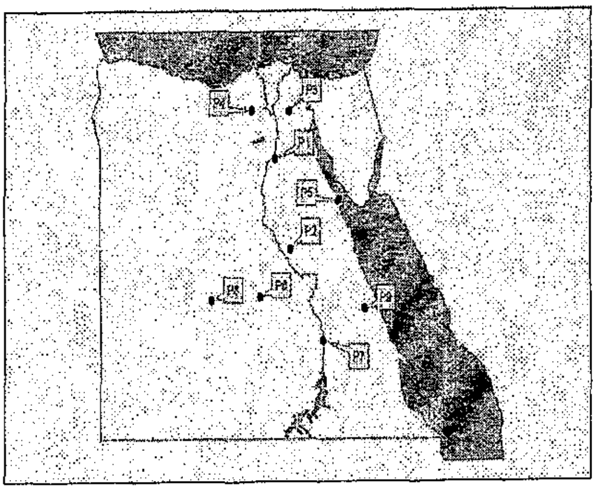

*Figure ( 1 ): The location of existing stations*

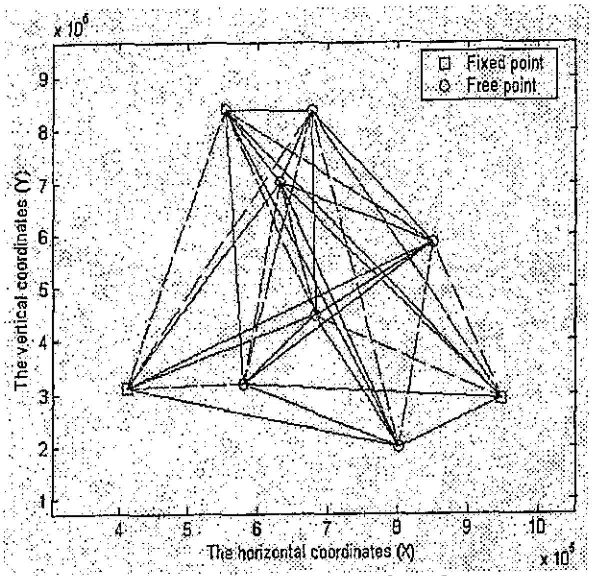

*Figure (2): Existing stations of a trilateration network*

## 7. DISCUSSION OF THE OBTAINED RESULTS

We used the standard deviation as a precision criteria at this example.

Table ( 3 ) and ( 4 ) include the precison before and after combination. This results shows that.

a) Before combination, the standard deviation of the existing points are ranged from (67.839)mm at point ($P_6$) to (213.03)mm at point ($P_4$), while after combination, the standard deviation of the final network are ranged from (59.158) mm at point ($P_1$) to (89.567)mm at point ( $P_4$).

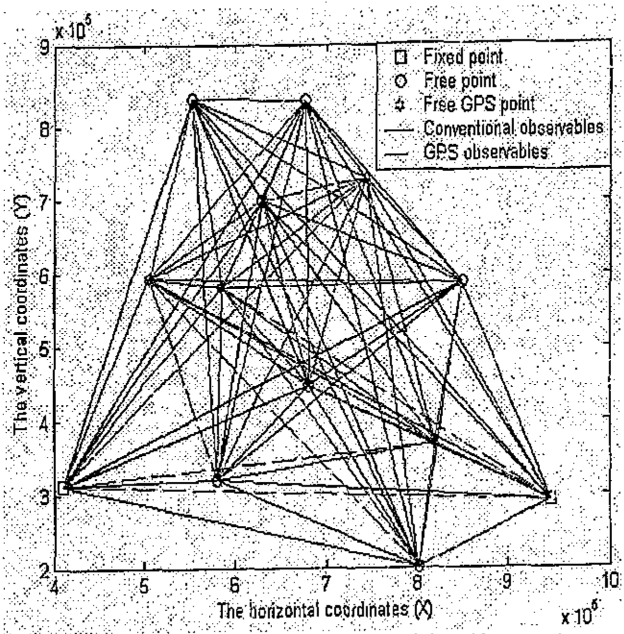

*Figure (3): The existing and added (GPS) netpoints*

b) The ratio between the standard deviation in x – axis ($\sigma_x$) and the standard deviation in y-axis($\sigma_y$) befor combination are ranged between (0.503) at point ($P_6$) to (1.898) at point ($P_3$), while the ratio between the standard deviation in x-axis ($\sigma_x$) and the standard deviation in y-axis ($\sigma_y$) after combination are ranged between (0.705) at point ($P_6$) to (1.233) at point ($P_3$), these results show that, the network becomes more precise after the combination process.

**Table (3)** The actual coordinate components of network existing points, their standard deviations and the ratio between the standard deviations

| Point | Actual coordinates of trilateration network points | | Achievable precision | | |
|---|---|---|---|---|---|
| | x ( m ) | y ( m ) | $\sigma_x$ (mm) | $\sigma_y$ (mm) | $\frac{\sigma_x}{\sigma_y}$ |
| $P_1$ | 630392 | 701155 | 165.76 | 104.78 | 1.582 |
| $P_2$ | 680862 | 446678 | 95.475 | 106.54 | 0.896 |
| $P_3$ | 676678 | 837230 | 210.54 | 110.95 | 1.898 |
| $P_4$ | 553255 | 839174 | 213.03 | 140.28 | 1.519 |
| $P_5$ | 850361 | 587060 | 123.77 | 111.21 | 1.113 |
| $P_6$ | 580034 | 320760 | 67.839 | 134.89 | 0.503 |
| $P_7$ | 801102 | 200532 | 83.86 | 107.74 | 0.778 |
| $P_8$ | 410229 | 310943 | fixed | fixed | fixed |
| $P_9$ | 947519 | 290448 | fixed | fixed | fixed |

**Table (4)** The coordinate components of final points (existing and adding of network points) and their standard deviations

| Point | coordinates of combined network points | | Achievable precision | | |
|---|---|---|---|---|---|
| | x ( m ) | y ( m ) | $\sigma_x$ (mm) | $\sigma_y$ (mm) | $\frac{\sigma_x}{\sigma_y}$ |
| $P_1$ | 630392 | 701155 | 72.662 | 59.158 | 1.228 |
| $P_2$ | 680862 | 446678 | 67.923 | 66.056 | 1.028 |
| $P_3$ | 676678 | 837230 | 86.441 | 70.117 | 1.233 |
| $P_4$ | 553255 | 839174 | 89.567 | 81.95 | 1.093 |
| $P_5$ | 850361 | 587060 | 76.903 | 75.003 | 1.025 |
| $P_6$ | 580034 | 320760 | 60.157 | 85.312 | 0.705 |
| $P_7$ | 801102 | 200532 | 70.586 | 80.813 | 0.873 |
| $P_8$ | 410229 | 310943 | fixed | fixed | fixed |
| $P_9$ | 947519 | 290448 | fixed | fixed | fixed |
| $D_1$ | 506421 | 594361 | 66.166 | 66.185 | 0.999 |
| $D_2$ | 743869 | 730306 | 75.964 | 73.179 | 1.038 |
| $D_3$ | 586148 | 581289 | 61.702 | 61.841 | 0.998 |
| $D_4$ | 820129 | 369529 | 74.857 | 77.037 | 0.972 |

## 8. CONCLUDING REMARKS

Depending on the obtained results and the analysis that carried out on it, we can summarize the following conclusions:

- The combination between GPS and terrestrial data provides more accurate network coordinates.
- Based on real terrestrial and GPS data of first order geodetic network, there is a significant improvement of the accuracy of all network points such as improvement of accuracy in the network coordinates, after combination, is found to be uncorrelated with the distance of the point under cosideration from the intial fixed point of the datum.
- Applying this combination beween GPS and terrestrial data increases the isotropy and homogeneity of the existing points.

## 9. REFRENCES

***Adnan** A.M. (1995).* Global Positioning System (GPS) Accuracy Investigations with Emphasis on Signal and Ephemeris, M. Sc. Thesis at the Faculty of Engineering, Cairo University, Cairo, Egypt.

***Doma** M.I. (2008).* The optimal improvement of geodetic network using interactive graphics system, Doctoral thesis at the Faculty of Engineering,Minoufiya University, Cairo, Egypt

***El-Tokhey M. and M.F. El-Maghraby (2002).*** Controlling extended engineering projects using GPS and Total Station Surveys through the proper treatment of scale and height factors, Civil Engineering Research Magazine (CERM), Faculty of Engineering, El-Azhar University, vol. (24), no. (3), p.p. 967-991.

***El-Habiby M.M. (2002).*** Effects of coordinate transformation from Helmert 1906 old system to WGS84 GPS new system on geodetic networks and related mapping system in Egypt, M. Sc. Thesis at the Public Works Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt.

***Even-Tzur, G. and Papo, H.B. (1996).*** "Optimization of GPS Network By Linear Programming" Survey Review, 33, 264,October 1996, pp 537-545.

***Fayad** A.T. (1996).* Merging both GPS and Terrestrial Data in the Computations of the Geodetic Control Networks. Doctoral thesis at the Public Works Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt.

***Hafez** A.E. (2003 ).* Studies on unification, densification and extension of the Egyptian Control Networks using GPS observations. M.Sc. degree in Civil Engineering. Public Works Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt.

***Kebbieh,** Y.K. (1995).* The Role of GPS Survey in Geodetic Control Networks, M. Sc. Thesis, Faculty of Engineering, Cairo University, Giza, Egypt.

***Kumar, M. and Reilly, J.P. (2006).*** "Is definition of WGS84 Correct" Coordinates, Volume II, Issue 12, December 2006.

***Rahil A.M., El Gohary A.M., Doma M.I. (2008).*** A new proposed approach for densification of the conventional geodetic networks using

GPS information, Civil Engineering, Research journal, Vol.31, No.1, January 2008, PP 101-106, Faculty of Engineering, Minoufiya University, Egypt.

***Stopar, B. (2001).*** "Second Order Design of Horizontal GPS net" Survey Review, 36, 44-53. (January 2001).

***US Army Corps of Engineering (2003).*** "NAVSTAR Global Positioning System Surveying EM 1110-1-1003", Department of the Army, Washington.(July 2003).

***Vaniček P. and E.J. Krakiwsky (1982).*** Geodesy : The Concepts. North Holland Publishing Co., Amsterdam

***Wolf H. (1982).*** "Objective of geodetic Networks and future plans. In : Proceeding of the International Symposium on Geodetic Networks and Computations, IAG. München, August 31-September 1981, vol. II.