Development of a local GPS-Leveling geoid model for the Gaza Strip Area

1 author:

M. A. El-Hallaq
Islamic University of Gaza

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, Volume 2, Issue 3, March 2012)

Development of a Local GPS-Leveling Geoid Model for the Gaza Strip Area

Maher A. El-Hallaq

Assistant Professor, Civil Engineering Department, Islamic University of Gaza, Palestine
mhallaq@iugaza.edu.ps

***Abstract*— Geoid model determination has an increased importance in most of the practical applications of geodesy in Palestine such as large-scale map production, GIS applications, and engineering surveying applications. A joint effort between the British Consulate in Jerusalem and a combined Palestine – Finland project was agreed in order to re-establish and improve the geodetic network in Palestine. A mission of a GPS survey team from Ordnance Survey International was funded by the British Consulate and conducted in the spring of 1999. Although vertical control is highly likely to be required to support engineering projects throughout Palestine, the new geodetic network that was established by the Palestine -Finland project does not meet this requirement. The stations that comprise the new geodetic network are three dimensional control points of known local horizontal coordinates but known ellipsoidal height rather than orthometric height. However, in order to obtain the necessary orthometric height for the points, a high quality geoid model is required. This research aims to develop a GPS-Leveling geoid model that provides a vertical control of the Gaza Strip area that is compatible with the use of GPS and to build up software to convert the GPS ellipsoidal heights to orthometric heights.**

***Keywords*— Geoid Model, Heights transformation, GPS, Leveling, Gaza Strip.**

I. INTRODUCTION

The geoid is an equipotential surface which would coincide exactly with the mean sea surface of the Earth, if it was to be extended through the continents. According to C.F. Gauss, who first described it, "it is the mathematical figure of the Earth," a smooth but irregular surface that corresponds not to the actual surface of the Earth's crust, but to a surface which can only be known through extensive gravitational measurements and calculations [1]. Despite being an important concept for almost two hundred years in the history of geodesy and geophysics, P. Vanek and others have defined it to high precision in recent decades. It is often described as the true physical figure of the Earth, in contrast to the idealized geometrical figure of a reference ellipsoid [2].

Being an equipotential surface, the geoid is a surface to which the force of gravity is everywhere perpendicular. This means that when traveling by ship, one does not notice the undulations of the geoid; the local vertical is always perpendicular to the geoid and the local horizon tangential component to it. Likewise, spirit levels will always be parallel to the geoid. A GPS receiver on a ship may, during the course of a long voyage, indicate height variations, even though the ship will always be at sea level. This is because GPS satellites, orbiting about the center of gravity of the Earth, can only measure heights relative to a geocentric reference ellipsoid. To obtain one's geoidal height, a raw GPS reading must be corrected. Conversely, height determined by spirit leveling from a tidal measurement station, as in traditional land surveying, will always be geoidal height [1].

The accuracy of GPS height measurements depends on several factors but the most crucial one is the "imperfection" of the earth's shape. Height can be measured in two ways. The GPS uses height (h) above the reference ellipsoid that approximates the earth's surface. The traditional, orthometric height (H) is the height above an imaginary surface called the geoid, which is determined by the earth's gravity and approximated by MSL. The signed difference between the two heights—the difference between the ellipsoid and geoid—is the geoid height (N). FIGURE 1 shows the relationship between the different models and explains the reasons why the two hardly ever match spatially [3].

Gaza Strip lies along Egypt south and Mediterranean Sea west. It is about 45 km long and 6.5 to 12 km wide and covers an area of 365 km2. Its topography is flat and rising to a maximum height of 95 m above the mean sea level.

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, Volume 2, Issue 3, March 2012)

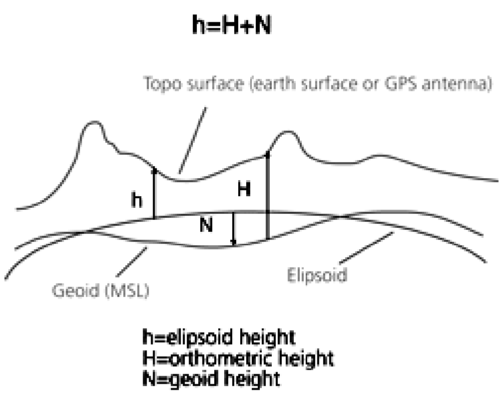

FIGURE 1: THE RELATIONSHIP BETWEEN THE DIFFERENT MODELS OF THE EARTH SURFACE

A joint effort between the British Consulate in Jerusalem and a combined Palestine – Finland project was agreed in order to re-establish and improve the geodetic network in Palestine [4]. A mission of a GPS survey team from Ordnance Survey International was funded by the British Consulate and conducted in the spring of 1999. FIGURE 2 shows the Finland coordinated point's network in the Gaza Strip. Determination of horizontal locations using GPS in the Gaza Strip is based on these stations.

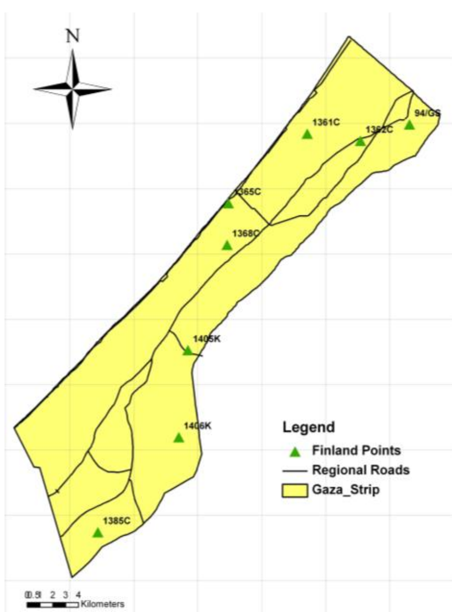

FIGURE 2: THE GEODETIC NETWORK IN THE GAZA STRIP AREA

II. PROBLEM STATEMENT

The transformation between ellipsoidal heights and orthometric heights has become more important since the satellite based positioning techniques, especially GPS, were being used in a wide range of geodetic and surveying applications. Geoid model determination has an increased importance in most of the practical applications of geodesy such as large-scale map production, GIS applications, and engineering surveying applications especially in Palestine. Although vertical control is highly likely to be required to support engineering projects throughout Palestine, the new geodetic network that was established in the Palestine - Finland project does not meet this requirement. The stations that comprise the new geodetic network are three dimensional control points of known local horizontal coordinates (X,Y) but known ellipsoidal height ($Z_{ellipsoid}$ = h) rather than orthometric height ($Z_{elevation}$ = H). A strong need has been arisen to make benefit from the third coordinate $Z_{ellipsoid}$ that the GPS can calculate.

III. RESEARCH OBJECTIVES

This research aims to:

A. Build a sufficient database to serve the vertical control in the Gaza Strip.

B. Establish the first local GPS-Leveling geoid model that provides a vertical control of the Gaza Strip, which is compatible with the use of GPS.

C. Develop software to convert the GPS ellipsoidal heights to orthometric heights and facilitate using the developed model.

IV. METHODOLOGY

The methodology steps can be summarized as follows [5, 6]:

A. Data Collection

Gathering geospatial data, at first, is very essential. Data about Gaza Strip features including surveying and geodetic networks is to be collected. This requires contacting all the local institutions such as surveying authorities, municipalities, organizations, centers, etc in addition to international groups as British consulate, Ordnance Survey in Britain, Finland institutions, etc. Moreover, performing field measurements including GPS surveys is very essential.

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, Volume 2, Issue 3, March 2012)

B. Validation Procedure

Upon data collection, a validation procedure is to be established. This step contains different types of checks in order to ensure a high precise and more accurate data. For this purpose, field surveys are one of these checks.

C. Creation Of An Archive

The next step is to maintain the collected data through a hierarchal database in which it can be easily retrieved, displayed, updated etc. The use of GIS as a tool for managing is necessary in spatially analyzing these data. From a data management perspective, metadata is important for maintaining the investment in spatial data. A metadata creating based on a standard can be helpful for the documentation of geospatial data of the Gaza Strip features.

D. Geoid Computation

A precise geoid model is an important part of the geodetic infrastructure. To serve the practical geodetic and surveying applications, determining the geoid model of a limited area as an analytical surface using homogeneously distributed GPS/Leveling reference points with appropriate density constitutes the subject of this research. From this view point, the following steps are to be performed:

- All benchmark reference points in the Gaza Strip are to be well-documented using ArcGIS software. This presents these reference points in a geographic format and decides if densification procedure is required.
- Choosing number of the reference points in modeling considering the topography of the region and also keeping the homogeneous distribution.
- Choosing another number of the reference points in testing to ensure the accuracy of the developed geoid model.
- Examining the accuracy of both modeling and testing benchmark points by conducting field survey that includes leveling traverses.
- Performing a high accurate GPS survey for all reference points using three GPS base and rover receivers. Two receivers are to be held over two zero- order of the Finland - Palestine project points while the third is over the reference benchmark station.
- Using interpolation and geostatistical methods to model the geoid undulations in the area based on the modeling reference stations. One of the fitting surface methods which can be used is the Inverse Distance Weighing method (IDW).
- Testing the developed geoid by checking the undulations in the testing stations to make sure that the performance of the model is acceptable.
- Developing software to assist using the developed model.

E. Interpretation Of The Results

A comprehensive interpretation of the results is to be determined with obtained conclusions and recommendations.

V. Geoid Development

A. Data Collection

After extensive field survey including leveling and GPS measuring in addition to data validation checks, 403 GPS/Leveling points were collected. The number of points is adequate to model such small area. 353 points were selected as modeling benchmarks and the rest 50 points are used to evaluate the performance of the developed model. FIGURE 3 illustrates the distribution of both modeling and testing benchmark points in the area. The distance between any two modeling points do not exceed 3 km. All collected data is documented and archived in ArcMap GIS database. This can help in the spatially analyzing process of this data in addition to facilitate storing, retrieving, updating and manipulating it.

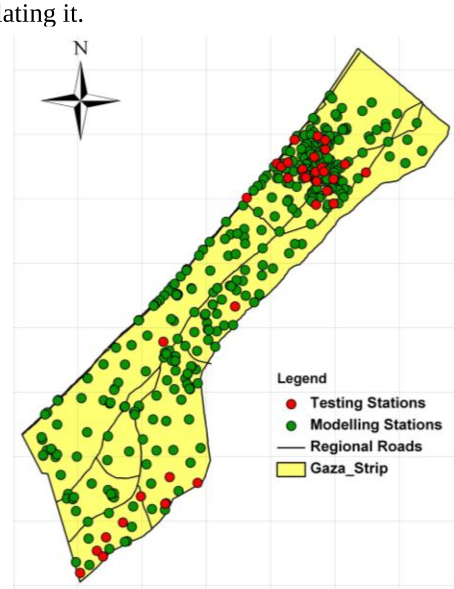

FIGURE 3: The distribution of modeling and testing benchmark points in the area

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, Volume 2, Issue 3, March 2012)

B. Geostatistical Interpolation Algorthims

Interpolation methods are most common approaches that are used while modeling the geoid heights (N) in a local area. There are different interpolation algorithms and each of them can have different results when interpreting data. Some of these:

- Inverse Distance Weighting to a Power
- Kriging
- Minimum Curvature
- Nearest Neighbor
- Polynomial Regression

For the first stage in this study, the Inverse Distance Weighting to a power (IDW) is chosen to build up the model. IDW method calculates the undulation of a considered point by interpolating the undulation in the surrounding neighboring points that lie within a user-defined searching radius. Since geoid undulation changes for distances more than 3000 m, modeling points are selected so that a distance between any two points should not exceed this length. Data points that lie progressively farther from the considered point influence the computed value far less than those lying close to it. Eqs. (1-2) illustrate how to compute the geoid undulation of a point as related to the surrounding reference points.

$$N = \frac{\sum_{i=1}^{n} W_i N_i}{\sum_{i=1}^{n} W_i} \quad \ldots\ldots\ldots\ldots\ldots\ldots.. \quad (1)$$

Where,
N = geoid height (undulation) of a considered point.
N_i = geoid undulation value of ith reference point.
W_i = weight of ith reference point.

$$W_i = \frac{1}{D_i^n} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where,
D_i = distance between the considered point and ith reference point.
n = power of the distance, it can be 1, 2, 3 or 4.

To ensure what searching radius and power that give the best accuracy while using this method, distances at (2000, 2500, 3000) m and powers from 1 to 4 are trialed.

C. Software Development

Software is strongly needed to facilitate using the model in which GPS ellipsoidal heights can be converted to orthometric heights. It is also important for analyzing and testing the model. Software is built using C sharp programming language and named as PNGM version 1. PNGM stands for Palestine National Geoid Model. It has the capability to import data from GPS receivers and from any other database format like EXCEL, ACCESS, etc. It is also flexible to select power and searching radius. In addition, modeling data is not built in the program and can be imported; therefore, PNGM can be used in other areas. FIGURE 4 shows a screenshot of the graphical user interface of PNGM and steps used to test the model by PNGM are illustrated in FIGURE 5. FIGURE 6 shows an example for ellipsoidal heights transformation of some GPS points taken in the Gaza Strip to elevations and constructing a report for the results. This report can then be exported in any format like EXCEL, SHP, PDF, etc.

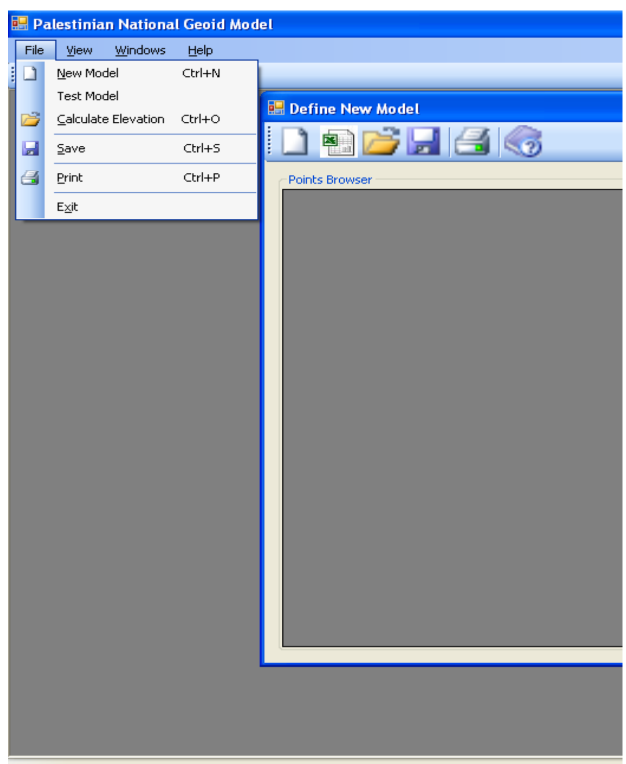

FIGURE 4: The graphical user interface of PNGM

IJETAE
EXPLORING RESEARCH AND INNOVATIONS

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, Volume 2, Issue 3, March 2012)

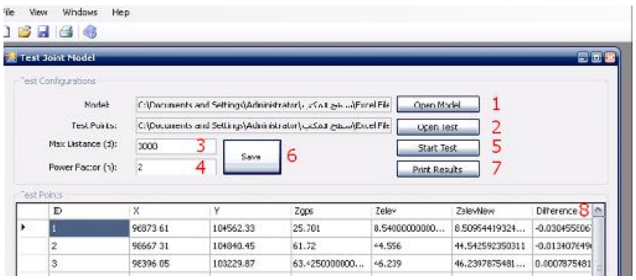

FIGURE 5: PNGM STEPS TO TEST THE MODEL

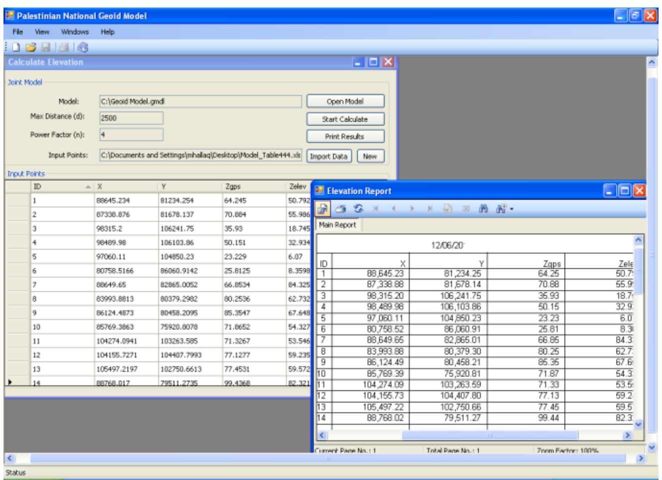

FIGURE 6: AN EXAMPLE FOR ELLIPSOIDAL HEIGHTS TRANSFORMATION AND REPORTING

D. Results Analysis

After developing the software, testing the model becomes easy. Considering the 50 testing Benchmark points, their elevations are computed using PNGM as illustrated in Figure 5. As mentioned earlier, choosing suitable power and searching radius are necessary to reach the best accuracy. The measured elevation of each point of the 50 testing benchmarks is compared with its known elevation. Table 1 shows the RMS of the results at different powers and searching radii.

As a result, it can be seen that the model fitted the data with ± 4.28 cm root means square error at searching radius 3000 m and power n = 4. It is an indicator that the model can be used to compute the elevations of new points within this accuracy range.

TABLE I

The RMS in (m) of the results at different powers and searching radii.

Power n	Searching Radius (meter)		
	2000	2500	3000
1	0.0613	0.0569	0.0586
2	0.0577	0.0552	0.0565
3	0.0560	0.0547	0.0556
4	0.0550	0.0543	0.0428

VI. Conclusion And Future Work

1. A sufficient database was performed to archive and analyze all the Benchmark points in the Gaza Strip using GIS techniques.
2. A GPS Leveling geoid model was developed to model the Gaza Strip area with an accuracy ± 4.28 cm RMS at a searching radius 3000 m and power n = 4.
3. A graphical user interface was introduced to facilitate using the developed model.
4. Other data modeling techniques such as Kriging can be used and added within PNGM.
5. It is recommended to combine the developed model with another gravimetric geoid model for the area.

Acknowledgements

At first, all thanks and appreciations go to Allah for His unlimited blessings and for giving me the strength to complete this research. Special thanks are extended to the Scientific Research Deanery at the Islamic University of Gaza for its valuable financial support that enabled me to finish the practical issues. My appreciation is also extended to the working team; Ali Masri, Yamin Harbid and Saeed Abu Warda for assisting me to perform field surveys and data collection.

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, Volume 2, Issue 3, March 2012)

References

[1] Bomford G. (1980), Geodesy, Forth Edition, Clarendon Press, Oxford, England.

[2] Vanek P. and Martinec, Z., "Compilation of a precise regional geoid". *Manuscripta Geodaetica* 19, 1994: 119 –128

[3] Witold Fraczek "Mean Sea Level, GPS, and the Geoid" Esri Applications Prototype Lab. (URL: http://www.esri.com/news/arcuser/0703/geoid1of3.html)

[4] British Consulate-General at Jerusalem, 1999 Geodetic Network for West Bank and Gaza Strip. Addendum to Final Report, Occupied Territories 129B/98, Palestine.

[5] Erol B. and Celik R. N., "Precise local geoid determination to make GPS techniques more effective in practical applications of geodesy", FIG working week 2004, Athens, Greece, 22-27 May 2004.

[6] Erol B. and Celik R. N., "Modeling local GPS/Leveling geoid with the assessment of inverse distance weighting and geostatistical kriging methods", Athens, Greece, 2005.