

Establishment of National Grid Based on Permanent GPS Stations in Israel

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ABSTRACT: The ultimate goal of the Survey of Israel (SOI) is to be capable of restoring and defining cadastral boundaries in Israel with an accuracy of 5 cm, at a 95 percent confidence level. In order to achieve this goal, we should be able to measure accurate and reliable horizontal control points and define their rectangular coordinates. Measuring new control points at this accuracy in a homogeneous network can be done by using GPS techniques underpinned by reliable, permanent GPS reference stations. However, integrating measurements performed during the last decade in classical networks (which were characterized by lower accuracy levels) with measurements based on permanent GPS reference stations poses a problem. The Israeli Geodetic Control Network will be based on an array of permanent GPS reference stations. A new datum, called ILGD05 (Israeli Geodetic Datum 2005), was defined for these stations. The transformation of geographic coordinates in ILGD05 to an improved national grid was adopted in a manner that would minimize changes in the existing rectangular coordinates values. This paper describes how the Survey of Israel met the demands and capabilities of the innovative technology. Following a more detailed description of the problems, we discuss the options for improving geodetic control, as well as the reasons for the decisions that were made. The paper suggests a strategy for the implementation of the proposed change in Israel, which will lead us into a new era in geodesy and surveying.

Introduction

New survey regulations for the State of Israel were prepared by the Survey of Israel (SOI) and officially issued on June 1998. A major item in the new regulations was the replacement of the existing (old) Israeli Grid (which dates back to 1920) with the New Israeli Grid (NIG). The NIG was the result of a readjustment of the available classical geodetic observations (Laplace azimuths, horizontal angles and distances). A specific geodetic projection called ITM—Israel Transverse Mercator—was developed. It minimizes coordinate differences between the old and the new grids to less than 1 meter in the northern part of Israel which contains about 95 percent of the population. In order to achieve this, the unusual scale of 1.000,0067 was adopted, and the central meridian chosen is a fictitious one (for details see Adler and Papo 1984).

Readjustment was carried down to 4th-order networks, for a total of about 24,000 triangulation points. The 1st-order network has a density of about one point per 100 square kilometers, while at the 4th-order level's density is a 100

times higher. The accuracy of a 4th-order point is estimated to be better than 10 cm (standard deviation), relative to the nearest 1st-order point. The coordinates of the three top orders were released in 1993 and were used mainly for governmental cadastral projects. Since July 1998, every new geodetic project in Israel has had to comply with NIG. The majority of those new projects have been executed on the basis of GPS measurements obtained by using at least three control points with NIG coordinates for a local datum definition. This datum definition is achieved by adjusting the free local GPS network to these control points, using four or seven parameter transformations and ITM projection equations. The results are obviously dependant upon the specific control points used for the project. Due to the low accuracy of the basic control points there are inconsistencies in the order of up to 10-20 cm between neighboring projects.

Due to the high density of the population in Israel, land is quite expansive. In view of the high cost of land and in order to prevent boundary disputes between neighbors, the ultimate goal of the Survey of Israel is to define the cadastral boundaries with an accuracy of 5 cm, at a 95 percent confidence level (Steinberg 2001). As explained above, the existing horizontal control network could not meet this goal.

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Therefore, the Survey of Israel had to search for a way to improve the geodetic control.

Options for Improving Geodetic Control

In 1996 the Survey of Israel, together with the Geological Survey of Israel (GSI), established an accurate network of 160 control points for geodynamic research, which included a 1st-order (3D) geodetic control network called G1 (Ostrovsky 2001). Three GPS permanent stations were established at the same time, constituting the basis of an array of permanent GPS stations. Because of its nature, access to most of the G1 network points is difficult, and they are not convenient for everyday use. There was a plan to establish a 2nd-order 3D geodetic control network (G2) for the further densification of the G1 network, which would have added a 10 by 10 km network of easily accessible points. The network was to include about 300 points, serve as an appropriate substitute to the existing network of about 20,000 points, and ascertain the desired accuracy. This plan was carried out only partially, while 25,000 new control points in the 4th to 7th orders were measured by GPS (see above). These points are usually used for densification purposes by traverses and for cadastral and other projects.

The Survey of Israel checks and approves all new control points (totaling approximately 50,000 points), as well as all cadastral projects (about 1,000 per year). It should be noted that in order to utilize the suggested G2 network, a surveyor must operate at least two GPS receivers and utilize at least two G2 control points. However, due to new developments in GPS technology, surveyors will be able to use a single receiver once an array of permanent GPS stations has been established.

The Israeli Active GPS Network (GIAN)

Israel has a network of permanent GPS stations (GIAN) consisting of 13 stations (Figure 1). The network provides a reference frame for precise GPS measurements. It was designed and constructed to serve basic and applied geophysical research, and it will serve as the major geodetic control network of Israel. Point RAMO is the

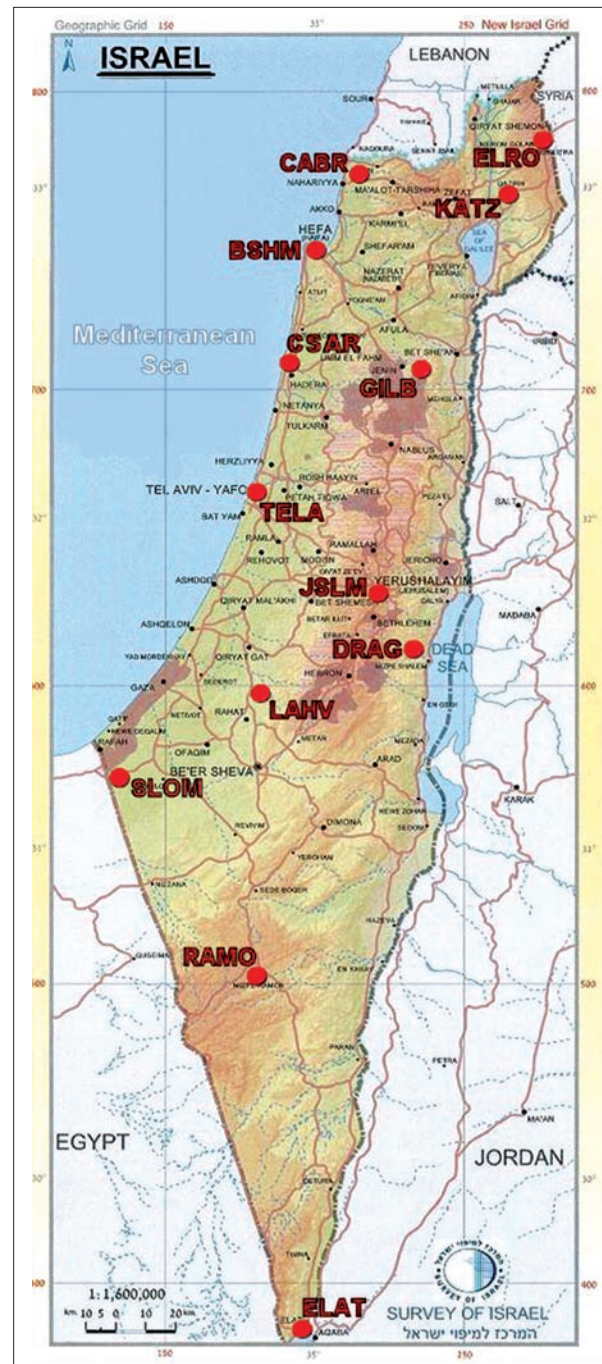


Figure 1. Location of permanent GPS stations in Israel.

official IGS (International GPS Service) station in Israel.

Each station is equipped with a geodetic GPS receiver, chock ring antenna, AC power, and emergency backup power. The GPS receivers are connected to a control room equipped with master and backup servers, through frame relay connections. The GPS data flow to the server in real time using a 5-second receiver sampling rate. GPS raw data are gathered into 3-hour

interval files and posted on the internet. The network of permanent GPS stations is controlled by the RTD software (<http://www.geodetics.com>). The software relies on epoch-by-epoch technology to monitor changes in station coordinates due to deformation and lost qualities.

Until recently, the GIAN network was mainly used for geodetic and geophysical research and less for surveying purposes because of the relatively short observation time span and OTF (On-The-Fly) ambiguity resolution used, which limited the distance to a reference station, and because of the lack of transformation parameters between the WGS84 system and the mapping system. Economically and practically there is no need to increase the number of permanent GPS stations in the northern and central part of Israel much above the current number. However, additional permanent sites may be needed in the southern part of Israel.

In order to enable GPS surveying over the entire state of Israel with direct connection to the permanent GPS network, VRS (Virtual Reference Station) technology has been applied. GPS data for a virtual reference station are computed using data from all the permanent GPS stations in Israel. The user can select a virtual station close to his project, which will supply him with a short observation time span and enable the use of a single-frequency receiver. The VRS data are processed using Geo++ software (<http://www.geopp.com>). In the near future, an RTK (Real Time Kinematic) option will be added to the GIAN network.

Direct connection to the GIAN network or using the VRS together with datum transformations should yield the ITM coordinates for any new control point, with a centimeter-level accuracy.

Datum Definition and Datum Transformation

Geodetic datum is a set of parameters and control points used to mathematically define the size and shape of the Earth, as well as the origin and orientation of the coordinate systems used to map the Earth. Modern geodetic datums range from flat-earth models used for plane surveying to complex models used for international applications, which completely describe the size, shape, orientation, gravity field, and angular velocity of the Earth. The datum is the basis for a plane-coordinate system.

The diversity of datums in use today and the technological advancements that enable global positioning measurements that are accurate up to a decimeter level require careful datum selections and conversions between coordinates in different datums.

If the Global Positioning System is used, GPS positions and vectors are referenced in the WGS-84 datum developed by the U.S. Defense Mapping Agency (http://earth-info.nga.mil/GandG/tr8350/tr8350_2.html). The reference ellipsoid of this datum is practically equivalent to the reference ellipsoid defined by GRS-80, which is the reference ellipsoid of ITM.

Transformation parameters describe the relations between two different datum systems. A typical transformation contains seven parameters: three translations, three rotation angles, and one scale parameter. Three points, at least, which have spatial coordinate values in both datum systems, enable calculating the seven parameters. It is expected that classical networks will differ from modern GPS-based networks, due to the methods of measurement and computation. Between these two systems there may be accumulated errors, local and regional systematic errors, and dynamic deformations.

The set of transformation parameters is determined by a least-squares solution, which minimizes the sum of the squares of the residuals at the corresponding points. The residuals can be used to measure the goodness of fit between the two systems, depending on the quality of both datums. In our case, each point from the GIAN network was connected by GPS observations to the nearest 1st-order control points. A local datum transformation was calculated in order to assign NIG coordinates to each permanent GPS station. Thus, a set of NIG coordinates was produced for the GIAN points. The accuracy of those coordinates is practically equivalent to the accuracy of the classical 1st-order control network.

A permanent GPS-based network is obviously more accurate, reliable, and homogenous than a classical network. Hence the motivation to use a permanent GPS network as the high-level network is obvious. A set of coordinates that was valid for GPS day 275 of the year 2004 (October, 1, 2004) in the ITRF2000 coordinate system was set as the fixed coordinates set for the permanent GPS stations. This set of coordinates defined a new datum for GIAN, called ILGD05, the Israel Geodetic Datum 2005. The ITRF2000 position estimation of the GIAN sites

resulted in a model fitting the position time series estimated daily using static positioning of 24-hour batches of 30-second GPS observations by SOPAC (Scripps Orbital and Permanent Array Center). The model included site velocities, co-seismic and post-seismic deformations, and annual and semi-annual fluctuations. The modeled daily ITRF2000 static positions have a horizontal precision (one sigma) of about 1mm and a vertical precision of about 3 mm, hence providing an accurate datum definition (Bock et al. 2004). The velocity field model was not adopted because of an actual tiny relative movement between the permanent GPS stations (less than 2 mm/year). Therefore, the set of coordinates should be updated periodically, corresponding to the dynamic deformation.

The parameters of a 3D similarity transformation were computed by a conventional seven-parameter fitting between the ITRF2000 datum and the NIG datum, based on 13 permanent stations. The seven-parameter transformation showed residuals at the level of a few centimeters, which is within NIG's accuracy level. The horizontal residuals can be seen in Figure 2. However, these residuals do not indicate a systematic horizontal distortion.

The adjusted plane coordinates, resulting from the seven-parameter transformation fitting process, were adopted as the new plane coordinates for the permanent GPS stations. A second implementation of the similarity transformation between the ITRF2000 datum and the new plane coordinates led to a set of parameters which supplied practically zero residuals in the least-squares process. Using these seven parameters (referred to as the "official parameters") with the fixed ITRF2000 coordinates in any GPS-based project will insure receiving the same ITM coordinates of any GPS-measured point independent on the permanent GPS station that the GPS project is connected to.

Israel's 2005 Grid: An Improved Plane Coordinate System

As mentioned in the introduction, the Survey of Israel replaced the Israeli coordinate system with NIG in 1998. The readjustment of the old network was essential, due to gross errors and inconsistencies in the old computations, and it included many additional observations that were adjusted locally. The decision to modify the coordinate system (at the kilometer level)

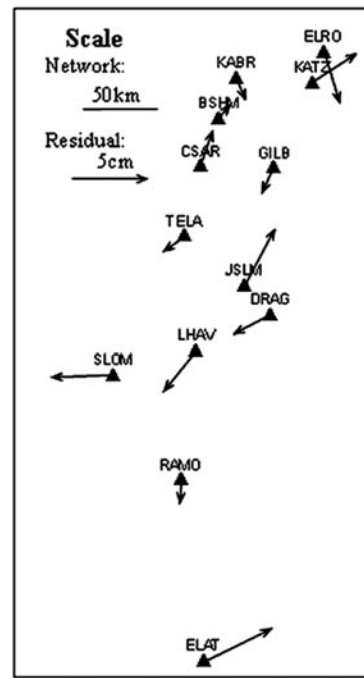


Figure 2. Horizontal residuals resulting from a seven-parameter transformation between the ITRF2000 datum and the NIG datum.

was mainly in order to distinguish between the old and the new values. The change was drastic: a shift of 50 km in the y axis and 500 km in the x axis. At the meter level, a non-regular change of some decimeters in the northern part of Israel, as well as up to several meters in the southern part, was incorporated.

Although a change was introduced to a modern projection (Transverse Mercator instead of Cassini-Soldner spheroidal coordinates), the selected scale factor (1.0000067) seems odd. The central meridian, which in the old system passed through an existing major triangulation point near Jerusalem, was shifted to a non-existent point with some arbitrary longitude (not even a whole number) to facilitate the required rotation. The minimization of coordinate differences between the old and new grids was important, mainly in order to keep the grid lines unchanged on large-scale maps. It is also useful wherever an accuracy of one meter is sufficient.

New dilemmas now became apparent: on the one hand, a state-of-the-art grid was established and in that context it is timely to "fix" the odd scale and to choose the central meridian to be, for example, 35° , which would suit the shape of Israel very well. On the other hand, that choice might cause a big change of coordinates at the decimeters level, with all its disadvantages. A

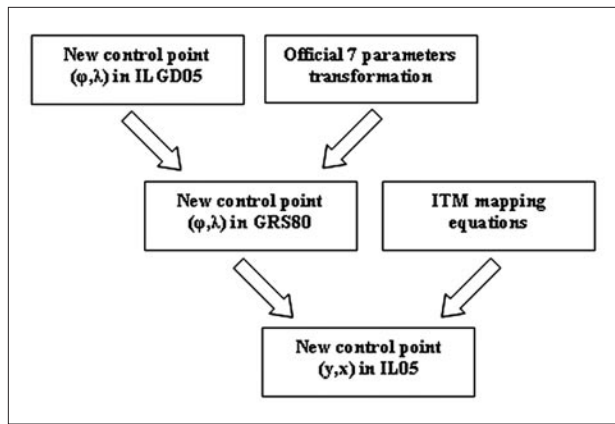


Figure 3. A flow chart for calculating new control points in the improved plane coordinate system of Israel, the IL05.

new shift of the grid at the kilometer level is unacceptable due to the very short time that has passed since the last transit to the NIG (it has not yet been fully assimilated). A change of coordinates at the decimeters level might help to distinguish between the coordinate systems; but it may prove to be disastrous in the case of undetected mistakes (i.e., wrong identification of the grid that the point belongs to).

Also, it is important to note that in case of large differences between the coordinate systems, the Survey of Israel would have to transform all the cadastral boundary coordinates to the new system, before starting to use it. On the other hand, the existing situation is temporarily tolerable even though it does not fulfill the ultimate goal. Considering these issues, the Survey of Israel decided to keep to the existing projections and mapping equations. It did however adopt the adjusted plane coordinates for the permanent GPS stations that resulted from the seven-parameter transformation adjustment process as the basis for a new plane coordinates system named Israel 2005 (IL05). Figure 3 shows the flow chart for calculating the new control point in the Israel 2005 coordinate system.

Transition to a New Era

As of January 2005 every new control point will be based on GIAN permanent GPS stations, either directly (with the aid of VRS when required) or using hierarchical measurements. The higher quality control points in this hierarchy will be measured using GPS only, at least up to the 4th-order (distances of about 1 km between neighboring points). The coordinates of all the old triangulation points will be can-

celed, unless measured in the new system using GPS.

The treatment of the control points measured during the last decade using GPS and their densification (approximately 50,000 points) will be as follows: the first layer of old control points that were used for local datum definitions in each GPS densification project will be re-measured directly, in relation to GIAN. The new (improved) coordinates will replace those that were used for the local datum definition. There are less than 1000 of these points. A further computation will consist of four- or seven-parameter transformations of the free GPS networks mentioned in the introduction, followed by traverse computations (where further EDM densification was carried). The establishment of a new geodetic data-base, which will include the measurement connections between the points, will assist in this process. At the final stage, several average shifts in the y and x axis will be calculated for each cadastral project, based on the coordinate differences of the relevant control points. The accuracy of these shift values is estimated to fulfill the desired ultimate goal of the Survey of Israel.

Conclusion

In order to have an accurate, reliable, homogeneous and consistent national grid, the Survey of Israel established an array of permanent GPS stations equipped with VRS options. This combination created the primary geodetic control network, providing the ability to measure control points with an accuracy of up to centimeter level. Even though this might have seemed like an appropriate occasion to correct some unusual parameters of the mapping equations, practical issues dictated otherwise. These changes will not be implemented, so that no further revolutions will occur in the plane coordinates system that was only officially introduced in June of 1998.

However, the surveyors' work in Israel is being revolutionized: very soon it will be possible to measure control points, cadastral boundaries, and points for topographic mapping, as well as complete engineering surveys within a few seconds, using a single GPS receiver in real time. It should be emphasized that our techniques enable direct access to the plane coordinate system without the need for local transformations from a geodetic coordinates system to the plane coordinates system. It seems to be a

unique solution that may prove useful for many countries and cadastral organizations.

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