Modernizing Greece's Geodetic Infrastructure

HEPOS: Designing and Implementing

HEPOS, the HEllenic POsitioning System, is a nation-wide RTK network that will modernize the geodetic infrastructure of Greece. The establishment of HEPOS is part of the project "Information and Technology Infrastructure for a Modern Cadastre" which is run by Ktimatologio S.A., a state-owned private sector firm that is in charge of establishing the Hellenic Cadastre. HEPOS will contribute to the establishment of the Hellenic Cadastre by offering an inexpensive way of systematic collection of precise and homogeneous spatial data.

By Michail Gianniou

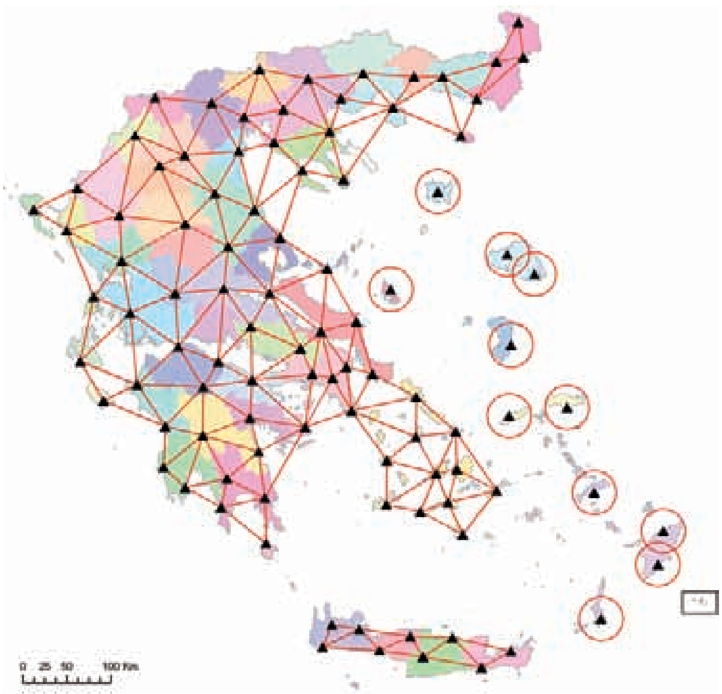

Figure 1: The established HEPOS network consisting of 98 reference stations.

Implementation: framework and timeplan

Ktimatologio S.A. will manage and operate the system offering positioning services to the contractors of the Hellenic Cadastre and to any other GPS users that need sub-meter or centimeter positioning accuracy.

The decision to establish HEPOS was made at the end of 2003. One-and-a-half years was needed to design the system, carry out all the necessary formalities and prepare the tender documents. Following EU policy there was a period of two weeks for public consultation. The tender documents were modified to consider the adopted proposals and the tender was announced following EU procedures in October 2005. The period for submitting offers was 56 days. This seems to be a very short interval for preparing an offer for such a complicated project. However, Ktimatologio S.A. had been in contact with the interested potential bidders since the beginning of 2004, so actually there was much more time for preparation. Due to the formalities that needed to be followed and the complexity of the offers, it was a year before the contract between Ktimatologio S.A. and the selected bidder, Trimble Europe B.V., was signed.

The first reference station was installed four months after the contract was signed. In about another three months all 98 reference stations as well as the control centre were installed. It must be mentioned that the timeplan to be followed was extremely demanding both for Ktimatologio S.A. and the contractor. Nevertheless, the installations were concluded as required and at the time of writing, HEPOS is in the workout phase. The system is planned to be operational by the end of 2007.

Important design and preparation issues

The first step towards implementation of HEPOS was estimation of the budget and the time needed for establishment of the system. Special attention was paid to making realistic estimates, as unrealistic cost and time estimates present serious risks for a project. These realistic assessments were two of the most challenging tasks, because they assume detailed knowledge of the system's architecture. Visits to other operating networks offered valuable information for the design of a system. However, every network is built in a unique way and approaches vary, especially regarding the telecommunication solution which depends on the infrastructure of each particular country. The way of connecting the reference stations to the control centre is very critical for good performance of an RTK network. The data should be transferred to the control centre within one second of the epoch of measurement. In the past this was hard to achieve without using dedicated lines. Today, ADSL-based lines can in many cases be used for connecting the reference stations to the control centre.

A critical task for the design of HEPOS was the estimate of the number of reference stations needed. This was a very challenging issue for many reasons. Firstly, the rough terrain of Greece limits satellite visibility making many places inadequate for installing a reference station. Secondly, the need to cover most of the Greek islands implied multiple restrictions increasing the number of reference stations. As can be seen in Figure 1, 57 reference stations are enough for covering the whole mainland, while 41 additional reference stations are needed to cover the majority of the islands. The geographic distribution of the islands implied the use of 11 single reference stations to cover the islands of the east Aegean Sea. Another aspect that had to be considered was the stability of the reference stations. To ensure maximum stability, the reference station antenna must be

an RTK Network

Figure 2: A typical roof-mounted HEPOS antenna.

Figure 3: A typical wall-mounted HEPOS antenna.

installed on a special construction on a geologically stable area. The use of robust concrete pillars on bedrock is a typical solution. However, the most suitable places from the geological point of view are often unpopulated and do not have the required infrastructure: buildings, power and telecommunication networks. Building infrastructure in such places may need years of preparation. The use of existing buildings, on the other hand, saves time and has many other advantages like protection, easier accessibility etc.

The task of estimating the number of reference stations was further complicated by the tight schedule, which did not allow selection of the sites out in the field. To overcome the issue, a special application which allows the computation of satellite visibility at a particular location was developed by GIS specialists at Ktimatologio S.A. Using this application, the locations of the reference stations could be determined in the office, saving travelling costs and - more importantly- valuable time. The application is capable of computing the visibility for a user-defined elevation angle. This functionality is necessary because the ideal site, which has clear sky above 5 degrees elevation, cannot always be found, especially when other criteria like accessibility and existing infrastructure should be also fulfilled. Where obstacles at 5 degrees could hardly be avoided, the visibility was checked for higher values, like 7 or 10 degrees. Obstacles at these elevations were accepted in difficult areas under the condition that they affect only a limited part of the horizon. Following this procedure, Ktimatologio S.A. reached the "proposed design" of HEPOS that the contractor had to accomplish. This proposed design proved to be a very realistic one, as in most cases a site could be found very close to the proposed one.

An important milestone in the implementation of HEPOS was the decision to proceed with one tender asking for a complete system. The alternative was to proceed with three different tenders: one for the receivers, one for the networking software and one for the telecommunication network. The chosen turnkey solution offers important advantages. Firstly, it reduces the high risk of three tenders. Secondly, it simplifies the compilation of the technical specifications as the desired functionalities of the system can be requested directly without the need to specify the characteristics of the different system components that have to work together. Furthermore, one tender simplifies dramatically the supervision and coordination of the whole project. Another proven choice was to include in the contract an initial period of operation of the system. This way the running costs (telecommunication network and rents for the reference station buildings) are included in the economical offer and can be evaluated.

Other important steps during the preparation were the modification of building regulations to allow the installation of the antennas, the creation of the needed company structure for the operation of HEPOS and, finally, the selection and registration of trademark and www address.

Reference stations

All HEPOS reference stations are equipped with Trimble NetRS receivers with Zephyr Geodetic antennas. The antennas are used together with Trimble spherical domes for stopping snow and other debris from collecting on the antennas. This is important in a network with 98 reference stations where some stations are situated hundreds of kilometers away from the control centre. For the antennas two types of mounts are being used: roof mounts and wall mounts, as can be seen in Figures 2 and 3. Masts of 10 centimeters in diameter are used to ensure stability against wind load. All metal parts installed outdoors are made of stainless alloys.

Inside the building all the reference station equipment is situated in a rack, as can be seen in Figure 4. The racks have fans with thermostats for ensuring normal operating temperature for all devices. Inside a rack the GPS receiver, the UPS, the NPS (Network Power Switch) as well as the telecommunication devices for the primary and the backup lines to the control centre are hosted. The NPS allows rebooting of the devices remotely from the control centre. This enables the operators of HEPOS to solve malfunctions within a short time without actually visiting the reference stations.

Figure 4: The rack used for reference station equipment.

Control centre

The HEPOS control centre is located in an environmentally-controlled room at the headquarters of Ktimatologio S.A. in Athens. Following advice from the IT Department, rack-mountable equipment for the control centre had been required by the technical specifications. Thus, all equipment can be situated in a 42U rack. All six application servers can be controlled by a single KVM switch included in the rack. This approach dramatically reduces the room needed, especially when compared to the use of multiple desktop servers building a "computer pool". For better weight distribution, it was decided to use a second rack for hosting some of the battery packs of the UPS, as the total weight of the UPS and the six battery packs exceeds 700 kilograms, which is too much to be loaded in a single rack together with all the other equipment. A reference station is installed at the control centre, which offers a good reference for estimating the latency of the incoming data from all the other reference stations.

Telecommunication network

The HEPOS telecommunication network consists of several components. The reference stations are connected to the control centre using MPLS VPN ADSL lines. In a few cases, where no ADSL node was available, ISDN connections are being used. The mean latency of the incoming data over a week varies between 0.15 and 0.40 seconds which is considered quite satisfactory. As backup lines, GSM/GPRS connections are being used. The use of completely independent means for the primary and the backup lines eliminates the possibility of a parallel failure of both systems. For serving the RTK users, who connect to HEPOS via GPRS using the NTRIP protocol, an internet line is being used. The same line offers access to the HEPOS web site and the web server that prepares the RINEX files for the post-processing applications. In the case of limited GPRS coverage in some locations, the user can also connect to the control centre using GSM. An access server enables the connection of up to 60 parallel users, a number that can be expanded to 480 by simply adding more lines. As the use of GPRS is more inexpensive than the use of GSM and the coverage of GPRS is improving, it is expected that the request for GSM connections will decrease in the future.

Services offered

HEPOS supports all common GPS positioning techniques. For post-processing applications the user can request RINEX data from any of the 98 reference stations as well as from a VRS (virtual reference station) at any required location within the area of the 87 networked stations. The duration of the RINEX data and the observation interval are selectable. RINEX or Compact RINEX format can be requested. For real-time applications DGPS and RTK are supported. Both DGPS and RTK can be used in single-base mode or in network mode. For network RTK, VRS, FPK and MAC approaches are supported. For real-time applications the data are transmitted in versions 2.3, 3.0 and 3.1 of the RTCM format as well as in the CMR+ format.

Geodetic aspects

From the geodetic point of view, HEPOS should embody the national Coordinate Reference System (CRS) of Greece. On the other hand HEPOS should be able to incorporate a new geodetic datum that will replace the existing one in the near future. For those reasons a GPS campaign has been made for estimating the ETRS'89 coordinates of trigonometric points of the national network and establishing adequate transformation parameters. During this HEPOS campaign, about 2500 trigonometric points were measured. These points are evenly distributed all over Greece and correspond to about 10% of the total number of points in the national trigonometric network. The measurements were taken in less than 6 months using 12 dual-frequency GPS receivers. According to the specifications, the sampling interval was 15 seconds, the elevation mask 15 degrees and the minimum observation time was set to 1 hour. Due to the tight timetable of the project, there was no possibility of setting the minimum observation time higher. The one-hour minimum duration had to be extended under poor DOP or difficult signal reception conditions, due for example to obstacles or electromagnetic interferences. It is considered that, under normal conditions, this observation time is enough to achieve 1-2 centimeter accuracy in the horizontal position and slightly lower accuracy in the heights. These levels of accuracy are satisfactory when measuring a classical trigonometric network, where the heights have been mainly determined using trigonometric leveling techniques. For ensuring as low noise as possible in the observations, the specifications required the use of modern models of GPS receivers. The contractor used 12 Trimble 5700-5800 receivers. The use of receivers of the same architecture and antennas of the same kind was for the benefit of precision mainly due to avoidance of unmodeled differential antenna phase-centre effects. The specifications required that every trigonometric point had to be measured from at least two reference stations and the baseline length was limited to approximately 40 kilometers. The coordinates of the reference stations were computed using EUREF-EPN reference station. These computations were made by the Department of Geodesy and Surveying at the Aristotle University of Thessaloniki, Greece through ongoing research collaboration. The processing of the baselines from the reference stations to the trigonometric points was done by the contractor. All baselines were processed using IGS precise orbits.

As a first step towards the estimation of transformation parameters between ETRS'89 and the national CRS, a seven-parameter similarity transformation was computed over the entire country. Apart from some outliers, the maximum systematic residuals of the transformation are about 2.5 meters. The results of the transformation reveal the degree of internal consistency of the trigonometric network. The spatial distribution of the residuals shows local distortions that are typical for a conventional trigonometric network. Similar distortions have been revealed in many trigonometric networks around the world. Of particular importance is the behavior of the residuals in the Greek islands where the triangulation had to be done over the sea and over distances up to 150 kilometers. Figure 5 shows the residuals of the transformation in the Aegean islands and the surrounding areas.

Beside the nationwide transformation, seven-parameter similarity transformation sets have been computed for smaller areas of the country. In addition, gridding algorithms are being evaluated by the Aristotle University of Thessaloniki. The final transformation model will be defined by analyzing the results of all these calculations. In any case, the implementation of the final model must allow seamless work in daily surveying practice.

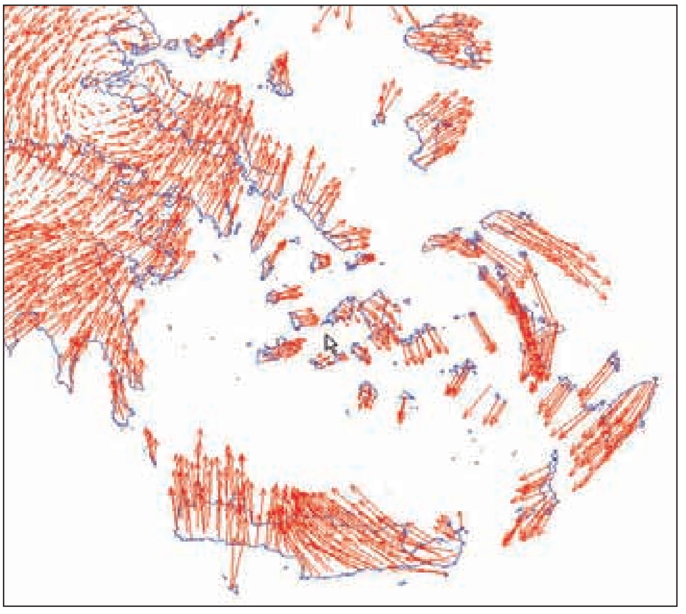

Figure 5: Residuals of the nationwide seven-parameter similarity transformation.

Geodynamic aspects

In the previous section, the way in which the existence of the islands affects the homogeneity of the trigonometric network was described. Unfortunately, another factor has a stronger impact on the quality of the trigonometric network, namely geodynamic phenomena. Greece is, from the geodynamic point of view, the most active country in Europe. Various projects have revealed tectonic displacements in the order of 1-2 centimeters/year. These movements mainly affect the homogeneity of the network over longer distances. For the majority of the points local consistency is maintained. Thus, problems can very occasionally be caused, across an active fault, for example. For regular surveying in restricted areas using trigonometric points, the effects of the geodynamic phenomena can be ignored. However, the operator of a national GNSS network has to take into account the dynamic behavior of the coordinates of the reference stations. Based on EUREF data, the differential movement between northern Greece and Crete, with respect to ETRF2005, amounts to 2 centimeters/year. There are different strategies to deal with this issue. The one to be followed in HEPOS will be decided after some initial time of operation of the network that will allow the estimation of the relative movements among the 98 reference stations of the system. In any case the situation should be treated in a way that guarantees coordinate stability for the user.

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