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Real-time Positioning in ETRS89 using the Hellenic Positioning System

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Summary. – The HEllenic POsitioning System (HEPOS) was established in 2007 and is in use since February, 2008. This article describes the performance of the system in terms of data flow from the reference stations to the Control Centre, RTK initialization time, DGPS accuracy and quality of VRS data. Additionally, some issues concerning the stability of the coordinates of the reference stations are discussed. Finally, aspects related to coordinate transformation between ETRS89 and the national Coordinate Reference System are outlined.

1. – INTRODUCTION

The HEllenic POsitioning System (HEPOS) is an RTK network, which consists of 98 continuously operating GPS stations that cover the entire area of Greece. The network was developed by KTIMATOLOGIO S.A., a state-owned company that is in charge of establishing the Hellenic Cadastre. Data from the reference stations are collected in the Control Centre of the system and processed in real-time. In this way, the users can take advantage of the offered network-based techniques and, at the same time, the system operators can monitor the overall network performance in real-time. From a geodetic point of view, a local realization of ETRS89 was chosen as the geodetic frame of HEPOS. However, Greece has not yet officially introduced a new national Coordinate Reference System (CRS) that is based on the ETRS89 and thus, a coordinate transformation model was developed in order to support the current national CRS.

2. – DESCRIPTION OF HEPOS

2.1. - Architecture of HEPOS

HEPOS consists of 98 reference stations (RS) distributed all over Greece. The sites of the stations are depicted in fig. 1. The connections between stations denote areas where network solutions are available. The 78 RSs located in the mainland and nearby islands and the 9 RSs on Crete form two distinct areas where network solutions are offered. The 11 RSs on the islands of Eastern Aegean Sea are treated as single RSs. All RSs are equipped with Trimble NetRS receivers and Zephyr geodetic antennas with spherical domes. At the Control Center Trimble GPSNet software is used. A more detailed description of HEPOS can be found in Gianniou (2008a) and Gianniou (2009).

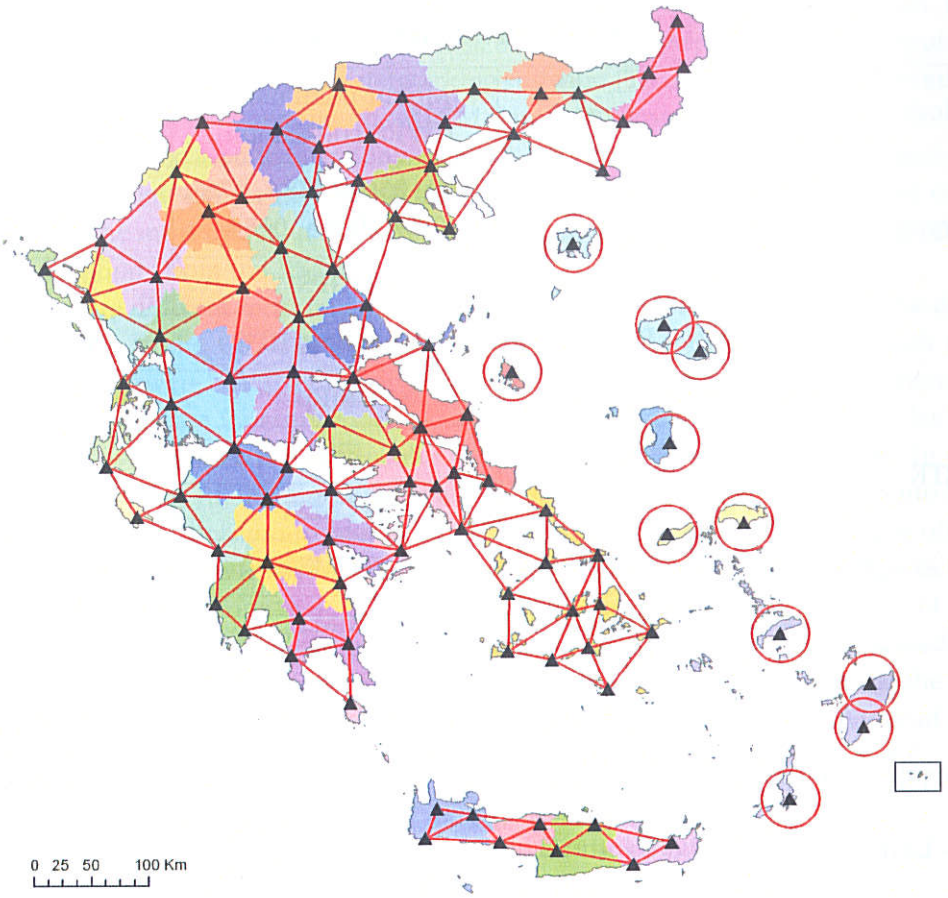

Fig. – 1 The 98 reference stations of HEPOS.

2.2. - Services of HEPOS

HEPOS supports all common GPS-techniques for post-processing and real-time surveying. Specifically, for network-based positioning the techniques of VRS, FKP and MAC are supported. Descriptions of these techniques are given by Landau et al. (2002), Zebhauser et al. (2002) and Wübbena et al. (2001). For post-processing applications, RINEX and Compact RINEX files are provided for RSs and VRSs at observation intervals of 1, 2, 5, 10, 15, 20, 30 or 60 sec.

HEPOS supports 150 parallel real-time users. Both GPRS and GSM connections are supported. Most of the users connect using GPRS. Nevertheless, HEPOS can serve also a large number (i.e. up to 60) of parallel GSM users. The supported techniques for real-time applications as well as the respective formats and mount-point names are given in table 1.

Table 1 – Real-time services offered by HEPOS

Mode	Technique	Format	Mount-point name (GPRS connection)	GSM support
DGPS	Single-Base	RTCM 2.3	019A, 030A, 038A, 076A 079A, 095A, 098A	No
	Network	RTCM 2.3	DGPS	Yes
RTK	Single-Base	RTCM 2.3	Single Base RTK	Yes
	Network (VRS)	CMR+	CMRp	No
	Network (FKP)	RTCM SAPOS	FKP	Yes
	Network (VRS)	RTCM 2.3	RTCM23	Yes
	Network (VRS)	RTCM 3.0	RTCM30	Yes
	Network (MAC)	RTCM 3.1	RTCM31	No

3. – SYSTEM PERFORMANCE

3.1. - Latency of incoming data

A crucial factor for the good operation of any RTK-network is the latency of the incoming data. To compute a position at a specific epoch, the RTK-receiver needs RTCM data for that epoch. In the case of conventional RTK, i.e. RTCM corrections coming from a single RS over radio-link, the time needed to generate the RTCM data at the reference station and to send them to the rover is generally short. On the contrary, the case of a RTK-Network is far more complex. Observations have first to be transferred from the RSs to the Control-Centre (CC), where they are processed to generate RTCM data, suitable for network-based techniques. RTCM data are then transmitted to the user via e.g. GSM or GPRS. The whole procedure takes considerably longer time, compared to the case of conventional RTK. The shorter this overall time is, the better the network performance. The specifications of HEPOS require that the total latency is less than 3 seconds.

The total latency depends mainly on four factors: a) the latency in outputting the data via the receiver's port, b) the time for transferring the data to the CC, c) the computation time at the CC and d) the time for sending the RTCM data to the user. The latency in outputting the data via the receiver's port is negligible for the receivers

of HEPOS (Trimble NetRS). The computation time at the CC depends on the software and the hardware used. In the case of HEPOS six servers of high computing power are used ensuring that the networking software (Trimble GPSNet) is operating effectively. The time for sending the RTCM data to the user depends entirely on the performance of the mobile telephony network. This could be considered as the most critical factor that affects the overall latency. However, the CC has no control over this issue. The most critical among the rest issues is the time needed for transferring the observations from the RSs to the CC.

There are different techniques for estimating the time needed to transfer the data from the RSs to the CC. The easiest way is to use the modules available with the networking software. GPSNet is using a module called Synchronizer, which provides the delay information for every epoch as well as average values. However, the delay for every RS at every epoch is given relative to the «fastest» station at that epoch. In the case of HEPOS the RS 098A is situated at the CC and its data are directly fed into the system, having practically zero latency. Thus, the relative delays of the data of the other RSs with respect to the RS 098A are very close to the absolute delays. Table 2 gives the statistics of the delays for a period of 54 hours describing the typical performance of the system. The values are obtained from the server that is used for collecting and feeding the data to the three network solution servers and the storage server. Note that the RS at the CC is excluded from the statistics, so they describe purely the performance of the ADSL lines (MPLS VPN network) used for the connection of each RS to the CC.

Table 2 – Statistics of the delays when transferring data from the 97 RS to the Control Centre

	Epoch delay (at a typical epoch)	Average delay (over 54 hours)
Mean	0.30 sec	0.24 sec
Min	0.06 sec	0.19 sec
Max	0.53 sec	0.36 sec

3.2. - RTK-INITIALIZATION TIME

Although post-processing techniques are still widely used, the trend is for real-time applications, i.e. RTK and DGPS. An important aspect for RTK users is the time needed to resolve the phase ambiguities, the so-called initialization time. The users of a GNSS-network expect the initialization time to be comparable to that of conventional RTK, i.e. receiving RTCM corrections from a single RS over radio-link.

Table 3 – HEPOS-DGPS vs automous mode: error statistics

Positioning mode	Horizontal error [m]		Vertical error [m]	
	Max ds	σ	Max |dh|	σ
Autonomous	1.70	0.34	4.79	1.71
HEPOS-DGPS	0.54	0.10	1.18	0.34

3.4. - Quality of VRS data

One of the main advantages of HEPOS is the support of network-based techniques. Currently, VRS is the most popular choice. According to the concept of VRS, the VRS observations are generated (using the data of the surrounding reference stations) as if they had been collected by a «physical» GNSS receiver at the same location. In order to achieve this within a network, several conditions must be fulfilled, i.e. use of appropriate modeling, correctly sited RSs and accurately computed coordinates of the RSs.

For assessing the quality of the VRS data produced by HEPOS several tests have been performed. One way to evaluate the positioning precision when using VRS data is by comparing the a-posteriori standard deviations of baselines flowing out from RSs to that of baselines flowing out from VRSs. These tests showed that the a-posteriori sigma values are practically identical (Gianniou, 2008a).

From a user's perspective, the accuracy of the VRS RTK is more interesting than its precision. To assess this level of accuracy the following test was performed. VRS data were computed at a point very close to RS 013A (fig. 5). Next, the baselines from the seven RSs (surrounding 013A, see fig. 5) to the VRS were solved. The baseline length ranges between 32 and 75 Km. Two hours of observations were used for each baseline. The processing was carried out using commercial software and broadcast ephemerides. The coordinates resulting from each baseline solution were compared to the nominal coordinates of the VRS. The differences between the nominal coordinates and the computed coordinates are given in fig. 6. Many other tests were performed in different areas of the network involving VRS data computed for positions far from RSs. Also these tests showed that the precision and accuracy of solutions from VRS stations are comparable. So, it is concluded that the VRS data produced by HEPOS are of high quality.

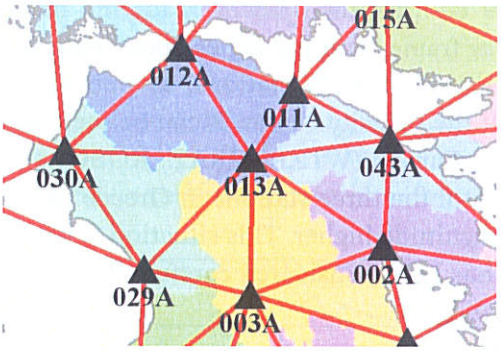

Fig. 5 – The reference stations used for the test.

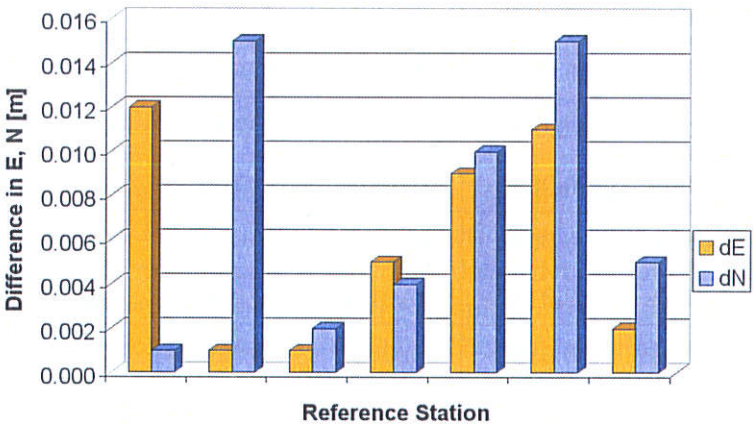

Fig. 6 – Differences between computed and nominal VRS coordinates.

4. – GEODETIC REFERENCE SYSTEM

The coordinate system of HEPOS is called HTRS07 (Hellenic Terrestrial Reference System 2007) and it is a realization of ETRS89. HTRS07 is realized by the coordinates of the RSs of HEPOS. The HTRS07 coordinates are expressed in ETRF2005, which was the current frame at the time of computations. A detailed description of HTRS07 can be found in Katsampalos et al. (2009).

4.1. - Coordinate stability

ETRS89 was introduced by EUREF in order to overcome the dynamic character of ITRS. For daily surveying activities, users do not have to consider any

change in the ETRS89 coordinates. However, for the maintenance of ETRS89, EUREF issues particular frames and publishes coordinate velocities. Table 4 gives the coordinate velocities of six EPN stations, as published by EUREF, and the computed magnitude of the velocity vector. It can be seen that the velocities of the three stations in central Europe (WTZR, GRAZ, KOSG) are in the order of 10-4 m/y, while the velocities of the three stations in Greece (AUT1, NOA1, TUC2) are one or two orders of magnitude higher. This situation is caused by the geodynamic activity in Greece and has been considered carefully for the realization of HTRS07 (Katsampalos et al., 2009).

Table 4 – Velocities of several EPN Stations

EPN Station	V_X [m/y]	V_Y [m/y]	V_Z [m/y]	$\lvert\vec{V}\rvert$ [m/y]
WTZR	0.0001	0.0003	0.0006	0.0007
GRAZ	−0.0003	0.0007	0.0008	0.0011
KOSG	0.0005	0.0003	0.0011	0.0012
AUT1	0.0049	0.0033	−0.0079	0.0099
NOA1	0.0125	−0.0118	−0.0211	0.0272
TUC2	0.0196	−0.0096	−0.0208	0.0301

Besides the motions of Greece with respect to Europe, due to the movements of the tectonic plates, abrupt displacements can occur as a result of strong earthquakes. During the first years of operation of HEPOS, several earthquakes took place. By analyzing the effects of these earthquakes, it was concluded that in most cases no permanent displacements were caused. However, certain strong events caused detectable displacements. For example, the seismic activity that took place in February, 2008 in the Sea SW of Peloponnese caused detectable displacements of 4 RSs (Gianniou, 2008b). Fig. 7 illustrates the Northing of the mostly affected RS (064A) computed in a daily base for a period of 20 days before and 20 days after the event. It can be seen that after the day of the earthquake (denoted in fig. 7 by «EQ») Northing was changed by more than 2 cm.

The dynamic behavior of the coordinates of the HEPOS RSs is an important issue for both the operation of HEPOS and the maintenance of HTRS07. The way to treat the change in coordinates is under consideration and will be decided after having a good knowledge of the velocity field for the whole of Greece.

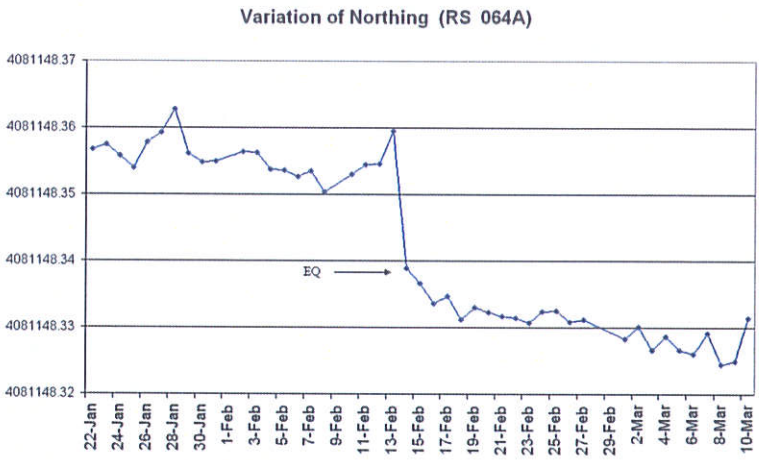

Fig. 7 – Change in Northing of a HEPOS RS caused by a strong earthquake.

4.2. - Coordinate Transformation

For the coordinate transformation between HTRS07 and the official national reference system HGRS87 (Hellenic Geodetic Reference System 1987) a transformation model has been computed. A detailed description is beyond the scopes of this paper and can be found in Katsampalos et al. (2009). This section describes the strategy followed by KTIMATOLOGIO S.A. regarding the development of the model and its implementation in the commercial geodetic GNSS products.

The transformation model was developed by the Department of Geodesy and Surveying at the Aristotle University of Thessaloniki, Greece under a research collaboration. A nation-wide 7-parameter Helmert transformation between HTRS07 and HGRS87 leaves residuals up to 2.5m. Thus, a transformation model that accounts for these residuals must be used. A key issue was the choice of the most appropriate model. Several approaches are used in other European countries, like:

– dividing the country in several areas and using a different 7-parameter model for each area (e.g. De Wulf et al., 2006);

– correction grids for Easting and Northing (e.g. Ordnance Survey, 2005);

– polynomial transformation (e.g. Bahl, 2006);

– affine transformation (e.g. Ollikainen, 2003);

The transformation between HTRS07 and HGRS87 is realized by the combined use of a country-wide 7-parameter transformation and correction grids for Easting and Northing. One of the advantages of this mathematical model was that it had been already implemented in commercial products in other countries and thus, it could be easily incorporated for Greece also. Indeed, a few months after KTIMATOLOGIO S.A. published the transformation algorithm and called the

GNSS manufacturers to implement it into their products, several brands offered this capability. This facilitates considerably the use of HEPOS for positioning in HGRS87, increasing the number of HEPOS users. Additionally, KTIMATOLOGIO S.A. made a standalone software for the transformation freely available at the website of HEPOS (www.hepos.gr).

5. – CONCLUSIONS

HEPOS is an RTK-network supporting all modern GPS-positioning techniques. As the number of professionals who use HEPOS in their everyday activities increases continuously, monitoring of the system becomes increasingly important. The latency of the data flowing from the reference stations to the Control Center is being constantly monitored using the functionalities of the networking software running in the Control Centre of HEPOS. The telecommunication network of HEPOS ensures a mean latency value in the order of 0.25 sec. This low data latency in combination with the well designed architecture of HEPOS secure the optimal performance of the system. This is being verified by the short initialization times achieved by the RTK-users of HEPOS.

The positional accuracy obtained by HEPOS has been assessed by means of various field tests. Using modern geodetic receivers in network-DGPS mode, accuracies of 0.10m and 0.34m (1-sigma values) are obtained for the horizontal position and the height, respectively. The typical accuracy of carrier-phase GPS positioning, i.e. cm level accuracy, is being fully achieved within HEPOS. The quality of VRS-data was proved to be equivalent to that of the physical reference stations.

Besides the positioning efficiency and accuracy offered by HEPOS, a critical factor for its success was the development of a transformation model, which allows positioning in the national coordinate system with an average accuracy level of about 8 cm throughout Greece. KTIMATOLOGIO S.A. followed a well designed plan to ensure that this model would be implemented in the commercial GPS equipment, i.e. RTK-receivers and office software. This was achieved to a very high degree and the users of HEPOS are exploiting the full potential of the system.

6. – ACKNOWLEDGMENTS

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