Evaluation of Reliability of Hellenic Positioning System (HEPOS) in Forest and Forest Area

Chrysanthi Argiropoulou, Kosmas-Aristotelis Doucas

Abstract— Permanent reference station networks have been already established all over the world and used with success in geodetic and surveying applications for high accuracy positioning. Following the example of this development, the Hellenic Positioning System (HEPOS) was created in Greece. The system constitutes the first Greek Network of Permanent GPS Reference Stations. The aim of the paper is to evaluate the reliability of the system in forest and forest lands. So an implementation of the system HEPOS and three RTK techniques of it – Single-Base, technique with Virtual Reference Stations (VRS-RTK) and Network DGPS –took place in five different forest environments: a) in an axis of forest road, b) under the canopy of high forest of broadleaf oak (Quercus frainetto), c) in forest grassland, d) in an urban type environment (buildings in forest environment) and e) a trigonometric point. The measurements were carried out in the University forest of Taxiarhi-Vrastanon Halkidikis. The results shows that the Single Base technique provides more precise results than the VRS technique, while the latter proved more effective than the Network DGPS technique under the canopy of high forest of broadleaf oak (Quercus frainetto) and in an urban type environment (buildings in forest environment). A variation in relation to the above conclusion is observed in measurements on the axis of the forest road, in the forestal grassland and on the trigonometric point, where the Single Base and VRS techniques appear to be equal and in any case superior to the technical Network DGPS technique. As for the measurement environments, the best results of positional accuracy were presented in order of priority, on the trigonometric point, in the forestal grassland, in the urban type environment (buildings in forest environment), in the axis of forestal road and finally under the canopy of high forest of broadleaf oak (Quercus frainetto). In the DGPS technique the line was different with the best results appear in the forestal grassland, then in the trigonometric point, in urban type environment (buildings in forest environment), in the axis of forestal road and finally under the canopy of high forest of broadleaf oak (Quercus frainetto).

***Index Terms—Permanent reference station, VRS, MAC, Single Base, Network DGPS,* RTK, accuracy.**

I. INTRODUCTION

It is known that the positioning precision and accuracy under forest canopy are markedly lower than in areas with unobstructed sky conditions because trees attenuate or brake GPS signals, (Rodríguez-Pérez et al, 2006). Several methods were developed to improve the accuracy and the precision on the positioning in difficult environments as are the forestal ones. One of these is the implementation of the permanent reference stations.

Manuscript Received on May 07, 2015.

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The permanent reference stations were used by government agencies from 1990's and the networking of the permanent reference stations became operational after 2000 (Gianniou and Mastoris, 2006). The basic idea is to use the information from all reference stations in the network and not only from the nearest station. A reference station acts as a central unit (Control Center), which collects data from all stations of the network. The information's are used to create more complete models that allow better estimates of errors. Then the corrections sent by the Control Center to the receivers (Delikaraoglou, 2006). When a user using network GPS techniques (and generally GNSS), does not use data (measurements or corrections) from a single reference station (Single-Base), but uses information from a single processing of measurements from several stations belonging to a network. Following the example of this development, the HEPOS (HEllenic POsitioning System) system was created in Greece by Ktimatologio SA, a state-owned private sector company that is in charge of establishing the Hellenic cadastre. HEPOS constitutes the first Greek Network of Permanent GPS Reference Stations. HEPOS consists of 98 permanent reference stations (RS) distributed all over Greece. The reference stations transmit their measurements to a control centre, which is situated at the headquarters of Ktimatologio SA in Athens. The user connects to the control center to get the required data for real-rime (RT) or post-processing applications (Gianniou, 2008b). Users can receive data either in real time via GPRS or GSMmodem for RTK applications, either via the web server for post-processing applications (Gianniou and Mastoris, 2006). The distances between two reference stations can not exceed 70 km. The 87 of 98 reference stations are networked stations, located in the mainland and used for network solution (VRS, FKP & MAC techniques) and the 11 are single reference stations, sited on the islands of Eastern Aegean Sea and used only for single base solution. There are also 7 reference stations used for Single-Base DGPS solution (Figure 1). The network of permanent GPS stations provides the possibility of positioning techniques such as the network technique RTK, which achieve high accuracies. Such network-RTK techniques are: the Virtual Reference Stations-VRS, the Area correction parameters-FKP (Flachen Korrektur Parameter) and the technical Master-Auxiliary Concept (MAC)-Main and auxiliary stations (Gianniou, 2008a).

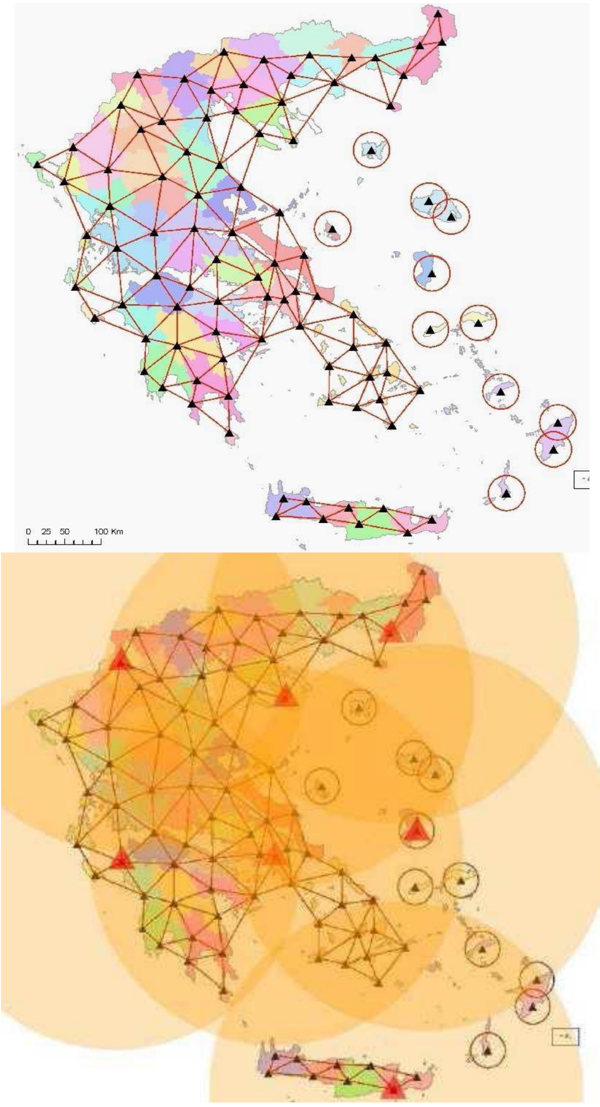

Fig. 1. The 98 permanent reference stations of HEPOS and the 7 permanent reference stations for Single-Base DGPS solution

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. For real-time applications DGPS and RTK are supported. Both DGPS and RTK can be used in single-base mode or in network mode. (Gianniou, 2008c). The HEPOS system provides upper accuracy when the network techniques are use. Using RTK techniques the accuracy in positioning is about few centimetres (cm). Using the DGPS technique the accuracy in positioning is better than meter (sub-meter accuracy), while using the HEPOS system can be rise through the 0.20 meter according to the user equipment (www.hepos.gr, accessed January 06, 2012).

II. STUDY METHODS

A. Material and Methods

The aim of the present paper is to evaluate the reliability of the HEPOS system in difficult environments as are the forestal ones and draw conclusions about whether the use of the HEPOS system is feasible and effective in such difficult conditions. To achieve the above purpose an implementation of the system HEPOS and three techniques of it – Single-Base technique, RTK technique with Virtual Reference Stations (VRS-RTK) and the Network DGPS technique– took place in five different forest environments: a) in an axis of forest road, b) under the canopy of high forest of Quercus frainetto (broadleaf oak), c) in forest grassland, d) in an urban type environment (buildings in forest environment) and e) a trigonometric point. The “Virtual Reference Station” concept is based on having a network of GPS reference stations continuously connected via data links to a control center. A computer at the control center continuously gathers the information from all receivers, and creates a living database of Regional Area Corrections. These are used to create a Virtual Reference Station, situated only a few meters from where any rover is situated, together with the raw data, which would have come from it. The rover interprets and uses the data just as if it has come from real reference station. (Landau et al, 2002). The use of the pseudorange corrections for real time positioning is known by the name of DGPS (Differential GPS) while the use of carrier phase corrections is known by the name of RTK (Real Time Kinematic) (Fotiou and Pikridas, 2006). DGPS is a method to improve the positioning and is a method relies primarily on GPS code measurements. Differential corrections may be used in real time or post-processed (Dana, 1996). The quality of the corrections is a function of the distance between the base station and the rover. (Oloufa and Aty, 2001). Single base technique is a technique that HEPOS system provides. In this method the data calculated from observations of one of the 98 reference stations HEPOS, (the closest). (www.hepos.gr). Much attention we gave to the values of the Position Dilution of Precision (PDOP) as well as to the number of satellites obtained during the positioning of each one point. Studies show that Position Dilution of Precision (PDOP), which is the most common value for expressing the quality of a GPS position, is more elevated under forest cover. PDOP value takes account of each satellite’s location relative to the other satellites in the constellation and their geometry in relation to the GPS receiver. The lower the value, the higher the accuracy. One other main factor in GPS accuracy seems to be canopy type (Piedallu and Gégout, 2005). The measurements took place during the month of May which means that the new oak leaves was deployed although the canopy of the trees was not fully developed. An estimate of the canopy is about the order of 60-70%. This means that the canopy affected the GPS receiver measurements since the phenomenon of multipath effects was strong due to the foliage which plays an important role in signal reception. Specifically the study concerns the determination of coordinates of points in the above five different environmental and topographical conditions, using the total station Leica TRC 407 whose measurements are taken as ¨true values¨ and the GPS receiver Leica GS09_GNSS which functions impeccably with the network of permanent stations of Reference HEPOS. The results were obtained by comparing the measurements of points as recorded by the GPS receiver Leica GS09 GNSS with the measurements of points as recorded by the total station Leica TCR 407. The time we spent at each point was 5 seconds and the measurements were made every 1 second. The programs that used for data processing was Leica Geo Office Tools (LGO - Tools) and the Excel program (Microsoft Office). The Leica Geo Office Tools (LGO - Tools) program used to transfer data from total station to the computer and the Excel program used for processing the results and calculation the errors. To draw conclusions about the accuracy obtained with HEPOS system and to compute the deviation from the true value we calculated the mean square error μ_τ the average of the mean square error μ_M and the positional accuracy error. The possible value L of measurements of total station Leica TCR 407 was using as true value.

The mean square error is given by the expression:

$$\mu_\tau = \pm\sqrt{\frac{(\varepsilon\varepsilon)}{n}} \quad (1)$$

where (ε) are the true differences n observations.
Practically, however, is impossible to calculate the differences (ε), because the true value X is unknown. So for the mean squared error we use the formula:

$$\mu_\tau = \pm\sqrt{\frac{(\varepsilon\varepsilon)}{n}} = \pm\sqrt{\frac{(w)}{(n-1)}} \quad (2)$$

The average of the mean square error is given by the expression:

$$\mu_M = \pm\sqrt{\frac{(vv)}{n(n-1)}} = \pm\frac{\mu_\tau}{\sqrt{n}} \quad (3)$$

(Doucas, 2001). The positional accuracy error defined by the mean square error (RMSEEN) of the coordinates (E, N) measured by GPS and controlled by the total station measurements (Ktimatologio SA, 2007). It is given by the expression:

$$RMSE_{EN} = \sqrt{\frac{(v^2E + v^2N)}{n}} \quad (4)$$

In this research 45 points measured in an axis of forest road, 13 points under the canopy of high forest of broadleaf oak (Quercus frainetto), 9 points in a forest grassland, 7 points in an urban type environment (buildings of the School of Forestry and Natural Environment, Aristotles University of Thessaloniki) and one trigonometric point.

B. Description of Study Area

The measurements were carried out in the University forest of Taxiarhi-Vrastanon Halkidikis (Greece). This forest is situated on the south and southwestern slopes of Mount Cholomonta Halkidikis and is about 73 km from Thessaloniki- Greece. (Administration and Management Fund of University Forests 2001).

III. RESULTS

A. Survey in axis of forest road

A.1. Survey using the Single Base–RTK technique

The station (075A) provided the corrections were located at Stratoniki Halkidikis-Greece, approximately 26 km away. The baseline is considered small to moderate and does not affect dramatically reduce the accuracy. The number of satellites ranged from 5 to 9, and at the most points (18) this number was seven. Only in 17 points of 45 the determination of ambiguity took place. The values of PDOP ranged from 2 to 11. At 32 points the geometry of the satellites was very good (PDOP <4) and the measurements can be considered accurate, at 9 points it was good (PDOP = 4-6) and the measurements can be considered good but not precise, and at 4 points (PDOP = 8-12) was bad and the measurements could be used for rough estimation of the position (Burlet ,2001).

A.2. Survey using the VRS-RTK technique

The number of satellites ranged from 5 to 8, and at the most points (16) this number was six. Only in 21 points of 45 the determination of ambiguity took place. The values of PDOP ranged from 2 to 7. At 28 points the geometry of the satellites was very good (PDOP <4), at 14 points it was good (PDOP = 4-6) and at 3 points (PDOP = 6-8) was moderate and the measurements could be used in calculations but are not accurate.

A.3. Survey using the DGPS technique

The big advantage of this technique is that the

Published By:
Blue Eyes Intelligence Engineering
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measurements are based on code and this fact greatly facilitates the process. The number of satellites ranged from 5 ranged from 2 to 5. At 44 points the geometry of the satellites was very good (PDOP <4) and at 1 point it was good (PDOP = 4-6).

B. Survey under the canopy of high forest of Quercus frainetto (broadleaf oak)

B.1. Survey using the Single Base–RTK technique

The number of satellites ranged from 5 to 8, and at the most points (5) this number was seven. Only in 2 points of 13 the determination of ambiguity took place. The values of PDOP ranged from 2 to 9. At 12 points the geometry of the satellites was very good (PDOP <4) and at 1 point was bad (PDOP = 8-12).

B.2. Survey using the VRS-RTK technique

The number of satellites ranged from 5 to 9, and at the most points (5) this number was seven. Only in 2 points of 13 the determination of ambiguity took place. The values of PDOP ranged from 2 to 5. At 10 points the geometry of the satellites was very good (PDOP <4) and at 3 points was good (PDOP = 4-6).

B.3. Survey using the DGPS technique

The number of satellites ranged from 4 to 9, and at the most points (6) this number was seven. The values of PDOP ranged from 2 to 3, so the geometry of the satellites was very good (PDOP <4).

C. Survey in a forest grassland

C.1. Survey using the Single Base–RTK technique

The number of satellites ranged from 5 to 7, and at the most points (5) this number was seven. The determination of ambiguity took place at all points. This is mainly due to the fact that the surveying was carried out in open sky without trees and other obstacles that affect the quality of the signal. The values of PDOP ranged from 2 to 4, so the geometry of the satellites, at all the points, was very good (PDOP <4).

C.2. Survey using the VRS-RTK technique

The number of satellites ranged from 6 to 7. Five points receive satellite corrections from 6 satellites and four points receive satellite corrections from 7 satellites. The determination of ambiguity took place at all points. The values of PDOP ranged from 2 to 3, so the geometry of the satellites, at all the points, was very good (PDOP <4).

C.3. Survey using the DGPS technique

The number of satellites ranged from 6 to 7, and at the most points (7) this number was seven. The values of PDOP ranged from 2 to 3, so the geometry of the satellites was very good (PDOP <4).

D. Survey in an urban type environment

D.1. Survey using the Single Base–RTK technique

The number of satellites ranged from 5 to 7, and at the most points (4) this number was five. Only in 5 points of 7 the determination of ambiguity took place. The values of PDOP ranged from 2 to 7. At 1 point the geometry of the satellites to 9, and at the most points (21) this number was seven. The values of PDOP
was very good (PDOP <4), at 5 points it was good (PDOP = 4-6) and at 1 point (PDOP = 6-8) moderate.

D.2. Survey using the VRS-RTK technique

The number of satellites ranged from 5 to 7. Four points receive satellite corrections from 5 satellites, two points receive satellite corrections from 6 satellites and one point from 7 satellites. Only in 5 points of 7 the determination of ambiguity took place. The values of PDOP ranged from 2 to 12. At 4 points the geometry of the satellites was very good (PDOP <4), at 2 points it was good (PDOP = 4-6) and at 1 point (PDOP >12) was very bad.

D.3. Survey using the DGPS technique

The number of satellites ranged ranged between 5 (three points), 6 (three points) and 7 (one point). The values of PDOP ranged from 2 to 5. At 4 points the geometry of the satellites was very good (PDOP <4) and at 3 points it was good (PDOP = 4-6).

E. Survey to a trigonometric point

E.1. Survey using the Single Base–RTK technique

The number of satellites was six. The determination of ambiguity took place. The values of PDOP was 3 so the geometry of the satellites was very good (PDOP <4).

E.2. Survey using the VRS-RTK technique

The number of satellites was six. The determination of ambiguity took place. The values of PDOP was 3 so the geometry of the satellites was very good (PDOP <4).

E.3. Survey using the DGPS technique

The number of satellites was six. The values of PDOP was 2 so the geometry of the satellites was very good (PDOP <4). Below is presented the table of results for all measurements that were performed in five different forest environments.

Table I. Results of survey: a) in axis of forest road, b) under the canopy of high forest of Quercus frainetto (broadleaf oak), c) in forest grassland, d) in an urban type environment (buildings in forest environment) and e) to a trigonometric point using the three techniques

TABLE 1						
technique	Errors	Environment of measurement				
		Axis of forest road	Canopy of high forest of Quercus frainetto	Forest grassland	Urban type environment	Trigonometric point
V R S	(μ_τ) on E	0,7444 m	1,1210 m	0,1032 m	0,3478 m	0,037 m
	(μ_τ) on N	0,7472 m	2,3739 m	0,0666 m	0,6627 m	0,041 m
	(μ_τ) on Z	3,8551 m	3,5960 m	1,7890 m	1,8356 m	1,731 m
	(μ_M) on E	0,1109 m	0,3109 m	0,0344 m	0,1314 m	-
	(μ_M) on N	0,1113 m	0,6584 m	0,0222 m	0,2505 m	-
	(μ_M) on Z	0,5746 m	0,9973 m	0,5963 m	0,6938 m	-
	$RMSE_{EN}$	**0,836** m	**1,594** m	**0,117** m	**0,521** m	**0,055** m
S I N G L E B A S E	(μ_τ) on E	0,3764 m	1,1673 m	0,0948 m	0,2978 m	0,044 m
	(μ_τ) on N	0,6965 m	2,0526 m	0,0527 m	0,1748 m	0,025 m
	(μ_τ) on Z	2,8055 m	3,3538 m	1,7605 m	1,6663 m	1,670 m
	(μ_M) on E	0,0561 m	0,3237 m	0,0316 m	0,1125 m	-
	(μ_M) on N	0,1038 m	0,5693 m	0,0175 m	0,0660 m	-
	(μ_M) on Z	0,4182 m	0,9301 m	0,5868 m	0,6298 m	-
	$RMSE_{EN}$	**0,781** m	**1,397** m	**0,103** m	**0,279** m	**0,051** m
D G P S	(μ_τ) on E	0,9891 m	1,3365 m	0,2347 m	0,7347 m	0,421 m
	(μ_τ) on N	0,6814 m	2,3590 m	0,3970 m	0,4176 m	0,400 m
	(μ_τ) on Z	3,7922 m	3,9932 m	1,4812 m	3,2897 m	0,054 m
	(μ_M) on E	0,1474 m	0,3706 m	0,0782 m	0,2777 m	-
	(μ_M) on N	0,1015 m	0,6542 m	0,1323 m	0,1578 m	-
	(μ_M) on Z	0,5653 m	1,1075 m	0,4937 m	1,2434 m	-
	$RMSE_{EN}$	**1,034** m	**1,996** m	**0,399** m	**0,727** m	**0,581** m

IV. CONCLUSION AND RECOMMENDATIONS

The number of received satellites was very satisfying for the Leica GS09_GNSS receiver, because in such environments, GPS receivers are unable to obtain data from all satellites due to the canopy. The forest canopy plays a key role to the determination of ambiguity. Even the more the canopy is dense so much more the ambiguities take place. A prerequisite to the determination of ambiguity is the open sky and no impediment to the reception. When these prerequisites are satisfying, the determination of ambiguity is possible to materialize even with a marginal number of satellites. In many points with great number of satellites and good PDOP the ambiguities was difficult to determinate. That has happened because of the effect of multipath error and the reflected of signals on the surface of the trees. In points at which the determination of ambiguity was materialized with a delay, the results were not good. So if the determination of ambiguity materialized with a delay the measurements may contain large errors. The accuracy in positioning under the canopy of high forest of broadleaf oak (Quercus frainetto), using the HEPOS system, is directly related to the density and the amplitude of the canopy. In fact this relationship is reverse. As the density and the amplitude of the canopy are increasing so the accuracy in positioning is reducing. This is because the signal of satellites under the canopy is attenuated. The accuracy in positioning is directly related to the positioning environment and affected unfavourably by difficult topographical conditions such as the streams and buildings are. In difficult environments the measurements are unsafe and should always be checked. The estimate of the positioning is very inaccurate and this leads us to conclude that it is necessary to pay great attention to the positioning in forest environments. From the comparison of measurements between the receiver GPS Leica GS09 GNSS using HEPOS and total station it becomes evident that the Single Base technique provides more precise results than the VRS-RTK technique, while the latter proved more effective than the Network DGPS technique under the canopy of high forest of Quercus frainetto (broadleaf oak) and in an urban type environment (buildings in forest environment). A variation in relation to the above conclusion is observed in measurements on the axis of the forest road, in the forestal grassland and on the trigonometric point, where the Single Base and VRS-RTK techniques appear to be equal and in any case superior to the technical Network DGPS technique.

As for the measurement environments, the best results, consideration the positional accuracy, were presented in order of priority, on the trigonometric point, in the forestal grassland, in the urban type environment (buildings in forest environment), in the axis of forestal road and finally under the canopy of high forest of broadleaf oak (Quercus frainetto). In the DGPS technique the line was different with the best results appear in the forestal grassland, then in the trigonometric point, in urban type environment (buildings in forest environment), in the axis of forestal road and finally under the canopy of high forest of broadleaf oak (Quercus frainetto).

The implementation of the Network DGPS technique of HEPOS system is easier than the implementation of the VRS and Single Base techniques (in difficult environments as are the forestal ones) because the measurements based on code and the determination of ambiguity it is not necessary. That makes the Network DGPS technique easier and more productive.

ACKNOWLEDGMENT

The authors would like to thank the Ktimatologio SA, for the provision of free, temporary password for application of real-time services of the HEPOS system. This research has been co-financed by the European Union (European Social Fund – ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: Thales. Investing in knowledge society through the European Social Fund.

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