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The Effect of the Canopy of Scots Pines (P. Sylvestris) in Positioning Accuracy Utilizing the Network of Permanent GPS Reference Stations of the Hellenic Positioning System (HEPOS)

Chrysanthi Argiropoulou, Kosmas-Aristotelis Doucas

Abstract— The creation of Permanent Reference Stations and the implementation of network positioning techniques can significantly improve the positioning accuracy in forested conditions. The Hellenic Positioning System (HEPOS) is the first Network of Permanent GPS Reference Stations in Greece. The aim of the paper is to test the positioning accuracy within a conifer forest of Scots pines (Pinus sylvestris) using HEPOS system and an implementation of four Real Time (RTK) GPS techniques: the Virtual Reference Stations (VRS), the Master-Auxiliary Concept (MAC) technique, the Single-Base technique and the Network-based DGPS technique. In the study area, pines with normal growth and pines with stunted growth and bushy appearance were found. So three measurement testing courses were established: first under closed canopy of isolated pines with busy appearance, second above canopy of isolated pines with busy appearance (open sky) and finally under closed canopy of pines with normal growth, that are forest cluster with high canopy density. 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, whose measurements are taken as ¨true values¨. The measurements were carried out in the national forest of Lailia, Serres, Macedonia, Northern Greece.

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

I. INTRODUCTION

GPS has been applied successfully in many areas of the forest industry. Typical applications include fire prevention and control, harvesting operations, insect infestation, boundary determination, and aerial spraying. GPS surveying is becoming the preferred method for forest boundaries determination. With real-time GPS, up to 75% time and cost reductions can be obtained (Ahmed El-Rabbany, 2002). GPS accuracy is much more variable in forested settings than in open conditions (Brian H. Holley and Michael D. Yawn, 2006). 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).

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Except of the forest canopy closure, the canopy type and the presence of the foliage (Stjernberg, 1997, Sigrist et al, 1999, Karsky et al., 2000, Mancebo and Chamberlain 2001, P. Holden et al, 2001, Piedallu and Gégout, 2005, Ch. Argiropoulou et all, 2012), the topography (Liu and Brantigan 1996, Burlet, 2001, Ch. Argiropoulou et all, 2012) and the GPS receiver type and quality (Darche, 1998, Wing et all, 2005) are also some of the main factors that influence the accuracy of GPS positions. Forest vegetation effects are the specific components of multipath (the reflection of satellite signals delaying arrival of signals to a receiver) that account for the majority of errors in GPS applications in forestry, and can be broadly categorized into the following: canopy closure (%), stand density (stems/ha), stand basal area (m^2/ha), stand height (m), species, stand age, and season (Scott D. Danskin et al, 2006). Also multipath is caused by multiple reflections of the signal and is a critical factor for ambiguity resolution. (Hofmann – Wellenhof et al, 2008). The most common value for expressing the quality of a GPS position is also the Position Dilution of Precision (PDOP). The PDOP is the dilution of precision taking into account the easting, northing and altitude direction. It is a unitless measure indicating the quality of satellite geometry. When the satellites are spread around the sky, the PDOP value is low and the computed position is more accurate. In the case when satellites are grouped closely, the PDOP is high and positions are less accurate. As the PDOP is directly related to the position accuracy, more satellites and a lower PDOP will usually mean better accuracy under forest canopy (Pirti, 2008). Studies show that Position Dilution of Precision (PDOP) 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 (Piedallu and Gégout, 2005). It is very important for the surveyors to survey in periods of good satellite geometry because if satellites are well spaced provide better results. Furthermore the GPS timing errors can be minimized and the positioning accuracy can be improved only if at least four satellites are tracked, namely are available in sky for positioning purposes and are used to calculate the position of a point. A prerequisite to ensure an RTK accuracy of a few cm, is to resolve phase ambiguities. That means that it must be ensured "fixed" solution before measuring a point.

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So a key in RTK measurements is the determination of ambiguity. The big question is how long it takes to resolve the ambiguity phase reliably from the moment where the receptor receives signals from the satellites (min 5 satellites). The number of the satellites is the main parameter for the reliable and fast resolution of ambiguity phase. As a general rule we can say that at least six (6) satellites are needed for small bases. RTK applications require short distances to reference stations in order to facilitate ambiguity resolution. The ambiguity inherent with phase measurements depends upon both the receiver and the satellite (Hofmann – Wellenhof et al, 2008).

Several methods were developed to improve the accuracy and the precision on the positioning in difficult environments as are the forestal ones. The creation of global and European Networks of Permanent Reference Stations and the implementation of network positioning techniques are the recent advances in GPS technology. 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 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 uses network GPS techniques (and generally GNSS: Global Navigation Satellite Systems) does not use data (measurements or corrections) derived from a single reference station (Single-Base) but uses additional information resulting from a single data processing from more 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 center, 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, or for post-processing applications via the web server (Gianniou and Mastoris, 2006). The distances between two reference stations cannot exceed 70 km. The 87 of 98 reference stations are networked stations, located in the mainland and used for network solution 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).

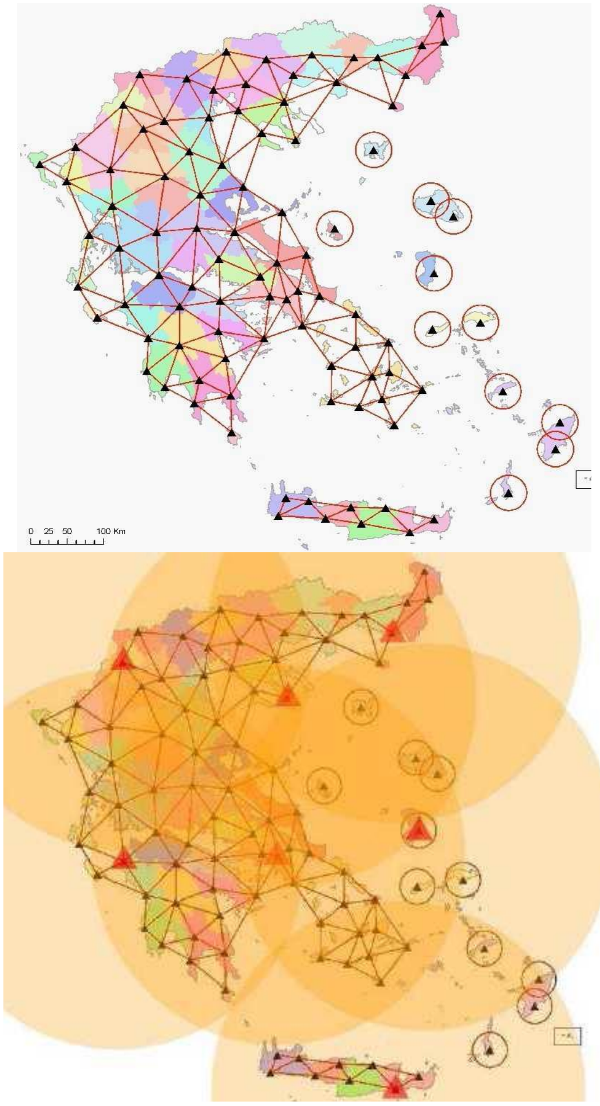

Fig. 1. The 98 permanent reference stations of HEPOS and the 7 permanent reference stations for Single-Base DGPS solution

The network of permanent GPS stations provides the possibility of positioning techniques such as the network RTK techniques, 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). The HEPOS real-time services can be used for measuring using the following GPS-techniques: Single-Base RTK, Network RTK (VRS, FKP and MAC techniques), Single-Base DGPS and Network DGPS. When using the HEPOS real time services, the user receives reference station data, the so-called corrections. These data are transmitted by the HEPOS Control Center in RTCM format (2.3, 3.0, 3.1, SAPOS) as well as in CMR+ format. When the network techniques are used the HEPOS system provides usually higher accuracy.

Using the real-time services of HEPOS and the RTK techniques a user can achieve cm-level accuracy by measuring at an unknown point for a few seconds only. On the other hand using the DGPS technique the accuracy in positioning is better than meter (sub-meter accuracy), while when using the HEPOS system can reach up to 0.20 meter depending on the user equipment (www.hepos.gr, accessed December 27, 2013).

II. Study Methods

A. *Material and Methods*

The aim of the paper is to test the positioning accuracy within a conifer forest of Scots pines (Pinus sylvestris). It must be noted that the experiment took place in a region outside of the network of permanent GPS reference stations of HEPOS system (Figure 2). The aim was a) to checked if the system was able to provide high positioning accuracy even in cases where the positioning carried out in an area out of the network but always in near distance from a single reference station (about 27 Km) and b) to checked if it is possible to use the GPS network techniques in the same positioning conditions. In the study area two forms of Scots pines were found: a) pines with normal growth and height about 15-20 meters and b) pines with stunted growth and bushy appearance and height about 1.5-2.0 meters. Three types of measurements were made: first under closed canopy of isolated pines with busy appearance, second above canopy of isolated pines with busy appearance (open sky) and finally under closed canopy of pines with normal growth that are forest cluster with high canopy density. HEPOS system was used and an implementation of four Real Time (RTK) GPS techniques took place: the Network-based technique with Virtual Reference Stations (VRS), the Network-based technique Master-Auxiliary Concept (MAC), the Single-Base RTK technique and the Network DGPS technique.

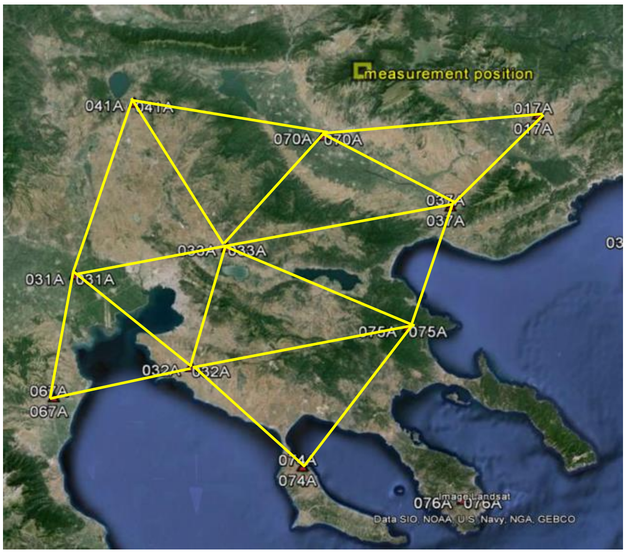

Fig. 2. The outside, of the network of permanent GPS reference stations of HEPOS system, measurement position

The surveying instruments that used for the study were: a) the Total Station LEICA TRC 407 whose measurements are taken as "true values" and b) the GPS receiver Leica GS09_GNSS which functions impeccably with the network of permanent Reference stations of HEPOS. The Leica GS09 surveying system, the controller and the GPRS modem were regulated depending on GPS technique that was applied, depending on the format of data that required and the IP address of HEPOS. The IP address of HEPOS is the address in which the GPRS modem would be connected in order to receive the corresponding data by the control center of HEPOS. So when the receiver was connected with the IP address of network of reference stations HEPOS using the NTRIP (Networked Transport of RTCM via Internet Protocol), the source-table of HEPOS was displayed in the screen of the controller. Corrections are sent via the IP address of the network of reference stations HEPOS. The source-table includes mount-points, which corresponding with each HEPOS technique. So, in this paper, from the Source Table was selected: a) the Mount-point RTCM 2.3 for VRS technique, b) the Mount-point Single-Base RTK for Single-Base RTK technique, c) the Mount-point DGPS for Network-DGPS technique and d) the Mount-point RTCM 3.1 for the MAC technique. Note that the choice of the nearest Permanent Reference Station becomes automatically. 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 measurements took place during the month of June 2013. The measurement GPS time at each point was 1 minute and were made every 1 second. The cut-off angle of the satellite signals was equal to 15 degrees. A good estimator of the impact of forest canopy on GPS positional fixes is the root mean-square-error (RMSE) because it depicts the deviation from the truth and not from the mean as is the case with the standard deviation (Sigrist et al, 1999). The (root) mean-square-error of measurements is a common measure of accuracy and is defined as the sum of variances of random errors (Mikhail & Gracie, 1981). So to draw conclusions about the accuracy obtained with HEPOS system and to compute the deviation from the true value the root mean-square-error (RMSE) and the positional accuracy error (RMSEEN) are calculated. RMSE were therefore computed for all fixes. The root mean square error (RMSE) measuring the distance between the GPS coordinates and total station coordinates. The root mean-square-error (RMSE) of the E (East) component is given by the expression (1):

$$RMSE_E = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(E_i - e_i)^2} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(U_E)^2} \quad (1)$$

where Ei are the total station coordinates, ei are the GPS coordinates and n are the total number of measurements. The root mean-square-error (RMSE) of the N (North) component is given by the following expression (2):

$$RMSE_N = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(N_i - n_i)^2} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(U_N)^2} \quad (2)$$

The root mean-square-error (RMSE) of the H (Height) is given by the expression (3):

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$$RMSE_H = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(H_i - h_i)^2} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(U_H)^2} \quad (3)$$

where Ei, Ni and Hi are the total station coordinates, ei, ni and hi are the GPS coordinates and n are the total number of measurements.

The positional accuracy error defined by the mean square error ($RMSE_{EN}$) of the coordinates (e, n) measured by GPS and controlled by the total station measurements (Ktimatologio SA, 2007). It is given by the expression (4):

$$RMSE_{EN} = \sqrt{\frac{(U_E^2 + U_N^2)}{n}} \quad (4)$$

where UE is equal with (Ei- ei), UN equal with (Ni-ni) and n are the total number of measurements. Much attention was given to the values of the Position Dilution of Precision (PDOP) as well as to the number of satellites obtained during the positioning and used to calculate the position of each one point, and also to the determination of ambiguity. These data were recorded during the execution of the field measurements and studied thoroughly during the treatment.

B. Description of Study Area

The measurements were carried out in the national forest of Lailia, Serres, Macedonia, Northern Greece in the subalpine vegetation zone (zone of cold resistant conifers -Vaccinio-Picetalia) at an altitude between 1588-1750 meters (pines in normal growth) and 1750-1823 meters (pines with stunted growth and bushy appearance) (Figure 3).

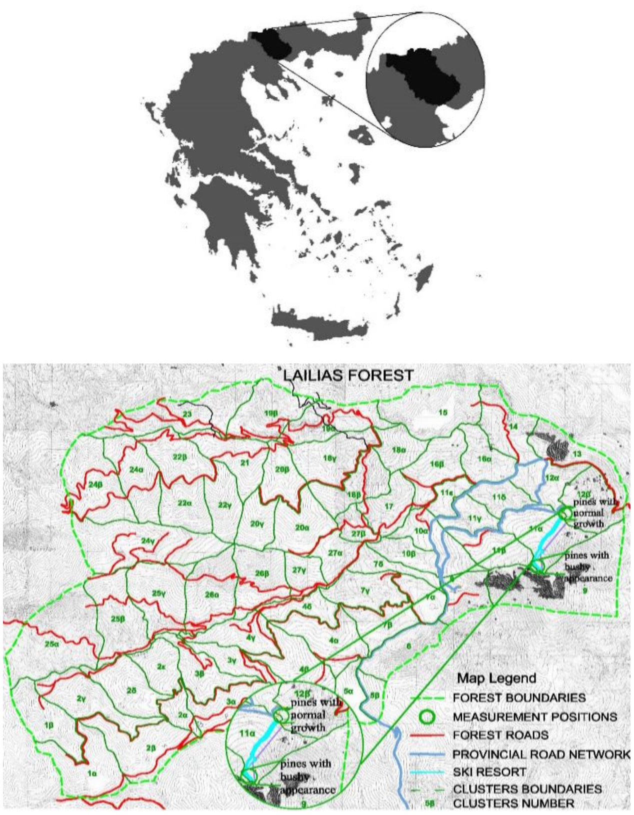

Fig. 3. Study Area

C. Vegetation Sampling Design

To assess the effects of vegetation on GPS position accuracy, sampling was conducted to include measurements above canopy of isolated trees with busy form (in open sky), measurements under a closed canopy of isolated pines with busy form and measurements under a closed canopy of pines with normal growth that are forest cluster (Figure 4).

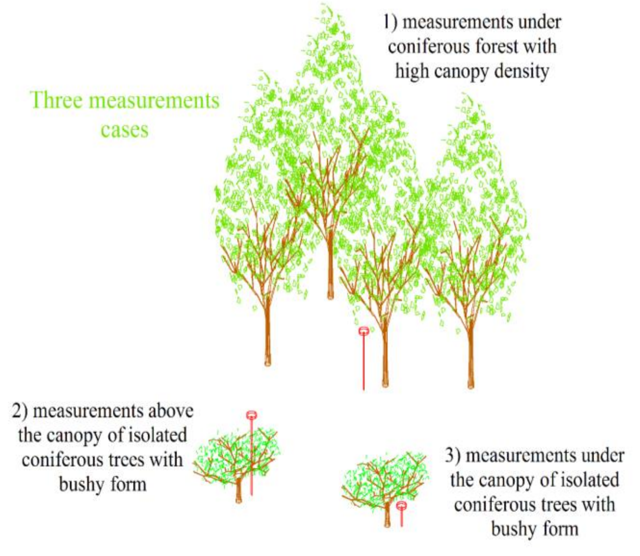

Fig. 4. Three cases of measurements

More specifically the measurements in open sky were carried out up of the canopy of pines with stunted growth and bushy appearance and in positions with trees height less than 2.0 meters. To achieve the above objective receiver antenna was placed above of the canopy of pines by adjusting accordingly the height of the pole to 2.00 m. In this measurement testing course the coordinates of twenty-five points were determined.

The measurements in closed canopy were carried out under the canopy of pines with bushy appearance and under the canopy of the pines with normal growth. To achieve this aim receiver antenna was placed under the canopy of pines with bushy appearance by adjusting accordingly the height of the pole to 1.40 m and under the canopy of pines with normal growth by adjusting accordingly the height of the pole to 2.00 m. In this measurement testing course the coordinates of the same twenty-five points of pines with bushy appearance and the coordinates of forty-four points were determined. Should be noted that the pines with bushy appearance was isolated trees while the pines with normal growth constitute a forest cluster with high canopy density (Figures 5 and 6).

Fig. 5. Measurements above (in open sky) and under the canopy of pines with bushy form

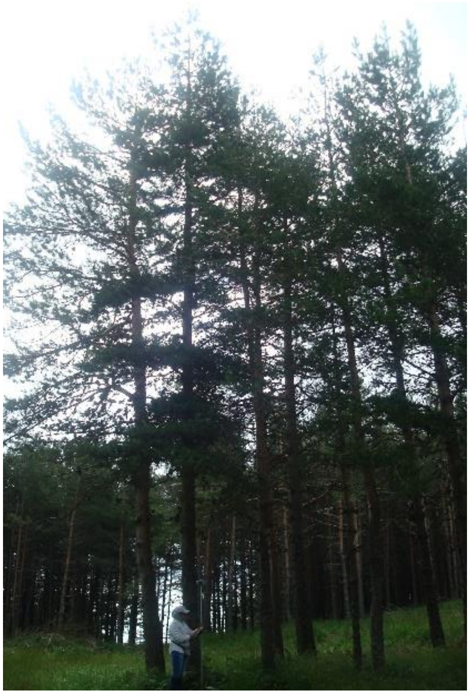

Fig. 6. Measurements under the canopy of the pines with normal growth

III. RESULTS

The number of observed satellites throughout the duration of the study ranged from five to nine. The PDOP indicator received values 2-3 for the 78.5% of points of work of pines with stunted growth and bushy appearance while the remaining 21.5% of points received prices 4-6. The same indicator received values 2-3 for the 74.5% of points of work of pines with normal growth while the remaining 25.5% of points received prices 4-6. Below are presented the tables of results for all measurements that were performed. More specifically the table I gives the number of points in which the determination of ambiguity took place for each technique and measurement position and then the tables II-V summarizes the results from all cases of measurements.

Table I. Number of points in which the determination of ambiguity took place (for all measurement points)

Measurement position		Techniques		
		VRS	MAC	SINGLE BASE
Under closed canopy of isolated pines with busy appearance	Height of the pole equal with 1,4m	6/25	6/25	9/25
Above canopy of isolated pines with busy appearance (open sky)	Height of the pole equal with 2,0m	18/25	15/25	19/25
Under closed canopy of pines with normal growth, that are forest cluster with high canopy density	Height of the pole equal with 2,0m	4/44	5/44	6/44

Table II. Results from all cases of measurement position utilizing the VRS technique

VRS Technique -HEPOS System					
measurement position		RMSE (Errors in meters)			
		E	N	H	EN
Under closed canopy of isolated pines with busy appearance	Height of the pole equal with 1,4m	0,236	0,271	1,625	0,359
Above canopy of isolated pines with busy appearance (open sky)	Height of the pole equal with 2,0m	0,153	0,190	1,658	0,244
Under closed canopy of pines with normal growth, that are forest cluster with high canopy density	Height of the pole equal with 2,0m	1,090	0,941	1,814	1,440

Table III. Results from all cases of measurement position utilizing the MAC technique

MAC Technique -HEPOS System					
measurement position		RMSE (Errors in meters)			
		E	N	H	EN
Under closed canopy of isolated pines with busy appearance	Height of the pole equal with 1,4m	0,278	0,250	1,735	0,374
Above canopy of isolated pines with busy appearance (open sky)	Height of the pole equal with 2,0m	0,271	0,221	1,593	0,350

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Under closed canopy of pines with normal growth, that are forest cluster with high canopy density	Height of the pole equal with 2,0m	0,812	1,189	1,870	1,440

Table IV. Results from all cases of measurement position utilizing the SINGLE BASE technique

SINGLE BASE Technique -HEPOS System					
measurement position		RMSE (Errors in meters)			
		E	N	H	EN
Under closed canopy of isolated pines with busy appearance	Height of the pole equal with 1,4m	0,267	0,292	1,729	0,396
Above canopy of isolated pines with busy appearance (open sky)	Height of the pole equal with 2,0m	0,184	0,258	1,624	0,317
Under closed canopy of pines with normal growth, that are forest cluster with high canopy density	Height of the pole equal with 2,0m	0,512	0,993	2,074	1,118

Table V. Results from all cases of measurement position utilizing the DGPS technique

DGPS Technique -HEPOS System					
measurement position		RMSE (Errors in meters)			
		E	N	H	EN
Under closed canopy of isolated pines with busy appearance	Height of the pole equal with 1,4m	0,311	0,305	1,707	0,435
Above canopy of isolated pines with busy appearance (open sky)	Height of the pole equal with 2,0m	0,289	0,316	1,809	0,428
Under closed canopy of pines with normal growth, that are forest cluster with high canopy density	Height of the pole equal with 2,0m	0,972	1,594	2,450	1,867

The data of the table II-V are represented graphically in diagram of figures 7-10. More analytically the bar with the red color represent the first case of measurements (a) under closed canopy of isolated pines with busy appearance. Respectively the bar with the blue color represent the second case of measurements (b) above canopy of isolated pines with busy appearance (in open sky) and finally the bar with the green color represent the third case of measurements (c) under closed canopy of pines with normal growth, that are forest cluster with high canopy density.

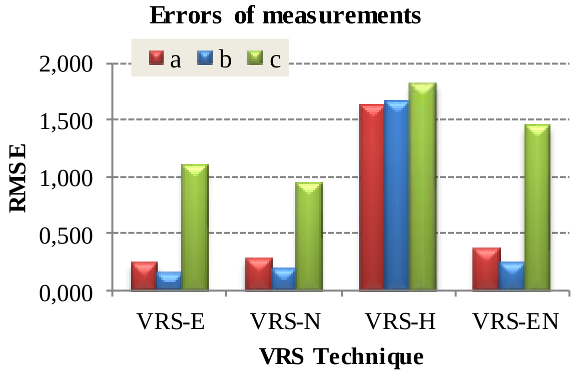

Fig. 7. Errors (RMSE) of all cases of measurements utilizing the VRS technique

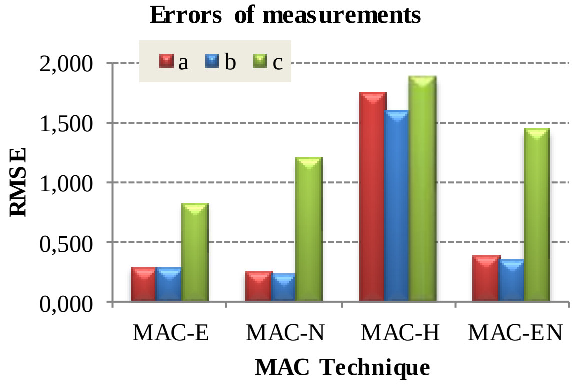

Fig. 8. Errors (RMSE) of all cases of measurements utilizing the MAC technique

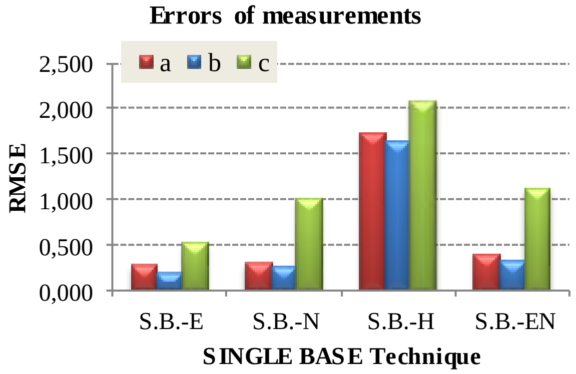

Fig. 9. Errors (RMSE) of all cases of measurements utilizing the SINGLE BASE technique

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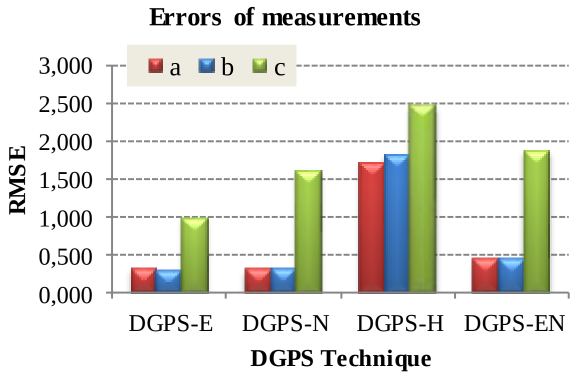

Fig. 10. Errors (RMSE) of all cases of measurements utilizing the DGPS technique

IV. Conclusion and Recommendations

The number of received satellites was very satisfying. In such environments, GPS receivers are unable to obtain data from all satellites due to the canopy. Although, in the forest the minimum requirements for the geometry of the satellites are not satisfied, the values of the PDOP indicator was very satisfactory. In many points with great number of satellites and good PDOP the ambiguities were difficult to determinate. We believe that this has happened because of the effect of multipath error and the reflected of signals on the surface of the trees. 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 (Table I). 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. The height and the condition of the trees (isolated trees or trees as a part of a stand) affect the accuracy in positioning. As the height of the trees increases so the accuracy is reducing. If the trees are isolated the accuracy is improved. If the trees are part of a stand the accuracy is lower than in isolated trees. As for the effects of the canopy, the best results, consideration the positional accuracy, of the implementation of all of the techniques, presented, in order of priority, a. above canopy of isolated pines with bushy appearance (open sky), b. under closed canopy of isolated pines with bushy appearance and c. under closed canopy of pines with normal growth, that are forest cluster with high canopy density (almost 100% canopy closure). Between open sky and close canopy of isolated trees the $RMSE_{EN}$ decreased by 0.115 m with the implementation of VRS technique, 0.024 m with the implementation of MAC technique, 0.079 m with the implementation of Single Base technique and 0.007 m with the implementation of DGPS technique. The above deviations are very small and we can say that the positioning on individual trees, even if they are high, can be done with a small degree of precarity. The $RMSE_{EN}$ between the open sky (isolated trees) and close canopy of pines with normal growth that are forest cluster decreased by 1.196 m with the implementation of VRS technique, 1.09 m with the implementation of MAC technique, 0.801 m with the implementation of Single Base technique and 1.439 m with the implementation of DGPS technique. Between close canopy of isolated trees and close canopy of pines with normal growth that are forest cluster the $RMSE_{EN}$ decreased by 1.081 m with the implementation of VRS technique, 1.066 m with the implementation of MAC technique, 0.722 m with the implementation of Single Base technique and 1.432 m with the implementation of DGPS technique. Results shows that the accuracy in positioning under the canopy is directly related to the density and to 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. Also the accuracy in positioning is much higher when the forest trees are isolated than when they are part of stand. The VRS technique provides more accurate results (in terms of the positional accuracy error-$RMSE_{EN}$) while the DGPS technique provides the worse results than the other techniques. The results showed that the HEPOS system provides the possibility of utilization of GPS network RTK techniques and also provides high positioning solutions even in the case that the positioning carried out in a region outside of the network. Consequently the HEPOS system can cope perfectly even in difficult surveying conditions, such as the positioning determination outside of the area of the network of permanent GPS reference stations and difficult surveying environments as are the forestal ones. The accuracy of positioning at the cases of above and under the canopy of isolated trees was about 0.30 meters in both East and North component and close to the meter in Height which is consistent with the declared accuracy of the HEPOS System. The accuracy of positioning in close canopy of pines in normal growth forms forest stands, on the other hand, was close and above the meter which suggests the effect of the canopy in positioning accuracy.

V. Acknowledgment

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