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FACTORS THAT AFFECT THE PRECISION OF POINT COORDINATES TAKEN WITH GPS EQUIPMENT IN MOUNTAIN AREA OF BRAŞOV COUNTY

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Abstract

The paper aims to identify and analyse factors that affect the precision of determination in the horizontal plane of points, located within a larger forest area in Brasov county.For this purpose 2704 point where measured using a GPS equipment. The precision of such measurements is affected by a series of factors like the forest canopy and the terrain orography. The coordinates of the points were obtained using the semi-kinematic method, Stop&Go with post-processing, which has an average precision, acceptable in this field. The points were then grouped according to the following criteria: localization, forest formation, orography, exhibition (S-N, E-V), forest consistency (<0.7, 0.7-0.8, 0.9-1.0), tree age (21-40 years, 41-60 years, 61-80 years, 81-100 years, >100 years).The points have been processed using software AutoCAD Map 3D and specific modules of ArcGIS. Data have been processed using a statistical program, Statistica 8.0. The distributions were analysed using several statistical indicators (maximum, minimum, mean, standard error of mean, mode, frequency of mode, standard deviation, coefficient of variation).Accuracies obtained were analyzed both for each category as well as for combinations of 2, 3 and 4 factors.After analysing all the results obtained, it can be expressed the idea that, on the whole, the accuracy of determining the point coordinates in forest lands is relatively good and that there are rare cases where exaggerated values are obtained.

Key words*: GPS, precision of measurements, statistical analysis, GIS*

INTRODUCTION

Once the property law had been adopted problems regarding the division of surface appeared. Given the great number of land owners it was necessary to establish and measure forest areas within the properties (Tereşneu et al, 2011). In this purpose the use of total station in mountain areas is not indicated and the use of photogrammetric methods is too expensive (Boş, 2011). The use of the GPS system is more suited for this situation, but the downside for this approach is that there exists, in these circumstances, a series of factors which affect the precision of measuring. Aside of the delays in the ionosphere and troposphere, of the ephemerides, the difference between the satellite and the receiver watch (Păunescu et al, 2012), the number of visible satellites (Wang et al., 2014), the precision can be affected by the forest canopy (Ordonez Galan et al, 2013, Weilin et al, 2000, Zhang et al, 2014), the terrain orography (Tereşneu, 2011, Tereşneu et al., 2011), the composition Ordonez Galan et al, 2011, Yosimura and Hasigawa, 2003) and the age of the forest. The paper aims to identify and analyse factors that affect the precision of determination in the horizontal plane of points, located within a larger forest area in Brasov County.

MATERIALS AND METHODS

The research was conducted in a forest area in Brasov County using two dual-frequency GPS receivers (a Trimble ProXT type and a Trimble ProXH type) , the cadastral plans, 1:5.000 scale, ortophotoplans from 2005 and land descriptions. The coordinates of 2704 point were obtain using the direct measuring method. The points were grouped according to the following criteria: localization, forest formation, orography, exhibition (S-N, E-V), forest consistency (<0.7, 0.7-0.8, 0.9-1.0), tree age (21-40 years, 41-60 years, 61-80 years, 81-100 years, >100 years). The data from the GPS receivers were processed using Trimble GPS Pathfinder Office and then were imported in AutoCAD Map 3D, where the thopology was created and the errors were corrected using the ArcInfo and ArcCatalog modules. The GIS project was concluded using the ArcMap module. The statistical analysis was realized using the Statistica 8.0 program (Tereşneu, 2007, Tereşneu et al, 2014).

RESULTS AND DISCUSSIONS

Table 1. Statistic description of observed distribution by location of points

Location of points	Min	Max	Mean	Standard error of mean	Mode	Frequency of Mode	Standard deviation	Coefficient of variation
Forest	0.100	15.400	1.022	0.028	0.600	133	1.007	98.580
Border	0.200	8.200	0.990	0.024	0.500	116	0.762	76.971
Forest Roads	0.100	6.000	0.556	0.041	0.300	60	0.573	103.145
Open wood	0.300	7.000	1.273	0.139	0.600	9	1.141	89.604
Alpine barren zone	0.100	0.500	0.128	0.005	0.100	82	0.056	43.832

Table 2. Mean, quartiles and percentiles depending on location of points

Location of points	Median	Quartile		Percentile			
		Lower	Upper	90.00	95.00	99.00	99.50
Forest	0.800	0.600	1.150	1.700	2.300	6.400	6.900
Border	0.800	0.500	1.200	1.800	2.300	3.900	5.400
Forest Roads	0.400	0.300	0.600	0.900	1.400	3.300	6.000
Open wood	0.800	0.600	1.600	2.400	3.400	7.000	7.000
Alpine barren zone	0.100	0.100	0.100	0.200	0.200	0.200	0.500

The tables presented above show a series of statistical indicators calculated for each category of point locations from the first column. Looking at the values from the eighth column we can state that the standard deviation is achieved for the points located in the forest area and the lowest for the alpine barren zone. The other locations have a standard deviation within the two limits.

The horizontal precision with the highest frequency is 0.1m for the alpine barren zone, 0.3m for forest roads, 0.5m for points located on borders and 0.6m for open woods and forests. We can see that the highest precision is obtained for the alpine barren zone.

By looking at the mean values for the horizontal precision we can state that the location with the highest precision on average is the alpine zone, followed by the forest roads. We can see that for the mean for the border, open wood and the forest area exceeds the value 1.000. Because of the high values of the coefficient of variation we can't use the mean to describe the experimental distributions. Even lower values for the coefficient of variation are obtained for the points situated in the alpine zone (43.8%).

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Other statistical indicators like the median, the quartile, the percentile and the analysis of the cumulative relative frequency distribution are more suitable for describing the experimental distributions.

The graph from figure 1 represents the cumulative relative frequency distribution in the case of the points located in the alpine barren zone. The median has a value close to the arithmetic mean only in the case of the alpine zone, but the difference between the two indicators reaches approximately 0.5 m in the case of open woods. 50% of observed values have a horizontal precision under 0.4 m when the point is located on forest roads and under 0.8 m when the point is located in forest areas, open woods or on the border. 75 % of observed values have a horizontal precision under 0.1 m for the points located in the alpine zone.10% of observed values have a horizontal precision over 0.9 m when the point is located in forest areas, open woods or on the border.

Because the problem of horizontal precision has a major importance in the forestry sector we will treat the points measured in the forest zone separately. For this purpose the points were grouped according to the following criteria: localization, forest formation, orography, exhibition (S-N, E-V), forest consistency (<0.7, 0.7-0.8, 0.9-1.0), tree age (21-40 years, 41-60 years, 61-80 years, 81-100 years, >100 years). The relative frequency distributions for each criterion are shown in figure 2.

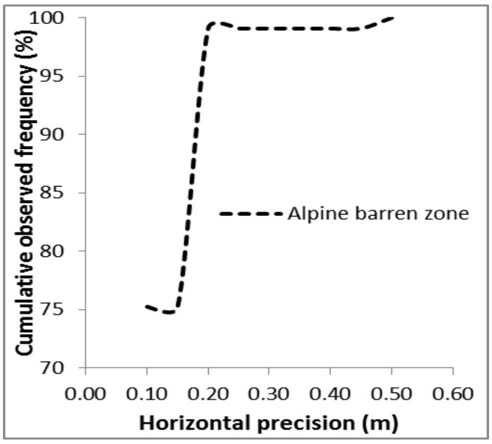


Figure 1.Distribution of cumulative relative frequency distribution by horizontal precision

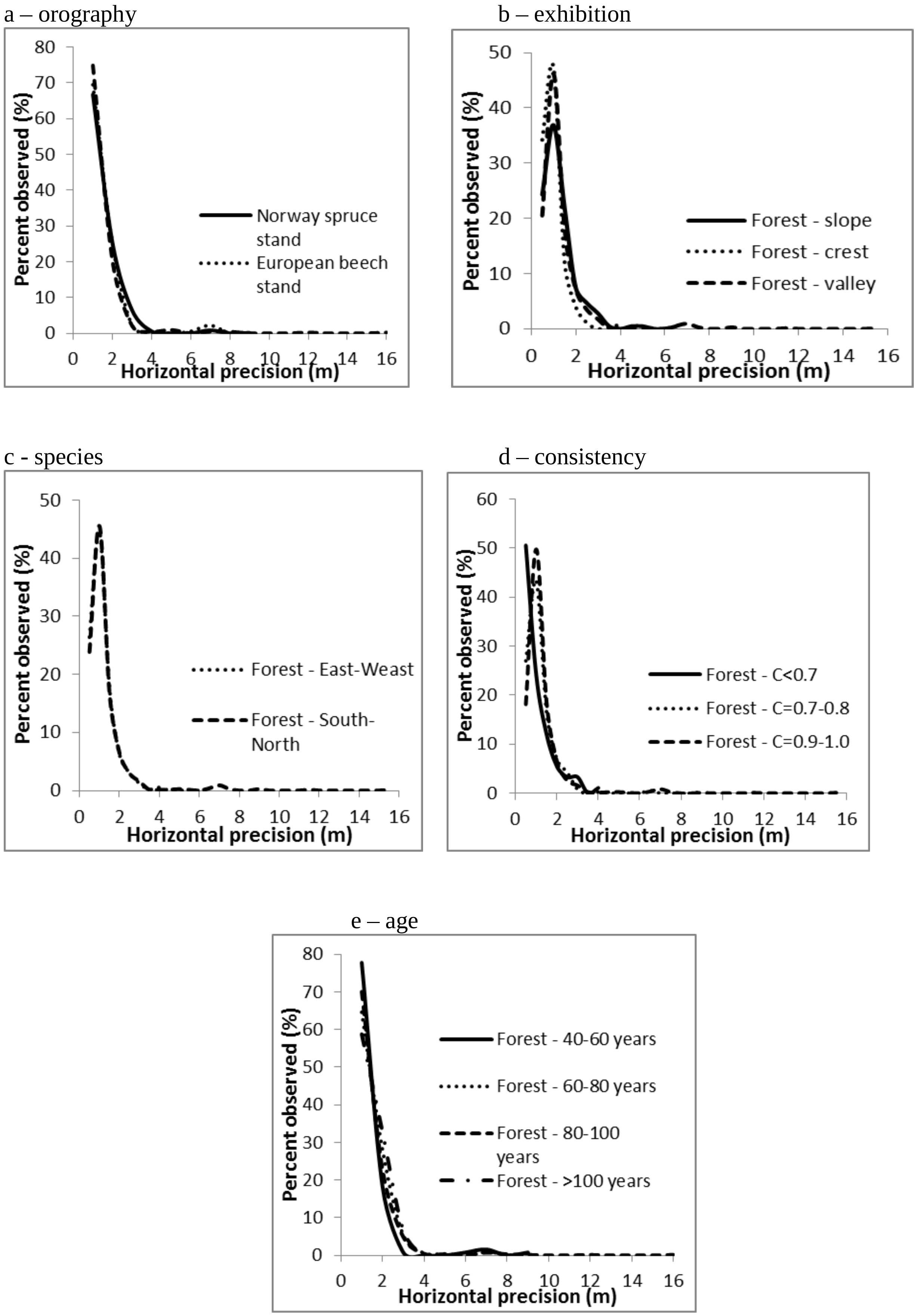


Figure 2. Relative frequency distribution observed for the points in the forest

Table 3. Points located in forest, grouped after five criteria

Number	Criterion	Category
1 2 3	Orography	Forest slope Forest-crest Forest-valley
4 5	Exhibition	Forest E-W Forest S-N
6 7 8	Species	Norway spruce European beech Mixed
9 10 11	Consistency	C<0.7 C=0.7-0.8 C=0.9-1.0
12 13 14 15 16	Age	21-40 years 41-60 years 61-80 years 81-100 years >100 years

Table 4. Statistic descriptive of observed distribution in forest by studied criteria

Nr. crt.	Categories of forests	Min	Max	Mean	Standard error of mean	Mode	Frequency of mode	Standard deviation	Coefficient of variation
1	Forest slope	0.300	6.200	1.077	0.052	0.400	27	0.767	71.246
2	Forest-crest	0.100	3.900	0.774	0.027	0.600	60	0.513	66.313
3	Forest-valley	0.100	15.400	1.129	0.044	0.700	77	1.211	107.285
4	Forest E-W	0.100	6.400	0.922	0.028	0.600	57	0.661	71.696
5	Forest S-N	0.200	15.400	1.091	0.043	0.600	76	1.190	109.057
6	Norway spruce	0.100	8.800	1.044	0.031	0.600	75	0.828	79.358
7	European beech	0.100	8.700	1.046	0.087	0.600	20	1.165	111.380
8	Mixed	0.200	15.400	0.998	0.059	0.400	48	1.213	121.571
9	C<0.7	0.100	3.600	0.818	0.077	0.500	18	0.734	89.725
10	C=0.7-0.8	0.100	8.800	0.973	0.041	1.000	39	0.784	80.585
11	C=0.9-1.0	0.200	15.400	1.102	0.039	0.600	95	1.127	102.268
12	41-60 years	0.100	8.700	0.936	0.105	0.400	19	1.174	125.474
13	61-80 years	0.200	6.900	1.094	0.036	multiple	59	0.802	73.272
14	81-100 years	0.100	15.400	1.034	0.044	0.500	67	1.136	109.826
15	>100 years	0.500	8.800	1.221	0.073	1.000	23	0.944	77.345

The results indicate a low variation of the horizontal precision for the points situated on the ridge, a mild one for the points located on the slope, and a large variation for points in a valley. At the same time, it is observed that the horizontal precision varies less for a terrain that has a favourable exposure in respect to the satellite's movement (E-W) then for a terrain which doesn't have a favourable exposure (S-N). In the case of a mixed forest the variation of the precision is higher than for the Norway spruce and European beech forests, which have the same interval of variation. The differences in consistency have led to a maximum of 3.6 m for forests with consistency less than 0.7, a maximum of 8.8m for forests with consistency between 0.7 and 0.8 and 15.4m forests with consistency greater than 0.9.

The arithmetic mean suggests a better horizontal precision for the points situated on the ridge (0.77m) than for the points located on the slope or in a valley, the last two having close values (1.07m and 1.12m).In the case of a forest area the average horizontal precision is inversely proportional with the consistency of the forest. For the forests with consistency under 0.7 the value of the average precision is

0.81m and it gets lower as the consistency rises.

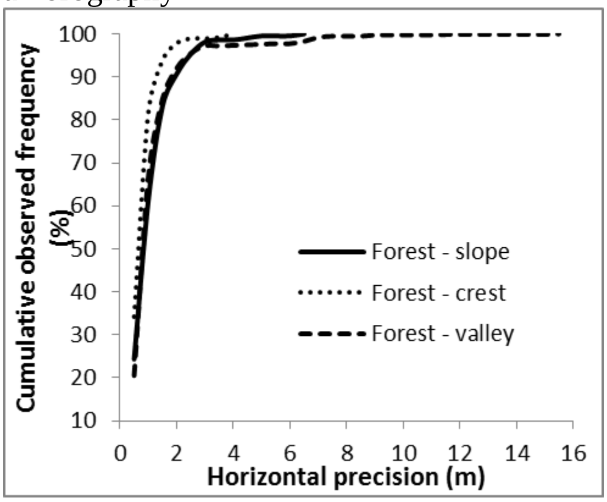
The age of the forest is also a factor which influences the precision. We can see that the mean horizontal precision is directly proportional (in value) with the age. An average precision of 0.93m was obtained for a 41-60 years old forest and a greater value of 1.22m for a 100 years old one.

For most cases, the standard deviation is higher than the arithmetic mean and the coefficient of variation is higher than 100% for European beech forests, mixed forests, forests that are located in a valley and for a 100 years old forest.

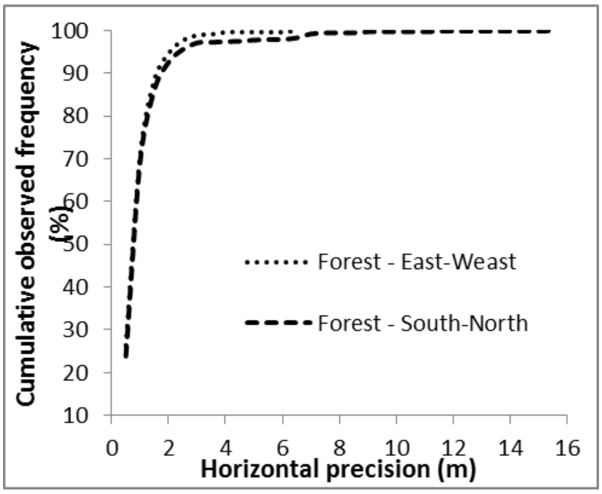
If we analyse the mode values in relation with each criterion we observe the following:

In case of orography the most frequent modal value is 0.7m for a forest located in a valley, 0.6m for a forest on a crest and 0.4m for a forest on a slope.

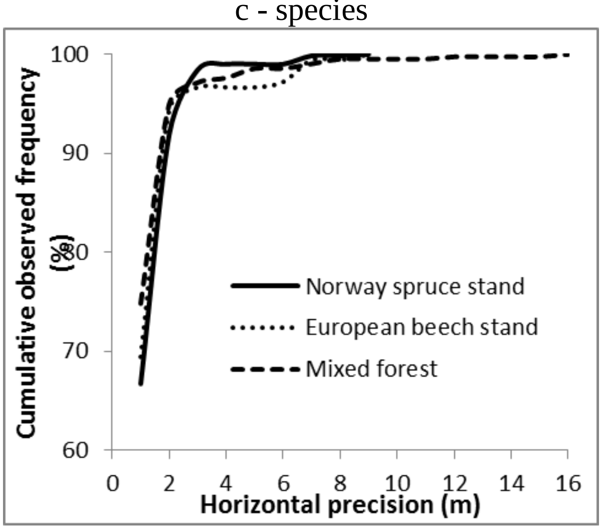
a - orography



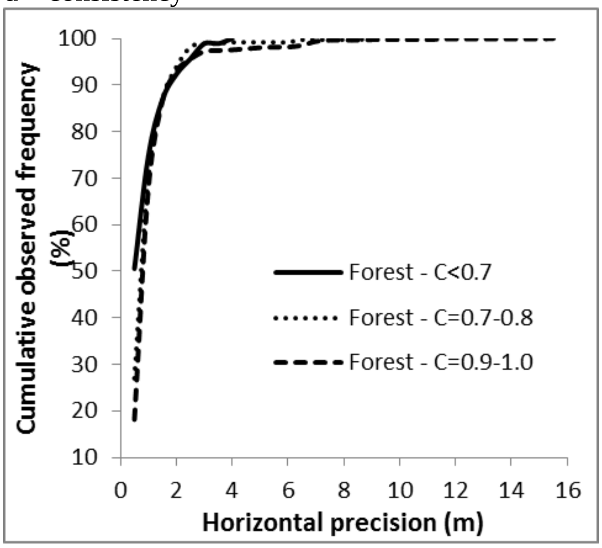
b – exhibition



c - species



d – consistency



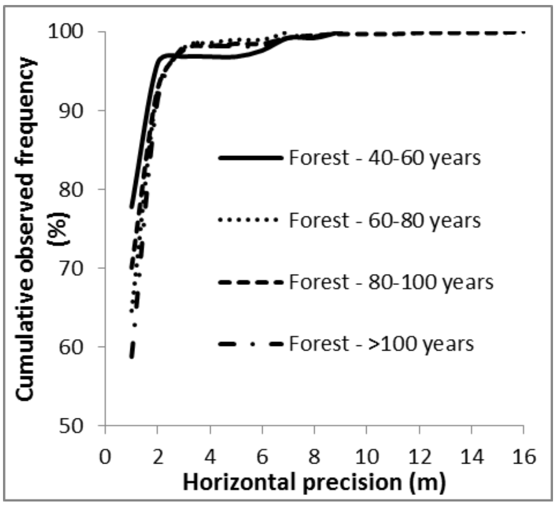


Figure 3. Cumulative relative frequency distribution observed for the points in the forest

In case of exposure the modal value is 0.6m for both cases analysed, but with a higher frequency in the case of S-N exposure (76).
In case of vegetation the modal value is 0.4m for mixed forests, 0.6 for both Norway spruce and European beech forests
In case of consistency the modal value is 0.5m for a consistency less than 0.7, 1.0m for a consistency between 0.7 and 0.8 and 0.6m for a consistency greater than 0.9
In case of age the modal value is 0.4m for the third class of age, 0.5m for the fifth class of age and 1.0m for a forest older than 100 years. To these results we add the analysis of the cumulative relative frequency distribution from figure 3.
Figure 3 reveals that a better horizontal precision in the case of a forest located on a ridge than in the case of a forest located on a valley or a slope (Fig. 3a). We can see that the exposition of the terrain does not affect the precision because of the overlapping of the curves in figure 3.b. For the rest three criteria we can add that better precision is obtained for a mixed forest (Fig 3.c), for a consistency less than 0.7 (Fig 3.d) and for a 41-60 years old forest.

Table 5. Median, quartile and percentile by the categories

Nr. crt.	Categories of forests	Median	Quartile		Percentile			
			Lower	Upper	90.00	95.00	99.00	99.50
1	Forest slope	0.900	0.600	1.300	1.900	2.500	4.100	4.900
2	Forest-crest	0.600	0.500	1.000	1.300	1.600	3.500	3.800
3	Forest-walley	0.900	0.600	1.200	1.900	2.500	6.800	8.700
4	Forest E-W	0.800	0.500	1.100	1.700	2.200	3.100	3.800
5	Forest S-N	0.800	0.600	1.200	1.800	2.400	6.800	8.700
6	Norway spruce	0.900	0.600	1.200	1.800	2.300	3.900	6.600
7	European beech	0.800	0.500	1.100	1.650	2.100	6.600	8.700
8	Mixed	0.800	0.500	1.100	1.600	2.000	6.800	7.100
9	C<0.7	0.500	0.400	1.100	1.800	2.500	3.600	3.600
10	C=0.7-0.8	0.800	0.500	1.200	1.700	2.200	3.900	6.300
11	C=0.9-1.0	0.900	0.600	1.200	1.800	2.300	6.700	7.100
12	41-60 years	0.600	0.400	1.000	1.500	1.900	6.600	8.700
13	61-80 years	0.900	0.700	1.200	1.800	2.300	6.400	6.600
14	81-100 years	0.800	0.500	1.200	1.800	2.500	6.700	7.100
15	>100 years	1.000	0.800	1.400	1.900	2.300	6.300	8.800

According to the median 50% of the values have a horizontal precision under 0.6m for points on a ridge, under 0.9m for points on a slope or in a valley, and under 0.8m for any exposure.The precision isn’t strongly affected by the vegetation (0.8 for European beech and mixed forests and 0.9 for Norway spruce).
In the case of a forest with consistency under 0.7 half of the points have a precision less than 0.8m and less than 0.8-0.9m for a higher consistency. In the case of a 41-60 years old forest, 50% of points have a precision under 0.6m, and a precision between 0.8 and 1.0m for older forests.
According to the 90.00 percentile 10% of points have a precision less than 1.8m for Norway spruce and less than 1.6m for European beech and mixed forests. In the case of a 41-60 years old forest, 10% of points have a precision less than 1.5m, and a precision under 1.8-1.9m for older forests. For 99% of the points the precision is less than 3-4m. The exposure only affects 1% of the points, the precision being less than 6-7m for a point situated in a valley, with N-S exposure in a for European beech or mixed forest, regardless of age. Only for 0.5% of the points the precision is less than 3.6-3.7m for a point situated on a ridge, with E-W exposure in a forest with consistency under 0.7. Precisions less than 8.0m were obtained only for 0.5% of

the points which are located in European beech, in a valley with N-S exposure.
If we take into account only two criteria we can establish the following conclusions.
The horizontal precision is not influenced by the species if the measurements are made in the vegetation season (Crainic, 2011).
The precision is strongly affected by the terrain orography, in the case of norwey spruce. The best results are obtained for the points on a crest, where there is a better satellite signal. Poor results, however pleasing, are also obtained for points located on a slope. The most unfavourable situation is recorded in the valley (Tereşneu, 2011, Tereşneu et al., 2011).
Age does not affect the accuracy of determining the coordinates of points in the norwey spruce. In the case of European beech is observed the same distribution of precision, the precision being higher on a crest and lower on a slope.
In the case of the European beech forest better accuracy has been established for points situated on sunny exposures, to the detriment of those located unfavourable exposure in respect to the satellite's movement(conclusion must be regarded with reserve until another experiments will confirm this).
After consolidating the results obtained from the point of view of three criteria of analysis, it is found several theories.
The best accuracy has been obtained in the case of norwey spruce situated on a hillside, between 21 and 40 years old or between 81 and 100 years old and it is found that the terrain orography has a huge impact on the precision.
In the case of norwey spruce situated on a hill the exposure does not affect the precision, but in the case of an European beech forest a better accuracy is obtained on sunny exposures, a sign that, during the season of vegetation, shaded exposures are unfavourable for obtaining the horizontal coordinates of points using GPS equipment.
Consistency has an influence on the studied parameter in the case of the norwey spruce located in a valley, for which accuracy is much better if consistency values are smaller.
Finally, analysing the influence of four factors, we can get the following conclusions.
The best accuracy is recorded in the case of norway spruce located on a crest or hill, over the age of 60 years, regardless of consistency.
Good precision is obtained in the case of norwey spruce situated on hill, included in 2nd and 5th class of age, regardless of consistency.
Acceptable results are obtained in the case of norwey spruce situated on hill, contained in class 3 of age, whatever their consistency.

CONCLUSIONS

The terrain orography has the most powerful and visible influence on the accuracy of determination in the horizontal plane of coordinates of points using GPS equipment type. A higher precision is obtained in the case of a forest located on a ridge than on a hillside. The forest situated in a valley has the worst precision. The influence of species is distinguished in combination with other factors, explained in following affirmations.
The sunny exposure favours the precision in the European beech forest, while in the norway spruce forest more favourable is a partially sunny exposure.
Forest consistency does not affect the precision of point's determination. This has approximately the same value regardless of the size of the consistency index.
Tree age does not have a visible influence on the accuracy, the values obtained being significantly closer, regardless of age class.
If we would make a ranking of the most favourable locations the first place would go to the alpine barren zone where there is no vegetation to block the signal and where we obtain the highest precision. The second place would go to the forest roads and the third to a Norway spruce forest located on a ridge or a slope, with over 60 years and with favourable exposure in respect to the satellite's movement.
As a result, the development of cadastral plans in such territories, using GNSS technology, is a viable and quick alternative, even if there are very large variations with regard to the level of accuracy, which has been influenced by various factors.

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