Forest canopy influence on the precision of location with GPS receivers

J. TUČEK, J. LIGOŠ

Technical University, Faculty of Forestry, Zvolen, Slovak Republic

ABSTRACT: This article presents the results of a test of three GPS receivers of GIS category (Topcon Turbo G1, Topcon, Magellan ProMark X-CM, Magellan, March II-E, Corvalis Microtechnology) in location under the entire cover of forest canopy. A network of 111 experimental points was established in the territory of Training Forest Enterprise (TFE) of the Technical University Zvolen, Forest District Kováčová, in variable forest and terrain conditions. Location of the points was measured by an exact terrestrial geodetic method and consequently by all receivers. To evaluate the location precision of each receiver we used the method of calculation of individual differences in co-ordinate values for each measurement, and calculation of average differences and their standard deviations for groups of measurements. The values of average co-ordinate errors and testing of the presence of systematic error were also calculated. To evaluate the influence of receiver type, stand age, tree species composition and terrain configuration multi-factor analysis of variance was used. General location error was 7.16 m for Topcon, 5.89 m for Magellan and 5.60 m for March. Difference between Topcon and the other two receivers is statistically significant. The influence of forest stand age is also statistically significant. The results of the test of tree species composition and terrain configuration influence are not unambiguous.

Keywords: GPS; location precision; forest canopy influence; Topcon; Magellan; March

Use of a new equipment on the basis of GPS could positively affect data input process to GIS and its updating as well. It is important that it could decrease the cost of data input and updating, too (MANSON 2000). CORTEAU and DARCHE (1997) note that GPS build connection between map, image or digital database and real, physical location on the Earth surface. A possibility of using such equipment for tracing and navigation (from the map, plan or image to real conditions) is their another important attribute.

GPS issues are not unknown in forestry (especially in a worldwide sense). Some articles were also published in Slovak and Czech journals (ŠEŠULKA, MALINA 1996; HALVOŇ 1998, 2000; VILČKO 1998). Most of these papers bring a description of the theoretical basis of the GPS system and data processing (very detailed and clear is presented by RAPANT 1998a,b). The knowledge of GPS use as an alternative to other types of geodetic measurements prevails in our conditions – geodetic points, ground control point location. Answers to the basic question for forestry are missing – if it possible to use GPS equipment for such measurements (and also for other) under forest canopy (or how the canopy influences the effectiveness and correctness of the measurement).

The knowledge of GPS use for thematic mapping and data collection for GIS digital databases is missing too – e.g. for direct integrated registration of location and attribution of information in digital form.

We presented an analysis of literature knowledge in both these fields in the paper by TUČEK et al. (2000). The conclusion is that the equipment on the GPS basis, sometimes called GPS/GIS, is effective in data collection in forested areas, for example also in forest stand description (forest taxation), in forest detail object location and attribute collection in forestry thematic mapping. In this paper we focus on the first of these issues – analysis of the forest canopy influence on the effectiveness and correctness of the GPS locating.

MATERIALS

Final correctness of the GPS locating is influenced by several factors such as: errors from signal transition through ionosphere and atmosphere, satellite and receiver timer errors, multipath effect errors and also by dilution of precision coming from satellites configuration expressed by DOP constant.

From the literature knowledge analysis we could state that the problem of GPS correctness in forestry has been studied for a long time. Detailed analysis in this field was presented in the paper by TUČEK et al. (2000) with

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ambiguous conclusions. Nevertheless, the basic statement is that measurement under forest canopy is (always) possible to do. Of course, canopy parts – leaves, needles and mainly stems and branches – could block and reflect a part of radio signals and degrade the receiver ability to fix location.

Regarding the literature knowledge it is necessary to note that GPS location correctness is importantly influenced by technical development of the equipment (even though they exist only for a short time). It is necessary to evaluate published data carefully. This assumption is confirmed by WOLNIEVICZ (2001), who states that the receiver age (even the used model of the same type of receiver) plays an important role because hardware and algorithms are more efficient in new equipment. Comparison of solutions is very problematic also from the point of view of the used measurement methods, actual measurements conditions (satellite availability and configuration, signal quality, terrain configuration), measurement regime, user parameters statement, and also the method of data processing. Some authors conclude that these factors could have a bigger influence than forest canopy (for example literature review by FIRTH, BROWLIE 1998). This problem is analysed in detail in the cited article by TUČEK et al. (2000) with the statement that user parameters – DOP to 6, SNR to 4 and elevation mask 10–15º – are regularly used in forestry conditions.

We give details on absolutely determined deviations from correct location in the paper by TUČEK et al. (2000) as well. In this article we give only solutions of very complex and extensive research for Trimble Pro XRS by KULIESIS and BAJORUNAS (2000). These authors introduced the range of location error (determined as a deviation from location by terrestrial geodetic measurement) 0.4–1.28 m with average 0.9 m for open areas, 0.96–1.92 m with average 1.27 m for coniferous stands (pine) and 1.08–4.77 m with average 1.91 m for broadleaved stands. There are also analyses of stand density, age and snow cover influence presented in this paper. Also WOLNIEWICZ (2001) drew similar conclusions determining higher correctness of a new model Trimble PathFinder ProXR compared with older one under forest canopy (4.69 m new and 7.73 old without postprocessing) and 1.21 m (new model) and 1.29 m (older model) after postprocessing. This author also states that receivers using real time DGPS signal of Global Surveyor reached better results (Leica GS5ORT 0.76 m). Postprocessing can improve the exactness of measurement but it induces a delay of data use.

METHODS

We verified the effectiveness of GPS receivers under forest canopy conditions in the territory of Training Forest Enterprise (TFE) of Technical University Zvolen, Forest District Kováčová. It is a typical mountain environment with variable terrain and forest stand conditions. We established a network of 111 experimental points in stands with different characteristics and different terrain configuration. In the same terrain and stand conditions 3–7 points were established. Location of these points was measured by an exact terrestrial method using electronic tachometer Elta 4 (Opton). Measurements of their locations started in the network of existing stabilised points in the TFE territory used for equipment testing, for ground control points, trigonometric points, etc.

Points were stabilised with wood pins and they were marked. We made a detailed description of stand conditions subsequently as it is done during stand description for the preparation of forest management plan (point was the centre of the described area, the 10 closest trees were measured and described – their height, diameter, tree species, etc.).

The Faculty of Forestry of Technical University does not own any GPS receivers. We have established co-operation with Slovak Environmental Agency (SEA) Banská Bystrica, the Ornth Company Banská Bystrica and Geotech Company Bratislava for experiment support. SEA provided a receiver Topcon Turbo G1 (Topcon), Ornth a receiver Magellan ProMark X-CM (Magellan) and Geotech a receiver March II-E (Corvallis Microtechnology). All receivers belong to GIS category that is commonly used for GIS databases data collection and thematic mapping. Basic technical parameters of used receivers are given in Table 1.

Table 1. Basic technical parameters of used receivers

Parameter	Topcon G-1	March II-E	Magellan Pro Mark X-CM
Number of frequencies	1	1	1
Number of channels	8	8	10
Memory amount	2 MB	2 MB	4 MB
Model	Hand-held + external antenna	Hand-held + external antenna	Hand-held + external antenna

We used an original software package provided by the receiver manufacturer for primary processing of measured data – Turbo 1 for Turbo G1, Magellan MSTAR for Magellan ProMark X-CM and PC GPS 3.6 for March II-E. Primary data processing provides co-ordinates in a WGS-84 co-ordinate system. Their transformation into the Slovak (Czech) national cartographic projection SJTSK (System of Trigonometric and Cadastral Network) was made in DatTra transformation software (DatTra™).

Differential GPS method with postprocessing was used in subsequent measurement processing. We used a reference basic station of SEA in Banská Bystrica at the distance of about 20 km from the territory of measurements. The experiment was carried out in September and October 2000 in the full in-leaf season. We used uniform determination of user parameters – 60 observations, DOP 6, elevation mask 15º for all receivers and measurements.

We used two methods for experimental result processing – precision of the location by individual GPS receivers and influence of the forest canopy and terrain configuration evaluation.

We compared the values of co-ordinates for all experimental points measured with GPS receivers with their exact values calculated on the basis of terrestrial measurement in the first method according to formulas:

$$\delta x_i = X_{iG} - X_{iGPS} \qquad \delta y_i = Y_{iG} - Y_{iGPS} \qquad \delta z_i = Z_{iG} - Z_{iGPS}$$

where: X_{iG}, Y_{iG}, Z_{iG} – exact, terrestrially measured values of co-ordinates,

$X_{iGPS}, Y_{iGPS}, Z_{iGPS}$ – values of co-ordinates measured with GPS receiver,

i – number of the point.

Exactness of measurements with individual receivers can be evaluated by calculation of the value of average difference and its standard deviation:

$$\delta\bar{x} = \frac{\sum \delta x_i}{n} \qquad \delta\bar{y} = \frac{\sum \delta y_i}{n} \qquad \delta\bar{z} = \frac{\sum \delta z_i}{n}$$

$$S\delta x = \pm\sqrt{\frac{\sum(\delta x_i - \delta\bar{x})^2}{n}} \qquad S\delta y = \pm\sqrt{\frac{\sum(\delta y_i - \delta\bar{y})^2}{n}}$$

$$S\delta z = \pm\sqrt{\frac{\sum(\delta z_i - \delta\bar{z})^2}{n}}$$

We used *T5*-testing for the evaluation of a possibility of systematic error. The basic hypothesis is that the average value of differences is equal to zero:

$$\delta\bar{x} = 0 \qquad \delta\bar{y} = 0 \qquad \delta\bar{z} = 0$$

T-value is used for testing (ŠMELKO 1988):

$$T_x = \frac{\delta\bar{x}}{\frac{S\delta x}{\sqrt{n-1}}} \qquad T_y = \frac{\delta\bar{y}}{\frac{S\delta y}{\sqrt{n-1}}} \qquad T_z = \frac{\delta\bar{z}}{\frac{S\delta z}{\sqrt{n-1}}}$$

We compared these statistical data with critical values of Student's *t*-frequency distribution for the level of significance $t_{0.025}$ and number of degrees of freedom $f = (n - 1)$. If $T < t_{0.025, f}$, we accept the basic hypothesis – that means the systematic error is not statistically significant. If $T > t_{0.025. f}$, we reject the basic hypothesis – that means the systematic error is statistically significant with probability of 95%. In these cases we corrected values of co-ordinates by the systematic error value.

We calculated standard errors of co-ordinates by means of equations:

$$m_x = \pm\sqrt{\frac{\sum \delta x_i^2}{n}} \qquad m_y = \pm\sqrt{\frac{\sum \delta y_i^2}{n}} \qquad m_z = \pm\sqrt{\frac{\sum \delta z_i^2}{n}}$$

$$m_{xy} = \pm\sqrt{0.5\,(mx^2 + my^2)}$$

Calculations of m_x, m_y, m_{xy} were done for each set of measurements (according to the receiver type).

We evaluated the influence of terrain configuration and forest stand characteristics in the second method. We distributed all measurements to the groups according to:

– *Receiver used*
  – Magellan
  – March II
  – Topcon.
– *Stand age*
  – below 35 years
  – 35–70 years
  – above 70 years.
– *Terrain configuration*
  – in valley
  – on slope
  – on ridge.
– *Tree species composition*
  – coniferous
  – broadleaved
  – mixed.

The distribution of measurements according to stand age does not correspond to common forestry schemes. We followed a possibility to establish three categories of forest stands (young, medium-aged, adult) with sufficient number of measured points. The results of measurements were processed as it was described for the first method of evaluation, then for each group except for individual m_{xy} using the calculation for a group of measurements for each point and its average amount. Due to this distinction the average location errors calculated by the first and second method are different. Differences in average values of deviations for groups were processed by analysis of variance ANOVA/MANOVA of STATISTICA package. The method of evaluation of several factors (influence) was used (receiver, terrain configuration, stand age, tree species composition). We want to find if the existing differences are not only random ones.

Basic hypothesis: $H_0 : \mu_1 = \mu_2 = \mu_3 = \mu_4$

Multiple probability tests (Duncan's tests):

$$S^2 = \bar{S}^2_A + S^2_R \qquad S^2 = \frac{\sum (x_i - \bar{x})^2}{n}$$

$$\bar{S}^2_A = \frac{\sum (\bar{x}_j - \bar{X})^2}{m}$$

$$S^2_R = \frac{\sum\sum (\bar{x}_{ij} - \bar{x}_j)^2}{n.m}$$

Test result: $F = \frac{S^2_A}{\bar{S}^2_R} \langle F_{\alpha/2}, f_1, f_2 ; F_{1-\alpha/2}, f_1, f_2 \rangle$

P-level represents probability that we reject the basic hypothesis, or we are wrong.

Table 2. Evaluation of location precision for individual receivers

Conditions	Co-ordinates		Number of obser-vations	Average difference (m)	Average absolute difference (m)	Standard deviation of differences (m)	*T*-test	Hypothesis evaluation	$t_{0.025}$	m_i (m)	m_{xy} (m)
					Magellan ProMark X-CM						
Under canopy	primary	Y		–0.79	4.81	6.82	–1.21	<		±6.87	±5.89
		X	99	0.29	3.47	4.70	0.64	<	1.980	±4.71	
		Z		–13.22	9.30	11.38	–12.12	>		±17.44	–
	corrected	Y		–	–	–	–	–		–	–
		X		–	–	–	–	–	–	–	
		Z		0.00	9.30	11.38	–	–		±11.38	–
Open area	primary	Y		0.50	2.48	2.95	0.48	<		±2.99	±2.89
		X	9	1.79	1.75	2.11	2.40	>	2.306	±2.77	
		Z		–1.74	6.93	8.92	–0.55	<		±9.09	–
	corrected	Y		–	–	–	–	–		–	–
		X		0.00	1.75	2.11	–	–	–	±2.11	
		Z		–	–	–	–	–		–	–
					March II-E						
Under canopy	primary	Y		–0.08	4.42	6.32	–0.11	<		±6.32	±5.60
		X	79	–0.55	3.43	4.75	–0.55	<	1.980	±4.78	
		Z		–10.54	10.21	14.66	–6.51	>		±18.06	–
	corrected	Y		–	–	–	–	–		–	–
		X		–	–	–	–	–	–	–	
		Z		0.00	10.21	14.66	–	–		±14.66	–
Open area	primary	Y		1.42	1.91	1.97	1.25	<		±2.43	±1.96
		X	4	1.20	0.45	0.57	3.62	>	3.182	±1.33	
		Z		0.82	2.64	3.21	0.44	<		±3.31	–
	corrected	Y		–	–	–	–	–		–	–
		X		0.00	0.45	0.57	–	–	–	±0.57	
		Z		–	–	–	–	–		–	–
					Topcon Turbo G1						
Under canopy	primary	Y		–0.70	5.67	7.27	–0.86	<		±7.30	±7.16
		X	76	–1.21	4.68	6.91	–1.58	<	1.980	±7.01	
		Z		–11.22	11.82	17.07	–5.91	>		±20.43	–
	corrected	Y		–	–	–	–	–		–	–
		X		–	–	–	–	–	–	–	
		Z		0.00	11.82	17.07	–	–		±17.07	–
Open area	primary	Y		0.81	8.04	9.93	0.16	<		±9.97	±7.50
		X	5	–1.37	2.53	3.38	–0.81	<	2.776	±3.65	
		Z		–13.63	11.12	12.41	–2.20	<		±18.43	–
	corrected	Y		–	–	–	–	–		–	–
		X		–	–	–	–	–	–	–	
		Z		–	–	–	–	–		–	–

Table 3. Analysis of the equipment influence (without other influences considered)

Receiver	Topcon	March	Magellan
Average location error m_{xy} (m)	5.88	4.43	4.59

Results of significance of differences

	Topcon	March	Magellan
Topcon			
March	0.017033*		
Magellan	0.026646*	0.781475	

*Statistically significant difference

RESULTS

In accordance with description of methods we performed primary processing of measured data with the software delivered by the GPS receiver manufacturer. We employed corrections calculated for the basic (reference) station of SEA by the differential postprocessing method. We transformed such corrected co-ordinates located in WGS 84 to co-ordinates in Slovak (Czech) national cartographic projection SJTK in DatTra transformation package environment.

Deviations of co-ordinates from correct values (calculated by the terrestrial method) for individual GPS receivers were designed to tables and processed as it is stated in the description of methods. Final summary is shown in Table 2. Average co-ordinate errors m_{xy} calculated for receivers using all points are as follows:

Receiver	In stand	On open area
Topcon	7.16 m	7.50 m
Magellan	5.89 m	2.89 m
March	5.60 m	1.96 m

Except for Topcon G1 the results are consistent with logical expectations that the error is higher under the forest stand canopy. In the Topcon case this discrepancy probably stems from a serious unexpected error in data recording or processing that we were not able to find and eliminate. It is to note that the number of measured points for receivers (and also for groups of measurements in subsequent evaluations) was not exactly equal (some measurements at some points were not usable).

If we evaluate a possibility of carrying out measurements under the complete forest cover, our experiment results are positive. Controversial is the question of their exactness, especially if we propose to use location by an GPS receiver for the construction of basic forestry map under valid technical rules in Slovakian conditions. For all receivers and also for all conditions of measurement (see details in next paragraphs) the value of maximum error was exceeded for the 4th ($u_{x,y}$ = 0.26 m) and also for the 5th ($u_{x,y}$ = 0.50 m) class of mapping (Instructions for creation, printing and archiving of state thematic maps in forestry).

If we propose to use GPS receivers for data collection to describe forest stands conditions, locating of elements of so called "forestry detail" that is less important and does not play the role of stand boundaries, ownership boundaries or that is not marked and stabilised in the terrain (e.g. footpaths, logging roads, compartment partitions, regeneration areas, ridges, streams, boundaries of pedological and typological units, etc.), it is possible to evaluate the achieved exactness as satisfactory.

The influence of different stand conditions and terrain configuration on measurement exactness was processed by multifactor analysis of variance. We evaluated all combinations of conditions for which we had a sufficient number of observations (see description of methods). We present the results of evaluation of the influence of used receivers on the location error (as a difference between GPS receiver location and exact terrestrial location) together with the results of statistical significance of differences in Table 3; it shows that the difference in average

Table 4. Analysis of the stand age influence (without other influences considered)

Stand age	Below 35 years	35–70 years	Above 70 years
Average location error m_{xy} (m)	3.42	5.12	6.19

Results of significance of differences

	Below 35 years	35–70 years	Above 70 years
Below 35 years			
35–70 years	0.003511*		
Above 70 years	0.000014*	0.067389	

*Statistically significant difference

Table 5. Analysis of the equipment and stand age influence

Stand age / Equipment	Topcon			March			Magellan		
	below 35 y	35–70 y	above 70 y	below 35 y	35–70 y	above 70 y	below 35 y	35–70 y	above 70 y
Average loc. error m_{xy} (m)	4.76	6.62	5.84	2.39	4.27	6.28	2.96	4.58	6.31

Results of significance of differences

Stand age / Equipment	Topcon			March			Magellan		
	below 35 y	35–70 y	above 70 y	below 35 y	35–70 y	above 70	below 35 y	35–70 y	above 70 y
Topcon / < 35									
Topcon / 35–70	0.100951								
Topcon / >70	0.280901	0.491790							
March / < 35	0.034729*	0.000120*	0.001653*						
March / 35–70	0.658737	0.043437*	0.159486	0.077039					
March / > 70	0.156167	0.751242	0.668708	0.000383*	0.077445				
Magell / < 35	0.104943	0.000998*	0.008764*	0.574320	0.191564	0.002616*			
Magell / 35–70	0.862361	0.077176	0.240232	0.046139	0.763705	0.126914	0.129820		
Magell / > 70	0.163586	0.757355	0.668565	0.000380	0.078485	0.974920*	0.002659	0.129969	

*Statistically significant difference

error for March (4.43 m) and Magellan (4.59 m) is not statistically significant. But the difference of both these values in comparison with Topcon average error (5.88 m) is statistically significant.

Table 4 shows the results of evaluation of stand age influence. Average differences in measurements in stands at the age below 35 years (3.42 m), between 35 and 70 years (5.12 m) and above 70 years (6.19 m) confirmed a logical

Table 6. Analysis of the influence of tree species composition and stand age

Species/ Stand age	Coniferous			Broadleaved			Mixed		
	below 35 y	35–70 y	above 70 y	below 35 y	35–70 y	above 70 y	below 35 y	35–70 y	above 70 y
Average loc. error m_{xy} (m)	3.55	5.53	7.66	2.66	5.49	7.05	4.08	4.56	5.79

Results of significance of differences

Species / Stand age	Coniferous			Broadleaved			Mixed		
	below 35 y	35–70 y	above 70 y	below 35 y	35–70 y	above 70	below 35 y	35–70 y	above 70 y
Coniferous / < 35									
Coniferous / 35–70	0.154588								
Coniferous / > 70	0.002618*	0.113207							
Broadleaved / < 35	0.468037	0.038612*	0.000189*						
Broadleaved / 35–70	0.155821	0.962497	0.112927	0.039136*					
Broadleaved / > 70	0.011143*	0.243756	0.618456	0.001180*	0.244987				
Mixed / < 35	0.666606	0.287537	0.009185*	0.278433	0.287663	0.031747*			
Mixed / 35–70	0.442269	0.460746	0.024195*	0.160587	0.457516	0.069509	0.695158		
Mixed / > 70	0.112607	0.832155	0.149984	0.025137*	0.809513	0.302760	0.220960	0.368586	

*Statistically significant difference

assumption that measurements in older stand will be less exact because of a higher frequency of solid obstacles (stems, heavy branches) and signal reflection (multipath effect). Difference in the location error between stands below 35 years and stands at the age of 35–70 years and also stands age above 70 years is statistically significant. Difference in the values for stands at the age of 35–70 years and above 70 years is not statistically significant.

Even though we expected it, our experiment results do not confirm the influence of tree species composition and terrain configuration on the measurement exactness.

Evaluation of results for influence combinations is more ambiguous. The results of evaluation of receiver type and stand age influence are given in Table 5. For all receivers individually a logical expectation is confirmed (see results in Tables 3 and 4) that the average value of location error increases with stand age. But statistical significance of value differences was confirmed in few cases.

The fact that the separate influence of tree species composition was not confirmed is also reflected in Table 6 where the results of the influence of stand age and its tree species composition are given. Errors indeed increase with stand age for all tree species composition groups (coniferous, broadleaved, mixed), but errors for broadleaved stands are lower than errors for coniferous stands (in literature it is vice versa). Statistical significance is present only in few cases again.

The results of evaluation of multiple influence combinations were not statistically significant or we did not have a sufficient number of observations in the groups of measurements for evaluation.

DISCUSSION AND CONCLUSION

Experiment measurements confirmed a possibility to use GPS location under the entire cover of forest canopy. Precision of location is markedly worse than it is published for "geodetic" category of GPS receivers. Regarding the quality, parameters and purpose of used receivers (GIS category) – errors reached 5–7 m. KULIESIS and BAJORUNAS (2000) published precision 1–2 m for a geodetic receiver Trimble Pathfinder Pro X, HRICKO and ŽÍHLAVNÍK (2001) 0.45–1.7 m and WOLNIEWICZ (2001) ca. 1.2 m. The tested receivers are not suitable for measurements for the construction of basic forestry maps under valid technical rules in Slovak conditions.

But it is possible to use them for data collection for GIS digital databases, for location of elements that are not marked and stabilised, or for location of elements that have not been localised until now because of high labour requirement. A typical example is forest stand description for development of forest management plan and thematic mapping (opening-up of forests, pedology, forest typology, etc.).

HRICKO and ŽÍHLAVNÍK (2001) stated that it is necessary to change technical rules, and they mentioned a possibility to combine GPS location (at places with less canopy cover) with classical terrestrial methods. We also add a possibility to use versatile laser equipment that should be connected directly to a GPS receiver or to a computer in data collection process. Offset measurements are very simple and effective.

Our experiment results confirmed the distinct influence of stand age on location error. The greater influence of broadleaved tree species composition and terrain configuration reported in literature was not confirmed.

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Vplyv lesného porastu na presnosť zistenia polohy pomocou GPS

J. TUČEK, J. LIGOŠ

Technická univerzita, Lesnícka fakulta, Zvolen, Slovenská republika

ABSTRAKT: Práca prezentuje výsledky testu troch GPS prijímačov z GIS kategórie (Topcon Turbo G1, Topcon, Magellan Pro Mark X-CM, Magellan, March II-E, Corvalis Microtechnology) pri zisťovaní polohy pod úplnou clonou lesného porastu. Na území Školského lesného podniku Technickej univerzity vo Zvolene, polesie Kováčová, bola založená sieť 111 meracích bodov v rôznych porastových a terénnych podmienkach. Poloha všetkých bodov bola určená presným pozemným geodetickým meraním a následne všetkými prijímačmi. Na posúdenie polohovej presnosti každého z prijímačov sme použili metódu s výpočtom individuálnych rozdielov hodnôt súradníc pre každé meranie a výpočtom priemerných diferencií a ich smerodajných odchýlok pre skupiny meraní. Vypočítali sme tiež hodnoty priemerných súradnicových chýb a testovanie prítomnosti systematickej chyby. Na posúdenie vplyvu typu prijímača, veku porastu, jeho drevinového zloženia a konfigurácie terénu sme použili viacfaktorovú analýzu variancie. Celková polohová chyba pre Topcon bola 7,16 m, pre Magellan 5,89 m a pre March 5,60 m. Rozdiel vo veľkosti chyby medzi Topconom a ostatnými dvoma prijímačmi je štatisticky významný. Vplyv veku porastu je tiež štatisticky významný. Výsledky testu vplyvu drevinového zloženia porastu a konfigurácie terénu nie sú jednoznačné.

Kľúčové slová: GPS; polohová presnosť; vplyv lesného porastu; Topcon; Magellan; March

Výsledná presnosť meraní GPS je ovplyvnená viacerými faktormi: chybami spôsobenými prechodom signálu cez zložky ionosféry a atmosféry, chybami hodín satelitu a prijímača, chybami spôsobenými prekážkami prechodu signálu, nachádzajúcimi sa v najbližšom okolí prijímača (multipath efect), a tiež znížením presnosti s ohľadom na vzájomné postavenie satelitov vyjadrené konštantou DOP (dilution of precision).

Zo štúdia literatúry vyplýva, že problematike presnosti zisťovania polohy pomocou GPS v lesných porastoch sa venuje pozornosť už dlhú dobu. Detailný rozbor literárnych poznatkov na túto tému sme uviedli v práci TUČEK et al. (2000), pričom uzávery neboli jednoznačné.

Zásadný poznatok je však ten, že merania pod clonou porastu je možné vykonať takmer vždy. Časti porastu – listy, ihličie a najmä kmene a vetvy – môžu však blokovať a odrážať časť rádiových signálov a degradovať tak schopnosť prijímača fixovať polohu.

K literárnym poznatkom je potrebné uviesť, že napriek relatívne krátkemu obdobiu overovania a používania GPS sú výrazne ovplyvnené technickým vývojom zariadení. Preto je potrebné posudzovať ich opatrne. Túto domnienku plne potvrdzuje WOLNIEVICZ (2000) konštatovaním, že vek prijímačov (dokonca použitý model toho istého typu prijímača) má dôležitú úlohu, pretože použitý hardware aj algoritmy sú u novších zariadení výkonnejšie. Vzájomná porovnateľnosť výsledkov je tiež problematická s ohľadom na metodiku vykonávaných meraní, momentálne podmienky meraní (dostupnosť satelitov, kvalita signálu, konfigurácia terénu), režim merania, nastavenie užívateľských parametrov či spôsob spracovania výsledkov. Podľa niektorých autorov tieto skutočnosti môžu mať dokonca väčší vplyv ako samotná clona lesného porastu (napr. FIRTH, BROWLIE 1998). Aj túto problematiku detailne rozoberáme v práci TUČEK et al. (2000) s konštatovaním, že v lesných podmienkach sa používa nastavenie DOP do 6, SNR do 4 a výšková maska 10–15°.

Overenie využiteľnosti GPS zariadení pod clonou lesného porastu sme vykonali na území Školského lesného podniku Technickej univerzity vo Zvolene, polesie Kováčová. Ide o typické členité prostredie s variabilnými terénnymi a porastovými podmienkami. Založili sme sieť 111 kontrolných bodov v porastoch s rôznymi charakteristikami a v rôznej konfigurácii terénu. Podľa možnosti sme v rovnakých porastových a terénnych podmienkach založili vždy 3–7 bodov. Poloha bodov bola zameraná presným pozemným geodetickým meraním elektronickým tachymetrom Elta 4 (Opton). Vychádzali sme pritom z polohy bodov zo siete trvale stabilizovaných bodov založených na území ŠLP pre rôzne účely (testovanie prístrojov, vlícovacie body pre fotogrametrické mapovanie, trigonometrické body atď.).

Body sme stabilizovali drevenými kolíkmi a vyznačili. Na každom bode sme uskutočnili popis porastu, ako sa vykonáva v rámci taxácie pri spracovaní LHP (bod bol stredom skusnej plochy, okolo neho sa vyberalo 10 najbližších stromov, ktoré sa ďalej hodnotili podľa známych pravidiel – drevina, výška, hrúbka atď.).

Pretože Lesnícka fakulta TU nevlastní GPS prijímač, nadviazali sme k zabezpečeniu meraní spoluprácu so Slovenskou agentúrou životného prostredia (SAŽP) Banská Bystrica, s firmou Ornth, s.r.o., Banská Bystrica a Geotech, s.r.o., Bratislava. SAŽP zapožičala prístroj Topcon Turbo G1 (Topcon), Ornth prístroj Magellan Pro Mark X-CM (Magellan), Geotech prístroj March II-E (Corvalis Microtechnology). Vo všetkých troch prípadoch ide o zariadenia v triede GIS presnosti, bežne používané pre napĺňanie databáz GIS a v tematickom mapovaní. Základné technické informácie o zariadeniach uvádzame v tab. 1.

Na prvotné spracovanie údajov sme použili výrobcom prístroja dodávaný software – pre Topcon Turbo G1 je to Turbo1, pre Magellan ProMark X-CM, Magellan MSTAR a pre March II PC – GPS 3.6. Prvotné spracovanie poskytuje súradnice v systéme WGS 84. Transformáciu do SJTSK sme vykonali v prostredí DaTra.

Merali sme metódou diferenciálneho GPS kódového merania s postprocesingom. Ako referenčnú stanicu sme použili stanicu SAŽP v Banskej Bystrici, vzdialenú od miesta meraní 20 km. Merania sme vykonali v dobe plného olistenia listnatých stromov v septembri 2000, resp. v menšej miere začiatkom októbra. Na všetkých prístrojoch sme jednotne používali nasledovné nastavenie užívateľských parametrov: 60 observácií, DOP 6, výšková maska 15°.

Na vyhodnotenie presnosti určenia polohy jednotlivými prijímačmi sme použili postup s výpočtom veľkosti individuálnych odchýlok pre každé meranie, priemernej odchýlky a jej smerodajnej odchýlky pre skupiny meraní a strednej súradnicovej chyby ako i testom systematických chýb. Pre posúdenie vplyvu typu prístroja, veku porastu, jeho drevinového zloženia a konfigurácie terénu sme použili viacfaktorovú analýzu variancie.

Celková priemerná veľkosť súradnicovej chyby pod porastom pre Topcon dosiahla 7,16 m, pre Magellan 5,89 m a pre March 5,60 m. Potvrdil sa štatisticky významný rozdiel v presnosti medzi Topconom a ostatnými dvoma prístrojmi (tab. 3). Štatisticky významný bol aj vplyv veku lesného porastu (tab. 4). Nie celkom jednoznačné sú výsledky vplyvu drevinového zloženia porastu, nepotvrdil sa vplyv konfigurácie terénu. Nejednoznačné sú aj výsledky vyhodnotenia kombinácie vplyvov (tab. 5 a 6).

V experimente vykonané merania potvrdili možnosť vykonávať merania polohy pomocou GPS pod úplnou clonou lesného porastu. Vzhľadom na kvalitu, parametre a určenie použitých prijímačov (kategória pre zber údajov pre GIS) je presnosť určenia polohy výrazne horšia ako sú výsledky publikované pre prístroje kategórie s geodetickou presnosťou. Veľkosť chyby dosahuje 5–7 m. KULIESIS a BAJORUNAS (2000) uvádzajú pre Trimble Pro X 1–2 m, HRICKO a ŽÍHLAVNÍK (2001) 0,45–1,7 m a WOLNIEWICZ (2001) asi 1,2 m. Testované prístroje teda nie sú vhodné na vykonávanie meraní pre potreby tvorby základnej lesníckej mapy podľa platných predpisov na Slovensku.

Je ich však možné použiť pre zbere údajov pre digitálne databázy GIS, pri meraní polohy objektov, ktoré nie sú v teréne presne vyznačené a stabilizované, prípadne pri zisťovaní polohy v prípadoch, kde sa doteraz kvôli prácnosti nezisťovala. Typickým príkladom môže byť popis porastov pri spracovávaní LHP a tematické mapovanie (sprístupnenie, pôdne, typologické a iné členenie).

HRICKO a ŽÍHLAVNÍK (2001) k tejto problematike dodávajú pravdepodobnú potrebu zmeny v smerniciach a pracovnom postupe – tvorbu, tlač a archiváciu tematického štátneho mapového diela s obsahom lesného hospodárstva ako aj možnosť vykonať merania pomocou GPS na miestach so zmenšenou clonou porastu – prieseky, cesty, obnovné prvky, lesné sklady – a od nich pokračovať klasickými terestrickými postupmi. K tomu je potrebné doplniť možnosť použitia kombinovaných laserových prístrojov, ktoré môžu byť priamo pripojené ku GPS prijímaču, resp. terénnemu počítaču pre zber údajov, čím sa vykonanie ofsetových meraní výrazne zjednoduší a zefektívni.

Výsledky nášho experimentu preukázali jednoznačný vplyv veku porastu na veľkosť polohovej chyby. Nepotvrdili sa poznatky z literatúry o väčšom vplyve listnatých porastov v porovnaní s ihličnatými porastami ani vplyv konfigurácie terénu.

Corresponding author:

Doc. Ing. JÁN TUČEK, CSc., Technická univerzita, Lesnícka fakulta, Katedra hospodárskej úpravy lesov a geodézie, T. G. Masaryka 24, 960 53 Zvolen, Slovenská republika
tel.: + 421 45 520 63 08, fax: + 421 45 533 26 54, e-mail: tucek@vsld.tuzvo.sk