Comparing Height of Individual Spruce Trees Determined on LiDAR Data with Reference Field Measurements

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Abstract. This paper analyses the possibility of biometric measurements on airborne laser scanning data within a spruce forest stand using as reference data aerial imagery (orthophotomaps) and intensive terrestrial measurements in sampling plots using FieldMap equipment, GPS and Vertex. One objective of the research is to estimate the relative difference between the LiDAR dataset and collected field data to ensure that there can be no confusion between trees determined in the field and on the LiDAR point cloud. Coordinates of the sample plot center are determined under canopy by GPS and from its position on LiDAR dataset which depend on the position of each tree determined in the sample area. In the areas covered by forest vegetation usually we cannot recognize the measured GPS sample plot centers on imagery or LiDAR dataset, so an indirect method is used. The position of clearly visible elements and GPS measured ground control points for areas without forest canopy are compared with LiDAR dataset and aerial orthoimagery to determine the relative difference between them. The DTM obtained from LiDAR dataset and a subset of classified LiDAR points are used to measure the height of individual trees inside the plot area. The height is computed as the difference between the Z-value of the highest point (local maxima) and the Z-value of the ground level (local minima). The measurements of LiDAR dataset correlated with field data show that relative differences between the two sets of geospatial data actually ranged up to 2-3 meters, which make possible the recognition of trees in the two datasets. The conclusion is that the center plots location determined with GPS equipment provides the accuracy needed to compare datasets of land with LiDAR dataset.

Keywords. Airborne laser scanning, biometric field measurements, data fusion, remote sensing.

1. Introduction

The accurate height estimation and fine spatial detail available through the use of airborne Light Detection And Ranging (LiDAR) instruments can provide considerable improvements to the timeliness, spatial coverage and detail of forest structural assessments, especially for vertical forest structure.[1]

LiDAR characteristics, such as high sampling intensity, extensive areal coverage, ability to penetrate beneath the top layer of the canopy, precise geolocation, and accurate ranging measurements, make airborne laser systems useful for directly assessing vegetation characteristics.[2]

In forestry, the advantage of LiDAR systems in comparison with conventional remote sensing technologies (optical, passive), which yield information only in horizontal forest pattern, relies on providing georeferenced information of the vertical structure of forest canopies.[3]

Measuring tree heights from the ground is often both difficult and very time consuming and during the last years, however, the use of LiDAR to measure tree heights became a real challenge.[4]

Recent studies states that beyond measuring mean tree heights for study plots and forest stands, some attention has been directed towards predicting individual tree heights and delineating individual tree crowns in LiDAR dataset [5]. Some studies [4], [6] suggest that tree height can be recovered from LiDAR data just as accurately as from ground measurements, or even more accurately.

During the last years, LiDAR forestry applications advance from landscape/stand scale to a local/tree scale.

Precise topography mapping from LiDAR dataset due to high vertical and horizontal accuracies and canopy penetrating capabilities [3], [7], [8], [9], [10] creates premises for a good forestry parameters extraction both at stand level and tree level.[2], [11], [12], [13], [14], [15], [16].

2. Methods

Test site. The test site is in Romania, Vâlcea county, in the area of Voineasa Forest District, within the Lotru river valley. The prevailing species are spruce (*Picea abies*) and beech (*Fagus sylvatica*) which are found in both pure and mixed stands. The area is in a mountain region, mostly covered with pasture and forest, water bodies and different types of constructions (Figure 1).

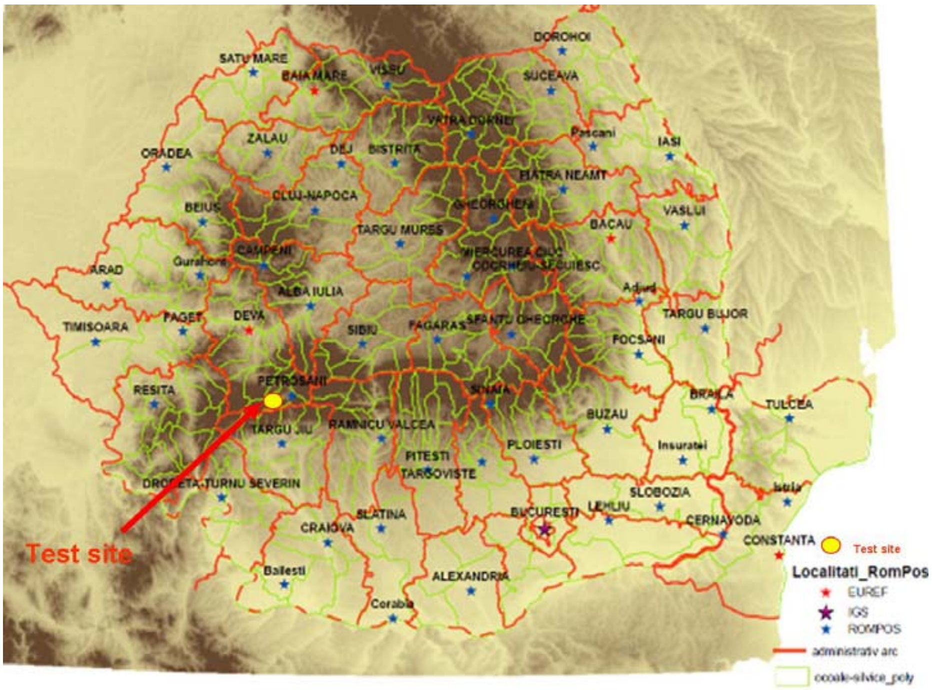

Figure 1: Test site location and terrestrial GPS reference stations.

Aerial images. Official orthoimagery were used provided by National Agency for Cadastre and Land Registration, obtained from aerial images in natural colours (aquisition year 2005) with 0,5 meters spatial resolution (Figure 2).

GPS measured data. The coordinates of the plot centers were measured using a Trimble Pro XH GPS receiver, working in double frequency L1/L2, with Zephyr external antenna and Trimble Terrasync Professional software installed on Trimble Recon PDA. The plot centers coordinates collected by GPS in geographic coordinates (Lon/Lat) on WGS 1984 ellipsoid were transferred, corrected and re-projected in the UTM coordinate system (the elevation reference HAE - High Above Ellipsoid) and exported in GIS format with the Trimble GPS Pathfinder Office software. To achieve the highest possible post-processing accuracy, to better assess the accuracy and compare results, many differential corrections were performed using data from the nearest GPS permanent ROMPOS and EUREF stations and by using H-Star technology.

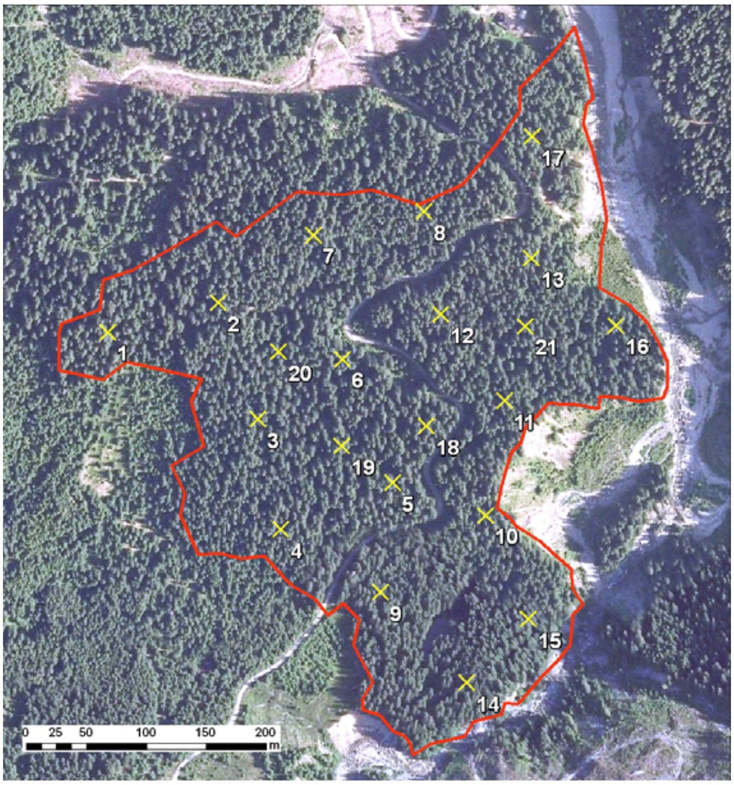

Figure 2: The GPS positioned plot centers, GPS measured forest stand limit and aerial orthoimagery.

ALS data. Airborne LiDAR dataset were used, collected in 2008-2009 by an airborne Riegl LMS-Q560 device connected with a precision GPS/IMU system, which allows laser measurements to be corrected in real time. Data was provided in "*las*" LiDAR dataset format, in UTM coordinate system, elevation High Above Ellipsoid (HAE). The density is 1.6 points (hits) per square meter for one strip. To manage, visualise, process and analyse airborne LiDAR dataset and imagery, two software packages were used:

- MARS Explorer - function-limited 30-day trial license - a commercial application developed by Merrick Company;
- FUSION – forestry oriented free software for managing geospatial data, developed and maintained by the USDA (United States Department of Agriculture) Forest Service.

The classification of LiDAR point clouds, DSM and DTM extraction were processed in MARS software. The raw LiDAR dataset was provided as unclassified points. For the DSM extraction, the first returns were considered, both single and multiple echoes (Figure 3a). For DTM extraction the single returns were classified by applying an automatic filter based on ground distance algorithm. Four classes were created: Ground, Small Vegetation, Medium Vegetation and High Vegetation. For the DTM extraction only the Ground class was considered (Figure 3b).

FieldMap reference data. FieldMap equipment (forestry professional software and equipment for field measurements) were used to determine reference data by measuring individual tree parameters. In order to obtain 90% accuracy, 21 plots were measured. Tree position, height, stem diameter and tree crown projection were determined (Figure 4). Tree heights were measured by Haglöf Vertex IV Hypsometer**.** All individual trees measured in these plots are spruce (*Picea abies*). Sample plot centers coordinates were determined under canopy by GPS so its position on LiDAR dataset depends on the position of each tree determined in the sample area (Figure 5).

a)

b)

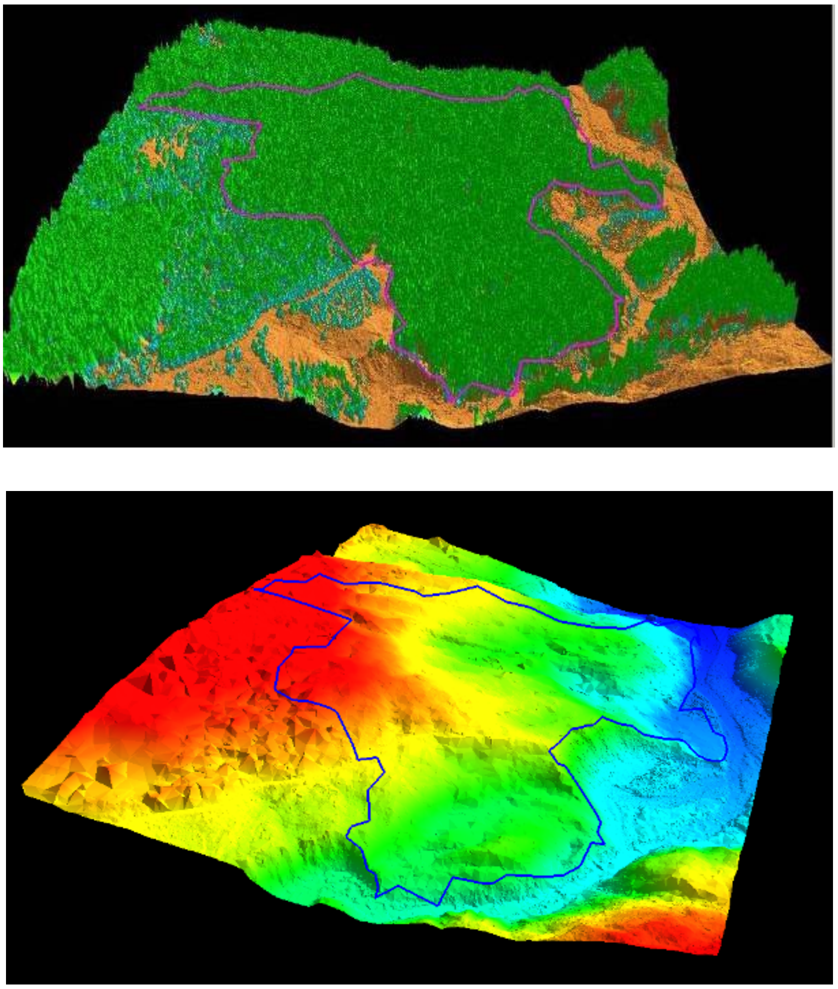

Figure 3: a) Classified ALS dataset, b) DTM extracted from ground class points.

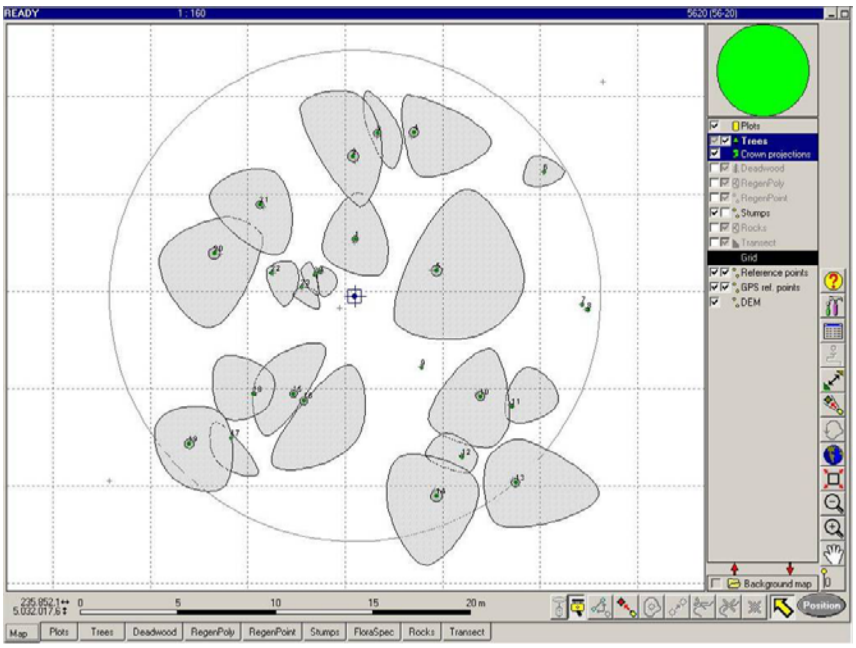

Figure 4: FieldMap plot display example.

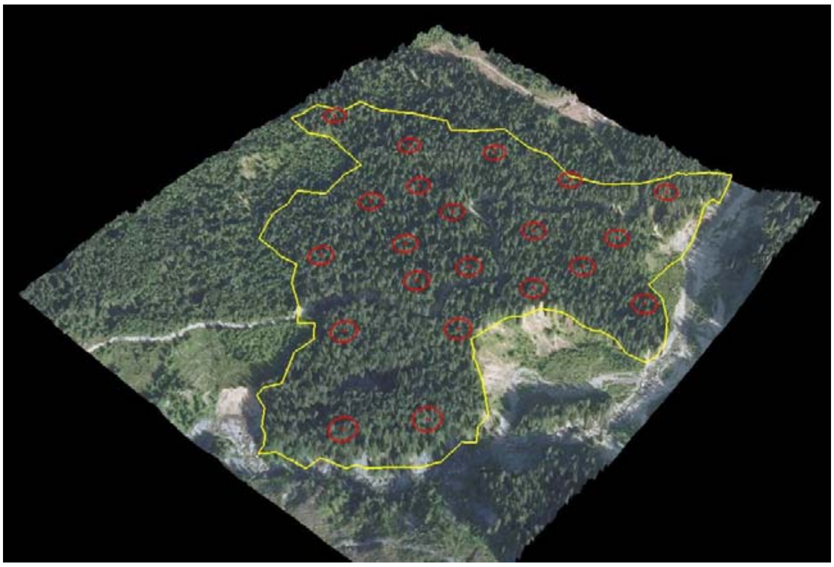

Figure 5: Data fusion of ALS dataset, aerial imagery and FieldMap measured plots positioned by GPS.

LiDAR dataset position analysis. The correct position on projection plan (x,y coordinates) is crucial to assure no confusion between each individual tree both on LiDAR dataset and FieldMap collected dataset. As soon as the plot centers were determined with GPS, each individual tree position accuracy, from a certain plot, depends on the GPS measurement accuracy of the center plot. In the areas covered by forest vegetation, the measured GPS sample plot centers on imagery or LiDAR dataset cannot be recognized, so an indirect method was used. The position of clearly visible elements and GPS measured Ground Control Points (named CHECK POINTS) for areas without forest canopy were compared with LiDAR dataset and aerial orthoimagery to determine the relative difference between them.

The GPS measurements were performed with a Trimble Pro XH, dual frequency, receiver with a Zephyr external antenna. H-Star technology was used and differential post processing correction using simultaneously three terrestrial reference stations data from EUREF (BACA, DEVA) and IGS/SOPAC (BUCU) networks. The accuracy of measurements was carefully studied and conclusion shows that the achieved accuracy was better than 60 cm, so we may consider sub-meter accuracy. It may be mentioned that the EGNOS SBAS did not work at measurement time (August 2010 and June 2011).

Relative position of check points points on aerial images. The first step was to estimate the relative accuracy between GPS points and aerial imagery using fiducial features visible on images and undoubtedly find in the terrain, such as fence corners, buidings, road intersections, etc. The GPS points were displayed on top of aerial images (Figure 6) and distances between the targeted points and the position of the GPS points were measured. Table 1 shows these distances for each point and also the azimut of displaicement (GPS to image point).

The next step was to compare aerial images with the LiDAR dataset. LiDAR datasets were represented using the MARS software, in colour conventional mode (ROYGBIV slice, violet - low altitude, red - high altitude). Features, visible both on aerial images and LiDAR dataset were selected, mainly building but also bridges. This features were vectorised in GIS environment (ArcGIS) and vectors were overlayed on top of LiDAR dataset (using MARS software) (Figure 6). Displacements were measured between similar corners of buildings (or other features) between the images and LiDAR dataset.

Table 1. Distance and azimut of displacement between image and GPS measured check points.

Check points	Distance	Azimut
1	0,78	210
2	1,51	246
3	1,55	212
4	1,35	175
5	1.26	115
6	2.01	237
7	1.91	202
8	1.43	214
9	0.86	267
10	1.72	201
11	1.51	255
12	1.5	182
13	1.09	104
14	4.31	339
15	1.07	30
16	2.96	145
17	6.84	255
19	2.04	334

Figure 6: Examples of check points picked up in the field (black x) and measured GPS position on aerial images (red x). Detailed zoom in on the right.

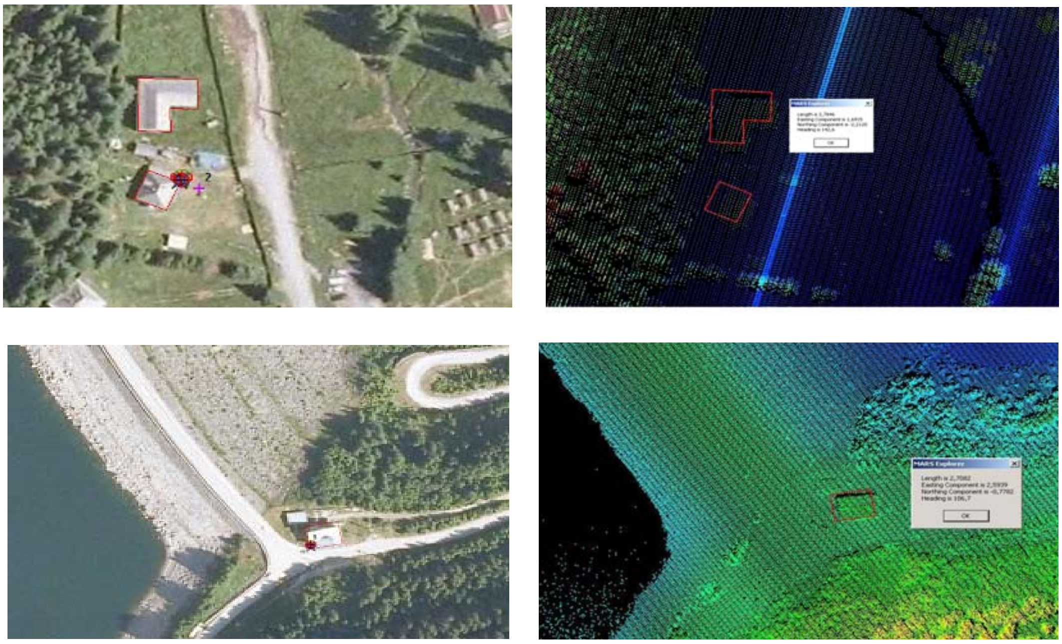

Figure 7: Two examples of aerial images (left) and LiDAR dataset (right) are displayed. Buildings were vectorised and layed on top of LiDAR dataset. Distplacement distances were measured with MARS software.

Table 2 shows the displacement in 12 such check points.

Table 2. Relative displacements between aerial images and LiDAR dataset in check points.

Check points	Distance	Azimuth
1	2,97	136
2	3,39	132
3	2,79	128
4	3,11	135
5	2,08	170
6	0,41	153
7	2,32	138
8	3,31	154
9	2,78	146
10	2,75	188
11	2,71	106
12	1,49	146

The DTM obtained from LIDAR dataset and a subset of classified LiDAR points was used to create a Canopy Height Model (CHM) and measure the height of individual trees inside the plot area. For CHM extraction the first returns were considered, both single and multiple echoes.

The height of visible trees was computed as the difference between the Z-value of the highest point (local maxima) and the Z-value of the ground level (local minima) collected in the tree database. Since the measurement of the spatial location of a tree top in FUSION is based on identifying the single highest discrete point, the draping of the CHM on the LiDAR point cloud served just for a better graphical reconstruction of the crown shape of the trees in order to improve visual recognition and pair-matching field and FUSION measured trees (Figure 8). At the same time, in the tree database the shift values between the tree planimetric position determined on the field and the tree top position determined on LiDAR dataset on the axes of coordinates (ΔX and ΔY) were collected. Also, for visible trees the differences between the height measured in the field and those measured on LiDAR dataset (ΔH) were computed.

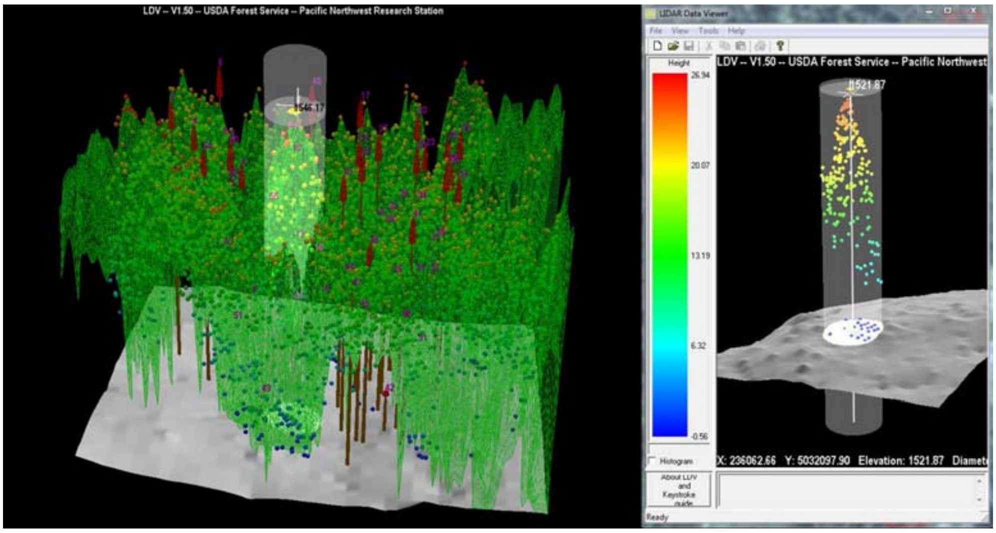

Figure 8: Tree height measurement in FUSION software.

3. Results

The GPS measured points were differentially corrected using three reference stations from EUREF/IGS/SOPAS networks. The achieved accuracy was under 60 cm.

Aerial image displacement compared with the check points (CP) positions is quite randomly distributed but a preference for SV direction may be observed. The weighted average of image displacement is 1.53 m on the azimuth of 198^{o} (Figure 9).

The shift between aerial imagery and LiDAR dataset measured in these GCP positions has a preference for SE direction. The weighted average shift is 2.51 m on the azimuth of 143^{o} (Figure 10).

By vector composing these two errors, the effective displacement between LiDAR dataset and GPS measured, GCP-s can be determined. The weighted average displacement is 3.60 m on the azimuth of 163^{o} (Figure 11).

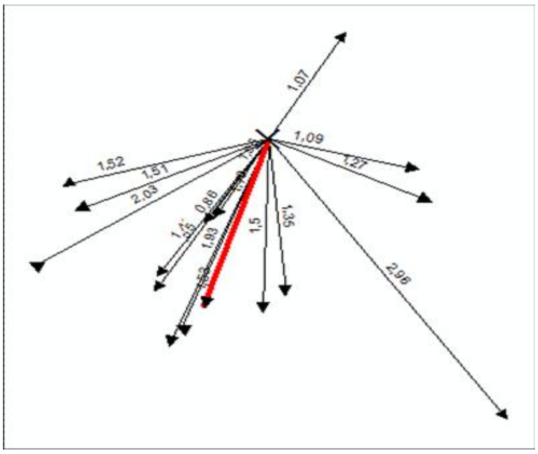

Figure 9: The relative displacement of aerial imagery compared with the GPS measured CPs.

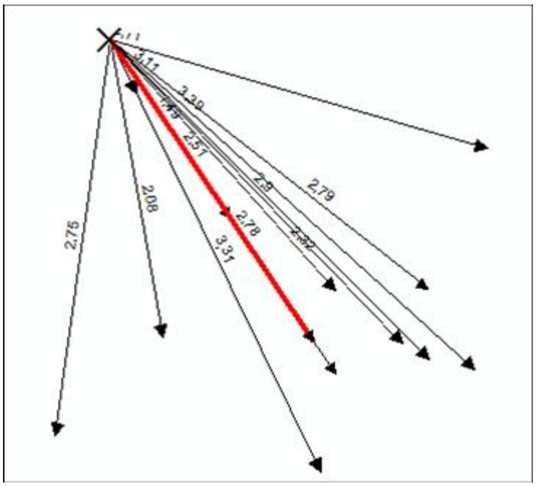

Figure 10: The relative shift of LiDAR dataset compared to aerial imagery in the measured positions.

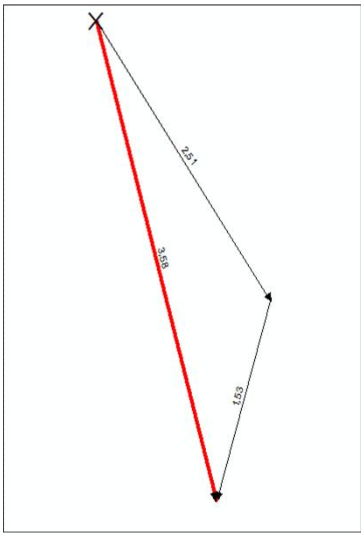

Figure 11: The composed relative displacement of LiDAR dataset compared with the GPS measured GCP.

When the field measured trees were represented in FUSION together with the CHM it was obvious that there is a shift between field and LiDAR dataset. The field measured tree bases being displaced comparing with the apparent tree tops visible on CHM. This shift can have three sources of errors:

- errors of GPS positioning of the center plots.
- errors of georeferencing the LiDAR dataset; it is possible that LiDAR dataset have their georeferencing error;
- errors of measuring the field data with FieldMap.

The shift being apparently systematic, in the same direction for the same plot, but different from other plots, is more likely that the source of error is the GPS positioning of center plots. Under thick forest canopy the GPS signal was weaker, especially in receiving the carrier signal and with a bigger PDOP and lower precision, as previously reported [12]. In such conditions the positioning accuracy was lower even by differential correction post-processing.

After the effective measurements in all 21 plots, the displacements between the visible trees for every plot, measured both on field with FieldMAP and with FUSION on LiDAR dataset were computed. The mean values and RMS error for the 3 direction displacements are shown in Table 3.

Table 3. Number of identified and measured trees on LiDAR dataset. The relative average displacement of the plot between FieldMap measured trees and those measured in FUSION.

ID_ plot	Number of trees in the plot	Number of trees measured on Li-DAR	% of meas-ured trees	LiDAR /Field position and height difference					RMS error for LiDAR /Field position and height difference			
				|ΔX|	|ΔY|	ΔH	Leng th	Azi-muth	ΔX	ΔY	ΔXY	ΔH
561	61	24	39	6.37	4.32	-1.46	7.70	236	6.39	4.37	7.74	2.55
562	40	22	55	1.42	3.64	-1.37	3.91	339	1.66	3.77	4.12	2.13
563	61	41	67	0.46	4.10	-1.12	4.13	354	0.81	4.21	4.29	1.78
564	72	34	47	0.91	0.07	-0.93	0.91	266	0.99	0.56	1.14	1.38
565	44	29	66	0.41	1.14	-0.24	1.21	200	0.57	1.23	1.36	1.23
566	49	20	41	0.81	0.93	-1.04	1.23	221	1.08	1.09	1.53	1.46
567	78	35	45	0.40	0.28	-1.47	0.49	305	0.61	0.65	0.89	1.72
568	68	40	59	1.03	0.29	-1.31	1.07	254	1.09	0.45	1.18	1.92
569	55	32	58	1.09	1.14	-1.34	1.58	316	1.18	1.23	1.7	1.55
5610	79	47	59	0.99	0.28	-0.87	1.03	286	1.14	0.71	1.34	1.39
5611	41	24	59	1.86	2.83	-1.08	3.39	213	1.93	2.98	3.55	1.63
5612	53	29	55	0.30	1.50	-1.06	1.53	169	0.42	1.53	1.59	1.46
5613	65	45	69	0.58	2.04	-0.46	2.12	344	0.79	2.1	2.24	1.15
5614	68	37	54	1.49	1.91	-0.95	2.42	322	1.53	1.95	2.48	1.69
5615	65	32	49	1.43	1.98	-0.92	2.44	36	1.49	2.03	2.52	1.49
5616	32	23	72	2.39	0.73	-1.51	2.50	253	2.43	0.87	2.58	1.7
5617	46	27	59	1.17	1.09	-0.79	1.60	227	1.27	1.17	1.73	1.15
5718	39	27	69	0.10	3.09	-0.30	3.09	358	0.67	3.14	3.21	1.3
5719	50	32	64	0.51	0.54	-0.58	0.74	223	0.6	0.78	0.98	1.14
5720	25	12	48	1.36	0.58	-0.83	1.48	247	1.38	0.75	1.57	1.06
5721	51	29	57	1.92	0.37	-1.39	1.96	101	2	0.66	2.11	1.96
Total	1142	641	56	-	-	-	2.22	257	-	-	-	-

The weighted average displacement between the trees from the 21 FieldMap measured plots (positioned by GPS) and those measured in FUSION on LiDAR dataset is 2.22 m on the azimuth of 257^{o} (Figure 12).

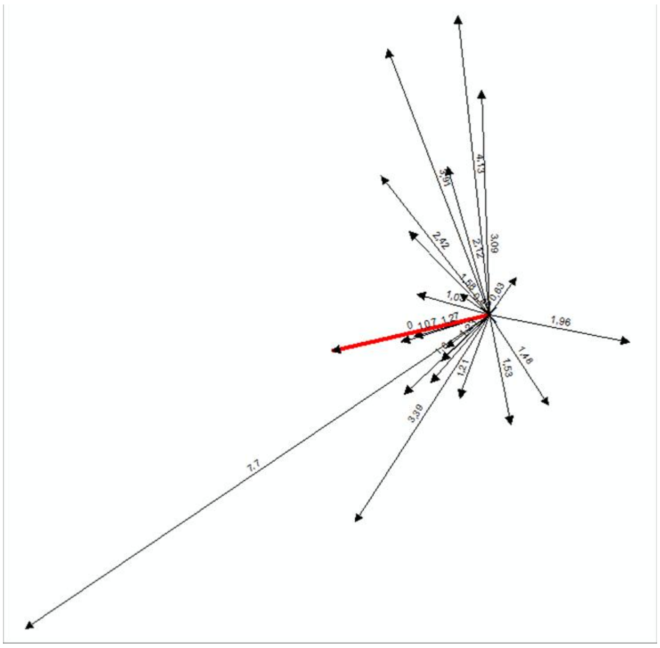

Figure 12: The plots relative displacement between the FieldMap measured trees and those measured in FUSION.

By comparing LiDAR and field measured heights corelation coefficients, the results showed a strong linear correlation between the datasets for all 21 plots (r = 0,812 – 0,990) and for all datasets (r = 0,972). The heights determined on LiDAR dataset are smaller than the field measured heights, mainly because the laser beam does not „catch" exactly the tree top, which brings a negative sistematic error (Table 3). For all the 21 plots, a RMS error of 2.71 m for planimetric positions and 1.6 m for height was calculated.

4. Conclusions

The measurements of LiDAR dataset correlated with field data show that relative differences between the two sets of geospatial data actually ranged up to 2-3 meters, which made possible the recognition of trees in the two datasets. The conclusion is that the center plots locations determined with GPS equipment provides the accuracy needed to compare between land and LiDAR datasets, a fact also proved by the strong correlation between the field and the LiDAR measured heights.

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