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Extraction of Individual Tree Parameters by Using Terrestrial Laser Scanner Data in Hyricanian Forest

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Background: In this study for the first time terrestrial laser scanning survey was implemented on upland Hyrcanian forest, through which a new method was applied to automatically extract DBH and tree position as a necessary step for height calculation and fitting the clustering as a circle.
Materials and Methods: Tree height extracted by fixing a cylinder around the trees center. The accuracies of these methods were investigated by field measurement. Among 4 shapes fitting algorithm, Monte Carlo had more suitable result to fitting circle in each height above the ground.
Results: Tree detection rates were 85% for *Carpinus betulus* and 87% for *Diyospyrus lotus* with respect to field measurement. R^2 and RMSE for DBH measurement were 0.98, 2.06 cm for *Carpinus betulus* and 0.98, 1.26 cm for *Diyospyrus lotus.* Value of R^2 and RMSE for height measurement were 0.96, 3.37 meters and 0.93, 3.02 meters for *Carpinus betulus* and *Diyospyrus lotus*, respectively.
Conclusions: The accuracy of DBH by TLS is very suitable, and about the height of trees we extracted underestimated value in comparison to field measurement and that we need to develop more effective algorithms in order to reach more accurate measurement of trees' height in Hyrcanian forest.

Keywords: Breast height, DTM, Forest inventory, LIDAR, Point cloud

1. Background

All forest inventory activities and management, including estimation of logging operation cost on forest road before construction, require the measurement of various parameters that describe the geometry of trees. In the simplest case, these parameters are limited to the tree's height and diameter at breast height (DBH) (1). Common methods of estimation of the total volume above the ground are traditional forest inventory that use volume tables according to the diameter at breast height (1.3 m) (2). There are some disadvantages to the traditional ground base methods, including time-taking, limited resolution, and lack of spatial information. In recent decades, LIDAR has provided a large number of significant benefits with high accuracy and lesser time in forest management, including harvest planning, locating roads, forest regeneration, etc. (1, 4, 5).

LIDAR technology, which has been used successfully to obtain very accurate tree and forest structural parameters in many areas (4, 5), is able to capturing millimeter resolution 3D data of objects by measuring the distance and intensity of a target using laser pulses (6). Having the distance (*d*), the polar range (θ), and the azimuthal angle (φ) of the emitted beam, we can obtain a set of spherical coordinates (d, θ, φ) and Cartesian coordinates (x, y, z) by transformation of d, θ, φ (7).

In the recent years, terrestrial laser scanner (TLS) has been used for forest inventory parameters assessment. TLS provides a very accurate measurement of object's position and shape (8). The parameters like DBH, tree density and height are easily acquired on forest stand, although the tree's height could also be affected by obscurity. Tansey *et al.* (9) carried out a research by using multiple scan to map a plantation of coniferous trees by applying Hough transformation method for automatic detection of stem and derive DBH with two least-square shape fitting algorithms. The RMSE for DBH measurement was between1.9-3.7 cm. The height estimation was not successful due to high stand density. Murgoitio *et al.* (10) also stated that tree parameter of 10 m from TLS in a single scan can be visible. Calders *et al.* (11) reported that the tree height accuracy of R^2 0.98 with RMSE of 0.55 meters when using TLS; they used measurement from destructive sampling for validation. Estimation of an accurate tree height is one of the major challenges in mixed and dense forest stand. There are many research projects on LIDAR-derived tree height from individual tree and plot level height measurement that indicate the accuracy of the LIDAR method was between R^2 0.80 – 0.98 (12, 13, 14). These studies were not undertaken in Hyrcanian forest whit high diversity, mixed and uneven-aged stands. Andersen *et al.* (15) used total station and TLS survey to extract tree parameters and found very high accuracy tree height in a forest composed of *Pinus ponderosa* and *Pseudotsuga menziesii*. Zawawi *et al.* (16) found that forest type was one of the key factors of accuracy of tree parameters estimated from TLS and airborne laser scanning (ALS).

2. Objectives

This study was part of a project about modeling forest road construction cost that was implemented for first time in Hyrcanian forest. One important element in road construction is the cost of cutting and logging tree in the useful width of the road. Therefore, we need a precise estimation of DBH and tree height, which are crucial parameters for tree volume calculations. With regards to the study area and the objective of the study, we used TLS to precisely calculate tree volume from the dense point clouds of two main species, *Carpinus betulus* and *Diyospyrus lotus*. In addition, new applications were used to automatically extract the diameter at breast height and tree position.

3. Materials and Methods

3.1. Test site

The study area is located in an upland Hyrcanian deciduous broad-leaved forest of Siahkal, at an altitude range of 450 to 650 m above sea level, Giulan province, north of Iran (Figure 1). The test site is located in a rather steep and somewhat rocky parts along a 900 meter road. The current research was conducted before the road construction, but all trees and shrub along the road width had been already cut. Besides *C. betulus* and *D. lotus*, *Quercus carpinifolia* and *Acer velutinum* constitute the other main tree species. Regeneration in this forest is natural.

3.2. Terrestrial Laser Scanner

The TLS measurements were performed with the terrestrial laser scanner system RIEGL LMS-Z420i and technical data of scanner presented in Table 1. TLS data were collected by a single scan approach and 18 scan position were made at the center of road line.

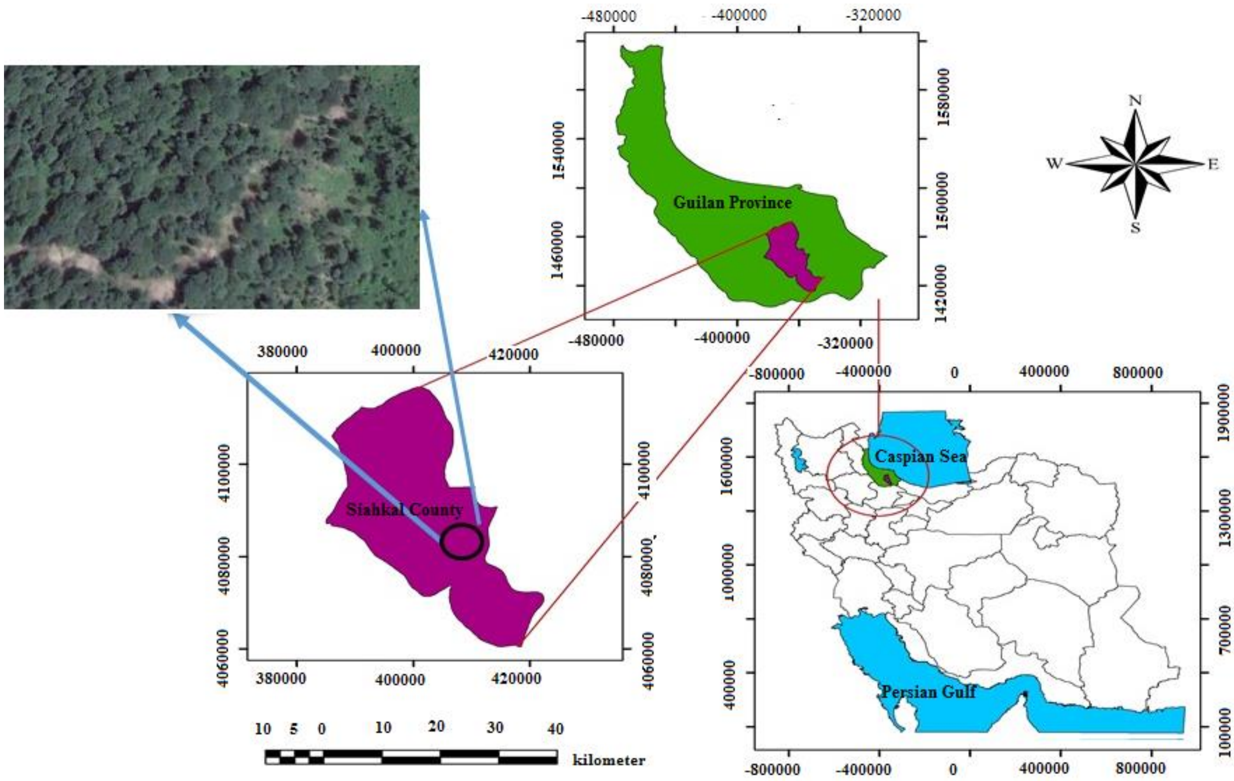


Figure 1 Location of the test site

Table 1 Technical data of the RIEGL LMS-Z420i

Parameter	Value
Measurement Range	2 - 1000 m
Accuracy	5mm
Minimum angle step width	0.004°
Horizontal field of view	360
Vertical field of view	80

The data was collected on August 6-8, 2015 (Figure 2). All scan position located in the proposed road way, all points of each scan position had their own co-ordinate system. Registration of laser data was performed by measurement a minimum of 3 tie points in each scan. Georeferencing needs a minimum of 3 known 3D control points in each scan position. The control information is separated into a horizontal and a vertical control network. This needs the transfer of the control data onto the targets using total station. The global horizontal coordinates of the entire station were initially determined using the existing horizontal control points. The leveling was performed by transferring the peak difference from the vertical management points to the entire station, followed by measuring the coordinates of the tie points with the known three-dimensional position of the total station. With the data of the global positions of the tie points, the georeferencing of the TLS determined by aligning the scans with a rigid body transformation, after which the point cloud data obtained with xyz information and converted to las files by using LAStools software.

Figure 2 Schematic picture (A) pick up point cloud data by TLS (B) laser scanner field set up

3.3. Ground inventory data

Field measurements (tree height and DBH) were recorded for each marked tree with diameter tap at 1.30 m height above the ground level. Suunto clinometer was used to measure the tree's height. All TLS positions were located in the corridor across the proposed forest road. All TLS point cloud was collected from 18 TLS position.

3.4. TLS data processing

Single-scan TLS data was used due to its low cost, fast and easy recording of the trees. During this study various software were used for processing and analysis of TLS data. The preprocessing of scan data like convert data format, reduce noise and filtering were carried out with the LAStools software (17). The new application (GIS3DTLS), developed by Koren *et al*. (18), was used to automatically detect the position of single trees and their DBH; cloud-compare software was used for extraction of trees' height. Based on tree parameter from field, point cloud below zero and above 55 meter were dropped (because the maximum height of trees was 50 meter in this area) from the point cloud data.

3.5. DBH and individual tree identification

The application "GIS3DTLS", developed by Koren *et al.* (18), was used to detect the position of single trees and automatically extract the DBH. Determination of the trees' position and diameter in one step is one of the advantages of this software. In order to extract the crescent form of the points, geometric approach technique –also called clustering method- was utilized (19). After generating DTM from cloud points, a horizontal slicing at 1.30 m height of the tree was generated for calculation of DBH. Grouping points of a dataset supported a similarity criterion possible with clustering methods. Points measured from identical stem were much closer to the points measured from completely different stems, and therefore points that were mirrored from identical cross-section are described by one cluster. This application used four shape fitting algorithms (least sq., highest distance, centroid and Monte Carlo) to fitting circle in every height on top of the bottom. The similarity was outlined as the distance from the clusters' centroid. When the fitting was successful and the calculated diameter at breast height (DBH) was inside a tolerance, then the tree's position and DBH were recorded.

3.6. Tree height measurement

After determination of the tree center, its height was measured as the difference between the lowest point (base of the DBH) and therefore the highest point in inside the cut cylinder. The point representing the terrain model is outlined as the lowest point in a vertical cylinder round the tree center coordinates (X,Y), the tree top is outlined as the highest point in a vertical cylinder round the tree center coordinates.

3.7. Statistical analysis

Descriptive statistic (minimum, maximum, mean, standard deviation) was done to show tree level information of both field and TLS measured inventory parameters. Regression analysis was carried out to show the relationship coefficient of determination (R^2) and root mean square error (RMSE) were calculated to compare TLS data extracted from tree inventory parameters with field measurement. R^2 indicated how well a model can explain the reality. Since normality could not be assumed for groups, the hypothesis that two alternatives were significantly different was tested using paired Wilcoxon signed rank tests. This test is based on the sign and magnitude of the rank of the differences between pairs of measurements. If the significance (p-value) was less than 5%, the difference was statistically significant. The use of a non-parametric test was based on the fact that the averages were not normally distributed. In addition, the number of averages in the test was small.

4. Results and Discussion

4.1. Tree identification and DBH estimation

Tree detection is crucial point in automatic algorithms. Success of tree detection varied due to distance from the scan center, forest density, field topography, and understory layers. Our method was successful in 30 cases out of 37 for *C. betulus* and 25 cases from 30 for *D. lotus*. Totally 12 faulty clusters were detected due to the presence of branches at the breast height and noise. In other words, some clusters caused by shrubs or branches may also be classified as trees by virtue of points being arranged in a circle within the cluster. This fault is related to highly dense and very close stems in some cases, especially in *C. betulus*. Furthermore, we extract better result for *D. lotus* than *C. betulus.* To avoid this incorrect classification, another slice a few cm above was considered (20). Figure 3 shows the clustering objects that classified as the trees in white color. One of the main advantages of clustering is that it can handle point clouds from more than one scanning position in the same way. It does not take account of shapes and is unable to separate several stems if their outermost points are closer than the maximal cluster size (19). In addition, the finding showed that Monte Carlo algorithm had the best result for clustering point cloud and fitting circle at the breast height.

Tree level statistics of breast height diameter measurement are given in Table 2. The result show that there was no significant difference between field and TLS measurement, and therefore TLS point cloud could measure DBH with very reasonable accuracy.

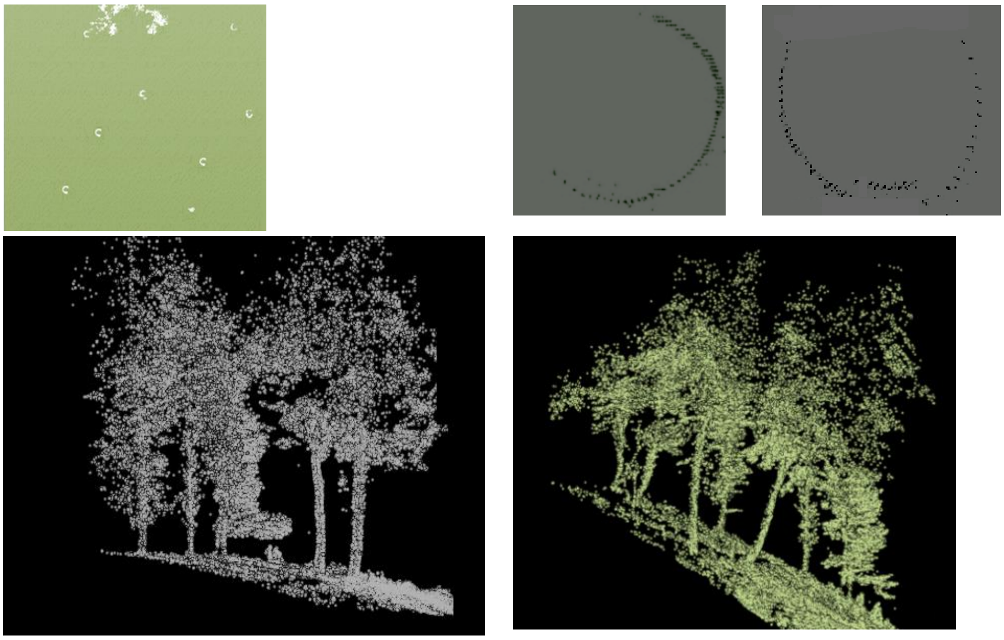


Figure 3 The horizontal point pulses for some trees

Table 2 Descriptive statistic of DBH measured in field and TLS for two test species

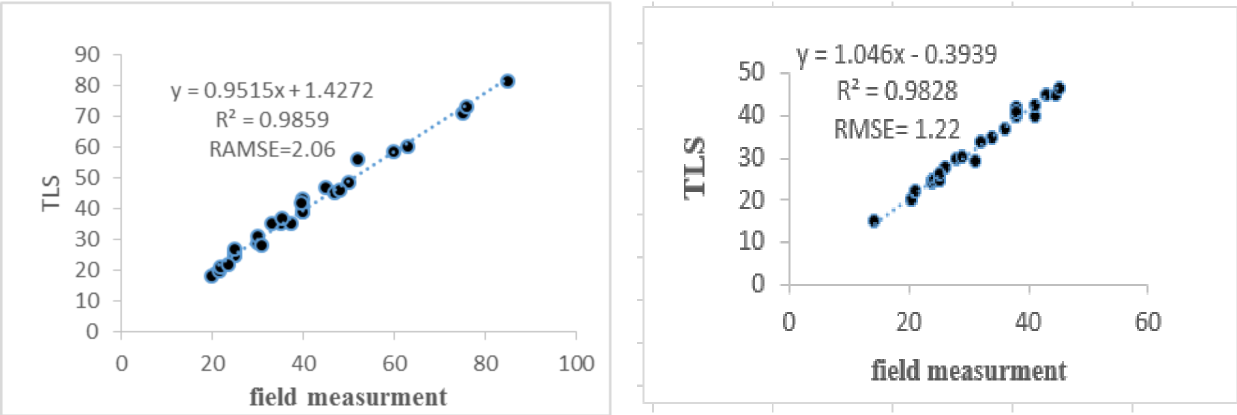
	TLS (CM)				Field (CM)			
Species	**Max**	**Min**	**Mean**	**Std**	**Max**	**Min**	**Mean**	**Std**
C. betulus	81.20	18	40.65	18.37	85	20	40.11	17.08
D. lotus	45	14.20	30.70	8.66	46.8	15	31.72	9.14

Table 3 Results of test comparing DBH from TLS data and field measurement

	C. betulus		***D. lotus***	
	Field DBH	TLS DBH	Field DBH	TLS DBH
mean	40.11	40.65	31.72	30.70
p-value	0.169		0.07	

The Wilcoxon signed-rank test also indicated no significant difference between the DBH measurements from field and TLS in both tree species ($p > 0.05$) (Table 3).

The correlation of individual tree DBH from field observation and TLS data was computed as shown in Figure 3. The R^2 value was 0.98 with RMSE 2.06 cm for *C. betulus* and 0.98, 1.22 cm for *D. lotus* (Figure 4), which was reasonably high. The results of DBH from field measurement and TLS data are very close. The suitable result for *D. lotus* might be due to its smoother and more cylindrical trunks.



a= *Carpinus betulus* b=*Diyospyrus lotus*

Figure 4 Scatter plot based DBH for field and TLS measurement

4.2. Tree height measurement

We measured the height of tree with 2 different methods, viz. field measurement and terrestrial laser scanner (TLS), after downloading TLS scan data for each position and trees' objects within each position, undertaking single scan adjustment through LAStools software. Trees' height were determined using cloud compare software by taking the trees' lowest and the topmost points into consideration. Trees' labeling and identity in the field were also utilized in the matching process of the software. The results showed dissimilarities among the statistics of the trees' height measurements (Table 4). There were about 3.37 and 3.02 meters difference between field measurements and TLS for *C. betulus* and *D. lotus*, respectively (Table 3). To compare the accuracy between field and TLS data, regression analysis was done. The trees level relationship analyses for two tree species are shown in Figure 5 a-b by scattered plots. The summary of fit for tree height is presented in Table 5. R^2 value is 0.96 for *C. betulus* and 0.93 for *D. lotus* and RMSE 3.22 and 3.01 m, respectively (Figure 5).

The Wilcoxon signed-rank test indicates a significant difference between the field and TLS measurements (p <0.05) (Table 5).

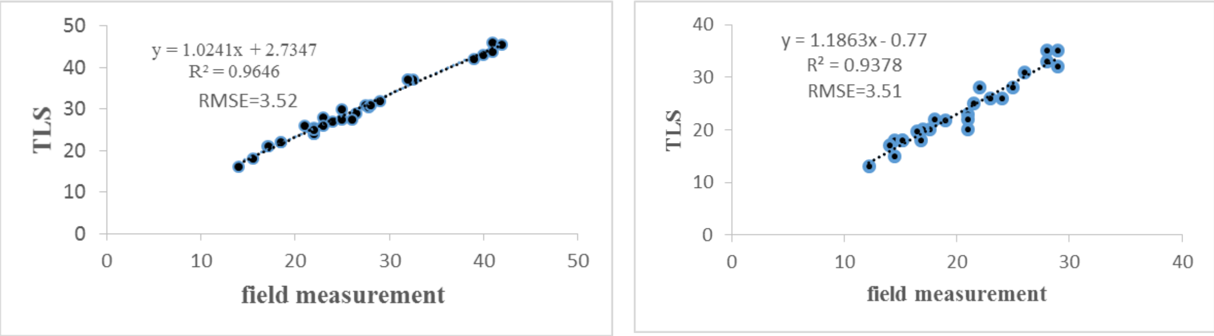
Our result showed we have underestimated height for trees. Overlapping of tree crown is the main testimony for erroneous estimation of tree height (23).

Table 4 Descriptive statistic of trees height measured in field and TLS

	Field (M)				**TLS (M)**			
Species	Max	Min	Mean	Std	Max	Min	Mean	Std
C. betulus	46	16	29.84	8.21	41.5	14.75	26.47	7.95
D. lotus	35	13	23.38	6.26	29	12.20	20.36	5.11

Table 5 Results of test comparing height from TLS data and field measurement

	C. betulus		*D. lotus*	
	Field height	TLS height	Field height	TLS height
mean	29.84	26.47	23.38	20.36
p-value	0.00		0.00	



a= *Carpinus betulus* b= *Diyospyrus lotus*

Figure 5 Scatter plot based trees height for field and TLS measurement

4. Conclusions

This study was carried out as part of the cost modeling prediction in forest road construction project that also includes precise estimation of cutting and logging cost of trees in width of the proposed road section. We used TLS data to provide very precise estimation of DBH and tree height as crucial parameters for tree volume calculations. The result showed accurate measuring of trees height are difficult, which was related to canopy dense covers (22) and heterogeneous stand (21) in this area, so that the laser pulses could not penetrate fully through the complex canopy to reach the top of trees and, hence, underestimated tree height in comparison with field measurement. Certainly, importance and sensitivity of forested areas using high resolution Lidar mapping will be more useful in future by developing more robust algorithm that can improve the estimation accuracy of the trees' height in Hyrcanian forest. Since the trees' parameters are required for estimation of commercial volume, it is very important for cost model of road construction. It is suggested that the trees' height and diameter above the ground be considered in future estimation by using TLS. Although, we extracted very excellent result with TLS, but it should be noted that this result was achieved in corridor across the proposed forest road, so in typical forest stand the result maybe different.

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Authors' Contributions

Akbar Najafi presented the study idea and developed the theory. Also he was the Corresponding author.

Iman Pazhouhan carried out the experiment and wrote the manuscript with support from Akbar Najafi.

Abolghasem Kamkar Rouhani designed and performed the experiments and analyzed the data.

Finally, all authors discussed the results and contributed to the final manuscript.

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Conflicting of Interest

The Authors state that there is no conflict of interest.

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استخراج پارامترهای مربوط به تک درخت با استفاده از تکنولوژی لیزر اسکنر زمینی در جنگل‌های هیرکانی

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مقدمه: در این مطالعه برای اولین بار کاربرد تکنولوژی لیزر اسکنر زمینی در برآورد پارامترهای مربوط به اندازه‌گیری درختان در جنگل‌های کوهستانی هیرکانی بررسی شد. هم‌چنین در این تحقیق از یک نرم‌افزار تخصصی که اخیرا جهت استخراج خودکار مکان دقیق و قطر برابر سینه تک درخت توسعه داده شده بود استفاده گردید،

مواد و روش‌ها: تعیین مکان دقیق درخت که اولین قدم برای به‌دست آوردن دیگر پارامترها می‌باشد، استخراج گردید. ارتفاع درخت نیز از طریق تعیین بیش‌ترین مقدار ارتفاع در محدوده تاج پوشش همان درخت از طریق روش برازش سیلندریک در حول خط مرکزی درخت به دست آمد. جهت تعیین دقت این روش از اندازه‌گیری زمینی استفاده گردید.

نتایج: نرخ تشخیص درختان توسط این روش برای گونه ممرز برابر با ۸۵ درصد و برای گونه خرمندی ۸۷ درصد شد. نتایج نشان داد که از بین الگوریتم‌های مختلف که برای خوشه‌بندی ابر نقاط در ارتفاع خاص جهت به‌دست آوردن قطر استفاده گردید، روش مونت کارلو بهترین نتیجه را کسب کرد. معیارهای آماری R^2 و RMSE برای مقایسه میزان برآورد شده توسط TLS و واقعیت زمینی استفاده شد، این آماره‌ها به‌ترتیب برای دو گونه ممرز و خرمندی در قطر برابر سینه ۰/۹۸ و ۲/۰۶ سانتی‌متر و ۰/۹۸ و ۱/۲۶ سانتی متر به‌دست آمد. مقادیر R^2 و RMSE برای ارتفاع در گونه ممرز ۰/۹۶، ۳/۳۷ و ۰/۹۳، ۳/۰۲ در گونه خرمندی به‌دست آمد.

نتیجه‌گیری: نتایج نشان داد که دقت برآورد قطر درخت توسط ابزار لیزر اسکنر زمینی بسیار دقیق و مناسب می‌باشد، اما در ارتباط با ارتفاع درخت مقادیر برآوردی کمتر از مقدار واقعیت زمینی در اغلب موارد بوده است. که نشان دهنده نیازمندی به توسعه الگوریتم‌های کاراتر در برآورد دقیق‌تر این پارامتر کلیدی مربوط به تک درخت می‌باشد.

کلمات کلیدی: DTM، LIDAR، ابر نقاط، اندازه‌گیری جنگل، قطر برابر سینه