

## A PRIMARY TEST RESULTS OF A HANDHELD MOBILE LASER SCANNER IN EXTRACTION OF TREE PARAMETERS

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### ABSTRACT:

Sustainable forest planning and management require accurate and precise information about the estimation of forest resources. In particular, two tree parameters are very important among the others: diameter-at-breast height (DBH) and height that are used to estimate the volume and biomass of the tree. With the development of Remote Sensing (RS), information about the tree parameters can be acquired in more accurately and precisely with laser scanning technology. In this study, a Handheld Mobile Laser Scanner (HMLS), called TORCH, was tested for extracting tree parameters with 3D Forest software. The TORCH uses the SLAM (Simultaneous Localization and Mapping) algorithm to locate the scanner in an unknown environment and register the obtained 3D point clouds. Estimated DBH and height parameters from HMLS data extracted using 3D Forest software were compared with the field measurements (i.e., reference data). The preliminary results of the study showed that estimated DBH from HMLS data were relatively higher than ground measurement, while estimated height from point clouds data was slightly lower than the reference data. The continuous improvement in mobile laser scanners will improve the success of the devices while acquiring 3D structural information of tree parameters and reducing the cost and time spent in forest inventory.

### 1. INTRODUCTION

Forests provide many ecosystem services, including but not limited to carbon storage and stabilization of the climate, the protection of biodiversity, and support of the livelihoods (Bauwens et al. 2016, Del Perugia et al. 2019, Baskent 2020). Collecting information on the current states and updating recent changes in forest resources are crucial for monitoring and managing forest ecosystem services. Forest inventory (FI) provides information related to forest variables, such as forested area, volume, biomass, and increments, to define the structure and assess the forest resources (Bauwens et al. 2016, Vatandaşlar and Zeybek 2020, Vatandaşlar and Zeybek 2021). Thus, accurate measurement of tree parameters in forest inventory is fundamental for sustainable forest planning and management.

In forest inventory, tree parameters are often measured within sample plots, which are established to represent the entire forest area. The most frequently measured tree parameter are diameter-at-breast height (DBH) and height that are strongly related to stem volume and above-ground biomass (Hopkinson et al. 2004, Watt et al. 2003, Stal et al. 2020). Besides, the number of trees, the tree location, height of crown, crown diameter, height of the first living branch are other tree parameters measured in forest inventory (Liang 2013, Bauwens et al. 2016). The measured tree parameters within the plot with traditional methods or direct measurements can be limited, time consuming, expensive, labor-intensive, and can lead to serious errors due to human-caused error or subjectivity (Liang 2013). Recent developments in remote sensing technology (RS) and precision forestry have offered objectivity, repeatable measurement, cost and time efficiency in the forest inventory (Bauwens et al. 2016, Vatandaşlar and Zeybek 2020, Fan et al. 2021).

Among the various remote sensing technology, the laser scanning technology, which is an active remote sensing technology, enables to collect highly precise and accurate tree-dimensional (3D) spatial data based on laser scanning, ranging, positioning, and measurement techniques. Due to characteristic of laser scanning technology, providing accurate and precise tree-dimensional (3D) structure of forest environment in different scales (i.e., from area-based approach (ABA) to individual-tree-based approach (ITD)), it has played a significant role in forest inventories since 1990s (Bauwens et al. 2016, Balenović et al., 2021). ABA uses Airborne Laser Scanning (ALS), which is preferred to assess forest parameters at plot and stand level (called wall-to wall mapping) for a larger area. On the other hand, ITD allows the extraction of individual tree parameters, hence, individual tree can be easily detected, segmented and modelled (Balenović et al., 2021).

In parallel with these features, there is a growing interest in utilizing terrestrial laser scanners (TLS) for forest inventory measurements in the past decades (Erikson and Karin 2003, Hopkinson et al. 2004). Although using TLS in forest inventory allows detailed digitization of forest plots with high level (in mm level) individual tree parameters extraction, the occlusion effect, which is caused by surrounding trees, is counted as one of the main limitations of TLS (Bauwens et al. 2016). In order to eliminate this problem, point cloud data for each plot needs to be collected from multiple positions. Thanks to recent developments in TLS technology, handheld mobile laser scanning (HMLS) systems, which can eliminate some potential drawbacks to traditional TLS setup, have emerged. Balenović et al. (2021) provided a detailed review about history, current status,

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improvements and perspectives of Hand-Held Personal Laser Scanning in forest inventory applications.

Since the HMLS does not require satellite positioning, forest cover is no longer a limitation in employing this system. Due to such advantages of the HMLS, the number of papers, conducted to examine the use of this system in forestry have increased recently. Bauwens et al. (2016) conducted a study to compare traditional TLS and HMLS in forest inventory and found that HMLS eliminated occlusion effects and provide the best result for DBH estimation compared to TLS approach. Stal et al. (2020) also used HMLS for assessing tree parameters, especially DBH. The results indicated that DBH values from HMLS was a useful alternative to ground measurements and produced quite similar results compared to TLS and ALS. In addition, Del Perugia et al. (2019) tested the performance of an HSML devices in forest inventory and the result shows that assessment of the single tree parameters was quite successful. Similarly, studies have been conducted by researchers (Vatandaşlar and Zeybek 2020; 2021, Fan et al. 2021) using different devices and algorithms in various forested environments. It was indicated continuous development in RS technology requires a repeated examination of this HMLS technology to assess the precise and accurate measurements of tree parameters.

In the present study, an HMLS system (called TORCH), which uses the SLAM (Simultaneous Localization and Mapping) algorithm to locate the scanner in an unknown environment and register the obtained 3D point clouds, was tested for extracting tree parameters such as diameter at breast (DBH) and tree height with 3D Forest software.

## 2. MATERIAL AND METHOD

### 2.1 Data Acquisition

The study was conducted by measuring 23 trees, located within the same parcel in Izmir Kâtip Çelebi University Campus (Turkey) (Figure 1). The parcel has flat topography. Vegetation is not dense, and trees are scattered around, not clustered. Also, there is no understory vegetation causing complexity.



Figure 1. The view from study area

Lidar data were acquired by using an HMLS device, called TORCH (Figure 2). TORCH uses a Velodyne LIDAR VLP-16 sensor, which has capability of 360° scanning with a range of 100 m and collecting point clouds at 10 Hz frequency. TORCH also has an Intel Core i7-7667U processor and a 7-inch touch screen. Some specifications of TORCH are given in Table 1.

Range	100 m
Lidar Accuracy	± 3 cm (relative)
FoV – Horizontal	360°
FoV – Vertical	30°
IMU – Roll and Pitch	0.1°
IMU – Heading	0.8°
Processor	Intel Core i7-7567U, 3.5 GHz
RAM	16 GB DDR4-2400
Storage	256 GB SSD
Weight	3.35 kg (including batteries)
Dimensions	341x223x129 mm
Operating Temperature	0°C – 45°C
Battery Life	2 hours (Hot Swap)

Table 1. Specifications of TORCH handheld mobile laser scanner

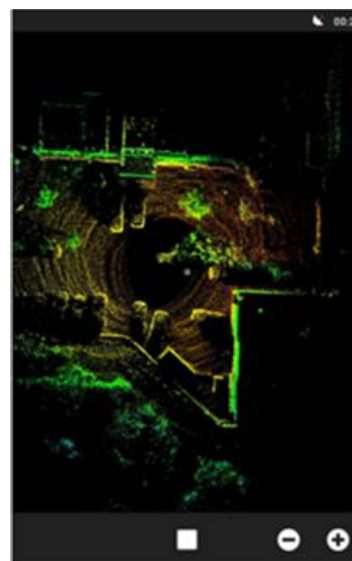


Figure 2. TORCH handheld mobile laser scanner (upper) and sample view of 7-inch touch screen on device (bottom).

Collected data from the LIDAR sensor is processed and can be seen on screen in real-time. TORCH uses the SLAM algorithm in mapping and positioning. TORCH saves point cloud data in “.las” format. Data were collected on December 3, 2021, and tree

height and DBH information was measured in the field and used as reference data (Figure 3). Tree height information was measured by using Vertex IV (Ab, 2007). All measured trees on the test area were stone pine (*Pinus pinea*). The DBH of trees is higher than 10 cm (ranging from 10 cm to 24 cm). The height of trees is less than 7 m (ranging from 3.4 m to 6.6 m). The raw point cloud data is given in Figure 4.



Figure 3. Some examples of the DBH measurement in the field

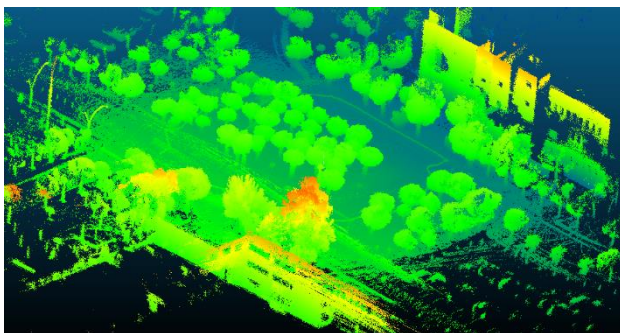


Figure 4. The raw point cloud obtained with TORCH

## 2.2 Data Processing

Raw point cloud data was processed with CloudCompare (<https://www.danielgm.net/cc/>), and tree information was extracted using 3D Forest software ([www.3dforest.eu](http://www.3dforest.eu)) developed by The Silva Tarouca Research Institute. Each software is licensed under the terms of general public license (GNU GPL). Hardware requirements for 3D Forest software are a 64-bit processor and at least 4 GB RAM memory (Trochta et al. 2017). This software processes the data by benefiting free libraries including: PCL (Rusu et al. 2011), VTK (Hanwell et al. 2015), Boost ([www.boost.org](http://www.boost.org)), LibLAS (Isenburg 2014) and Qt ([www.qt.io](http://www.qt.io)).

Prior importing point cloud data into 3D Forest software, the scanned data should be pre-processed in CloudCompare software

(Figure 5), including delineating boundary of area of interest, noise filtering. The noise filtering processed through an algorithm that locally fits a plane (around each point of the cloud) then removes the point if it is too far away from the fitted plane. This filter can be basically considered as a low pass filter.

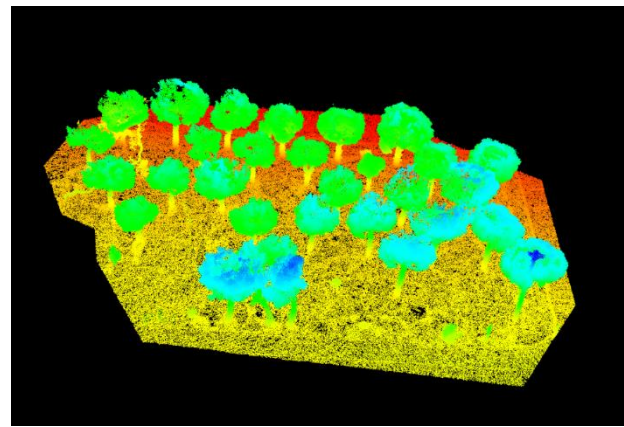


Figure 5. HMLS data imported into 3D Forest and colored by Z prior to segmentation.

Extraction of tree parameters with 3D Forest includes some steps, such as importing point cloud data into 3D Forest, segmentation of point cloud as Terrain cloud and Vegetation cloud using octree search method, individual trees segmented into Tree clouds, and estimation of DBH and tree height for each individual tree (Figure 6). The software does not only allow users to extract individual tree parameters such as DBH and height, but users also can obtain crown parameters and generate QSM (Quantitative Structure Model).

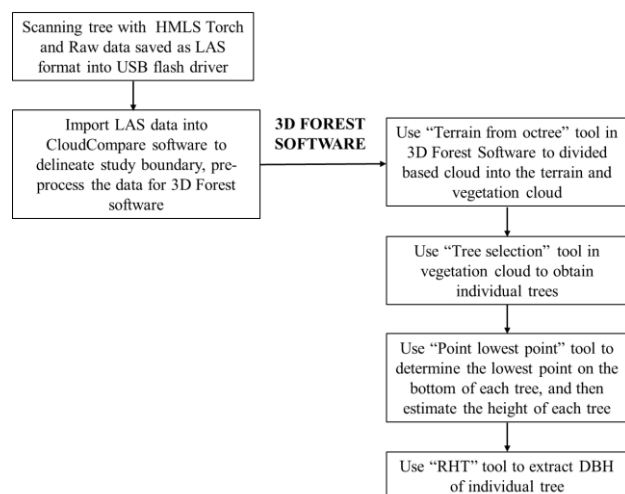
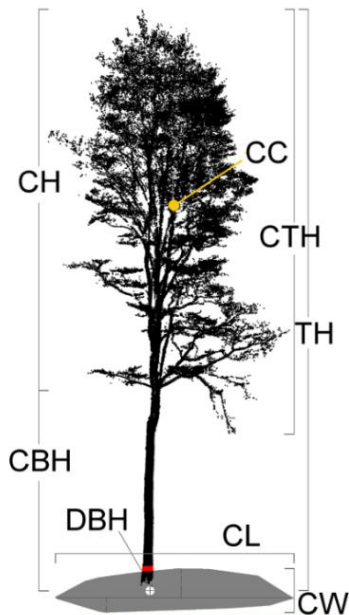


Figure 6. The workflow of the study.

For terrain extraction, 3D Forest can offer two methods: i) segmentation of the lowest points on the Z-axis based on a search in an octree structure; and ii) voxelization of the input cloud and selection of the lowest voxels on the Z-axis as the terrain (Trochta et al. 2017). In our study, first approach was employed. After, dividing the based cloud into vegetation and ground cloud, automatic segmentation of individual trees from Vegetation cloud were performed in 3D Forest based on the distance between points, minimal number of points forming clusters and the angle and distance between centroids of the clusters. However, some of the trees were not automatically detected, and detected as group. In that case, for these group of trees manual extraction tool was used. After each tree was successfully extracted, trees were



segmented. For all the steps in workflows, suggested parameters by Trochta et al. (2017) were applied along with the visual evaluation. Segmented trees are then ready for computing tree parameters such as tree position, tree DBH, tree height / tree length, stem curve and tree planar projection (Figure 7).



**Figure 7.** Extraction and visualization of tree parameters from a single tree cloud (Trochta et al. 2017): CBH–crown base height, CH–crown height, CTH–crown total height, CL–Crown length, CW–crown width, CC–crown centroid, DBH–diameter at breast height, TH–tree height, white sphere–tree position.

These parameters can be exported as text file (.txt). Obtained results from the software were compared with the field measurements (reference data). The mean, standard deviation (SD), standard error (SE) of DBH and Height for both HMLS data and reference data were calculated, and then compared by root mean square error (RMSE). The mean formula used in calculation of both DBH and tree height parameters, which were obtained from both HMLS data and reference measurement is given as following;

$$mean(\bar{x}) = \sum_{i=1}^n X_i/n \quad (1)$$

The SD and SE formula are given as following;

$$SD = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n}} \quad (2)$$

$$SE = \frac{SD}{\sqrt{n}} \quad (3)$$

The RMSE was calculated by using following formula:

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (x_{i(hmls)} - x_{i(ref)})^2}{n}} \quad (4)$$

where  $x_{i(hmls)}$  is measurement with TORCH, and  $x_{i(ref)}$  is reference measurement, n is number of trees.

### 3. RESULTS AND DISCUSSIONS

This study aimed to test a HMLS device (TORCH) in extraction of individual tree parameters. A summary of the reference data and estimated tree parameters from point cloud data extracted by using 3D Forest software is found in Table 2.

	DBH (cm)			Height (m)		
	Mean	SD	SE	Mean	SD	SE
Ref. data	18.54	4.12	0.86	5.36	0.78	0.16
HMLS data	24.22	3.76	0.78	5.08	0.74	0.15
RMSE	6.81			0.32		

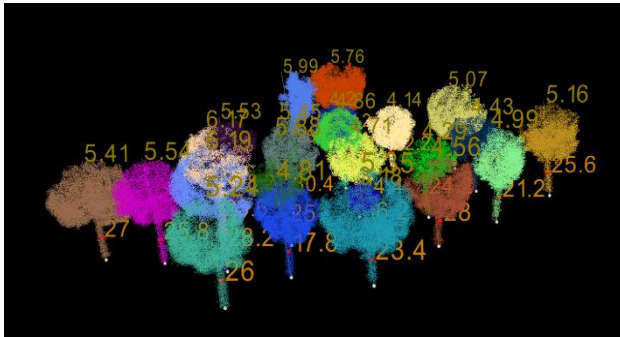
**Table 2.** A summary of the reference data and estimated parameters from HMLS data extracted by using 3D Forest software

Data acquisition was completed in five minutes using TORCH. Even though the area is small and flat compared to field measurements. The TORCH has Velodyne LIDAR VLP-16 sensor that scans data with a relative accuracy of  $\pm 3$  cm. In addition, SLAM algorithm calculates position of points with some errors. Depending on data acquisition, the accuracy can vary in centimetres level range. The TORCH has IMU on board, but user must carry the scanner by holding parallel to ground and move as slowly as possible. In this study, the data were acquired by walking around the parcel.

The results showed that mean DBH values from HMLS data were relatively higher than ground measurement, whereas estimated mean height from HMLS data were slightly lower than the reference data. However, calculated SD and SE from HMLS data for DBH and height were lower compared to ground measurements. Although HMLS devices provide accurate and reliable tree parameters, the size of the tree, quality of data, applied scanning approach, and segmentation method can affect the accuracy and precision of DBH and height estimation. A reviewed paper by Balenović et al. (2021), the current status of handheld laser scanning and its perspective in forest inventory application, indicated that previous studies obtained larger errors for trees with smaller DBH due to low point clouds density, small size target trees, and high noise. Similar results were observed in this study; overestimation increased with decreased DBH. On the other hand, our result for height estimation from HMLS data (RMSE: 0.32 m) is compatible with the literature (Balenović et al., 2021). Besides, DBH estimation in our study was larger compared to recent relative studies (Çakir et al. 2021, Stal et al. 2021, Vatandaşlar and Zeybek 2021). The device types which can have different scanning sensors, the SLAM algorithm, and the properties/complexities of trees together with the number of trees might cause these differences.

3D Forest, a free and open-source software, was used for this study. It has an easy-to-use Graphical User Interface (GUI) suitable for non-experts in TLS data processing. It allows users to compute many different tree parameters (i.e., tree base position, DBH, tree height, stem curve, tree planar projection), crown parameters and produces a detailed digital terrain model (DTM) of the study plot. Çakir et al. (2021) employed the 3D Forest Software using Lidar data from two different scanning devices for two distinct forest types (managed and urban forest). 3D Forest software produced comparable results to ground measurements for DBH extraction. However, these two study

areas are quite flat and have not got dense forest coverage like our study area. It would be better to test the software under different topography and forest coverage. In addition to being open-source software and not requiring expert knowledge to use the software, it is necessary to have powerful computer to analyze data within 3D Forest software. For our study, extracted DBH and Height value of the individual tree from HMSL data using the 3D Forest for entire study area can be seen in Figure 8. Also, Figure 9 indicated an example for determining lowest position on the bottom of a tree and extracted DBH value.



**Figure 8.** Measurement of DBH and Height from HMSL data in the 3D Forest for entire study area



**Figure 9.** Example of some automatically segmented individual tree (each color represent individuality) and determining lowest position on bottom of an individual tree

#### 4. CONCLUSIONS

Rapid recent advancements in lightweight laser scanner technologies increase their potential use in forest inventory, as well as forest management and planning. The performance of this technology requires continuous studies to examine feasibility of individual tree attributes estimation.

In this study, it is concluded that TORCH can be used to extract individual tree parameters. This primary test resulted relatively larger errors in DBH calculation, but it is clear that more comprehensive tests should be performed. The system selected for this study was developed by Leo Engineering company ([www.leomuhendislik.com](http://www.leomuhendislik.com)) and provides point cloud data of trees in “.las” format with sufficient enough point densities. So far, this system has not been tested in extraction of tree parameters. Following the future comprehensive tests of the device, the system could be suggested without doubt for using in forest inventory practices.

It is known that TLS provides more accurate results, but the HMLS systems show a great potential as well. For future studies, we are aiming to compare this system with other techniques such as TLS, and close-range photogrammetric systems in different types of forested areas with different structural complexities over different topographies. Also, in the present study, only two individual tree parameters (DBH and Tree heights) were extracted using 3D Forest software. It might be used to extract

other parameters such as crown diameter, crown height, first living branch height that can be helpful for living biomass and fire research studies in the future.

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