REGISTRATION, GEOREFERENCING AND PROCESSING OF MULTIPLE LASER SCANS ACQUIRED BY TERRESTRIAL LASER SCANNER FOR ESTIMATING TREE MORPHOLOGICAL PARAMETERS

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ABSTRACT:

The trees inventory is very important for forestry and environment-related issues, where tree morphology is one of the key components. LiDAR technology is being selected over other techniques for the trees three-dimensional mapping and inventory. In this paper a methodology for point cloud registration and georeferencing of LIDAR point cloud, and computation of tree morphological parameters, namely tree height, crown diameter, crown projection area is presented. The instruments used for the point cloud acquisition, registration and georeferencing were total station, global navigation satellite system, terrestrial laser scanner. Data from all three instruments were transformed into a common coordinate system that is Universal Transverse Mercator coordinate system. In transformed point cloud, the z-axis of the coordinate system is towards plumb line. The tree height, crown diameter, crown projection area are computed based on point cloud-derived canopy height model and tree top detection.

1. INTRODUCTION

The registration of multiple scans to cover a large area, such as urban parks or forest cover and georeferencing are the initial steps in the processing of raw laser scans collected by terrestrial laser scanning (TLS). In georeferencing, the laser scans point clouds are transformed into a geographic coordinate system that is Universal Transverse Mercator (UTM) coordinate system. Like total stations, the majority of contemporary TLS systems may be levelled, centred over a known point, and orientated to a known backsight. In order to georeference the point clouds, we can ascertain the scanner's position and orientation (azimuth) in the field. The procedure is known as direct georeferencing (Reshetyuk 2010). After obtaining georeferenced point cloud in which the coordinate system's z-axis is towards the plumb line, the height-based analysis can be used for the computation of trees morphological parameters.

The multiple laser scans are registered in a common coordinate system and further transformed into a geodetic coordinates using three different sorts of techniques: indirect georeferencing, direct georeferencing, and surface matching (Alba *et* al. 2007; Schuhmacher and Böhm 2005). Set of control points measured in geodetic system and TLS coordinate system are used for indirect georeferencing. At least three control points are used in the calculation of the registration parameters (three rotations and three translations). For the control points, we may utilise the targets positioned in the measurement space or distinguishable significant elements in the TLS point cloud data. The indirect georeferencing requires measuring the control points coordinates in the geodetic coordinates using terrestrial techniques (Alba and Scaioni 2007; Elkhrachy and Niemeier 2006). The marking and measuring of the control points are

labour and time intensive process. On the other hand, in order to achieve high precision, more control points should be used while georeferencing.

Direct georeferencing can be implemented using a variety of techniques. Lichti *et* al. (2005) and Scaioni and Polo (2005) determined the rotations between the axes of a laser scanner and geodetic system by mounting a telescope on the laser scanner. The telescope is used to rotate the laser scanner to aim in the direction of another point as part of the measurement. This method's application is constrained because it requires knowledge of both the observed points and the laser scanning station's coordinates. Another technique for direct georeferencing is to use global navigation satellite system (GNSS) or a compass with a laser scanner (Böhm *et* al. 2006; Schuhmacher and Böhm 2005). The Global Navigation for Satellite System (GNSS) receiver mounted on the laser scanner can be used to identify the coordinates of the laser scanning station in the WGS84 datum. The rotation of the scanner is controlled by a compass mounted on it or by a GNSS placed within the scanning region. The accuracy of the procedure is, however, diminished by the way the laser scanner, GNSS, and compass are configured. Another study used a TLS and GNSS combo to georeference laser scanning data. In direct georeferenced terrestrial laser scanner networks, errors and their propagation were studied in the paper of Lichti *et* al. (2005).

Additionally, the causes and consequences of a number of systematic mistakes prevalent in TLS datasets were discussed. According to the study, the width of the laser beam significantly affects how well the scan data is rotated. Wilkinson *et* al. (2010) described an independent method for orienting point clouds relative to the geodetic coordinate system. It was discussed,

how to do georeferencing using TLS and GNSS together. Rotation angles were calculated on the TLS with a precision of roughly 0.05 degrees using a dual-GNSS antenna setup. Georeferencing using surface matching is the process of registering new point clouds to an existing georeferenced point clouds. Least-square 3-D surface matching (Gruen and Akca 2005), iterative closest point (ICP) (Zhang 1994; Yang and Medioni 1992; Besl and McKay 1992), and more applications of surface matching are available (Nüchter *et al.* 2003).

According to Hyyppä *et al.* (2012), airborne laser scanning (ALS) has been extensively used to map forested regions, measure forest height, individual tree height, and crown diameter (depending on the density of the 3D point cloud). But for small residential areas, the tree height and crown diameter can be estimated using Terrestrial Laser Scanner (TLS). In this paper, we have segmented individual trees and estimated tree height, tree crown area.

For yield estimation and pesticide application, tree canopies are crucial (Liu *et al.* 2022). Accurate calculations of the fuels in the forest canopy are necessary for the prediction and mitigation of wildfire behaviour (Arkin *et al.* 2021). To achieve individual canopy extraction, a Euclidean distance clustering technique and a cloth simulation filter were utilised. Using six different techniques, including a manual approach and five point-cloud-based algorithms (convex hull, CH; convex hull by slices; voxel-based, VB; alpha shape, AS; and alpha-shape by slices, ASBS), canopy reconstruction and volume calculation were carried out after the determination of canopy height and width (Liu *et al.* 2021).

2. MATERIAL AND METHODS

2.1 Study area

In this paper, the study area was around 100 m^2, which was located in the Biotechnology Experimental Field in Motilal Nehru National Institute of Technology Allahabad, India. The study are includes low and high vegetation, other on-ground objects, such as boundary wall, vehicle parking shed, etc.
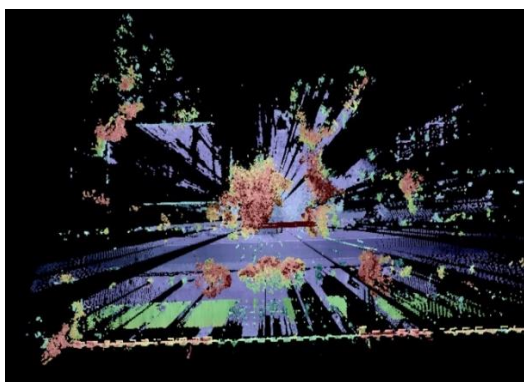
Figure 1. Top view of the study area point cloud collected using TLS.

2.2 Instruments

Figure 2. Instruments used for the experiment (A) TLS, (B) Total station (TS), (C) GNSS receiver.

2.2.1 TLS

The 3D point cloud of the study area was generated using FARO Focus3D X 330 HDR laser scanner (Figure 1 (A)) in August, 2021. The multiple scans were acquired, which covered low vegetation (i.e. plants) enclosed within the field boundary and trees in the surrounding area. It is a high speed 3D laser scanner in terms of data acquisition with the range lies between 0.6 m to up to 330 m. Also the distance measurement accuracy is $\pm 2\ mm$ and noise reduction goes up to 50%.

2.2.2 GNSS

Trimble R10 GNSS receiver (Figure 1 (C)) was used for georeferencing of laser scans. It has horizontal accuracy of 3 mm and vertical accuracy of 3.5 mm in high precision static mode. In real time kinematic mode it has accuracy of 8 mm and 15 mm in horizontal and vertical simultaneously. We have used GNSS in static mode to achieve maximum positioning accuracy.

2.2.3 TS

Trimble M3 total station (TS) was used in this study (Figure 2 (B)). It has 3 mm + 2 ppm EDM, which provides fast, accurate and reliable measurements. The least count for the angle measurement is 1″/0.2 mgon. Range of this instrument (under standard clear conditions) in prism mode is 5000 m. In this study, TS is used for the co-registration of 3D point clouds.

2.3 Experimental setup and data collection

In the experimental setup for the registration of laser scans, nine spheres and ten checkerboards were used. Two GNSS stations were fixed at the designated locations considering the clear sky view. Two scan positions were decided to cover the plant crops and trees. Placement of spheres and checkerboards were well distributed. From two positions, the TLS-based point cloud data acquisition was performed to cover plant crops and trees, which were further registered into a common TLS system's coordinate system using the software provided with the TLS system.

In the two GNSS stations located in the experimental field, at each GNSS station at least 2 hours of data was collected. After GNSS data collection the GNSS observations were processed to get station coordinate in Easting, Northing and Geoid Height. Two laser scans taken from the decided scan positions scanned the checker boards and spheres as well along with other scene objects. The TS was placed at one of the known GNSS stations and location of that known point was given as origin to the total station. Then all the checkerboard centres were measured using TS. The TS station was transferred to another location such that all checkerboards were covered.
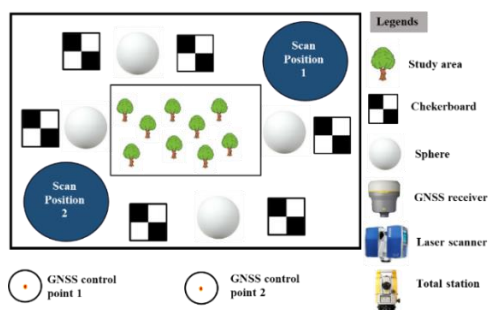
Figure 3. Experimental setup layout for point cloud data acquisition and georeferencing using LiDAR, GNSS and TS.

3. METHODOLOGY

3.1 TLS, TS and GNSS data integration

The integration of TLS and TS datasets are performed to generate point cloud in common coordinate system. It is performed by transforming TLS point cloud in its own coordinate system to the TS coordinate system. Next using GNSS-based measurements of the control stations, the point cloud is georeferenced. Figure 4 summarizes the workflow of various sensors data integration to generate georeferenced point cloud. First, few GNSS stations as control stations are fixed in the experimental field considering clear sky view. In our case, two stations were selected. Next, from these stations (at least two) the GNSS data is received for at least one hour. After that, GNSS data is processed using an application to obtain the coordinates (x, y, and z) of control stations. Then, TS is placed at one of the control station and coordinates of that stations is given as origin in the TS. As study area belongs to "UTM 44" coordinate system, so, it is selected in GNSS receiver while entering the parameters for the GNSS control station set up. After that, checkerboard centres are measured using TS (Figure 5). The checkerboard points are surveyed points, which are manually uploaded to the "Scene" software (FARO Scene software, 2019). TLS point clouds are pre-processed using "Scene" software. Data from TLS and TS are integrated using "Scene" software.
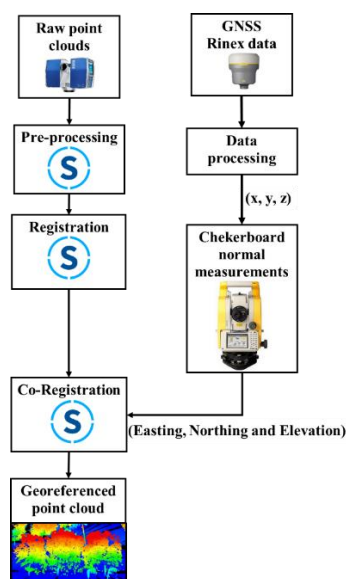

Figure 4. Overall methodology framework for TLS, TS, and GNSS data integration for generating georeferenced point cloud.

The overall methodology framework for combining all the observations/datasets acquired using TLS, TS and GNSS are shown in Figure 4. In this methodology, the TS is placed at a known point that is GNSS control stations. Checkerboard centre points are measured using TS and same TS points are used for TLS point cloud georeferencing.
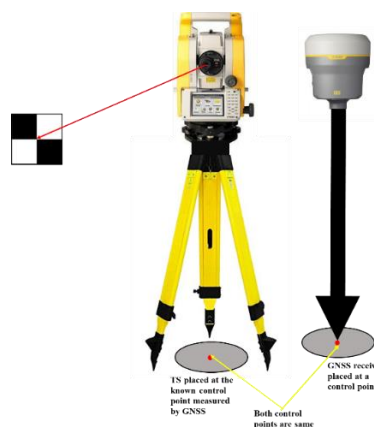
Figure 5. The surveyed point's (i.e. checkerboard's centre) coordinates measurement in UTM coordinate using TS and GNSS for the georeferencing of TLS point cloud.

3.2 Extraction of tree morphological parameters
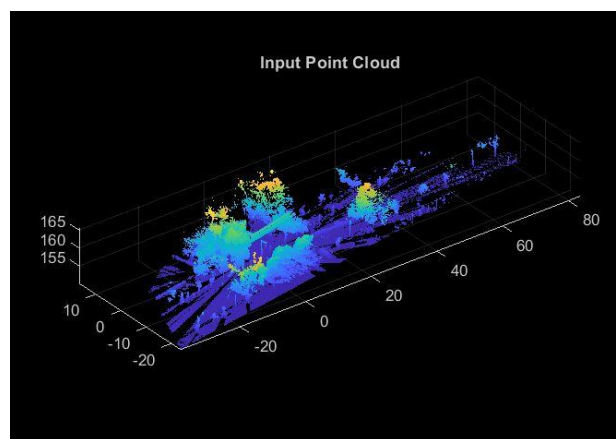
**Figure 6.** Georeferenced point cloud that is used as an input.

Now, georeferenced point cloud (Figure 6) is used for the extraction of tree segmentation and tree morphological parameters estimation. Sequence of processing steps is given in Figure 7, in which geo-referenced point cloud is taken as input.

Figure 7. The data processing methodology workflow for extraction of tree morphological parameters.

3.2.1 Ground segmentation and elevation normalization

Ground points were eliminated from the georeferenced point cloud and elevation was normalized for the non-ground points at the preprocessing steps (Figure 8).
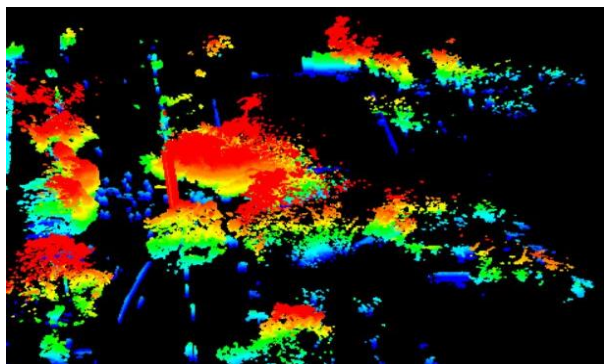
Figure 8. Off-ground 3D Point cloud view with normalized elevation.

3.2.2 CHM generation and tree top detection

The total percentage of the space that the vertical projections of the tree crowns occupy is known as canopy cover (CC) (Jennings *et* al. 1999). The percentage of pixels within a statistical unit (30 x 30 m grid) with a CHM value greater than the tree threshold (2 m) can be used to generate canopy height model (CHM) based CC (Equation 1).

$$CC = \frac{\sum CHM_{canopy}}{\sum CHM_{total}} \tag{1}$$

Where CHM_{canopy} is a representation of the canopy-related pixels in CHM (with a CHM value above 2 m). CHM_{total} stands for CHM pixels overall. LiDAR-derived CHMs have been utilised frequently to calculate CC (Chen and Hey 2011). The difference between digital surface model (DSM) and digital elevation model (DEM) was used to determine CHM.
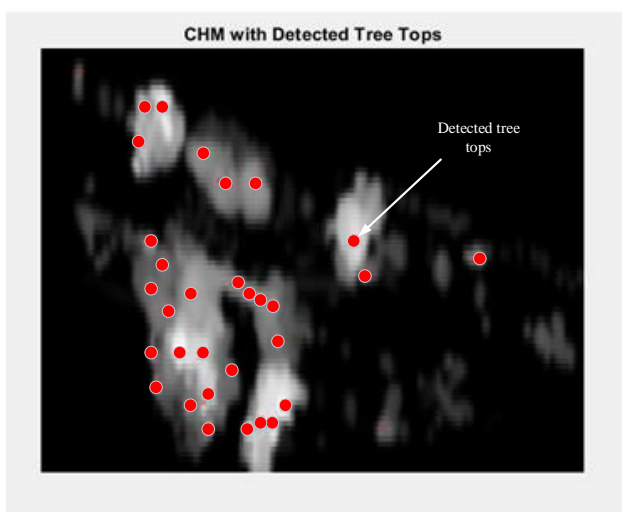

Figure 9. The view of CHM with detected tree tops.

The height of trees, buildings, and other structures above the topography of the ground is depicted in raster form by canopy height models (CHMs). For tree detection and segmentation, we used CHM as the input. CHM was generated using the pc2dem (Generate DEM and Put the Images) function in MATLAB using normalised elevation values as generated in the preprocessing step.

3.2.3 Individual tree segmentation

We used a marker-controlled watershed segmentation (Chen et al. 2006) for individual tree segmentation. This algorithm first generates a binary marker picture with a value of 1 designating the locations of the tree tops (Figure 8). Then, it applies minima imposition to filter out non-tree top minima from the CHM complement. Then individual trees are segmented using watershed segmentation on the filtered CHM complement. Individual tree segments are shown in Figure 10.
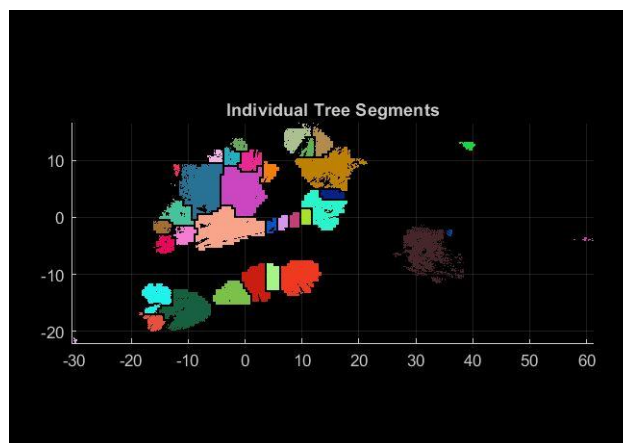
Figure 10. Individual tree segments obtained after segmentation.

3.2.4 Estimation of tree height and tree crown area

The method used for tree morphological parameters estimation identifies the points belonging to individual trees from labels. Then, tree morphological parameters such as tree height, tree crown diameter, and area are estimated. Convex hull algorithm, which returns the convex hull of a set of points in 3D space, was used for the estimation of tree crown area.

TreeID	NumPoints	TreeApexLocX	TreeApexLocY	TreeHeight (m)	CrownDiameter (m)	CrownArea (m²)
1	142	-29.63	-21.47	6.03	0.83	0.55
2	2966	-14.83	-17.94	10.96	3.42	9.23
3	12613	-17.11	-12.75	12.08	5.13	20.67
4	22475	-14.11	-5.11	8.33	3.31	8.62
5	7039	-13.79	-1.09	6.76	2.66	5.57
6	76603	-11.17	-17.85	14.25	7.77	47.46
7	73792	-10.19	1.34	7.19	4.79	18.07

Table 1. Tree morphological parameters for seven trees from the study area. Each row represents the parameters for individual trees.

4. RESULTS

The TLS scans were registered and georeferenced. Then after the normalized non-ground point cloud (Figure 8) was used for CHM generation. The CHM with detected tree tops is presented in Figure 9. After CHM generation individual trees are segmented from point cloud using marker-controlled watershed segmentation algorithm (Figure 10). Tree morphological parameters for individual trees were estimated using convex hull algorithm (Table 1).

5. CONCLUSIONS

Most of the work related to tree morphological parameters estimations are related to the airborne LiDAR system (ALS) data. Working with the TLS data for estimation of tree morphological parameters are less explored. This work is an effort towards developing processing framework for TLS-based survey; TLS scans registration, point cloud georeferencing, and estimation of tree morphological parameters using highly accurate and dense TLS data. This work is more suitable for the urban trees management.

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