Terrestrial laser scanning for tree parameters inventory

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Abstract. Presently, the application of Terrestrial Laser Scanning (TLS) technique in forest inventory is becoming widely spread due its high level of accuracy. It is able to provide precise and detailed tree attributes. This study aims to determine tree attributes from point cloud data captured from TLS and to validate the estimated tree attributes by using the conventional method of tree measurement. These attributes include diameter at breast height (DBH) of the tree, tree height, crown base height and average crown spread. They were estimated from both the TLS and conventional techniques. The DBH was estimated using the cylinder fitting model while tree height, crown base height and average crown spread were measured manually from the Cyclone software. Finally, this study has shown that TLS is a reliable technique for tree inventory and can be applied in forest management for easy, fast, and efficient estimation of forest biomass.

1. Introduction

Trees inventory of the forest biomass and planning for the tree harvesting is very important in forest management. The conventional way to plan the tree harvesting is done with a human eye. To make the harvest planning more accurate, tree measurement system is needed [1]. Developed models are presently in used to provide and increase sustainable management of forest resources with careful thought to several economic values of the forest resources such as wood production for building materials, pulpwood, biodiversity, and bioenergy [2]. Also, rise in the advancements of remote sensing technology has enable laser scanning technology to fill in the space of aerial photographs ability to see through the vegetation canopy. This permits a precise and detail measurements of underground forest vegetation, tree size, structure and terrain. The study of laser scanning technology in providing forest attributes and profile information have begun since the 1980s, this laser pulse had been applied to capture different forest tree attributes such as the canopy and the tree height accurately [3].

Three-dimensional detailed information about the tree biomass in the forest area is required in order to maximize the function and potential of the forest [4]. Several methods have been outlined to measure above-ground biomass, but primarily it can be divided into direct method (destructive sampling) and indirect method (non-destructive method). Using the destructive sampling method to develop a new technique would take a huge amount of resources and would involve cutting down a lot of large trees. On the other hand, utilizing the non-destructive method consists of developing the allometric equation or regression model, calculating from forest inventory data. Application of remote sensing and geographical information system (GIS) methods can also estimate the above-ground biomass. However, appropriate methods should be refined in order to estimate the above-ground
biomass using remote sensing integrated with field measurement: this concept would reduce the labor-intensive data collection when it comes to a large area [5]. The tree parameters that are present in every tree in a forest show an interaction or communication process between one tree and another. There are various ways to compute the biomass and parameters, which include direct and indirect methods. Direct methods use equipment that is directly in contact to the trees and they have the ability to determine the wanted parameters without using mathematical derivations. Although, presently there are several other techniques used for the estimation and validation, yet the direct methods are still used as the best method. Example of direct methods include: stratified clipping, allometrics, litter traps method and the scaffolding approach. While indirect methods depend on mathematical derivations which are used to compute the wanted parameter from several easily measured parameters. Example of direct methods include: point quadrat method and inclined point quadrats, photogrammetry method, LiDAR methods e.g. ALS and TLS, radiation measurement, spherical densitometer [6].

Laser scanning technology has come into an existence since 1960’s but applying it as a measurement tool is a new concept. Manufacturers of laser scanning systems are producing good and quality scanning equipment which are presently used in a wide range of applications such as building construction, forestry, and environmental studies etc. This is based on the manufacturing company and application specifications [7]. The Terrestrial Laser Scanning is very easily and conveniently transported equipment. The laser rangefinder is able to capture millions of discrete 3D points corresponding to the positions of the objects around the scanner. TLS is different from Airborne Laser Scanning (ALS) because it is able to capture more point clouds both in small and large areas. Most of the energy of ALS is directly at the top most part of the canopy, while that of TLS is directly at the base and sides of the canopy and other tree parameters, but this depends on the type of tree, the tree height and canopy constellation. Presently, most TLS researches are trying to use these point cloud data to create new two-dimensional structures of tree, validate leaf area index (LAI) etc. Also this same method is applied to perform forest inventory [8]. More researches are greatly focusing on providing highly detailed, accurate and precise three-dimensional models of trees.

For obtaining the tree parameters, previous researchers employed various methods that can be grouped into conventional method and methods that are based on remote sensing technology. Conventional methods of tree parameters measurements for biomass estimation and allometric equation development were based on destructive approach. Tree need to be cut and its individual parts were measured including their weight [9]. Previous studies have introduced various methods in estimating the biomass for each tree parts. In this context, looking into accounts on the problems, issues and solutions given by various researchers and using the importance of TLS data as mentioned, this research is focused on how to generate the point clouds from the TLS, the extraction of the tree parameters, finally to validate the measured parameters.

2. Materials and Method

Detail methodology for this research is divided into four main phases as shown in Figure 1. First is data collection and processing, second is pre-processing of point clouds, third is the estimation of tree parameters and lastly is the validation of the parameters with real values measured from the field.

2.1. Data collection

Two types of data were collected using the Leica Scan Station C10 TLS device and field measurement data. The Leica Scan Station C10 is a Time-of-Flight laser scanner which is embedded with a digital camera inside it. Before the data collection, site observation was first carried out to figure out the best position to fix the scanner and the targets. After that, critical placement of the scanner was done by a proper set-up position and leveling it because it needs to be placed at a location that can cover the whole tree at maximum view which can also scan the targets that has been placed. After the scanning process was conducted, registration of 3D point cloud was carried out to visualize the complete study area using Cyclone software. This TLS device has a very high speed in terms of 3D and is used for specific measurements because of its high accuracy and precision.
This scanner is capable of scanning at least 300m distance object with the accuracy of 4.5 mm. In this study, the scanning resolution is set to medium density of data acquisition with 0.05 m vertical and horizontal point spacing. Furthermore, the longest distance between the scanner and the tree was 15m. Three scan stations were used for this research to get a full coverage of the study area and the targets positions were kept constant. Six sphere targets used on the scanning field.

2.2. Pre-processing of point cloud
The data pre-processing started with preparing the raw data for further processing. All this was done in the Cyclone software, which there are several interfaces that are commonly used to process point cloud data. The interfaces are Scan World, Control Space, Model Space View. After this, next step was registration of point cloud data. Registration is a process of adding all the scan stations data in a single view or a single scan world. In this study, the registration process was done using target to target method. The registration error result has the maximum error of 0.002m and the minimum of 0.001m. During this process of registration, all scan world need to be added in the registration form. Auto add constraints function was used to add all the targets that were scanned during the scanning process. After adding the constraints, the registration process can proceed, and the errors of the registration is shown in the constraints tab menu. When all this is successful, registration needs to be in freeze registration mode. In this mode, any point cloud data changes are not allowed.

2.2.1. Filtering of Unwanted Points Cloud. In order to get the object or place of interest from the newly created model space, all unwanted points have to be removed from the model space such as noise, buildings, cars etc. this is known as filtering process. Figure 2a and 2b shows the model space for before and after filtering.
2.3. Extraction of single tree parameters
The next step after 3D point cloud generation is extraction of the tree parameters which was done in Cyclone 7.3 version. Parameters extraction is divided into total tree height (TTH), diameter at breast height (DBH), crown height and average crown spread. In this study, total tree height and crown base height were computed manually from the cyclone software using multi-pick mode in the tool bar to measure the distance from point to point. The total tree height is measured starting from the bottom level to the top most part of the tree as seen in figure 3a, while the crown base height was measured starting from the top of the tree to crown base height ending point (figure 3b). Previous studies have shown that estimation of tree crown volume is very important for the management of plantations [10].

Figure 2. (a) Model space before filtering  
Figure 2. (b) Model space after filtering

Figure 3. (a) Total tree height  
Figure 3. (b) Tree Crown base height

Figure 4. Diameter at breast height (DBH)
To measure diameter at breast height of tree, TLS shows a relying result for DBH. Cylinder fitting method in Leica Cyclone was used to estimate the DBH of the tree as shown in Figure 4 which was retrieved at 1.4 m height above the ground level from TLS datasets.

2.4. Validation of the tree parameters by comparing both records
Evaluation of results is divided into two parts i.e. field measurements and estimated tree parameters using point clouds generated from TLS. The TLS-based parameters estimates will be compared with the parameters value derived from field measurements. Root mean square error (RMSE) and mean absolute error (MAE) in equation 1 and 2 are used in this research to analyze the results of the comparison.

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RMSE = \sqrt{\frac{\sum_{i=1}^{n} (D_i - D_m)^2}{n}}
\]

\[
MAE = \frac{\sum_{i=1}^{n} |D_i - D_m|}{n}
\]

where \(D_i\) is the estimated tree attributes from point clouds and \(D_m\) is the tree attributes measured in the field and \(n\) is the number of samples used in the analysis.

3. Results and discussion
3.1. Estimation of single tree parameters
Tree detection and measurement of various parameters were obtained manually from the point clouds using the Cyclone software. The result for the tree DBH was obtained at the height of 1.4m above the ground level using the cylinder fitting method showing very small RMSE value of 0.062 cm with an MAE value of 0.047 cm respectively. The estimated result of the DBH of the tree was 0.410m while the tape measurement was 0.435m which shows very little difference. TLS value for the DBH shows very accurate and reliable result. Also, Table 1 shows RMSE and MAE of field measured DBH with estimated DBH. Measurement of tree height and crown base height were obtained using the multi-pick mode tool in Cyclone software to measure distance from point to point. Figure 3a. shows the TLS results of tree height estimation based on the single tree height measurement from the point clouds. The crown base height of the tree was measured with TLS point cloud data only without using the tape measurement method due to its limitation. The estimated tree height of the single tree using TLS has the value of 16.937m and the tape measurement of the same tree height was 18.137m. TLS underestimates the tree height value with a difference of 1.2m. Table 1 shows the RMSE and MAE of field measured tree height with estimated tree height.

Figure 3b shows the crown base height measurement of the single tree using only the TLS method of tree parameters estimation. This measurement was obtained using the Cyclone software and the result of CBH was 14.692 while that of the average crown spread was 12.473m. The tape measurement of the average crown spread was also obtained with the value of 12.442m. Both methods of tree measurement show a reliable result because there is only little difference of the values. Table 1 shows the RMSE and MAE of field measured average crown spread with estimated average crown spread.
Table 1. Total RMSE and MAE of field and estimated measured tree parameters

| Tree Parameter   | RMSE (cm) | MAE (cm) |
|------------------|-----------|----------|
| Tree height      | 189       | 153      |
| DBH              | 0.062     | 0.047    |
| Avg. crown spread| 0.074     | 0.032    |

3.2. Assessment of estimated single tree parameters

The quality of these measurements shows the accuracy and completeness of the measurement results as gotten and derived from the model in software Cyclone 7.3. The validity of these measurements was done by comparing the TLS results with the measurements from the conventional method i.e. measuring tape and also using the RMSE and MAE methods of estimation of data. Due to the limitation of using measuring tape, only the tree height, tree DBH and the average crown spread were compared and validated. Table 2 shows the comparison of the measurements done using terrestrial laser scanner (TLS) and tapes, also showing the differences between the two methods of the tree parameters extraction in centimeter.

Table 2. Comparison of measurements

| Tree Parameter   | TLS (cm) | Tape (cm) | Difference (cm) |
|------------------|----------|-----------|-----------------|
| Tree height      | 1693.7   | 1813.7    | -120            |
| DBH              | 41.1     | 43.5      | -2.4            |
| Avg. crown spread| 1247.3   | 1244.2    | 3.1             |

Furthermore, the results of the single tree measurement show that the RMSE for average crown spread measured using point clouds of TLS in cyclone software is 3.1cm. TLS method is almost equivalent to field measurement with very little difference. The tree was not affected by the tall buildings and poles of the study area. This also contributed to the accuracy of the measurement. Likewise, TLS shows a relying result for DBH estimation with the total difference of -2.4cm. This method provided almost the same result of DBH compared to the field record. In the other hand TLS underestimated the tree height value with a difference of 1.2m compared to the tape measurement.

4. Conclusion

This paper presents the results of both TLS and conventional techniques for tree inventory. The estimation of the tree attributes from the point clouds data has been done i.e. diameter at breast height (DBH) of the tree, tree height, crown base height and average crown spread. It has clearly shows the reliability of TLS in estimation of tree attributes. Also, this methodology can be employed to improve the establishment of detailed allometric equation for forest measurement in tropical regions. Furthermore, it produced a unique 3D model of the tree with a very relying resolution. The difference between TLS and conventional tree measurement values in this research was insignificant. Therefore, the use of TLS increases more detailed tree data measurement for the forest in a much easier and faster way which is assumed to save time, energy, and cost.

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