

Estimation of 12 Biomass Parameters and Interaction between the Trees Using Terrestrial Laser Scanner

Irwan GUMILAR, Hasanuddin Zaenal ABIDIN, Eko PRASETYO, Ekus KUSTIWA,
Indonesia

Keywords: Biomass, Crown, Forest, TLS, Tree

SUMMARY

Biomass has an important role to control the earth's climate and the mitigation of the climate change. Indonesia is one of the countries with rich biomass resources, especially in forestry, plantation, and agricultural sectors. The technology to measure the 12 biomass parameters to calculate the biomass potential in the forestry sector continues to develop. One of the new methods that are being developed is by using Terrestrial Laser Scanner (TLS). In this research, the TLS is applied to measure the 12 biomass parameters, which consist of the parameters of the trunk, crown, and the parameters between trees. The methodology of this research consists of literature study, measurement planning, acquisition data, processing the TLS data, calculating the value of the desired parameters, and validating the TLS measurements by comparing them with the measurement results using measuring tapes. The objects of this research were 2 mahogany trees (*Swietenia mahagoni*). The result of this research is the measured 12 biomass parameters which are related to the competition between trees. The validation result shows that the difference between the measurement and the measurement using tapes is 1 mm – 7,73 cm. The TLS can be applied in forestry and analyze the complex 3 dimensional shape of the trees, especially the growth plasticity of the crown of the trees. The measurement using TLS has obstacles in areas with high wind intensity, which causes the shape of the object to be inconsistent.

Estimation of 12 Biomass Parameters and Interaction between the Trees Using Terrestrial Laser Scanner

Irwan GUMILAR, Hasanuddin Zaenal ABIDIN, Eko PRASETYO, Ekus KUSTIWA, Indonesia

1. INTRODUCTION

Forest is an ecosystem which consists of landscape containing natural resources, dominated by trees in the natural environment where each cannot be separated from the other (Act Number 44 Year 1999). Forest can act as a regulator to control the climate change and its mitigation through its ability to absorb the carbon particles from an area of the forest.

To maximize the function and potential of the forest, three dimensional information of the biomass spread in a forest area is required. Biomass is an organic matter produced by photosynthetic process, either as a product or a waste [Sutaryo, 2009]. The biomass parameters that are formed in every tree in a forest represent the interaction process between a tree and another.

There are several methods to calculate the biomass parameters, namely direct methods and indirect methods. Direct methods use instruments that have direct contact to the material of investigation and that are able to determine the desired parameters without using mathematical derivations. Although nowadays there are already other techniques used for validation, the direct method are still regarded the best choice. Some direct methods are: allometrics, stratified clipping and the scaffolding approach, and litter traps method. In contrast to the direct methods, indirect approaches are based on mathematical derivations or assumptions which are used to calculate the desired parameter from another easily measured parameters. Some indirect methods are: point quadrat method and inclined point quadrats, MacArthur and Horn'-photographic method, hemispherical photography, LIDAR and optical point quadrat methods, radiation measurement, TRAC and MVI, DEMON, spherical densiometer [Seidel, 2011].

Presently, a new technology using non-contact methods is available, namely the three dimensional terrestrial laser scanner, which can give spatial information from the trees with very high resolution [Seidel, 2011]. This technique, commonly known as the Terrestrial Laser Scanner (TLS), can give comprehensive information of the structure of the tree, and thus allows the research regarding the canopy process and the interaction between trees. The aim of this research is to apply the TLS to measure the 12 vegetation biomass parameters related to the interaction between trees.

2. MATERIAL AND METHOD

2.1 Biomass Parameters Related to the Interaction Between Trees

The planting distance between trees, size, and identity are the most often used parameters to characterize the competition of the target tree with its neighbour, in the case of magnitude and general direction of the pressure from the occurring competition [Seidel, 2011]. To determine and predict the competition between neighbour trees, 12 parameters are used, listed as follows [Seidel, 2011]:

1. Total tree height (TTH)
2. Diameter at breast height (DBH)
3. Crown base height (CBH)
4. Crown height (CH)
5. Coordinate of the center of the stem at ground level (CCG)
6. Height of maximum crown projection area (HCPA)
7. Maximum crown projection area (CPA)
8. Center of the crown at the height of maximum crown projection area (CCC)
9. Crown projection area at the height of maximum crown projection area of focal tree (CPAcomp), only for neighbour trees and the center of the crown at the height of the CPAcomp, (CCatCPAcomp), only for neighbour trees
10. Degree of tree asymmetry and its direction expressed as a vector (abbr.ASYM)
11. Horizontal distance between the CCC of the focal tree and the CCatCPAcomp of the neighbour tree (HD)
12. Horizontal distance between the CCG of the focal tree and CCG of the neighbour tree (DCCG).

The illustration of the parameters can be seen in Figure 1. The use of those parameters related to the interaction also can be seen in Figure 1.

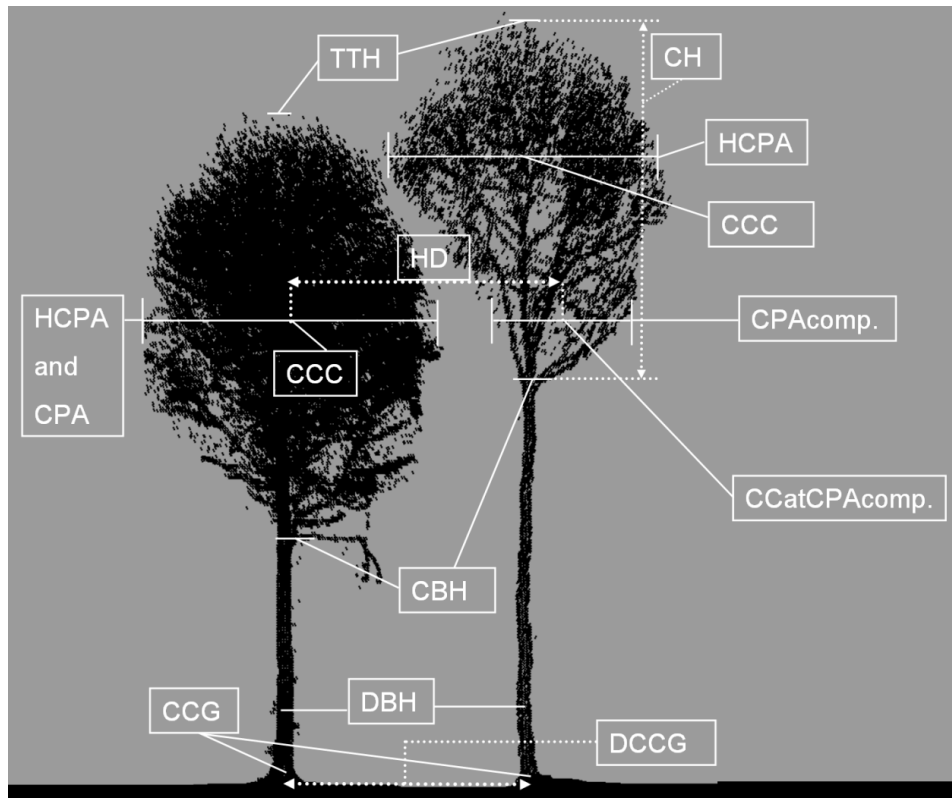


Figure 1. The parameters to represent the interaction [Seidel, 2011]

In this research, 2 mahogany trees were used. These trees are located at ITB Campus in Jatinangor.

2.2 Terrestrial Laser Scanner

Terrestrial Laser Scanner (TLS) is a method to capture objects on the earth's surface using laser. The surface data can be visualized into 2 dimensional (2D) or 3 dimensional (3D) models, and can be used for various applications. The advantage of this method is that it is able to obtain the position of the object points (point clouds) in a huge amount and high precision in a relatively short time [Reshetyuk, 2009]. However, the TLS has limited range, up to 1 km for long range TLS. Therefore, to obtain the data of a large and complicated object, the placement of the device must be considered and planned well [Quintero et al. 2008].

The measurement system of the TLS consists of distance measurement and angle measurement systems. For distance measurement, the TLS is divided into two types, namely pulse based and phase based. In this research, a pulse based TLS was used and the distance measurement utilized the pulsed time of flight (TOF) method. Pulsed time of flight is a distance measurement based on the round-trip travel time when the pulse is emitted until it is received by the receiver of the device. The travel time is then used to calculate the distance between the object and the laser scanner [Seidel, 2011].

According to [Reshetyuk, 2009], distance measurement using pulse based TLS follows the equation 1:

$$R = \frac{ct}{2} \quad (1)$$

where:

- R : the distance between the TLS and the object;
 c : the speed of light on air ($\approx 3 \cdot 10^8$ m/s);
 t : the time travel of the laser when it is emitted and received

Angle Measurement System

Apart from distance measurement, the TLS also has an angle measurement system which can be used to obtain the coordinates of the objects. This system consists of angular encoders that measures the horizontal direction and vertical angle of the TLS laser beam to the objects.

Coordinates Calculation

To obtain the coordinates of the objects using TLS, there are several parameters that have to be measured for every object, namely:

- Distance (R);
- Horizontal direction (φ);
- Vertical angle (θ).

The TLS also measures the intensity of the reflected laser beam from every point cloud. The principle of the TLS measurement is illustrated in Figure 2.

2.3 Data Acquisition

Study literature regarding the theories of TLS application in forestry was done in preparation step. These theories were then used to plan the measurement trials using TLS in forestry. In this step, a training to use Leica Scan Station C10 device and processing the point clouds as scanned by the device. Finding the appropriate location and trees were done afterwards.

2.4 Data Acquisition Planning

After finding the research location, the next step is data acquisition planning. The design planning for the device and targets positions was done in this step. The primary consideration of placement of the device and targets is that the scan must cover all trees. This planning is also related to accommodation and licensing in the study area

2.5 TLS Data Acquisition

Data acquisition using TLS was done following the design which was made in the planning step. The device was moved 7 times, while the positions of targets were unchanged. There were four targets used in this step, namely: 2 HDS 6 inch and 2 HDS 3 inch. The weather was fine and a little windy. The locations of the targets can be seen in Figure 2.3 and Figure 3.

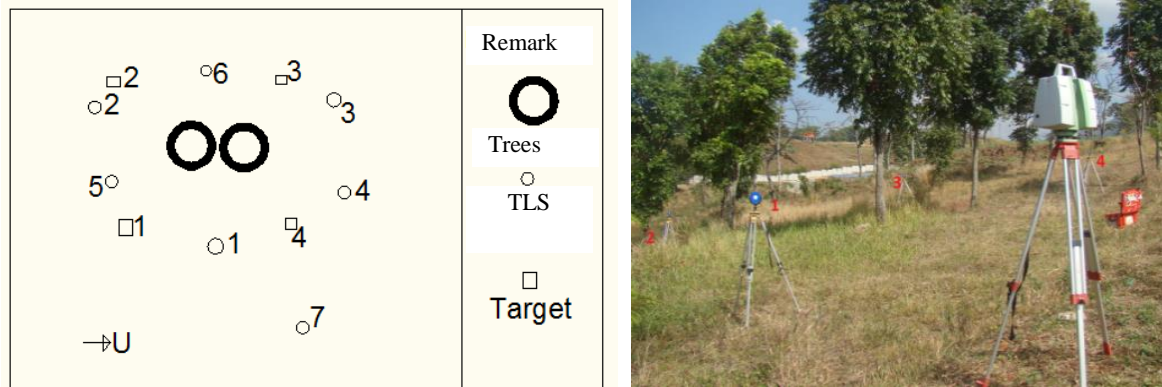


Figure 3. TLS data acquisition strategy (a) and field data acquisition (b)

2.6 Data Acquisition Using Measuring Tapes

The purpose of acquiring data using measuring tapes is to validate the results from the TLS. The tapes were used to measure the diameter at breast height (DBH) of both trees and the distance between the trees.

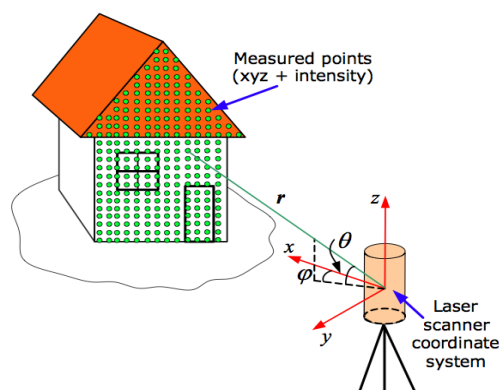


Figure 2. The principle of TLS measurement (adapted from [3])

The relation between measurement data (r, φ, θ) and coordinates (n, e, u) can be written in equation 2.4 [Reshetyuk, 2009]:

$$X_i = \begin{bmatrix} e_j \\ n_j \\ u_j \end{bmatrix} = \begin{bmatrix} r_j \cos \varphi_j \cos \theta_j \\ r_j \sin \varphi_j \cos \theta_j \\ r_j \sin \theta_j \end{bmatrix} \quad (2)$$

where:

- r_j : distance from the time travel of the laser to the;
- φ_j : horizontal angle between the aim of the laser and the e-axis of the device;
- θ_j : vertical angle between the horizontal plane and the aim of the laser to the object;
- e_j : coordinate e of point clouds in the device coordinate system;
- n_j : coordinate n of point clouds in the device coordinate system;
- u_j : coordinate u of point clouds in the device coordinate system;.

The methodology of this research consists of several steps, namely: preparation and TLS data acquisition, registration process, filterization, georeferencing process, 3D modelling, video making, and analysis and discussion. These steps will be described in the following sections to answer the conclusion of the research.

3. RESULT AND DISCUSSION

After the scanning process was finished, the next step is the process to create the model by using point clouds from the scanning. Creating a model space to obtain the biomass parameters include several steps, namely: registration, filtering, and modeling. The software used in this process is Leica Cyclone 7.1.1.

Registration is a process to combine the scanning data. In this research, the registration was done using target to target method. This method is the best registration method and faster because the reference points are already determined. The scanning results has the maximum error of 0.006 m and the mean of 0.002.

After the registration process, model space can be created. In this process, all point clouds scanned from all the device locations are combined to create a three dimensional model of the desired objects. Several undesired points are also modeled in the model space, known as noise. The noise has to be removed in the filterization process. In this research, the filterization was done using manual method. The model space before and after filtering can be seen in Figure 4.

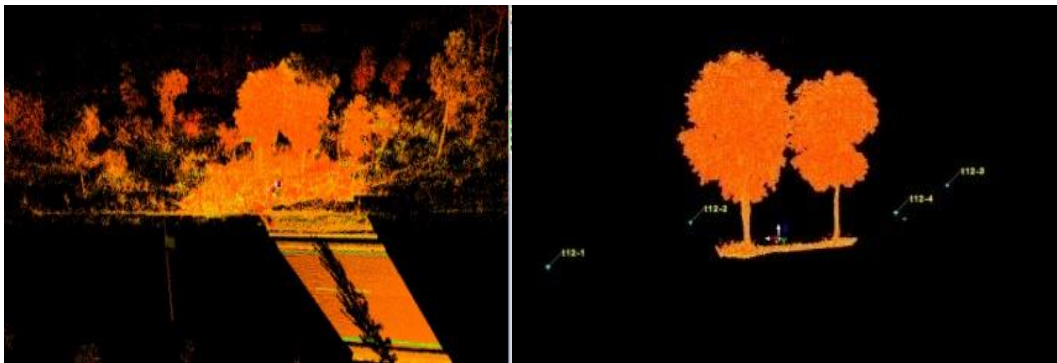


Figure 4. Model space before (a) and after filterization (b)

The next step after modeling is calculating the biomass parameters, which was done in Cyclone 7.1.1. The results of the calculation can be seen in Table 2.1.

Table 1. Biomass parameter from the TLS measurement

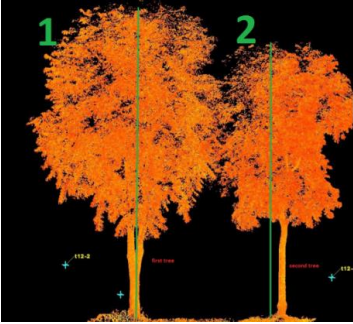
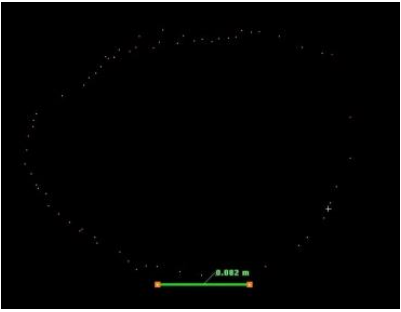
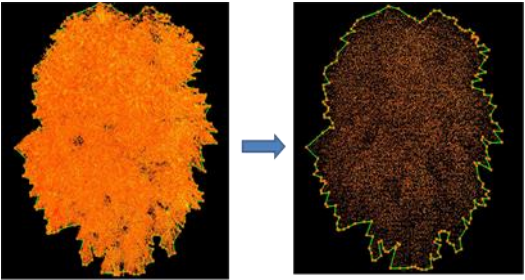
NO	Parameter	Measurement	Figure
1	TTH	Tree 1 : 8,685 m Tree 2 : 7,507 m	
2	DBH (first tree)	Diameter : 0,249 m	

Table 1. Biomass parameter from the TLS measurement (continued)

NO	Parameter	Measurement	Figure
	CPA (first tree) Leaf Area	19,325 m ²	

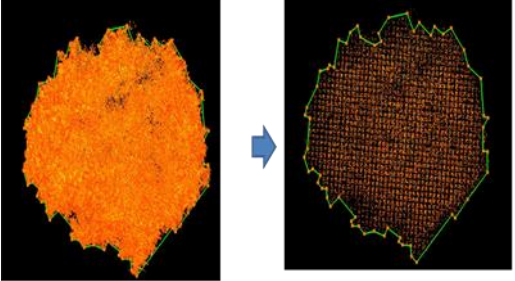
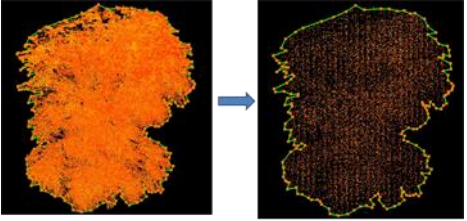
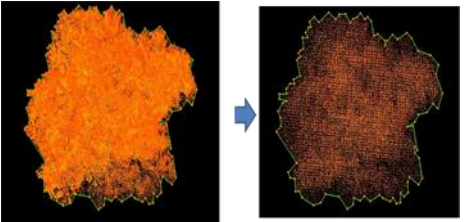
Estimation of 12 Biomass Parameters Using Terrestrial Laser Scanner (7812)

Irwan Gumilar, Hasanuddin Zaenal Abidin, Eko Prasetyo, Ekus Kustiwa and Rizqi Abdulharis (Indonesia)

FIG Working Week 2015

From the Wisdom of the Ages to the Challenges of the Modern World

Sofia, Bulgaria, 17-21 May 2015

9	(First tree)	20,461 m ²	
10	CPA (Second tree)	15,010 m ²	 
	Leaf Area (Second tree)	12,488 m ²	

Estimation of 12 Biomass Parameters Using Terrestrial Laser Scanner (7812)
 Irwan Gumilar, Hasanuddin Zaenal Abidin, Eko Prasetyo, Ekus Kustiwa and Rizqi Abdulharis (Indonesia)

Table 1. Biomass parameter from the TLS measurement (continued)

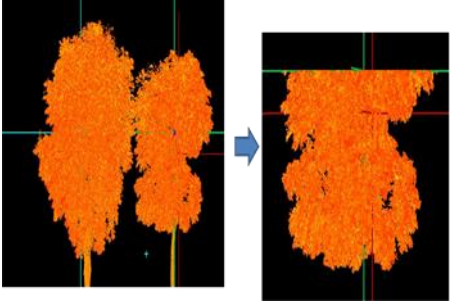

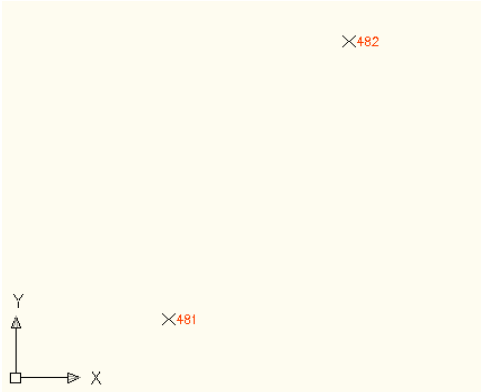
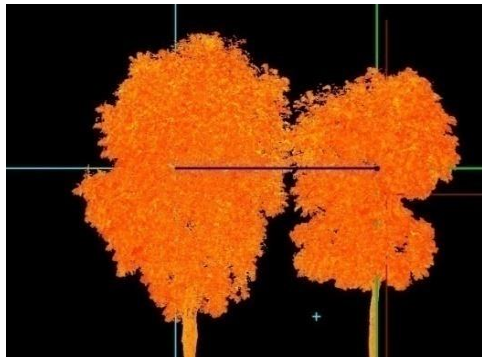
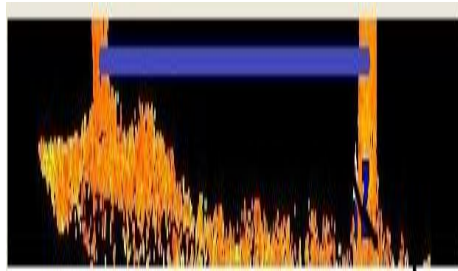
NO	Parameter	Measurement	Figure
12	CPAcomp	10.872 m ²	
14	CCatCPAcomp	X: -6.435 m Y : 1.650 m Z : 5.137 m	
15	abbr.ASYM	First tree : Angle : 31°47'14.11" Distance : 0,418 m Second tree: Angle : 227°41'6.46" Distance : 0,468 m	 <p>The plotting in the first tree 481 is CCC, and 482 is CCG.</p>

Table 1. Biomass parameter from the TLS measurement (continued)

NO	Parameter	Measurement	Figure
16	HD	4,568 m	
17	DCCG	4,243 m	

As seen from the parameter values in Table 2.1, the CPA value and leaf area for the first one are larger. This shows that the first tree have better growth. The value of the diameter at breast height (DBH) also shows that the first tree has larger diameter. From the height of the trees, the first tree is also taller than the second tree, which even shows that the first tree grows better. However, from the abbr.ASYM parameter which shows the growth vector, it can be seen that there is a competitive interaction between the trees. The value of abbr.ASYM shows that both trees have growth vector in the opposite directions. This shows that naturally, both trees avoid the occurring competition. Further research regarding the occurring interaction needs to be done and hopefully can give a reference for procedures of planting/silvicultural in order to obtain maximum results on the target plants.

Based on measurements using TLS, the known HD value (4,568 m) is larger than the DCCG value (4,243 m), which means there has been a pressure between both trees for as far as $\pm 0,325$ m. This suggests a competition between both trees in order to obtain a space for them to grow. Larger DBH and HCPA show that the first tree has a faster growing ability. As a form of adaption to competition, the second tree tends to have a faster vertical growth than its horizontal one ($CBH-1 > CBH-2$ and $CH-1 < CH-2$). This means than even though the second tree has smaller DBH, the free branch height (as a commercial tree parameter) of the second tree is higher than that of the first tree. Thus, it is very likely that the second tree's height can be higher in the future than the first tree, in order to win the competition to obtain the sunlight.

The validity of these measurements indicates the accuracy of the measurement results as obtained from the model in software Cyclone 7.1.1. The validation was done by comparing the TLS results with the measurements from measuring tapes. Due to the limitation of the measuring tapes, only DBH, CBH, and DCCG can be compared. The results can be seen in Table 2.

Table 2. Comparison of measurements

Parameter	TLS	Tapes	Difference
DCCG	424,3cm	431 cm	-7,7cm
First tree			
DBH	24,9 cm	25,6 cm	0,7 cm
CBH	164,3cm	169,3cm	-5,0cm
Second tree			
DBH	17,6 cm	17,6 cm	-0,1cm
CBH	259,1cm	264,7cm	-5,6cm

4. CLOSING REMARK

From this research, it can be concluded that the TLS can be applied in forestry to measure the 12 biomass parameters which are related to the interaction between trees. The measurement results using the TLS at 2 tree samples in ITB Jatiningor can be seen in Table 6.1.

Table 6. 1 The results of the 12 parameters

No	Parameter	Results	
		Tree 1	Tree 2
1	TTH	8,685 m	7,507 m
2	DBH	0,249 m	0,176 m
3	CBH	1,643 m	2,591 m
4	CH	7,042 m	4,916 m
5	CCG	X: -6,867m	X: -6,629m
		Y: -2,506m	Y: 1,730 m
6	HCPA	5,631 m	4,615 m
7	CPA / Leaf Area	19,325 m ² /20,461 m ²	15,010 m ² /12,488 m ²
8	CCC	X: -7,087m	X: -6,283m
		Y: -2,861m	Y: 2,045 m
		Z: 5,137 m	Z : 4,538 m
No	Parameter	Results	
		Tree 1	Tree 2
9	CPAcomp		10,872 m ²
	CCatCPAcomp		X: -6,435m
			Y: 1,650 m
			Z: 5,137 m
10	Abbr.ASYM	31°47'14.11''	227°41'6.46''
		0,418 m	0,468 m
11	HD	4,558 m	
12	DCCG	4,243 m	

TLS can create 3-dimensional model of the tree crown with unique coordinates for each point, making the model unique for each tree with resolution that can reach up mm level. The measurement results using the TLS can be used because the difference between the TLS measurements and conventional method using measuring tapes is 1 mm – 7,7 cm.

REFERENCES

1. Quintero, M. S., Genechten, B. V., Bruyne, M. D., Ronald, P., Hankar, M, and Barnes, S. 2008. *Theory and practice on terrestrial laser scanning*. The Learning Tools for Advanced Three Dimensional Surveying in Risk Awareness Project (3DRiskMapping).
2. Reshetyuk, Y. 200). *Terrestrial laser scanning, error source, self-calibration, and direct georeferencing*. Saarbrucken, Germany: VDM Verlag Dr. Muller.
3. Seidel, D. 2011. *Terrestrial laser scanner application in forest ecological research*. GottingenGermany: Gottingen Center for Biodiversity and Ecology
4. Sutaryo, D. 2009. *Perhitungan biomassa*. Wetlands International Indonesia Programme, Bogor.

BIOGRAPHICAL NOTES

Dr. Irwan Gumilar was born in Bandung 29 March 1978. He got bachelor degree in 2001 from the Department of Geodetic Engineering Institute of Technology Bandung, and finished his doctoral degree in 2013 from Department of Geodesy and Geomatics Engineering Institute of Technology Bandung. Since 2010, he has been working as lecturer and researcher at the Department of Geodesy and Geomatics Engineering Institute of Technology Bandung

CONTACTS

Dr. Irwan Gumilar
Geodesy Research Group, Institute of Technology Bandung
Jl. Ganesa 10 Bandung
Indonesia
Tel. +62-22-2534286
Fax + 62-22-2534286
Email: igumilar@gd.itb.ac.id
Web site: geodesy.gd.itb.ac.id