FOREST PLANTATION INVENTORY, ESTIMATION AND ANALYSIS OF PARAMETERS USING LiDAR DATA

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ABSTRACT: Acquisition of accurate forest biophysical parameters for forest management, inventory, biophysical modeling, and habitat analysis is labor intensive and time-consuming. Existence of airborne Light Detection and Ranging (LiDAR) data can supplement and supplant these. Derivatives produced from LiDAR such as Digital Terrain Model (DTM), Digital Surface Model (DSM), Normalized Digital Surface Model (nDSM) and Canopy Height Model (CHM) applied with algorithms are used to determine and estimate forest inventory parameters of Pine tree (*Pinus caribean*) plantation. This study was conducted to evaluate the capability of low dense LiDAR derived data to extract forest biophysical parameters from detecting and measuring individual trees in Compartment 87 of BFI, Siloo, Malitbog, Bukidnon. Using the inverse watershed segmentation in ArcGIS 10.2, 941 out of 961 (98%) actual standing trees in the field were detected. Results show that there is a positive relationship between the tree height and DBH at field measurement, thus tree height derived from LiDAR can supplement in estimating DBH. It was also observed that there is a relationship between the tree height and DBH derived from LiDAR and actual field measurement. Based on the findings, low dense LiDAR data shows the capability and limitations in extracting forest parameters.

1. INTRODUCTION

Forest inventory is important to determine the condition, characteristics, and classification of a forest resource. This activity is done in-situ and is usually laborious and time-consuming. Existence of Light Detection and Ranging (LiDAR), a remote sensing technology, supplemented these measurements. Application of such technology can supplant the field inventory in-situ. This has been applied in several studies such that of Kim, et. al. (2012), Kwak, et. al. (2006), Silva, et. al. (2013), and Reitberger, et. al. (2007) among others.

Derivatives produced from LiDAR such as Digital Terrain Model (DTM), Digital Surface Model (DSM), Normalized Digital Surface Model (nDSM) and Canopy Height Model (CHM) applied with algorithms can be used to determine and estimate forest inventory parameters of different forest types and tree plantations. Tree height, location, crown diameter, number of stems, stem diameter, and basal area are just some of the parameters that can be obtained with LiDAR application on forest inventory (Hyyppa, et al., 2004). LiDAR application in determining some of these parameters in a pine forest was conducted in the studies of Kwak, et. al. (2006) and Rahman & Gorte (2008).

A 182-hectare plantation of Caribbean Pine (*Pinus caribaea*) is situated at Barangay Silo-o, Malitbog, Bukidnon under the management of Bukidnon Forest Incorporated (BFI). It was established around 1982-2007, which has been financially supported by New Zealand. A low dense LiDAR data of the said pine plantation was gathered last August 2013. Its forest inventory parameters using LiDAR derivatives are determined in this study.

This paper generally aims to evaluate the capability of low dense LiDAR derived data to extract forest biophysical parameters through detecting and measuring individual trees at the study area. Specifically, this study aims to delineate tree individual; determine its crown diameter; and estimate its DBH using LiDAR data. Result of this study provides data on the estimated tree parameters and serves as reference for future researches. Significant reduction on the labor-intensive conduction of forest field inventory is also realized at the end of this study.

2. METHODOLOGY

2.1 Study Area

The study area is located at the Caribbean Pine (*Pinus caribean*) plantation of Bukidnon Forest Incorporated (BFI) at Barangay Silo-o, Malitbog, Bukidnon (Figure 1). It is geographically located at 8°29'23.43"N 124°59'27.54"E. The 2-hectare pine plantation has a 2.5x5 m interval within each tree.
The average elevation at the study site is 988.45 masl (max: 1,009.82 masl, min: 969.94 masl). This is shown in figure 2. below. Meanwhile, average slope at the study site is 33.69%, which belongs to an extremely steep category. It ranges from 0.49% (little or no slope) to 148.94% (excessively steep slope) as shown in figure 3.

2.2. LiDAR Data

The airborne LiDAR data used in the study was obtained on August 2013 provided by the University of Philippines Diliman. The LiDAR data have x position accuracy of +/- 20 cm and y position accuracy of +/- 100 cm. The average point density of 2 points/m² with an average spatial resolution of 0.5 meters consider the LiDAR data as low dense.
2.3 Field Data

Forest inventory recording the biophysical parameters of individual trees was conducted last November 2014. These parameters included tree height, tree position and diameter at breast height (DBH). Individual tree stand as well as the corner points of the 2 ha plot was acquired with the use of Total Station (TS) instrument, while DBH of trees was measured using tree caliper.

2.4 LiDAR Derivatives

LAStools software was used in processing the LiDAR derivatives. Digital Terrain Model (DTM) or last returns subtracted with the Digital Surface Model (DSM) or first returns generated Normalized Digital Surface Model (nDSM). The Canopy Height Model (CHM) was derived using lascanopy extension of LAStools. These generated LiDAR derivatives were used for delineating individual tree crown as well as height measurement of individual trees.

2.5 Crown Delineation

In delineating individual tree crown, inverse watershed segmentation (IWS) was used using ArcGIS 10.2 software. The IWS method used the application of watershed segmentation by inverting a raster surface, the individual tree crown were delineated as corresponding individual hydrologic drainage basins (Wannasiri, et al., 2013). The generated CHM or nDSM of the study area was inverted turning the individual tree top upside down into depressions. Automated segmentation using ArcHydro extension of ArcGIS was executed to delineate tree crowns from generated depression model. Based on the delineated individual tree crown, zonal filtering tool of ArcGIS was performed locating the individual tree tops based on the maximum value of the depression model. The located maximum pixel in a certain delineated tree crown serves as the tree position, the tree height was then determined using the upright CHM or nDSM.

2.6 Estimation of DBH

The relationship of field measurements for individual tree heights and DBH was computed. The determined correlation with consequent equation was used to estimate the measurement of tree DBH aided with the generated individual tree height using the IWS on the LiDAR data.

2.7 Statistical Analysis

Results of LiDAR estimated forest parameters are compared with the field measurements to determine the efficiency of LiDAR data. Determination of $R^2$ for the relationships and determination of standard deviation (SD) for the values extracted were performed in this study.

3. RESULTS AND DISCUSSION

3.1 Delineation of Tree Crown

The process of tree crown delineation detected 941 individual trees over the 960 actual standing trees at the study area. This means that 98% of the trees were detected. Figure 4. shows the delineated tree crowns at the study area with its location. This is quiet high as compared to the studies of Rahman, et.al. (2009), Reitberger, et.al. (2007), and Persson, et.al. (2002). The result of the segmentation can be categorized similarly with the result in the studies of Leckie, et.al. (2003) and Koch, et.al. (2006).

Crown delineation in this study was made through IWS application in ArcGIS 10.2. It was estimated that the crown area of the pine trees at the study area ranges from 3.11m to 86.05m with an average of 21.6m. Meanwhile, the crown diameter was observed to range from 1.99m to 10.47m, with an average of 5.08m. Determination of tree crown is an important forest inventory parameter as it is used for quantifying and analyzing tree growth, biomass estimation through remote sensing, atmospheric pollution mitigation, estimation of carbon sequestration, and vulnerability assessment for forest fires.
3.2 Accuracy Assessment of Tree Heights

Tree height of Pine at the study area ranges from 18.5m to 32.9m acquired on field measurements. On the other hand, a range of 19.17m to 31.8m tree height was derived from the LiDAR data. Correlation of individual tree height from field and LiDAR data was computed as shown in Figure 5. $R^2$ was determined to be at 0.662, signifies a strong relationship. In addition, a standard deviation (SD) value of ± 1.2567m was obtained. This indicates that 69.6% of the values in the dataset were within the range of accuracy and the remaining 30.4% are considered as the outlying values for this study.
3.3 Accuracy Assessment of DBH

Equation 1 was derived from the relationship of the field measurements for tree height and DBH. With this, estimated DBH was calculated using the LiDAR-derived tree height. Base on the field measurement, DBH at the study site ranges from 20cm to 48cm while LiDAR-derived DBH ranges from 19.7 to 47.63. R² for the DBH measurement between the field and LiDAR was 0.18987, considered to be a very weak relationship (Figure 6). Moreover, the SD for the LiDAR-derived DBH was ±33.67. It was observed that given the calculated SD, only 53.6% of the LiDAR-derived DBH values are within the range of accuracy for the applied equation. Furthermore, this also means that 46.4% of the LiDAR-derived DBH values are erroneous.

\[ y = 0.009 \times + 0.0865 \]

Equation 1. Relationship of the field measurements for tree height and DBH

Based on the acquired results, it was observed that that the remaining 2% undetected trees during the segmentation, R² of 0.66 for the accuracy assessment of tree height, and R² of 0.18987 for the accuracy assessment of DBH was affected by the following factors: merging treetops, cut trees, and overlapping canopies due to height and elevation variation at the study site.

Slanting tree stands at the study area was observed, which have resulted to merging treetops. Cases such as tree is leaning towards another tree are present at the area and this could be one of the explanations on why the result for segmentation was imperfect. Other trees would have not been detected during the segmentation due to its short height compared to its other surrounding trees with respect to the dense canopy observed at the study area. These factors could have affected the produced nDSM of the Pine plantation. This can be compared to the study of Reitberger, et.al. (2007), based on the findings, observed cases of some trees covered with taller trees, the LiDAR-derived data for tree height becomes erroneous. Rahman, et.al. (2009) has also observed that LiDAR data may fail to reflect the exact structure of a dominant tree together with its undergrowth vegetation due to forest interception in the LiDAR signal. Varying elevation at the area is also considered as one of the factors for some undetected tree stands.

Furthermore, it is noteworthy that this study used a low dense LiDAR data (2 points/m²) which could have also limited the findings of this study.

4. CONCLUSION

This study shows detection of Caribbean Pine trees of up to 98% using a low dense LiDAR data. It has also identified that the average crown area of the detected pine trees was 21.6m while the average crown diameter was 5.08m. The study also determined that the study site have trees with height that ranges from 19.17m to 31.8m (LiDAR-derived). LiDAR-derived height showed a strong relationship (R² = 0.662) with the set of height that was actually measured from the field. Its SD has identified that 69.6% of the values was within the range of accuracy. This shows a good indication that LiDAR data has the ability to estimate forest parameters at a certain area at a specific time. Additionally, LiDAR-derived DBH ranges from 19.7cm to 47.63cm. However, a very weak relationship was detected when this data was compared to actual DBH measurements from the field (R² = 0.18987). Upon calculating the SD for DBH, it has been found that only 53.6% of the LiDAR-derived DBH values are within the range of accuracy and the remaining 46.4% is erroneous.
Problematic values in this study were believed to have been affected by the following: merging treetops, cut trees, and overlapping canopies due to height and elevation variation at the study site. Moreover, higher point density of LiDAR data is more advantageous to delineate much accurate individual trees, tree crown and other applicable forest analysis.

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