A COMPARISON OF LAI MEASUREMENT BY WAVEFORM LIDAR DATA AND MULTI-RETURN LIDAR DATA

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Abstract: The leaf area index (LAI) is a key forest parameter which can be used for the estimation of forest ecosystems or forest fire activity. Since to investigate all the trees or vegetation in forestry for LAI measurements in field surveying is almost impossible, one way to measurement LAI is to take some samples to represent the whole forest in the study area. To acquire the geometric structure of forestry, the Light Detection And Ranging (LiDAR) system has been considered as an efficient technique due to the effective data collection of a large area. The penetration of forest canopy is also an important characteristic compared with other surveying technique such as Photogrammetry. LiDAR data directly provides the three dimensional points which can be classified as ground points and non-ground points. The purpose of this research is to compare two kinds of data sources: waveform data and multi-return LiDAR data for the LAI estimation. Since the waveform data records the intensity values along the laser lighting path, more physical features and echoes can be extracted. Some weak or overlapping echoes can be therefore further extracted by a developed echo detector. Those extra-points are expected to improve the estimation of LAI values compared with only using the multi-return points. The study area is located in Nanrenshan of Pingtung County, Taiwan. In this study we use two kinds of laser penetration index (LPI) which can be translated into LAI values. The first type of LPI is calculated by the ratio of the numbers between ground points (< 1m height) and total points. The second is the ratio of the intensity between ground points and total points. After compared with the in-situ measurements of LAI which were measured by the LI-COR LAI-2000 Plant Canopy Analyzer, our preliminary results show the LAI values can be better estimated by the waveform LiDAR data than the multi-return LiDAR data.

1. INTRODUCTION

Forest has plays a critical role in earth. It can maintain biodiversity and store global carbon; hence how to manage the forest is becoming more and more important. One of the key parameters for investigating forest inventory is leaf area index (LAI). LAI is the total one-sided green leaf area per unit area in broadleaf canopies and has been used for forest ecosystems by numerous studies. Generally speaking, there are two main categories of methods to estimate LAI: in-suit and remote sensing. Although the direct measurement is the most precise way, the cost is that sometimes the forest needs to be destroyed and the process is usually time-consuming. Furthermore, some instruments have been developed to estimate the LAI in in-suit measurement such as LAI 2000 Canopy Analyzer (Licor Inc., Nebraska) and hemispherical canopy photography (Rich, 1990). Since to investigate all the trees or vegetation in forestry for LAI measurements in this way is almost impossible, the forest survey usually adopts some samples to represent the whole forest in the surveying area.

Remote sensing can provide a way to obtain the large scale for forest measurements. And the normalized difference vegetation index (NDVI) and Light Detection And Ranging (LiDAR) data are the two common resources to estimate LAI in remote sensing. NDVI is a simple indicator that can assess whether the target being observed contains live green vegetation or not. Although NDVI can estimate LAI, the efficiency is less than LiDAR. (Griffin et al., 2008).LiDAR systems have been widely used in mapping earth's surface and especially in forest application, since it has the significant characteristics which can penetrate through the canopies and see the structure under the canopy. Nowadays, many studies started to use LiDAR data to estimate LAI. (Jacob et al., 2011)(Korhonen et al., 2011) (Solberg et al., 2009) Based on the penetration information contained in LiDAR data, many leaf penetration index (LPI) have been derived to connect to LAI. (Solberg, S. 2010)(Hopkinson, C. and L. Chasmer, 2009) However the broad-leaved forest is more luxuriant than the coniferous forest, a laser can hardly completely penetrate through the canopy. Usually only parts of laser energy can reach to the middle layer of forest and grounds. This leads to the conventional LiDAR system produce fewer points under the canopy since the return echoes from the surfaces under the canopy could be too weak to be detected. The losing number of points could decrease the accuracy of LAI measurements derived from the used point clouds. In this study, we used the point clouds extracted from waveform data to compare with the point clouds provided by the LiDAR system. The waveform points were extracted by a wavelet-based echo detector, and the detector can deal with the weak and overlapping echoes in waveforms (Wang, 2012). In this study, our objective is using waveform points to improve the accuracy of LAI measurement in the broad-leaved forest.

2. METHODS AND DATA DESCRIPTION

2.1 Study area

Our study area locates in the Nanrenshan Forest of Pingtung County, south of Taiwan. It is a nature tropical monsoon forests ecological zone, with a mean temperature of 23℃ and an annual rainfall of 2,200 mm. The entire study site was approximately within a rectangle of size 20×20 m. We selected 11 trees whose locations were measured.

2.2 In-suit data

The In-suit LAI data was measured by LAI 2000 Canopy Analyzer. LAI-2000 is an instrument designed to measure the ratio between the light below canopy and above canopy. It conducts a fisheye light sensor which simultaneously measures light intensities in five concentric Field of Views at central zenith angle of 7, 23, 38, 53 and 68 degrees. The method is described in Welles and Norman (1991). They derived the relation between LAI and gap fractions at different zenith angles by using a linear regression approach.

The filed measurements by LAI-2000 were on 25th May 2012.Eight plots were chosen to measure the LAI values along 8 directions in every 3~5 m distance around the trees.(Figure 1) (Jacob et al., 2011)

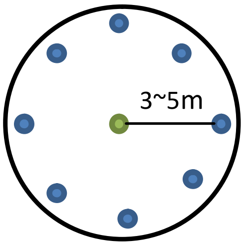

Figure 1: The diagram of in-suit measurement

2.3 Laser scanner data

The LiDAR data were acquired by Leica ALS60 system on 21th 23th and 24th October 2011. The Leica ALS60 system can provide two kinds of data: 3D points (multi-return data) and waveform data. The details of the LiDAR system are listed below. (Tab.1) In this study, we use wavelet-based echo detector to extra return echoes compared with multi-return points. (Wang, 2012) In Figure 2, one can see that the number of points from waveform data is more than those from multi-return data. The density of multi-return LiDAR in this area is 6-8 points per square meter while the density of waveform LiDAR is about 8-10 points per square meter.

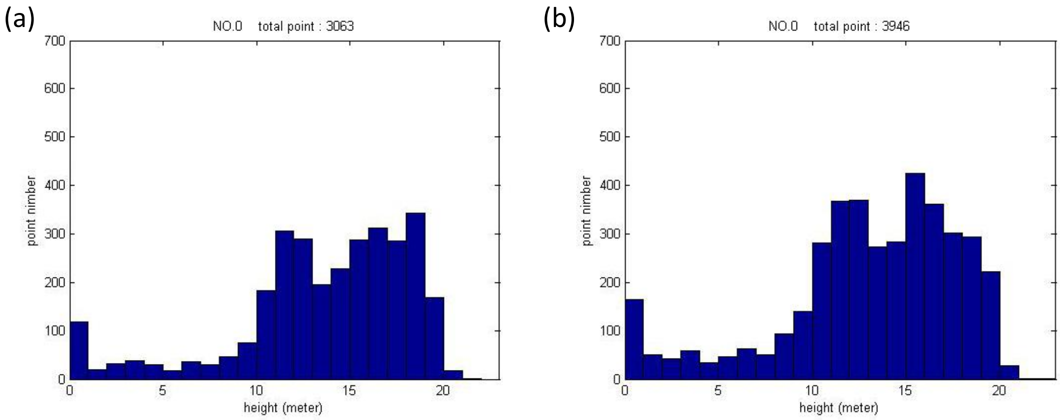

Figure 2: Comparison of number of points with (a) multi-return LiDAR data (b) waveform LiDAR data

Table 1: The characteristics of Leica ALS60system.

Scanning height	Scanning frequency	Field of view	Accuracy
200m-5000m	100Hz	75°	Placement : 7 – 64 cm Vertical : 8 - 24 cm

2.4 Methods

We use the waveform points and the multi-return points to derive LPI in the same method (Figure 3). The first step to calculate the penetration rate of LiDAR data is removing the noise points in LiDAR data. And then classify the points into ground and non-ground by using Terrascan on Microstation. The DEM can be then generated from the classified ground points.

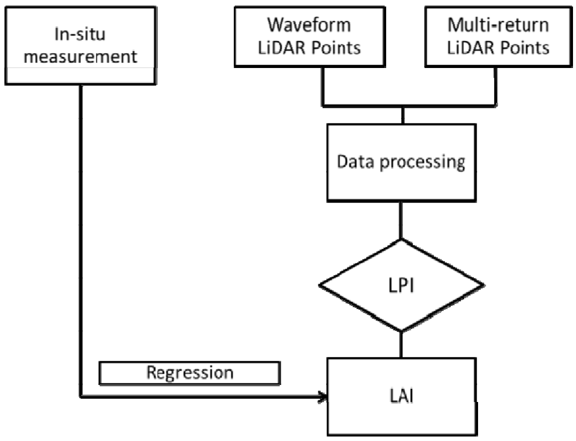

Figure 3: The flowchart of the approach in this study

After obtaining the DEM, we can calculate the normalized elevation of each point by minus the elevation between LiDAR point and DEM. Then we use the normalized elevation to classify the points into a class which is lower than 1 meter. The threshold of 1 meter was chosen because it is the height of LAI-2000 in filed LAI measurement. The Laser Penetration Index (LPI) of each plot can be calculated by two following equations shown as:

$$LPI_1 = \frac{\sum(\text{number of } < 1\text{m points})}{\sum(\text{number of total points})} \quad (1)$$

$$LPI_2 = \frac{\sum(\text{intensity of } < 1\text{m points})}{\sum(\text{intensity of total points})} \quad (2)$$

Where $\sum(\text{number of} < 1m\ points)$is an index of the number of points with height < 1m
$\sum(\text{number of total points})$ is an index of the number of total points
$\sum(\text{intensity of} < 1m\ points)$ is an index of the intensity of points with height < 1m
$\sum(\text{intensity of total points})$ is an index of the intensity of total points

The basic idea of these two equations is the directly relationship between the canopies and LiDAR laser beam, which is according to the ideal of the penetration rate of the canopies. And the penetration rate can be defined by the gap fraction, which can transform into LAI by the following equation. (Solberg, S. 2010) And the parameter ofβ is a linear regression values calculate by the LAI measurement between in-suit data and LiDAR data.

$$LAI = \beta \times \ln(LPI^{-1}) \quad (3)$$

3. RESULTS

Table 2 shows the LPI-LAI correlation by using multi-return points and waveform points respectively. The highest correlation is 0.83696 which is obtained from the LPI_1 of waveform points. The standard deviation of different equations and data is about 0.2~0.3; and the β is around 1. For the utilized equations of LPI, it seems that the performance of LPI_1 is better than LPI_2. Consequently the results using waveform points are better than using multi-return points in these two equation manners. It indicates that the waveform points could improve the accuracy in LAI measurements.

Table2: The relationship between LPI-LAI for multi-return points and waveform points.

LiDAR data	Index	β	Std.	Correlation
Multi-return	LPI_1	1.3257	0.22186	0.77312
Multi-return	LPI_2	0.9802	0.27075	0.66410
Waveform	LPI_1	1.3776	0.20185	0.83696
Waveform	LPI_2	1.0115	0.22956	0.74820

(β is a parameter in the equation 2. ; Std. is standard deviation; Correlation is the compare with the in-suit measurement)

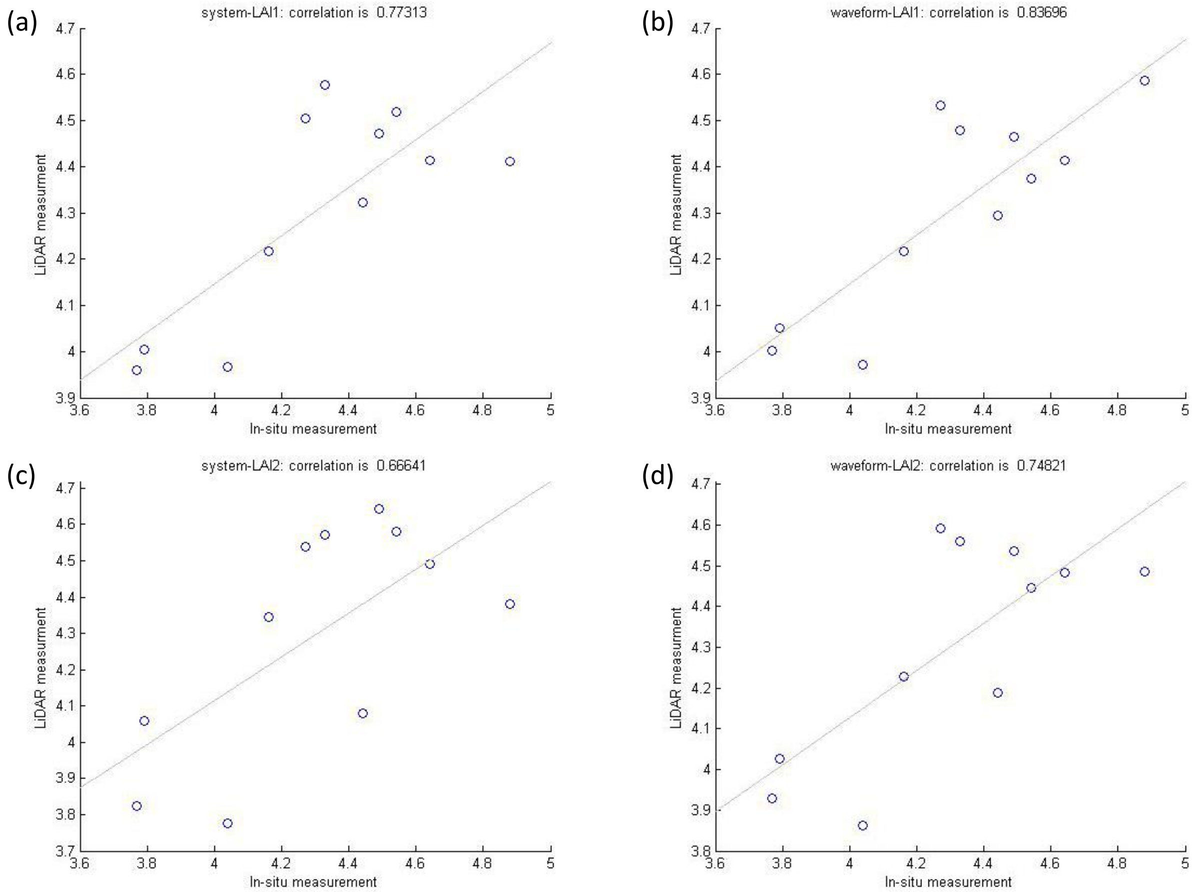

Figure 4: Relationships between LAI measurement by LAI-2000 and LiDAR data with (a) LPI_1 by multi-return LiDAR data (b) LPI_1 by waveform LiDAR data(c) LPI_2 by multi-return LiDAR data (d) LPI_2 by waveform LiDAR data

4. CONCLUSIONS

This research attempted to assess and compare two LPI equations by using different LiDAR data. Table 2 displays that the correlation of the LPI-LAI measurement is around 0.6~0.8. The experiment results show that LPI derived from waveform points is better than those from multi-return points. This could be due to that the waveform points contain more points rather than multi-return points. In other words, the waveform points could represent the forest structure more completely. The experiments also show that the correlation of LPI_1 is higher than LPI_2. This reason could be that the intensity is still not very a reliable measurement in Today's systems.

In future works, we would like to investigate more characteristics in waveform LiDAR data which could be used to link to LAI measurements. Since the waveform data contains more information of the interactions between targets and the emitted laser, a better performance of the LAI measurement is expected by using the derived waveform features.

5. ACKNOWLEDGEMENTS

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