MOVING FORWARD WITH LIDAR REMOTE SENSING: AIRBORNE ASSESSMENT OF FOREST CANOPY PARAMETERS

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Abstract
The use of airborne Light Detection and Ranging (LIDAR) to evaluate forest canopy parameters is vital in order to properly address both forest management and ecological concerns. This study was conducted in the Piney Woods region of East Texas around Huntsville, Coldspring and Livingston. The overall goal of this paper is to develop the use of airborne laser methods in evaluating various canopy parameters such as percent canopy cover and Leaf Area Index (LAI). Both these parameters are of interest in determining biomass and carbon models as well as fuel loads. Scanning LIDAR can be used to assess both canopy cover and LAI as well as fuel loads. The primary objective of this project is to develop scanning LIDAR methods to estimate LAI and canopy cover over both coniferous and hardwood forests. For accuracy purposes, the parameters of interest are assessed by both airborne and ground-based methods. Measurements by all methods are compared and LIDAR canopy data is evaluated for accuracy. The methods described in this study show great potential for driving changes in forest inventory practices concerning the accurate assessment of canopy parameters.

Keywords: LIDAR, Percent Canopy Cover, LAI, Height Bins

Introduction

This project attempts to determine the percent canopy cover and leaf area index (LAI) of a region through use of LIDAR. Percent canopy cover, also known as canopy closure, is defined as the percent of a forest area occupied by the vertical projection of tree crowns. LAI is defined as the one sided green leaf area per unit ground area. These parameters are especially important in estimating carbon models and biomass, but are also useful in studying carbon sequestration. Percent canopy cover and LAI are also helpful in examining global climate change, fuel models, and fire risk, as well as aiding in forest inventory and management. The use of airborne LIDAR to evaluate forest canopy parameters is vital in order to properly address both forest management and ecological concerns in a timely and cost-effective manner.

Objectives

This project attempts to meet the following goals:

1) to develop scanning LIDAR methods to estimate LAI and canopy cover over both coniferous and hardwood forests;
2) to develop a frame to fuse scanning LIDAR data with multispectral imagery and improve estimates over large areas from local to regional scales;
3) to generate maps of percent canopy cover and LAI for the study region.

Study Area

The region to be studied is the Piney Woods near Huntsville, Texas, shown in Figure 1. It is composed of 18.20sq.mi. and contains part of Sam Houston National Forest with an urban interface. *In situ* data is used for accuracy assessment purposes. This data is from sixty-two plots in the study area, taken from May to July, 2004. These sixty-two plots were inventoried and their canopies photographed using a hemispherical lens.

Figure 1: Study Area

Methods

Figure 2 demonstrates the methodology used in this study. Note that LIDAR data is used to generate both LIDAR-derived canopy cover and a canopy height model (CHM). Airborne LIDAR has been shown to be accurate in estimating biophysical parameters of forest stands (Popescu et al. 2004).

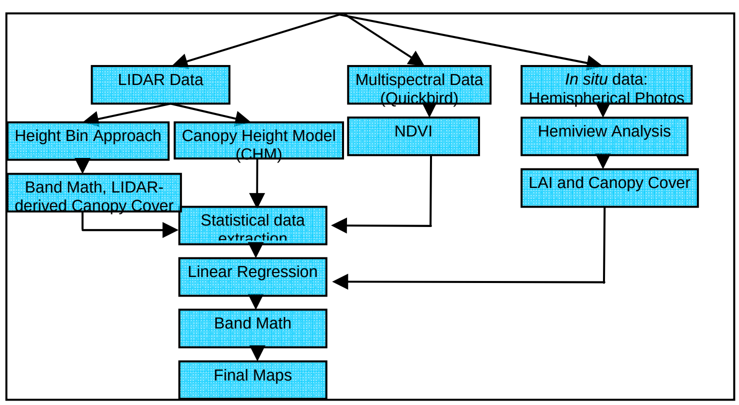

Figure 2: Methodology

The normalized difference vegetation index (NDVI) calculated from Quickbird data can be used to estimate LAI (Curren et al. 1992; White et al. 1997). Statistical data is extracted from all three of these parameters and is then used to formulate a model based on ground reference data taken from the hemispherical photos. This model is then entered into ENVI image processing software using Band Math and used to generate regional maps of percent canopy cover and LAI.

Hemispherical Photography

Hemispherical photography is an accurate method of evaluating percent canopy cover and LAI (Riaño et al. 2004). An example of hemispherical photography is shown in Figure 3. These photographs are analyzed using HemiView, a Delta-T Devices software application, in order to determine local percent canopy cover values and LAI values (Hemiview. 2005). These values are then compared with corresponding values found using the LIDAR height bin method to determine if LIDAR-derived canopy cover accurately predicts percent canopy cover and LAI.

Figure 3: Hemispherical Photograph

Height Bins

The height bin method is used in this project. The term "height bin" refers to a subdivision of LIDAR height returns. In the case of this project, the LIDAR returns are sectioned as follows:

- Bin 1: 0-0.5ft
- Bin 2: 0.5-1.0ft
- Bin 3: 1.0-1.5ft
- Bin 4: 1.5-2.0ft
- Bin 5: 2.0-5.0ft
- Bin 6: 5.0-10.0ft
- Bin 7: 10.0-15.0ft
- Bin 8: 15.0-20.0ft
- Bin 9: 20.0-25.0ft
- Bin 10: 25.0-30.0ft
- Bin 11: >30.0ft

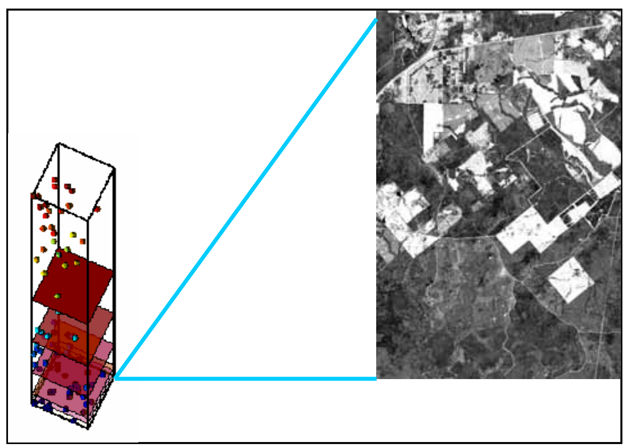

Figure 4: Height Bin 1

Figure 4 illustrates the height bins method while highlighting Height Bin 1. The lower four height bins correspond to field data (in half-meter increments) while the upper bins are spaced in five-meter increments. The entire LIDAR point cloud is broken down into small segments to be analyzed in this manner. This particular method uses the upper seven height bins to determine canopy cover. The formula used to determine LIDAR-derived canopy cover is:

$$CC_{lidar} = \Sigma(Height\ Bins\ 5\text{-}11) / 100$$

This LIDAR-derived canopy cover is used to successfully formulate linear models of percent canopy cover and LAI.

Linear Regression
Linear regressions are performed using SAS software in order to relate various statistical properties of the LIDAR and MSS data to *in situ* data. The following parameters are used in the regression equations:

- x_{cc_lidar} = mean, LIDAR-derived canopy cover
- s_{cc_lidar} = standard deviation, LIDAR-derived canopy cover
- x_{ndvi} = mean, NDVI
- s_{ndvi} = standard deviation, NDVI
- X_{chm} = maximum value, CHM
- x_{chm} = mean, Canopy Height Model (CHM)
- s_{chm} = standard deviation, CHM
- CC = percent canopy cover
- LAI = leaf area index

Results

Four regressions are performed, resulting in the following models:

- **Model 1:** Percent canopy cover using all available variables

$$CC_{all\_var} = 0.52859 + 1.09915\, x_{cc\_lidar} - 1.29972\, x_{ndvi}\ ,\ \ R^2 = 0.4689$$

- **Model 2:** Percent canopy cover using only LIDAR-based variables

$$CC_{lidar\_var} = -0.03363 + 0.63479\, x_{cc\_lidar} + 0.00682\, X_{chm}\ ,\ \ R^2 = 0.3815$$

- **Model 3**: LAI using all available variables

$$LAI_{all\_var} = 0.03032 + 3.55182\, x_{cc\_lidar},\ \ R^2 = 0.7769$$

- **Model 4:** LAI using only LIDAR-based variables

$$LAI_{lidar\_var} = 0.03032 + 3.55182\, x_{cc\_lidar},\ \ R^2 = 0.7769$$

All variables left in the models are significant at the 0.15 level. Models 3 and 4 are identical, indicating that only LIDAR-based variables are significant in predicting LAI. Therefore, only one set of graphical results is shown. Below, in Figures 5, 6 and 7, the predicted (regression) results are compared to the observed (*in situ*) results for both percent canopy cover and LAI. As one can easily determine from these graphical representations of the regressions, Model 1 is superior to Model 2 for percent canopy cover. Model 3 is chosen as the default model for LAI.

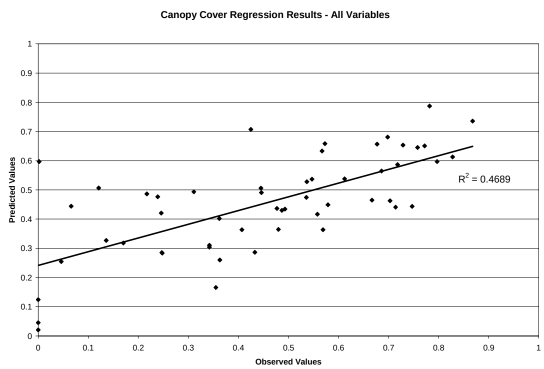

Figure 5: Canopy Cover, All Variables

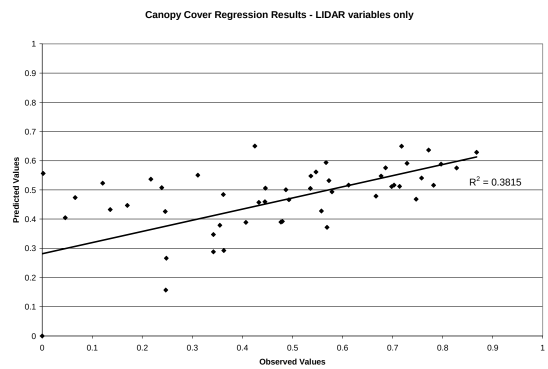

Figure 6: Canopy Cover, LIDAR Variables

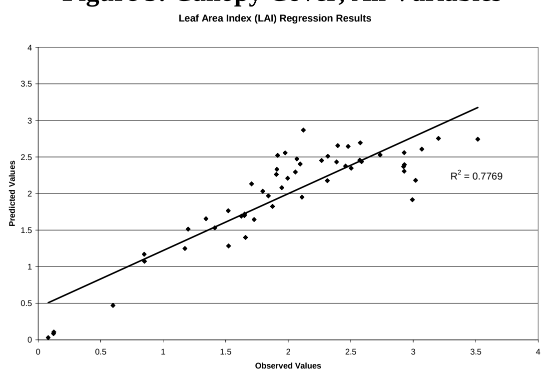

Figure 7: LAI Regression

The correlation coefficient for the percent canopy cover regression using both LIDAR and NDVI statistics (Model 1) is approximately 0.47 and the correlation coefficient for the LAI regression (Model 3) is approximately 0.78. Thus Models 1 and 3 are chosen to generate regional maps of canopy cover and LAI, shown in Figures 8 and 9.

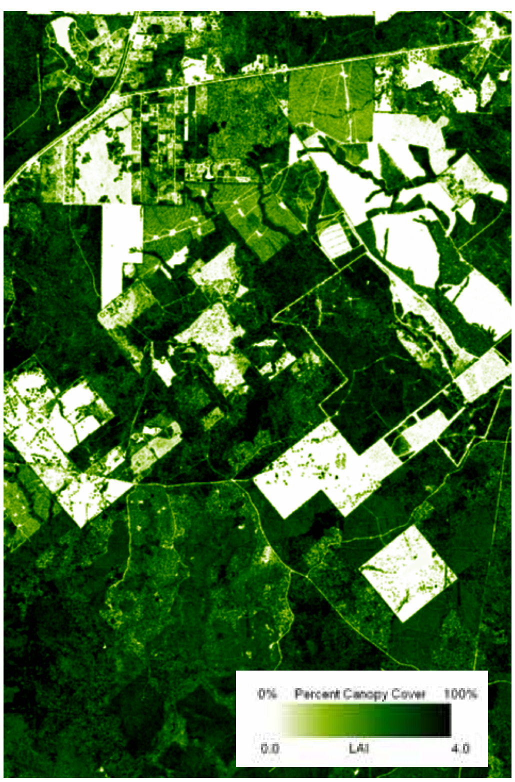

Figure 8: Percent Canopy Cover

Figure 9: Leaf Area Index

Discussion and Conclusions

As one can see from the correlation coefficients and Figures 5 and 7, the predicted regression results for LAI (*LAI*) are highly correlated with the actual results, and the predicted results for canopy cover (*CC*) are fairly correlated as well. While more work is needed to refine these particular models, the height bin method has shown much potential for being a future standard method of LIDAR analysis in determining percent canopy cover and LAI. This method could one day be used in analysis packages, as it allows one to depict the vertical distribution of a forest canopy.

References

CURREN, P.J., DUNGAN, J.L., GHOLZ, H.L. 1992. Seasonal LAI in Slash Pine Estimated with Landsat TM. Remote Sens. Environ. 39:3-13.

HEMIVIEW ONLINE DOCUMENTATION. 2005. Dynamax Inc., Houston, Texas.

POPESCU, S.C., AND WYNNE, R. H. 2004. Seeing the trees in the Forest: Using Lidar and Multispectral Data Fusion with Local Filtering and Variable Window Size for Estimating Tree Height. *Photogrammteric Engineering & Remote Sensing* 70(5):589-604.

RIAÑO, D., VALLADARES, F., CONDÉS, S., CHUVIECO, E. 2004. Estimation of leaf area index and covered ground from airborne laser scanner (Lidar) in two contrasting forests. *Agricultural and Forest Meteorology*. 124:269-275.

WHITE, J.D., RUNNING, S.W., NEMANI, R., KEANE, R.E., RYAN, K.C. 1997. Measurement and remote sensing of LAI in Rocky Mountain montane ecosystems. Can. J. Remote Sensing. 27:1714-1727.