INTEGRATION OF WAVEFORM LIDAR AND HYPERSPECTRAL DATA TO ESTIMATE STRUCTURAL ATTRIBUTES OF TROPICAL FORESTS

Jinha Jung and Melba M. Crawford

Purdue University
School of Civil Engineering
550 Stadium Mall Drive, West Lafayette, IN 47906

Estimation of forest structural attributes is important in biodiversity and global carbon cycle studies. These estimates can be used to predict important forest characteristics such as aboveground biomass (AGBM), which helps determine the amount of carbon in terrestrial vegetation pools. Traditional field sampling-based estimation methods are not only time consuming, expensive, and limited to local scale studies, but may also be biased by different crews and field conditions throughout the campaign period [1], [2]. To tackle these issues, both active and passive remote sensing technologies are being used in large scale studies. High resolution optical data have proven useful for determining canopy extent and horizontal structural information such as gaps and patches, but have limited information related to chemistry. Synthetic Aperture Radar (SAR) provides all-weather coverage over extended areas for determining biomass, but physical models are highly parameterized, and estimates saturate in dense canopies. Recently, interest has increased in discrete return and full waveform LIDAR (LIght Detection And Ranging) [3], [4], [5], [6] for characterizing vertical structure of forest and hyperspectral [7] image data for analysis of forest chemistry.

Data acquired by different sensors provide information on different aspects of a target, potentially providing opportunities to exploit synergisms through multi-sensor analysis. Fusion techniques, which involve fusion of data or fusion of output of analysis derived from individual sensors, are currently of interest in many fields of remote sensing data analysis and have been applied to estimate forest structural attributes by several researchers. Some authors [8], [9] have investigated the integration of discrete return LIDAR and multispectral data. Others [10] studied fusion of SAR (Synthetic Aperture Radar) and multispectral data to estimate forest characteristics. While several combinations of multi-sensor data fusion have been investigated, to our knowledge no research has focused on the integration of full waveform LIDAR and hyperspectral data, which is the goal of this study.

We propose a novel approach to integrate full waveform LIDAR and hyperspectral data which utilizes LIDAR waveform decomposition results to co-register waveform LIDAR with hyperspectral data, and perform forest structural attributes estimation using the integrated data. While synergisms clearly exist between hyperspectral and LIDAR data, integration strategies are complicated by differences in data acquisition architectures. Hyperspectral data are acquired in pixel based architecture; hence each pixel represents a spectral response of a single location, and pixels are regularly located over the Earth's surface. LIDAR data are acquired in an irregular point based architecture, so each set of discrete returns or waveform is a combination of responses from multiple heights and horizontal spatial locations, and waveforms are not regularly located over the earth surface.

The proposed method for integrating full waveform LIDAR and hyperspectral data consists of three main steps; 1) waveform decomposition, 2) georeferencing of the decomposed components, and 3) reconstruction of effective waveforms for a co-registered pixels using the georeferenced components. This new approach decomposes a return waveform into a mixture of Gaussian components using the approach of Jung and Crawford [17]. The 3D coordinates of individual components, each characterized by the corresponding amplitude and standard deviation, are computed by combining the location (obtained from GPS) and attitude (obtained from IMU), and the range measurement (obtained from the estimated mean of the component). In the waveform reconstruction step, an effective waveform for a pixel co-registered with hyperspectral data is reconstructed by combining Gaussian pulses generated by the components which occur within the area represented by the pixel. Biometric features, including maximum and mean canopy heights, number of canopy layers, canopy cover extracted from the co-registered LVIS data are combined with spectral features from hyperspectral data for classification and estimation of AGBM.

The methodology is evaluated using airborne LIDAR and hyperspectral data acquired at the La Selva Biological Station in northeast Costa Rica. The station is a 1,536 ha tropical research facility, which is heavily used by international researchers who have contributed to a rich database of *in situ* and remotely sensed data. Landcover consists of a mixture of old-growth forests, selectively logged primary forests, secondary forests, early successional pasture, and abandoned plantations [11]. Large footprint, full waveform LVIS (Laser Vegetation Imaging Sensor) and hyperspectral HyMap (Hyperspectral Mapper) data were acquired over the study area on March 10, 2005 and March 25, 2005, respectively. Discrete return small footprint airborne LIDAR data were also acquired on March 13-14, 2006. Researchers [12] reported that field measured elevations were successfully predicted from the estimated ground elevation using the small footprint LIDAR data with $r^2 = 0.994$, root mean squared error (RMSE) = 1.85 m. For the current study, the LIDAR point cloud data is used to create a DTM (Digital Terrain Model) and a DSM (Digital Surface Model) with spatial resolution 5m. Canopy heights are computed from the differences between the DTM and DSM model values, and the estimates are used to calculate AGBM based on allometric equations from [13] and [14]. Even though approximately a one year time gap exists between LVIS + HyMap and LIDAR point cloud data acquisition, it is reasonable to use these data to develop a regression model since Clark et al. [15] reported the maximum of mean 1-yr height increments of the tropical wet forest at La Selva is less than 80 cm per year, which is not significantly larger than the vertical accuracy (approximately 30 cm) of LIDAR data. The three-dimensional physical and biological structure of the forests at La Selva were directly measured [16] at 55 randomly selected locations from June 2003 to March 2005 using a movable 46 m tall modular tower. The field measurements from the towers, and canopy heights and AGBM derived from small footprint LIDAR are used as ground reference information to develop the model in this study. Biometric features are extracted from the decomposed LVIS waveform data and combined with HYMAP data for classification. Due to limited ground reference information on both detailed land cover and biomass, tower data were extrapolated using spatial-spectral segmentation. Assuming homogeneity of the segments, a statistical model to estimate AGBM for the site was then developed.

REFERENCES

[1] Stephen A. Y. Omule, "Personal bias in forest measurements," *Forestry Chronicle*, vol. 56, no. 5, pp. 222–224, 1980.

[2] R. E. McRoberts, J. T. Hahn, G. J. Hefty, and J. R. Van Cleve, "Variation in forest inventory field measurements," *Canadian journal of forest research*, vol. 24, no. 9, pp. 1766–1770, 1984.

[3] Hans-Erik Andersen, Robert J. McGaughey, and Stephen E. Reutebuch, "Estimating forest canopy fuel parameters using lidar data," *Remote Sensing of Environment*, vol. 94, no. 4, pp. 441 – 449, 2005.

[4] Jason B. Drake, Ralph O. Dubayah, David B. Clark, Robert G. Knox, J. Bryan Blair, M. A. Hofton, Robin L. Chazdon, John F. Weishampel, and Steve Prince, "Estimation of tropical forest structural characteristics using large-footprint lidar," *Remote Sensing of Environment*, vol. 79, no. 2-3, pp. 305 – 319, 2002.

[5] M. A. Lefsky, D. J. Harding, M. Keller, W. B. Cohen, C. C. Carabajal, F. D. B. Espirito-Santo, M. O. Hunter, and R. de Oliveira Jr, "Estimates of forest canopy height and aboveground biomass using icesat," *Geophysical Research Letters*, vol. 32, pp. 22, 2005.

[6] M. A. Lefsky, Michael Keller, Yong Pang, Plinio B. de Camargo, and Maria O. Hunter, "Revised method for forest canopy height estimation from geoscience laser altimeter system waveforms," *Journal of Applied Remote Sensing*, vol. 1, 2007.

[7] Martin Schlerf, Clement Atzberger, and Joachim Hill, "Remote sensing of forest biophysical variables using hymap imaging spectrometer data," *Remote Sensing of Environment*, vol. 95, no. 2, pp. 177 – 194, 2005.

[8] Sorin C. Popescu, Randolph H. Wynne, and John A. Scrivani, "Fusion of small-footprint lidar and multispectral data to estimate plot-level volume and biomass in deciduous and pine forests in virginia, usa," *Forest Science*, vol. 50, no. 4, pp. 551–565, 2004.

[9] John W. McCombs, Scott D. Roberts, and David L. Evans, "Influence of fusing lidar and multispectral imagery on remotely sensed estimates of stand density and mean tree height in a managed loblolly pine plantation," *Forest Science*, vol. 49, no. 3, pp. 457–466, 2003.

[10] M. Moghaddam, J. L. Dungan, and S. Acker, "Forest variable estimation from fusion of sar and multispectral optical data," *Geoscience and Remote Sensing, IEEE Transactions on*, vol. 40, no. 10, pp. 2176–2187, Oct 2002.

[11] Deborah A. Clark, Lucinda A. McDade, Kamaljit S. Bawa, Henry A. Hespenheide, and Gary S. Hartshorn, *La Selva: ecology and natural history of a neotropical rain forest*, The University of Chicago Press, 1994.

[12] J. R. Kellner, D. B. Clark, and S. P. Hubbell, "Pervasive canopy dynamics produce short-term stability in a tropical rain forest landscape," *Ecology Letters*, vol. 12, pp. 155–164, 2009.

[13] Paul M. Rich, Kaius Helenurm, Daniel Kearns, Suzanne R. Morse, Michael W. Palmer, and Linda Short, "Height and stem diameter relationships for dicotyledonous trees and arborescent palms of costa rican tropical wet forest," *Bulletin of the Torrey Botanical Club*, vol. 113, no. 3, pp. 241–246, 1986.

[14] S. Brown, *Estimating biomass and biomass change of tropical forests: a primer*, vol. 134 of *FAO Forestry Paper (FAO)*, FAO, 1997.

[15] Deborah A. Clark and David B. Clark, "Getting to the canopy: Tree height growth in a neotropical rain forest," *Ecology*, vol. 82, no. 5, pp. 1460–1472, 2001.

[16] David B. Clark, Paulo C. Olivas, Steven F. Oberbauer, Deborah A. Clark, and Michael G. Ryan, "First direct landscape-scale measurement of tropical rain forest leaf area index, a key driver of global primary productivity," *Ecology Letters*, vol. 11, pp. 163–172, 2008.

[17] Jinha Jung and Melba M. Crawford, "A two-stage approach for decomposition of icesat waveforms," in *Geoscience and Remote Sensing Symposium, 2008. IGARSS 2008. IEEE International*, 2008, vol. 3, pp. 680 – 683.