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Determination of Wetland Vegetation Height with LIDAR

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Abstract: Light Detection and Ranging (LIDAR) is a new technology that offers a potential alternative to field surveying and photogrammetric techniques for the collection of elevation data. It has the advantages of being rapid accurate and able to map areas that are difficult to access. LIDAR has demonstrated the capability to accurately estimate important vegetation structural characteristics such as forest canopy height. For these reasons, airborne LIDAR data were used to compare vegetation height determinations with field observations on one selected transect in the vicinity of Lake Hatchineha in Florida, USA. The approach was based on the LIDAR and field measurements. The results showed that the lowest height (0 cm) appeared to be open water and barren fields. Vegetation heights of 0-30 cm corresponded to short grassy areas and 90-180 cm corresponded to medium height plants. Tall plants were determined to be vegetation heights ranging from 180 to 365 cm and very tall plants were determined to range from 365 to 600 cm. In addition, vegetation heights ranging from 600 to 1200 cm and from 1200 to 1700 cm corresponded to low and medium-height trees, respectively. Sources of potential error in determining forest tree canopy height were found to evolve from the fact that medium-height tree branches were sometimes reflected and recorded as a first hit and so were incorrectly classified as either low tree or tall plant classes. The results showed that, in most cases, while field and photogrammetric methods fail to determine tree and other plant heights, they could be accurately detected by using LIDAR classification in the wetlands where the ground is not visible. The next step will be to try to find a correlation between LIDAR vegetation heights and water boundaries.

Key Words: LIDAR, Wetland, Vegetation Heights, Vegetation Classification, Remote Sensing

LIDAR Yardımı ile Sulak Alanlardaki Bitkilerin Yüksekliklerine Göre Sınıflandırılması

Özet: Light Detection And Ranging (LIDAR) arazi ölçümleri ve fotoğraf tekniklerine alternatif sunan topoğrafik yüksekliklerin belirlemesinde (1) zaman kazanımı (hızlılık) (2) doğruluk oranı yüksek ölçümler yapmak ve (3) ulaşılması zor olan alanların haritalanması gibi pek çok avantajı olan yeni bir teknolojidir: Son zamanlarda özellikle ormanlık alanlarda LIDAR yardımı ile yapılan ölçümlere dayalı bitki uzunlukları ve diğer yapısal özelliklerin belirlenmesinde doğruluk derecesi yüksek sonuçlar alındığı gözlenmiştir. Bu çalışmada Amerika'nın Florida'da eyaletinde yer alan Hatchineha gölü etrafındaki sulak alanda LIDAR ölçümleri ile arazi ölçümlerinin uyumu test edilmiştir. LIDAR yardımı ile elde edilen bitki yükseklikleri arazi ölçümleri belirlenen doğrusal hat üzerinde yükseklik ölçümlerinde sıfır cm (0) olan yerlerdeki arazi örtüsünün ya su yüzeyi yada çıplak arazi alanları olduğu tespit edilmiştir. Bununla birlikte LIDAR yardımı ile bitki yüksekliklerinin 0-30 cm olarak tesbit edilen alanların arazide çimenlik kısa bitkiler olduğu belirlenmiştir. Yine bu hat üzerinde 90-180 cm olarak belirlenen yüksekliklerin orta yükseklikteki bitki örtüsünün olduğu belirlenmiştir. Arazide 180-365 cm yüksekliklerde belirlenen bitki örtüsü LIDAR yardımı ile yüksek doğru şekilde belirlenebilmiş ve uzun boylu bitki olarak tarif edilmiştir. Aynı zamanda çalışma alanında 365-600 cm olarak belirlenen bitki yükseklikleri ise çok uzun bitki diye sınıflandırılmıştır. Bitki yüksekliklerinin 600-1200 cm olduğu alanlar kısa boylu ağaç olarak belirlenirken bitki yüksekliklerinin 1200-1700 cm arasındaki alanlarda ise orta boylu ağaçların varlığına rastlanmıştır. Bununla birlikte bazı alanlarda orta boylu ağaçların dallarından olan ilk donus LIDAR çok uzun bitki veya kısa ağaç olarak sınıflandırıldığı belirlenmiştir. Çalışma alanında fotoğraf ve geleneksel methodlarla elde edilmesi zor olan bitki ve ağaç uzunluklarının tesbiti LIDAR yardımıyla kolaylıkla ve yüksek doğruluk derecesinde tesbit edilebilmiştir. Bir sonraki aşama ise LIDAR ve diğer uzaktan algılama verileri ile bu bitki yüksekliklerinin ve sulak alanların sınırları ile nasıl bir ilişki içinde olduğu tesbit edilmeye çalışılacaktır.

Anahtar Sözcükler: LIDAR, Sulak alanlar, Bitki Yükseklikleri, Bitki Sınıflaması, Uzaktan Algılama

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Introduction

Light Detection and Ranging (LIDAR) has become one of the cutting edge technologies in the remote sensing field. Recently, this technology has been used in a variety of applications, such as the determination of accurate water depths (Lillesand and Kiefer, 2000; Lee 2003), mapping of wetlands and shallow water (Irish and Lillycrop, 1999), high-resolution mapping of topography under forest for geomorphic investigations and hydrologic modeling (Harding and Berghoff, 2000), and structural differentiation between forest ages (Lefsky et al., 1999a; Weishampel et al., 2000).

LIDAR data are collected as the aircraft flies overhead. The LIDAR system is comprised of a pulsed laser, a Global Positioning System (GPS) receiver, and an Inertial Navigation System (INS) unit (for measuring the angular orientation of the sensor with respect to the ground) (Ritchie, 1996; Lefsky et al., 1999a; Lefsky et al., 1999b; Jensen, 2000; Maune, 2001).

Fundamental to LIDAR is a laser altimeter that determines the distance from the sensor to the physical surface by measuring the elapsed time between a laser pulse and its reflected return signal (Ritchie, 1996; Flood and Gutelius, 1997; Jensen, 2000; Maune, 2001; Hudak et al., 2002). Bachman (1979) explained that this measured time multiplied by the speed of light measures twice the distance to the target. Processing of the return signal may identify multiple pulses and returns. As a result, trees, buildings and other objects are noticeable in the LIDAR pulse, permitting accurate calculation of their heights (Nelson et al., 1988). Studies using real-time field data have indicated that LIDAR data can provide non-asymptotic estimates of structural attributes such as the stand volume of forests (Lefsky et al., 1999a).

Hudak et al. (2002) and Maune (2001) stated that LIDAR has become an alternative remote sensing technology that promises to both increase the accuracy of biophysical measurements and extend spatial analysis into the third (z) dimension. LIDAR sensors directly measure the 3-dimensional distribution of plant canopies as well as sub-canopy topography, thereby providing high-resolution topographic maps and highly accurate estimates of vegetation height and canopy structure (Hudak et al., 2002; Maune, 2001). Even though some of the laser energy will be backscattered by vegetation above the ground surface, only a portion of the laser energy is required to reach the ground to produce surface measurements (Jensen, 2000; Maune, 2001). Both of these partial returns (vegetation and ground) can be stored by the LIDAR instrument, allowing measurement of both vegetation canopy height and ground surface elevation (Lefsky et al., 1999b; Lillesand and Kiefer, 2000; Rees, 2001).

LIDAR offers an alternative to field surveys and photogrammetric techniques for the collection of digital elevation models (DEMs) for mapping large areas with high accuracy in a short time (Lefsky et al., 1999a; Lefsky et al., 1999b). Traditional survey and photogrammetric techniques for determining ground elevations are limited in several ways. The primary disadvantages of traditional surveying are its substantial time and labor requirements and associated costs (Rees, 2001). According to Baltsavias (1999), Jensen (2000) and Maune (2001), photogrammetric methods for determining elevations from aerial photographs and satellite images are an established alternative to field surveys. On the other hand, these photogrammetric methods are inaccurate in forested areas, such as wetland forests, where the ground is not visible (Baltsavias, 1999). In these cases, LIDAR can be an accurate and cost-effective alternative to mapping environmentally sensitive areas such as wetlands (Jensen, 2000; Maune, 2001).

Ritchie (1996) stated that there is excellent agreement between LIDAR measurements of height in both temperate deciduous forests and desert scrub. He also found that vegetation height measurements can be made accurately even on vegetation of short height, smaller than 1 m, at least in low-slope environments. Since LIDAR has the ability to collect data from both ground and vegetation surfaces without the necessity to access wetland areas, LIDAR data can be useful for measuring vegetation height and classifying wetland areas based on vegetation height (Lefsky et al., 1999a).

The purpose of this study is to investigate the use of LIDAR data to determine the approximate land cover classes based on the vegetation height in a wetland area and to compare the result with the field-surveyed vegetation height method explained by Tiner (1999). If LIDAR determines the vegetation height on this transect successfully, further research will take place to classify the LIDAR data and compare it with other remote sensing imagery to investigate whether LIDAR is useful for determining wetland boundaries.

Materials and Methods

Study Area

The test site was a 2.5 km stretch on the western shore of Lake Hachineha in central Florida (Figure 1). The 1800 m long transect was selected from the test site to examine the vegetation height classification. Two areas on the transect were extracted for closer examination. The majority of the study area is composed of wetland forest, marsh vegetation and upland forest. In the test site, plant vegetation heights were not more than average tree height as determined from ground surveying.

Data Processing

LIDAR data used for this research were acquired on March 22, 2002. Two LIDAR "channels" were used in this study. Returns from vegetation (first pulse) produced the LIDAR vegetation channel (ground + vegetation) and returns from the ground (obtained by filtering the data) produced the LIDAR ground channel (last pulse).

The Optech ALTM 1020 system was used to acquire the LIDAR data. Both first pulse and last pulse returns coupled with first and last pulse intensity LIDAR measurements were collected. The LIDAR acquisition took approximately 4 h to collect. Fifty percent LIDAR overlap was planned for this area to ensure adequate ground point distribution in the vegetated areas. A flying height of 1500 feet (457.2 m) above ground, scanning frequency of 16 Hz and LASER firing rate of 5000 Hz ensured high accuracy topographical results. LIDAR data were processed and supplied in space-delimited ASCII files by a commercial company (Waggoner Eng. MS). The data were provided in 2 file types for this study: vegetation hits and ground hits. In order to apply standard image classification techniques, the randomly distributed LIDAR data were converted into raster data sets. The ERDAS Imagine software package was used to generate digital elevation models (DEMs) from the ASCII files with a 1-m ground cell. These DEMs are based on a grid where the contents of each grid cell represent the height of the terrain in that cell. It consists of X, Y and Z coordinates.

A constructed ground surface from the ground only elevation (Figure 2b) was subtracted from the vegetation plus ground elevation (Figure 2a) by creating a model (Figure 3) in the ERDAS model maker to produce a height model for only vegetation heights (Figure 2c).

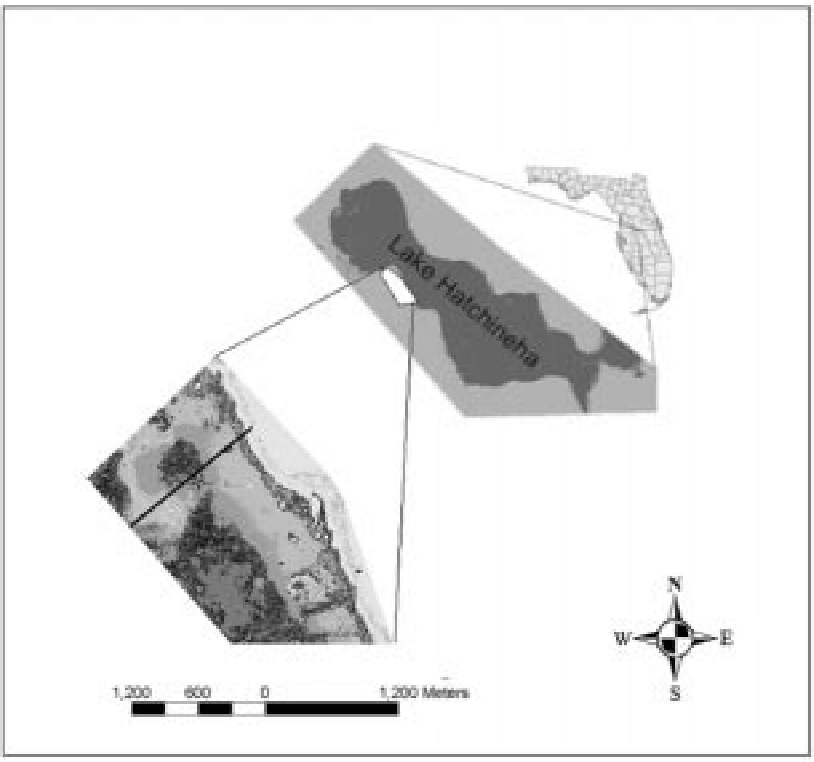

Figure 1. Study area.

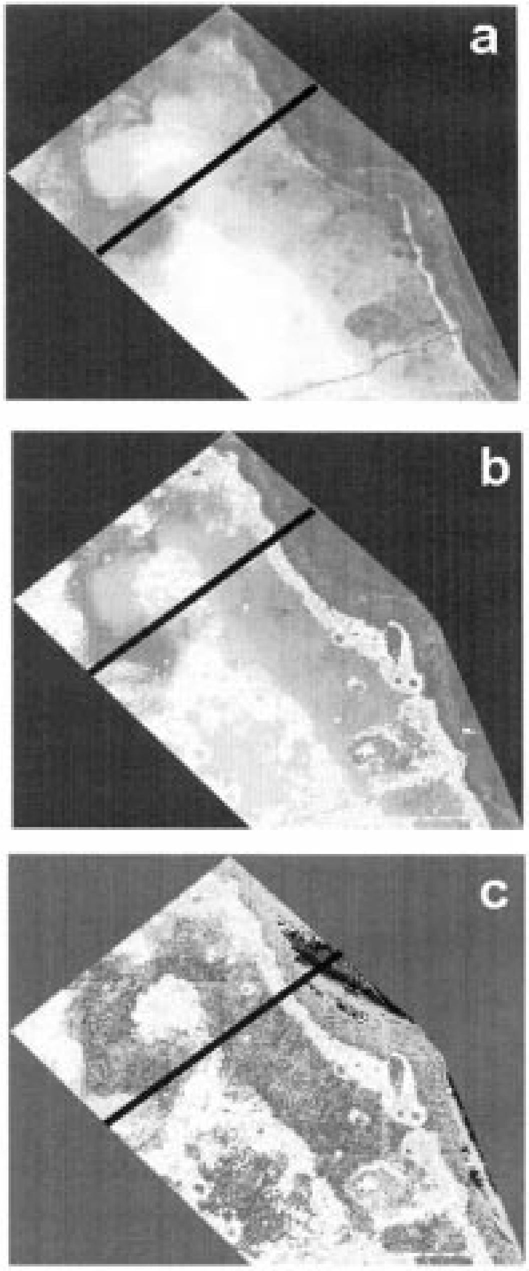

Figure 2. Elevation models in study area (a) Ground surface (b) Vegetation plus ground (c) Only vegetation height.

Heights from LIDAR channels including only vegetation heights were converted to centimeters to ensure sufficient precision using integer values even on short vegetation heights, smaller than 100 cm (Ritchie, 1996). ERDAS software was used to generate an 1800 m transect on the LIDAR images (Figures 2a-c).

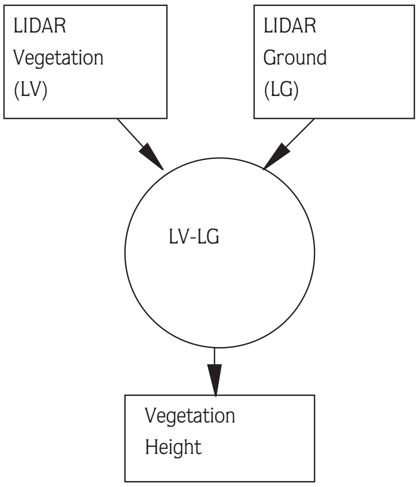

Figure 3. Model created by the ERDAS model maker for height analysis.

Field Measurements

The study test site was selected based on the existence of a marsh area in which vegetation height was not more than any average tree determined from field trips and inspection of USGS digital orthophoto quarter quadrangles (DOQQ). Field photos were taken to use in the analysis of classification on the selected transects. Three field trips (April 1, 2002, April 15, 2002, and May 29, 2002) were made to the study site to verify the vegetation heights on the ground. Since there was only an 8-day difference between the first field trip and the LIDAR acquisition date, trees and wetland vegetation around the study area were not dramatically different. Certain types of vegetation heights were randomly measured on the transect (Table 1) using flexible tape and 16 ground elevation points collected using a GPS at 300-m intervals on the 1800-m transect, as demonstrated in Table 1, for comparison with the LIDAR data. In wetlands, the height of vegetation is often used to classify the vegetation communities into different levels. Tiner (1999) explained that while the 6-m height separates the tree level from the shrub for wetland plant community descriptions, it might be worthwhile to identify height classes for individual species.

The measured vegetation height from 16 randomly selected points and the 16 collected GPS points were compared with LIDAR elevations and LIDAR heights with the same coordinates respectively using basic linear

Table 1. GPS and LIDAR elevation and vegetation height.

GPS Elevation (cm)	LIDAR Elevations (cm)	Measured Vegetation Height (cm)	LIDAR Vegetation Height (cm)
1585	1575	30	0
1606	1603	110	100
1603	1600	600	582
1686	1671	780	759
1624	1593	650	603
1515	1506	1700	1606
1562	1550	0	10
1589	1600	180	203
1534	1531	200	196
1603	1600	1300	1100
1600	1608	500	478
1585	1560	480	501
1580	1570	370	402
1599	1600	0	0
1644	1649	1200	1210
1638	1646	185	200

regression analysis to determine how LIDAR differed from GPS and field measurements.

Results

The result showed that similarities exist in both the ground surveying observation and the LIDAR detected vegetation height on the selected transect. With LIDAR, the highest vegetation elevation on the transect was 3400 cm (Figure 4a) and the highest vegetation height above ground was 1700 cm (Figure 4c). With the ground observation, vegetation elevation was 3500 cm. Ground surveying confirmed that this is very close to what is generally found in the field and with a visual inspection of Figure 4c. The 8 classes described by Tiner (1999) were present in this transect . It was also observed that the 6-m height separates the tree level from the shrubs for wetland plant communities on the examined transect. Classes identified with LIDAR were: (1) Water, (2) Herb and Shrubs, (3) Low Plants, (4) Medium Height Plants, (5) Tall Plants, (6) Very Tall Plants, (7) Low Trees, and (8) Medium Trees.

After LIDAR data were examined, detailed field surveys were performed on the transect to see whether the LIDAR results were correct. The following ranges were measured in the field based on the wetland classifications described by Tiner (1999): (1) herb and shrubs (very low) (< 30 cm), (2) low plant (30-90 cm), (3) medium-height plant (90-180 cm), (4) tall plant (180-365 cm), (5) very tall plant (366-600 cm), (6) low tree (600-1200 cm) (7) medium tree (1200-3000 cm). Open field and water were not measured but were used as zero height.

On the transect, the highest vegetation height classes were cypress trees and oak trees. When the data were queried for only the vegetation height channel, as Figure 5 shows, the lowest height (0 cm) generally corresponded to water or bare earth, as noted during the field visits. In low-slope areas vegetation heights between 0 and 30 cm corresponded to short grassy areas, herbs, and shrubs on the ground survey as Ritchie (1996) and Tiner (1999) described (Figure 5). As Tiner (1999) illustrated, vegetation heights between 90 and 180 cm found on the ground survey were classified as medium height plants as shown in Figure 5. Vegetation heights between 180 and 365 cm also were found on the transect and this location was classified as tall plants in Figure 5.

Because some of the laser energy was backscattered as described by Jensen (2000) and Maune (2001), very tall vegetation and low trees were misidentified in many places where the vegetation height was between 365 and 600 cm. However, in most cases the 365-600 cm vegetation heights were located where only very tall plants were present on the ground.

Areas with 600-1200 cm vegetation heights were found to correspond to the low trees class in the only vegetation height channel (Figure 6). Medium height trees were observed in the study area very easily. Most of them were cypress trees and oak trees of 1200-1700 cm heights on the ground. In this study area, no tall trees were found as described by Tiner (1999). In some cases medium tree branches were reflected as a first hit and were shown as low trees or tall plants classes (Figure 7). In addition, there was some confusion between the low trees and very high plants classes, similar to what was observed by Ritchie (1996). Low and medium tree branches were reflected in the first hit and created confusion between tall and very tall plants classes (Figure 7). This may be as a result of some tall plants and very tall plants being the same height as low trees on this transect. In particular, LIDAR identified the water, medium trees and low plants very accurately (Lefsky et al., 1999a). The vegetation height may indicate different size categories of land cover but it does not identify vegetation species.

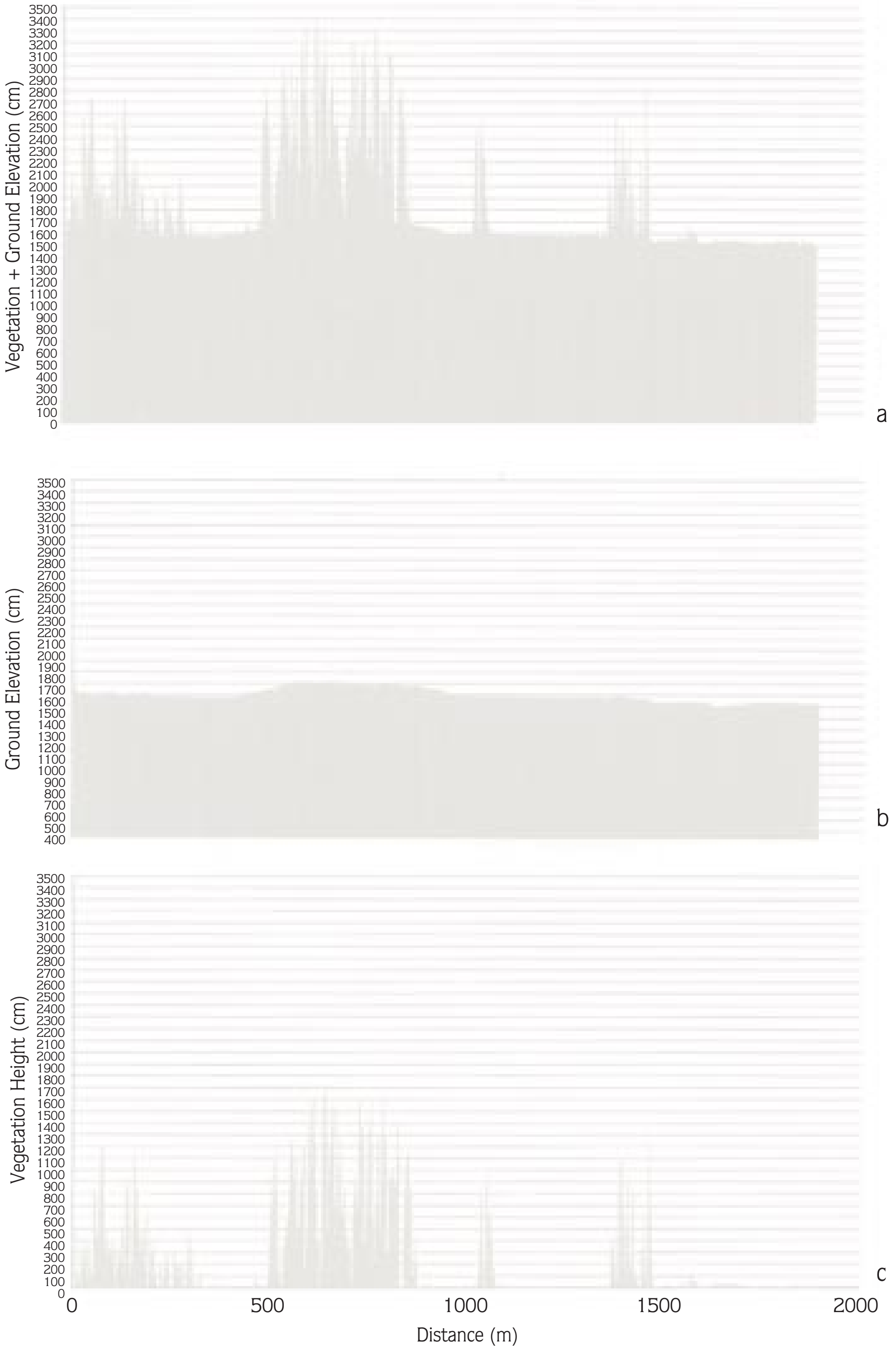

Figure 4. Transect profiles (a) Ground (b) Vegetation (c) Only vegetation heights.

The R^2 of the regression of LIDAR elevations to GPS elevations with 16 points was 92.7% (Figure 8) and the R^2 of the regression of the LIDAR heights to the measured heights was 99.2% at the 95% confidence interval (Figure 9). This shows that using LIDAR is of benefit in mapping wetland areas.

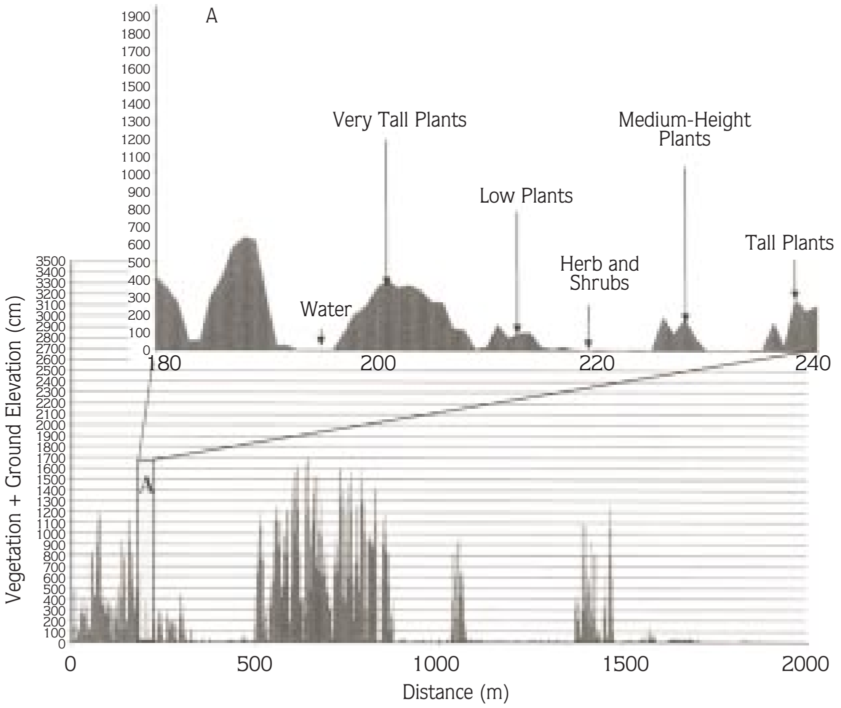

Figure 5. Transect showing plant heights.

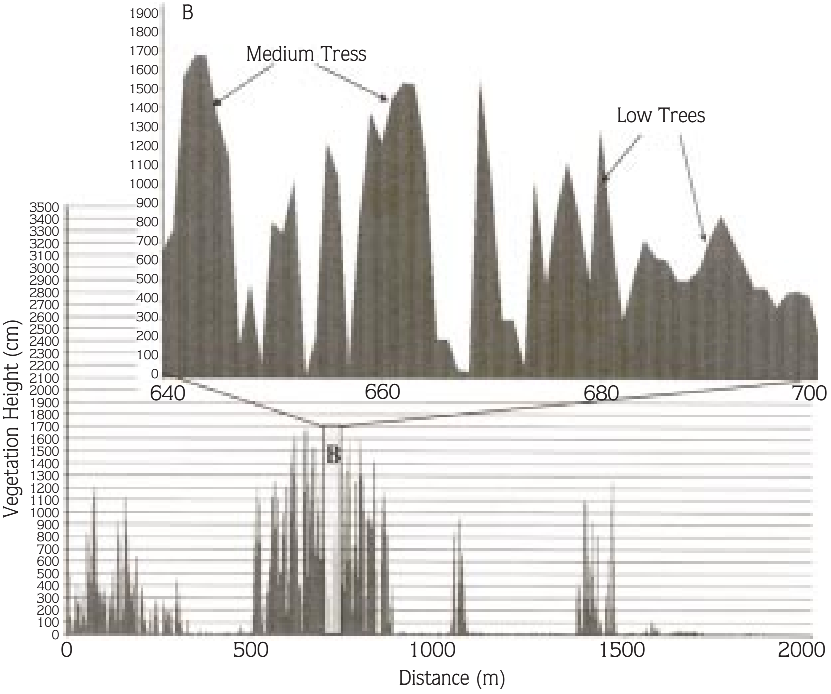

Figure 6. Transect showing tree heights.

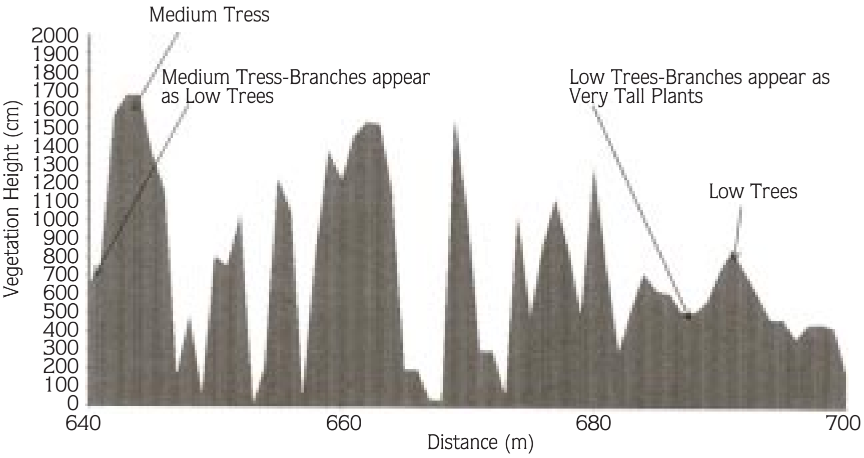

Figure 7. Transect showing misclassification of vegetation heights.

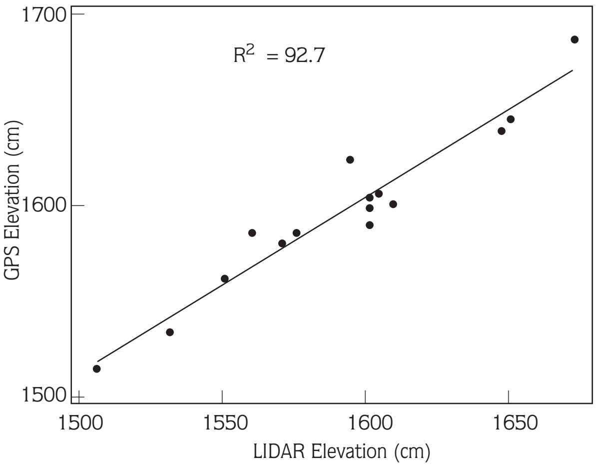

Figure 8. LIDAR elevations and collected GPS elevations.

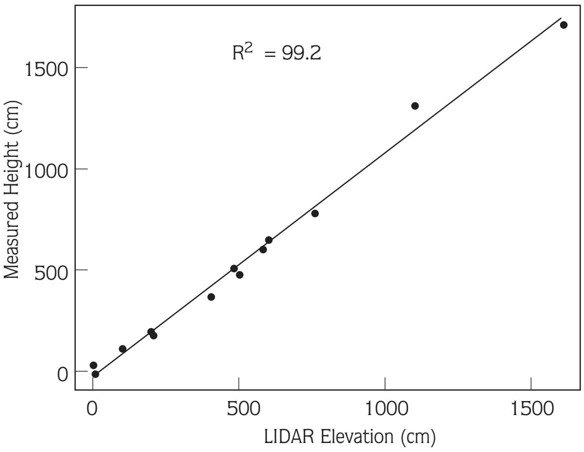

Figure 9. LIDAR height and collected measured heights.

Discussion

The most practical use found for LIDAR data in regards to wetlands in this study is for the classification of vegetation based on height. LIDAR-based wetland vegetation height classification was shown to be an appropriate method in terms of the determination of the size of vegetation. Because LIDAR has no spectral information, vegetation classification was limited to vegetation heights. It was found that vegetation classification based on height with LIDAR is an accurate and cost-effective alternative to mapping the wetlands where the ground is not visible. Field observations verified the existence of similarities between the field and LIDAR detected canopy heights.

Florida's wetlands are flat and even daily rainfall can cause significant changes in grassy areas. Other than the first field trip, 2 other field trips were made to the field to verify the land cover (for trees). Since the ground data used for analysis and used as reference data were collected during the first field trip (April 1, 2002), the characteristics of the ground data (only vegetation) from the first field trips were similar to the LIDAR imagery acquired on March 22, 2002.

LIDAR shows great potential for integration with ecological research precisely because it directly measures the physical attributes of vegetation canopy structures that are highly correlated with the basic plant communities at land cover levels. Further studies integrating LIDAR with multi-spectral images may provide more information about land cover that approaches the species level and determined water boundaries for wetland areas.

The method and results of this research can be modified to other geographic places, but researchers have to be careful since the results could differ from one geographic environment an other. For instance, the first field trip to the study site was 8 days later than the date of the LIDAR acquisition of data. This could cause significant differences in the results in different environments.

Further studies should consider the testing of more transects in different areas of the study site to derive conclusions about whether LIDAR could replace traditional methods of mapping wetland areas.

Acknowledgments

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