TROPICAL TREE MORPHOLOGY USING AIRBORNE LIDAR DATA

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ABSTRACT: Mangrove crowns were delineated using active sensor LIDAR (LIght Detection And Ranging) data by a crown delineating model developed in this study. LIDAR data were acquired from airborne survey by a helicopter for the estuary of Macouria in the northeast coast of French Guiana. The canopy height image was derived from LIDAR vector data by calculating the difference between ground and non-ground data. The mangrove site in the study area was classified to three sectors by the time of mangrove settlement; Mangrove 1986, 2002 and 2003. The estimated crown of Mangrove 1986 was reliable defined for their size, number and volume because of larger crown size and bigger variation of crown height. The tree crown size of Mangrove 2002 and 2003 by the model was overestimated and the number of trees was much underestimated. The estimated crown was not for single crown but a crown group due to homogenous crown height and spatial resolution of LIDAR data. However the canopy height image derived from LIDAR data provided three-dimensional information of mangroves.

Keywords: Mangrove, LIDAR, crown delineating model, crown size, crown height

1. Introduction

As a kind of tropical tree, Mangroves provide various goods of wood for fuel, construction, drugs and food items and play an important role in a nursery and a refuge for numerous species of animal (Nagelkerken *et al.*, 2000). Thus mangrove morphology is significant for not only understanding structure of mangroves but also natural resource management in tropical region. However the collecting data about mangroves by direct access is not easy and expensive because they are in remote area with accessibility problems due to mud, movable coastline, density of the trees and difficulty of penetration for survey. With point data sample based on a filed sampling, it's difficult to have a good representation of the canopy as well as the mangrove. Remote sensing tools could be a solution for obtaining data from this area.

Remote sensed images from satellite and airplane were widely applied for application of forest environment. Kimes et al. (1996) proposed an estimation method for forest age using Landsat TM (Thematic Mapper) and digital terrain model by an artificial neural network. Two-dimensional remote sensed images provide passively spectral signature of vegetation in forest. By the way, LIDAR (LIght Detection And Ranging) permit that three-dimensional topographical information can be obtained in near real time and then it is automatically georeferenced (Axelsson 1999).

By measurement of distance and GPS (Global Positioning System), LIDAR can provide automatically georeferenced topographic data rapidly. This three-dimensional information obtained from LIDAR allows estimating tree heights and volumes by Nilsson (1996). Leckie et al. (2003) evaluated individual tree crown using combined data with LIDAR and multispectral image.

Automatic segmentation of crown was conducted for conifers and broad-leaved trees by Culvenor (2002) using high spatial resolution airborne images. A tree crown delineating model was proposed by Hyyppä et al. (2001) for forest inventory in the boreal forest zone using LIDAR. The advantage of LIDAR data is the automatic orthorectification vector data directly obtained from the sensor. Therefore the time of processing data could be saved and the position and height of object can be precisely defined by the LIDAR data.

The objective of study is to characterize mangrove morphology in tropical region using airborne LIDAR altimeter data. A canopy height image will be derived from the vector data of the LIDAR first and last returns. A delineating model of mangrove crown will be developed using the canopy height image. The polygon of mangrove crown derived from the model could be employed for characterizing each tree structure and mapping the tree morphology.

2. Data Acquisition

2.1 Experimental site

The Amazon River discharges million tons of sediments annually, forming mud banks in the Atlantic Ocean along the coast of Brazil and Venezuela including the coast of French Guiana. Experimental site was selected as an area where recent banks were developed. The estuary of Macouria River was perfect place in this condition, at 52.53°-52.51° west longitude and 5.06°-5.08° in north latitude (Figure 1). Mangroves in this site started to establish in 1986 and recent. Mangroves can be classified to three generation by the time of their settlements. The oldest mangrove started to establish before 1986 (Mangrove 1986), the second one started in 2002 (Mangrove 2002) and the last one started in 2003

(Mangrove 2003). Figure 2 shows photographs for the three sectors of Mangrove 1986, 2002 and 2003.

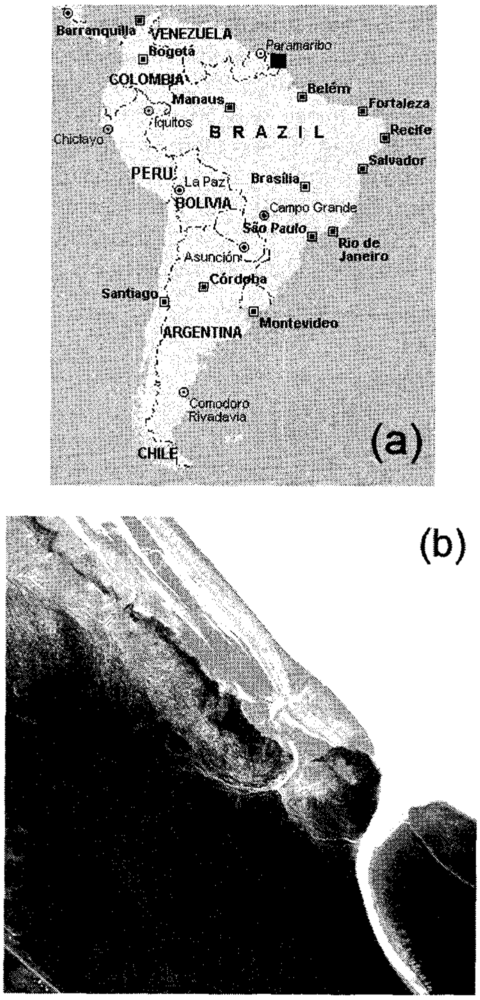

Figure 1. Experimental site of mangrove in black filled square (a) and (b) in grey image.

2.2 Field campaigns

Field campaigns were carried out in 2003 and 2004 for collecting data about tree height, size, crown dimension, density. The details of these field data are summarized in Table 1. The field data were used to evaluate estimated tree dimension derived from LIDAR data using the automatic crown delineating model developed for this study.

Table 1. Inventory of mangroves in during field campaigns

	Density (ea/ha)	Canopy height	Tree diameter	Crown diameter
Mangrove 1986	100	20 m	30 cm	5 m
Mangrove 2002	50000	8 m	5-6 cm	2 m
Mangrove 2003	100000	1.5-5 m	2-3 cm	1 m

2.3 LIDAR data

The observation of airborne LIDAR on the site of Macouria covers a surface of 3.28 km^2. LIDAR data were acquired from a sensor board on a helicopter. The sensor used near infrared band (900 nm) for observation, the flight height was about 115 m and the sampling rate was 30 kHz with ±30° of swath angle. The horizontal position and vertical altitude accuracy is 15 to 20 cm by using inertial navigation system and two dual frequency GPS receivers. All vector data were 12,073,826 points for the first returns from the surface. The observation company had classified the data of the last returns to ground elevation data for deriving digital elevation model (DEM) before provided the data for this study. Thus all the first returns data and the DEM data interpolated at 4 meter spatial resolution were employed in this study

The LIDAR data were converted to a raster image. The horizontal spacing between vector data is several centimetres to 1.0 m. Pixel spatial size was decided to 50 cm. Each pixel value in the raster image was derived from four nearest points from the centre of the given pixel by interpolation using inverse distance weighted function (Figure 2).

By the interpolation, raster images were derived for digital surface model (DSM) from the first return data for DEM. To obtain absolute canopy height, canopy height image was calculated by subtractions altitudes of DEM image from those of DSM image.

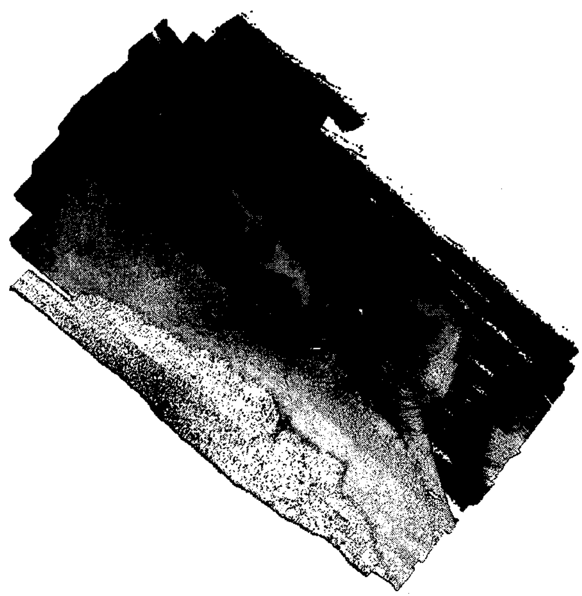

Figure 2. Converted LIDAR intensity raster image

3. Classification and crown delineation

In the site, an important criterion of recognition to various generations of trees is the height difference between generations and canopy structure and opening.

The mangrove generations was classified by ISODATA unsupervised classification in ENVI 4.0 using canopy height image of LIDAR. Three classes were distinguished; trees of 1 m to 6 m, trees of 6 m to 10 m and trees higher than 10 m. The canopy height image was segmented by the three classes. These three segmented sectors were also classified by their ages, like the time of settlement; Mangrove 2003, Mangrove 2002 and Mangrove 1986, as mentioned in Section 2.2 (Figure 4). Tree crown delineation was applied to the modified segmentation image with different threshold for the classes.

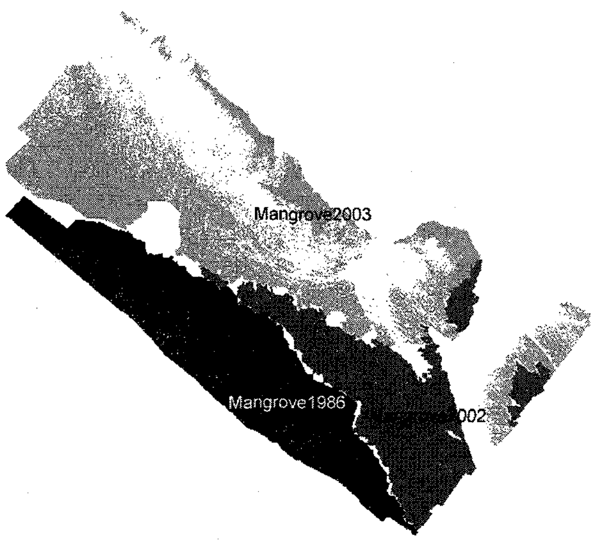

Figure 3. Three sectors by their ages and heights for Mangrove 1986 (black), Mangrove 2002 (darker grey) and Mangrove 2003 (brighter grey), respectively.

For automatically delineating mangrove crowns, the canopy height image was solely employed to the crown delineating model because mangrove crowns was defined more clearly in the image than in others.

The processing of mangrove crown delineation is applying Gaussian filter to the canopy height image of LIDAR, determining local maxima and local minima, thinning local minima network, splitting and merging polygons, and defining the last polygons.

4. Results and Discussion

The delineating model of mangrove crown needs to have appropriate thresholds for height ranges and window sizes of Gaussian smoothing filter, local maximum and local minimum. The histogram of canopy height image was derived for the segmentations of mangrove generation. In the histograms, the height of Mangrove 1986 varied from 0 m to nearly 40 m with peaks at 1.15 m and 3.2 m, had plat zone from 4.9 m to 7.5 m and descended from 7.5 m gradually. Therefore there were smaller or broken trees in this region and the crown of bigger trees may start from 7.5 m high. The height of Mangrove 2002 varied as Gaussian distribution from 0 m to nearly 11 m with a peak around 7 m. The histogram of Mangrove 2003 presented heights from 0 m to 8 m with a peak at 3 m but the histogram was shown from 1 m to 8 m because crowns below 1 m is not detectable by the model using the canopy height image. The mangrove in the study area was classified with 1 m to nearly 6 m for Mangrove 2003 because the resolution of canopy height image was 50 cm, 6 m to 10 m for Mangrove 2002 and higher than 10 m for Mangrove 1986. The moving window size of Gaussian smoothing filter was differently applied to three segmentations of mangrove; 7×7 pixels, 5×5 pixels and 3×3 pixels for Mangrove 1986, 2002 and 2003 respectively.

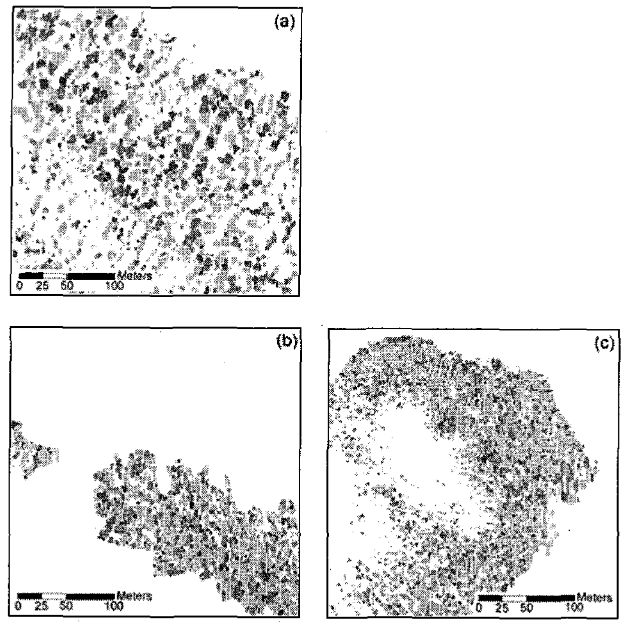

Figure 4. Polygons of mangrove crown for Mangrove 1986 (a), 2002 (b) and 2003 (c) generated from LIDAR canopy height image.

The model was applied to the three sectors of canopy height image separately with the different thresholds. For the results, the model provided polygon images for each sectors. The polygon images were superposed on the canopy height image for deriving estimated mangrove crown dimensions from the model, presented in Table 2. The mangrove polygon images for sub regions were shown in Figure 5 (a), (b) and (c) for Mangrove 1986, 2002 and 2003, respectively. Generally estimated crown size was the biggest for Mangrove 1986, the second for Mangrove 2002 and the smallest for Mangrove 2003.

Table 2. Morphological statistics of estimated mangrove crowns from LIDAR data

	Mangrove		
	1986	2002	2003
Height range	8 m–40 m	4 m–12 m	1 m–6 m
Crown area	21.2 m^2	13.8 m^2	8.8 m^2
Crown diameter	4.6 m	3.7 m	2.6 m
Average of maxima	22.4 m	9.8 m	4.0 m
Average of height	15.2 m	7.8 m	3.1 m
Crown volume	170.1 m^3	43.7 m^3	13.4 m^3
Trees per hector	118	394	605

In the crown polygon image of Mangrove 1986, there were lots of spaces between crown polygons. These spaces were results in selection by survival competition between mangroves. The crown of Mangrove 1986 was rather precisely estimated by the model because of the spaces by the selection and clear height difference between crowns. The estimated crown has a little bit smaller size of crown diameter than those and a litter bit bigger density of trees than those. The irregular crown form or split crown was difficult to define as a crown. There were peaks at 1.15 m and 3.2 m in the height histogram of Mangrove 1986, which were heights in the spaces between the crown polygons. In the space, there might be dead trees or smaller trees that newly start to grow about 3.2 meter high. Also there are new settlements of the ferns about one meter high as presented in the histogram of Mangrove 1986. There was little space between crown polygons in the crown polygon images for Mangrove 2002 and 2003. The estimated crown size for Mangrove 2002 and 2003 by the model was bigger than those of the field data, expect of crown heights. The estimated tree density was much lower than that of the field data. Unlike the crown height of Mangrove 1986, those of Mangrove 2002 and 2003 were homogeneous without space between tree crowns. It make difficult to define local minima of each tree crown in the canopy height image. However the model found some spaces between crown groups. Therefore the estimated crown of Mangrove 2002 and 2003 was a polygon of adjoined tree crowns instead of a tree crown. In addition the spatial resolution of canopy height image was critical for delineating tree crown by the model. The LIDAR vector data in this study have nearly 1 m of spacing between spots. The tree crown below 3 m might be not possible to delineate them exactly because the height difference in a tree crown may not be determined. By the way, the general crown volume of Mangrove 2002 and 2003 can be evaluated using crown heights and crown area. This crown volume data would be useful for estimating mangrove population with field data.

5. Conclusions

Airborne LIDAR data provide valuable information about mangrove morphology by delineating crowns and counting mangroves to substitute conventional inventory method by human or as complementary data. An automatic delineating model of mangrove crown was developed for counting and determining size of mangroves using LIDAR data.

For the delineation of mangrove crown, LIDAR surface vector data were acquired from a sensor boarded on a helicopter. LIDAR data were filtered to ground data for DEM and the difference between DEM and non-ground LIDAR data was calculated. Canopy height image was derived from the difference by converting to raster image. The study area was classified to three sectors by the time of mangrove settlement and the tree height using the canopy height image; Mangrove 1986, Mangrove 2002 and Mangrove 2003. The delineation model was developed using the canopy height image and separately applied to three sectors by adjusting thresholds. The model delineated tree crowns and determined crown size and number for Mangrove 1986 with reliable precision because of their larger crown size and bigger variation of crown height. There were unclear mangrove crowns due to their irregular crown forms, multi-tops, holes in the centre, and superposed branches. The smaller and younger mangroves of Mangrove 2002 and 2003 were not properly delineated single crown but a group of mangrove crown due to homogeneous of canopy height and spatial resolution of LIDAR data. However the general mangrove crown volume could be estimated using the canopy height image.

The canopy height image needs being in higher spatial resolution especially for younger mangroves with denser vector data by taking an advanced LIDAR sensor. Using canopy height image in higher spatial resolution, the shapes of smaller mangrove crown could be described more precisely.

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