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Interpretation of Upper-Storey Canopy Area in Subtropical Broadleaved Forests in Okinawa Island Using Laser Scanning Data

(Interpretasi Ruang Kanopi Lapisan Atas Hutan Subtropika Berdaun Lebar di Pulau Okinawa Menggunakan Data Imbasan Laser)

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ABSTRACT

Conventional forest inventory practice took huge of effort, and is time- and cost- consuming. With the aid of remote sensing technology by light detection and ranging (LiDAR), those unbearable factors could be minimized. LiDAR is able to capture forest characteristic information and is well known for estimating forest structure accurately in many studies. Forest monitoring related to forest resource inventory (FRI) becomes more effective by utilizing LiDAR data and it is tremendously useful, especially to distinguish information on density, growth and distribution of trees in a selected area. In this study, LiDAR data was utilized aimed to delineate crown cover and estimate upper-storey canopy area in Yambaru Forest using object-based segmentation and classification techniques. Agreement between field survey and LiDAR data analysis showed that only 33.7% of upper- storey canopy area was successfully delineated. The low accuracy level of canopy detection in Yambaru Forest area was expected mainly due to tree structure, density and topographic condition.

Keywords: Canopy area; LiDAR; Okinawa; subtropical forest; upper-storey

ABSTRAK

Amalan inventori hutan secara konvensional memerlukan tenaga kerja, masa dan kos yang tinggi. Dengan bantuan teknologi penderiaan jarak jauh seperti imej LiDAR, faktor-faktor tersebut dapat diminimumkan. LiDAR mampu mencerap maklumat berkenaan ciri hutan dan banyak kajian telah membuktikan teknologi ini dapat menganggarkan struktur hutan dengan tepat. Pemantauan hutan berhubung inventori sumber hutan (FRI) menjadi lebih efektif dengan penggunaan data LiDAR dan ia sangat bermanfaat terutama bagi membezakan informasi kepadatan hutan, pertumbuhan dan taburan pohon di kawasan terpilih. Dalam kajian ini, data LiDAR digunakan untuk menganggarkan lapisan atas kanopi pokok dengan menggunakan teknik pengelasan dan segmentasi berdasarkan objek. Keputusan kajian menunjukkan hanya 33.7% ruang kanopi lapisan atas pokok dapat dikesan hasil perbandingan antara analisis data LiDAR dengan data daripada tinjauan lapangan. Aras ketepatan yang rendah dalam mengesan kanopi di kawasan Hutan Yambaru menggunakan data LiDAR dijangka disebabkan oleh faktor-faktor pengaruh seperti struktur pokok, kepadatan dan keadaan topografi di kawasan tersebut.

Kata kunci: Hutan subtropikal; keluasan kanopi; lapisan atas; LiDAR; Okinawa

INTRODUCTION

The distribution of subtropical forests in Japan is limited from south-west of Kagoshima in Ryukyu chain islands to southward of Taiwan including Amami, Iriomote and Okinawa Island (Sasse 1998). The forest spreads between 20º and 25ºN with rainfall above 1200 mm and mean annual temperature between 21 and 25ºC. In Okinawa main island, the subtropical evergreen forests are notably concentrated in the most northern region known as Yambaru. This area consists of diverse flora and fauna (Ito 2003) including IUCN Red List Threaten Species such as Okinawa spiny rat (*Tokudaia osimensis*), Okinawa woodpecker (*Dendrocopos noguchii*), Ishikawa frog (*Rana ishikawae*) and Okinawa rail (*Gallirallus okinawae*) (IUCN 2012). The natural vegetation predominantly ranges from subtropical to tropical broadleaved forest, which constitutes about 88% of the forest area and the remaining percentage belongs to native pine species (Shinohara et al. 1996). *Castanopsis sieboldii* (Japanese name: Itaji) was found as the dominant species in this area. The forest consists of high species diversity and relatively low canopy height with a large number of small diameter trees (Xu et al. 2008). In certain cases, the maximum tree height and diameter-at-breast-height (DBH) can reach up to 20 and 80 cm, respectively, depending on the topographic, soil and forest condition.

Yambaru forest offers remarkable forest services mainly for timber production, education, water supply, conservation and recreational purposes. The forest is notably treasurable and the importance of this area for endangered flora and fauna species has been a great issue for various stakeholders who urged for rapid protection and conservation in certain forest areas. In 2012, Yambaru was registered as one of the nominees for UNESCO world heritage site. Due to this reason, forest assessment and monitoring efforts are currently being conducted by the Forestry Department of Okinawa Prefectural and the Ministry of Environment together with other related agencies (Ryukyu Shimpo 2013).

Monitoring and assessment activities in this area are scheduled once every five years. The assessment aims to measure physical characteristics of trees such as height, DBH, tree condition and plot location for tree growth and timber monitoring. At present, conventional forest inventory method known as Forest Resource Inventory (FRI) is a practical method used by the Forestry Department whereby in an establishment of 20×20 m plot, physical characteristics of the trees were measured and recorded. FRI took great effort and is cost and time consuming, particularly for plots located at a very complex vegetation and rugged terrain condition.

The topographical condition in Yambaru forest is an important factor that has significant influence on vegetation structure, tree distribution and pattern of disturbance such as landslides. Hence, this is also a main factor in creating hydrological gradient and influencing nutrient availability in Yambaru Forest (Enoki 2003). Rough terrain limits course of forest roads, while uncertain climate condition limits FRI work to be carried out throughout the year. Hence, the existence of poisonous snake called Okinawa Habu (*Trimeresurus flavoviridis*) is another challenge for technical staffs to enter the forest area.

Natural disturbance is another possible influence on the forest. Between August and October, frequent typhoons hit the island with heavy rainfall and strong wind, which cause severe erosion and forest damages. If this event occurs, FRI work needs to be suspended and it is unendurable by means of labor, time and cost consuming. Due to these factors, utilization of remote sensing and geographical information system (GIS) technologies is essential to overcome and reduce such difficulties including issues regarding FRI practice. Light detection and ranging (LiDAR) for example, provides wealth of information on surface elevation and is able to explain forest structure even in dense forest where photogrammetry technique fails. LiDAR operates with an active sensor to captured three-dimensional (3D) surface data and it is less weather dependent. Therefore by utilization of LiDAR data, an alternative solution for obstacles and limitations to access forests area from inaccessible and remote places can be resolved. The applicability and effectiveness of LiDAR in the forestry sector becomes prominent as it shows reliable and accurate estimation of different types of forests. For example, Fukushi et al. (2008) managed to achieve high level of accuracy of individual crown detection using LiDAR data, where 85.6% of tree crown from larch species was successfully detected in central Japan.

Extensive academic literatures have been published on the grandeur of LiDAR applications in forest and forestry sectors, especially in detecting and estimating forest resources in a shorter time, at a moderate cost and labor (Dees et al. 2012; Suarez et al. 2009). However, little remain unknown about this application on subtropical forest with complex landform like Okinawa Island. Therefore, by adapting difficulties and limitation of conventional FRI practices, this study attempted to show the potential use of LiDAR data to estimate tree crown areas based on upper-story canopy delineation of evergreen broadleaved tree in Yambaru and to further discuss constraints and limitations of LiDAR application on subtropical forest in Okinawa Island.

STUDY AREA

This study was conducted in the northern part of Okinawa Island, southwest of Japan. It belongs to the subtropical climate with annual rainfall of 2800 mm and annual average air temperature of 22.3ºC. Frequent typhoons occur in summer season between August and October every year, which is the main catastrophic event that influences forest structure. The study area was centered at 128º 12’ E, 26º 45’N in a small area in Compartment 79 of Yambaru forest (Figure 1). The forest belongs to Okinawa Prefectural where *Castanopsis sieboldii* is found as the dominant species with average DBH and tree height of 13.6 cm and 8.2 m, respectively. In general, the topographical condition in the 0.8 ha of test site area was in a steep and rugged terrain with an elevation level of 176 m.

MATERIALS AND METHODS

DATA COLLECTION

Raw LiDAR data observed by an airborne laser scanner (ALS) was the main data source for this study. It was in the form of point clouds data, which contained elevation points with x, y and z coordinate values, return pulse value, signal strength and intensity as well as GPS time. The data were obtained in April 2011 and flight characteristics are displayed in Table 1.

Digital Surface Model (DSM) and Digital Terrain Model (DTM) were derived by interpolation of point clouds information produced from LiDAR data. DSM contains elevation of all natural terrain features, vegetation and manmade features such as buildings and roads, while DTM contains elevations of land surface, excluding all manmade features like building and vegetation. DSM was created from the pulse of the first return and DTM was generated by interpolation of TIN data created from the pulse of the last return of ALS. Both elevation data were resampled as 0.5 m mesh products and preprocessing by filtering and smoothing was done to remove noises. The Digital Canopy Height Model (DCHM), which indicates the height of ground structure and trees was computed by subtracting DTM from DSM.

Besides LiDAR data, ortho-photo image captured in October 2011 with a resolution of 0.5 m on the Japanese Plane Coordinate System with JGD 2000 was also acquired as an additional reference data after segmentation process. In addition, field data collection was also done in ten plots that were spread in compartment 79. The measurements

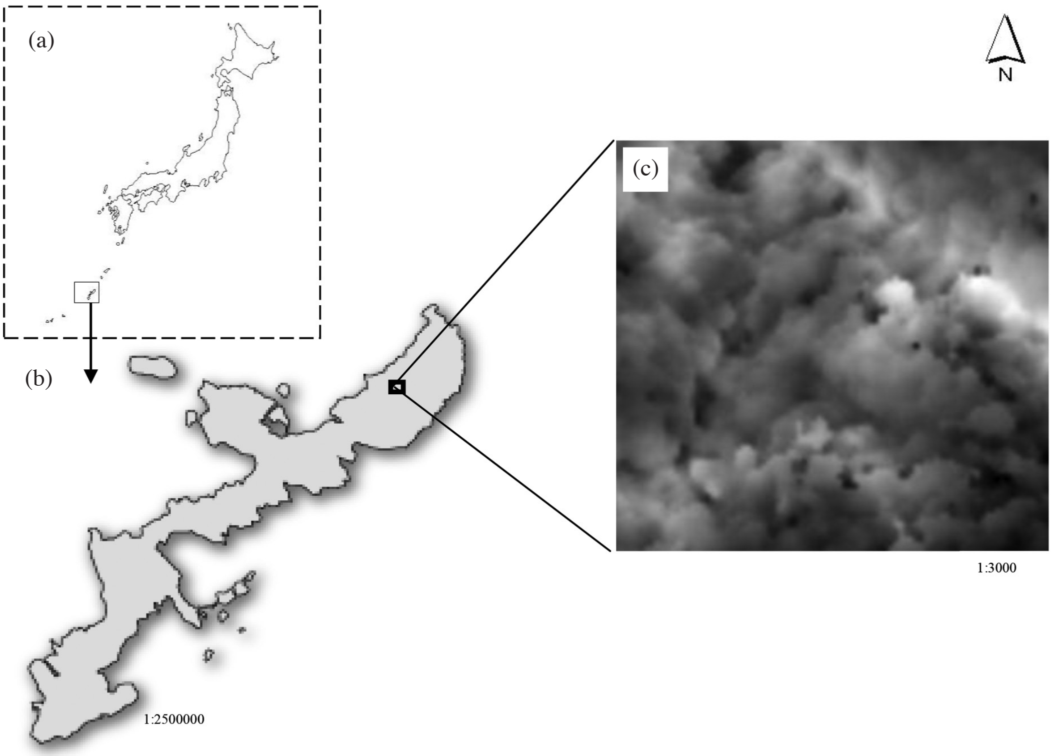

FIGURE 1. Map illustrates the location of (a) Okinawa Island of Japan (b) Okinawa Main Island and (c) location of study area in compartment 79 of Yambaru forest (image of LiDAR)

TABLE 1. Flight characteristics of LiDAR observed by Airborne Laser Scanner

Acquisition	25 April 2011
Instrument	ALTM 3100
Flight altitude	1100 m
Wavelength	1064 nm
Scan frequency	39 Hz
Scan angle	±20°
X and Y accuracy	55 cm
Z accuracy	15 cm

taken in each plot were tree DBH with >4 cm (at 1.3 m) using DBH tape, tree height (m) by measuring pole and the central position of each plot using hand-held GPS device model GARMIN 60CSx. The plot dimension was 20 × 20 m and the work was undertaken from October 2011 to November 2012. Plots were located in various topographical conditions with elevation and slope up to 323 m and 75 degree, respectively.

DATA PROCESSING AND ANALYSIS

In general, the process to delineate canopy from DCHM data took two main steps: Data preparation; and segmentation and classification (Figure 2). During data preparation stage, smoothing and edge detection algorithms were applied to reduce noises and enhance pixel edges in an image. It ensured canopy delineation and the rest of procedures to run well with less noise influence. Gaussian kernel 3×3 was chosen for image filtering, while Lee sigma edge extraction was performed to allow easy interpretation of tree boundaries and detection of tree canopy edges.

Next, the segmentation process was done to merge pixel into identical feature of image objects. Multi resolution segmentation algorithm was carried out on DCHM data and ortho-photo image was overlaid as a visual reference. The rule of thumb was homogeny pixels would produce larger objects, while heterogenic pixels would create small regions of segmented objects based on the chosen scale parameter (Baatz et al. 2001). There are five parameters that users can set using e-Cognition Developer7 software (Table 2). A scale parameter refers to an arbitrary value defined by users, whereby a larger value will result in larger image objects and vice versa. Defining the weight of the shape and compactness criterion were crucial parts in probing the best scale parameter for canopy delineation. Greater shape value indicates less influence of image color (spectral similarity), which will result in less spectral homogeneity effect in object generation. User can determine another two sub-criteria namely compactness and smoothness factors under shape criteria. Objects can become fringed (compact) or smooth based on user selections. Both criterion values ranged from 0 to 0.9. It was a trial and error process in defining the best scale parameter to satisfy users and to suit the result to the real world. However, coefficient of variation derived from the ratio of standard deviation and mean from a number of segmented features will show the best result. Low

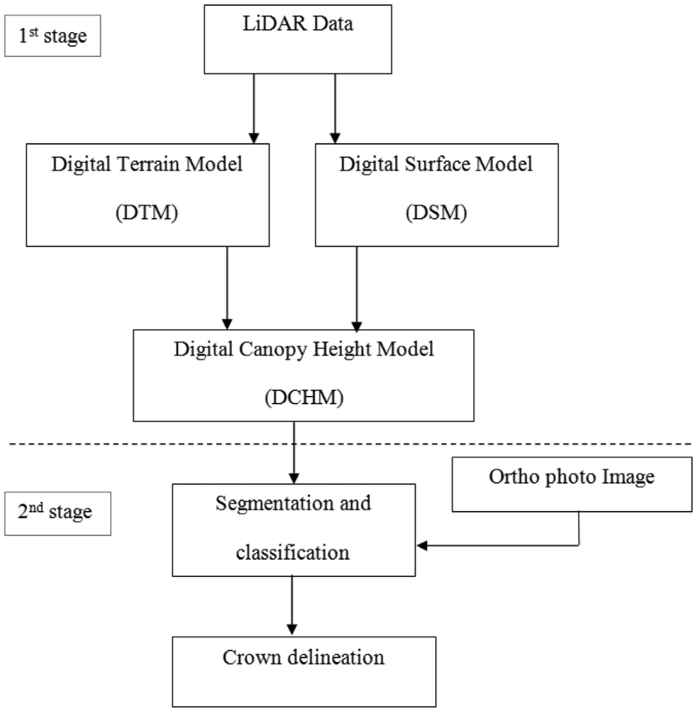

FIGURE 2. Workflow and data processes of canopy delineation from LiDAR data

TABLE 2. Scale parameters and criteria settings for six cases tested

Case number	Scale parameter	Shape	Color	Smoothness	Compactness
1	20	0.5	0.5	0.5	0.5
2	10	0.5	0.5	0.5	0.5
3	10	0.4	0.6	0.5	0.5
4	5	0.5	0.5	0.5	0.5
5	5	0.6	0.4	0.4	0.6
6	5	0.7	0.3	0.5	0.5

coefficient of variation means data has low variability and high stability.

Segmented image objects were classified into canopy and gaps classes. Objects with DCHM value less than a threshold value 5 m was classified as gaps, while other objects were assigned as tree crown. The threshold value was derived from several trial and error steps to eliminate errors produced by the filtering process. After eliminating gaps and unwanted effects, the tree height in each polygon was assigned based on maximum value using local-maxima algorithm function. Next, each crown was classified into three groups or classes namely high (height >15 m), medium (between 10 and 15 m) and low (<10 m) classes. This is to distinguish the distribution of trees based on its height (Figure 3). Classified canopy were exported as a shape file (point and polygon) for further analysis in ArcGIS software by ESRI version 9.3. Statistical analysis was computed to examine LiDAR data and field data collection as well as agreement between estimation of canopy cover by segmentation process of LiDAR data and field data collection on ten sample plots.

RESULTS AND DISCUSSION

All trial cases were compared and case number 6 was selected for further analysis as it has a lower coefficient of variation. A total of 1130 segmented objects were successfully delineated with the height and crown areas are summarized in Table 3. Based on field survey, a total of 1673 trees were found in all the plots. In general, the average tree height and DBH were at 7.2 m and 9.0 cm, respectively. Table 4 lists five out of 47 major species

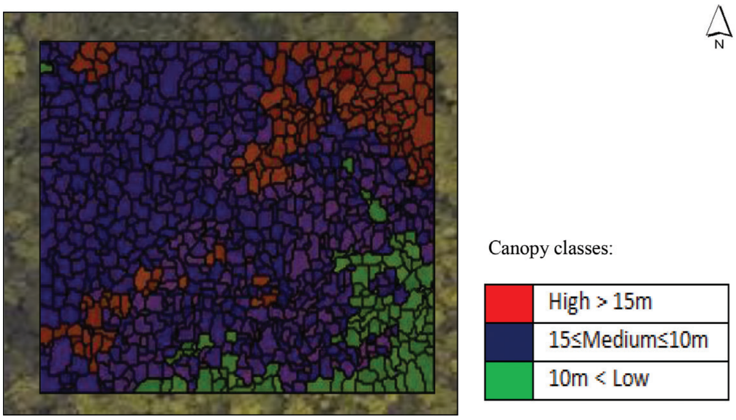

FIGURE 3. Canopy classification based on tree height from object-based segmentation result, overlay with ortho-photo imagery as reference

TABLE 3. Segmentation result for case number six

Variable	Min	Max	Mean±SD
Tree height (m)	8.1	21.3	13.9±2.4
Crown area (m^2)	0.75	39.7	7.3±4.8

TABLE 4. Dominant tree species found in surveyed plots

Species	No. of trees per ha	Mean DBH (cm)	Mean height (m)
Castanopsis sieboldii	1008	13.6	8.2
Daphniphyllum glaucescens	543	7.8	6.4
Myrsine segunii	475	5.9	6.0
Syzigium buxifolium	335	5.4	5.3
Elaeocarpus japonicas	273	6.5	5.9

recorded where *Castanopsis sieboldii* was found as the dominant species with mean DBH and height of 13.6 cm and 8.2 m, respectively. Based on Shinzato et al. (1986), most of these species are located at top layer of the forest and trees in the upper layers mostly range from 39 to 41 years in age. On the other hand, shrubs were mostly occurred at the lower slope of the forest.

The agreement between field data and LiDAR analysis showed that only 33.7% of the upper canopy was successfully delineated. The result was not as expected, since the capability of LiDAR is well known to detect individual trees with a greater percentage of accuracy (Chen et al. 2006; Fukushi et al. 2008; Persson et al. 2004). However, this is the main point of this paper where we would like to highlight the limitations or constraints of utilizing LiDAR data in a very complex topography and vegetation conditions of the subtropical forest in Okinawa Island.

There were studies that successfully achieved more than 80% level of accuracy in detecting individual tree using LiDAR data, particularly in plantation and coniferous forest (Fukushi et al. 2008; Wang et al. 2004). In other cases, Persson et al. (2004) discovered 71% of real tree numbers of spruce and pine in Sweden, while Chen et al. (2006) achieved 64.1% of absolute accuracy when isolating tree canopy in Savanna area.

Not all delineation process could produce highly accurate canopy detection. In mixed broadleaved forest of Yambaru, species ecology is the main reason of the unsuccessful of detecting canopy cover with high accuracy. *C. sieboldii* is a major broadleaved species dominating Yambaru Forest and it is characterized by natural sprouting regeneration (Shinzato et al. 2000). 84% of this species sprouted from main stumps and this event caused trees to develop in multiple branches rather than a single stand (Wu et al. 2001). Multi-stem trees have overlapped canopies, but it will be recognized as a single canopy by LiDAR. In addition, tree density is also another factor trigging crown overlapped. Vegetation in this area was considerably dense (4500 per ha) and trees were found standing close to each other. In our analysis, most overlapped canopies were segmented as a large single stem, which caused detection of large crown area during the segmentation process.

Topography is another issue influencing canopy delineation in Yambaru Forest. In the test area, the elevation arrays were from 115 to 176 m. Even though it was located on rugged terrain, elevation did not vary excessively. Neighboring trees grew at the same slope and elevation competing for the same light and nutrient. Availability of energy resulted in the coexistence of more tree species, hence increasing species richness and species equitability (Xu et al. 2008). When the competition rate is high in dense vegetation area, trees may grow about the same height and it will again cause canopy overlapping. This condition indeed influenced several trees to be grouped into a single canopy in the segmentation process.

Subtropical evergreen forest of Yambaru consists of complex environment, rich vegetation, rugged terrain, and different soil types, where not all variables can be measured accurately by LiDAR. The agreement between segmentation and field data was unfortunate and our case study yielded lower accuracy level compared with other studies on plantation or coniferous forest. However, a significant finding from Pitkanen et al. (2004) was reflected in our case study, where he showed that even though 70% of dominant trees could be distinguished perfectly, only 40% of individual crown delineation on heterogeneous forest could be detected. Trees with height less than 40-60% from the dominant species were concealed due to indeterminate tree condition (Korpela 2004). Bias towards larger trees, underestimation of understory tree, overestimation of individual canopy and merging of small tree crowns into a single big tree were the main factors in achieving low precision in canopy detection of heterogeneous forest (Asner et al. 2002). Laser scanning is the most remarkable technology for automated forest inventory and it gives quite accurate estimation of forest structure including crown sizes and tree height (Hyyppa et al. 2001; Imai et al. 2004; Naesset 2004). However, in this study further improvement is needed such as not only utilizing a single LiDAR data, but also integrating other high resolution data (i.e. IKONOS or QUICKBIRD) to enhance the accuracy level as well as applying improved technical methods for more reliable outcome.

Conclusion

Subtropical evergreen forest of Yambaru consists of complex vegetation and topographic conditions. Only 33.7% of the canopy was successfully delineated based on the agreement between field data and segmentation analysis by LiDAR data. In Yambaru, it was impossible to attain highly accurate canopy delineation due to different tree structures, densities and topographic conditions of the area. Trees with multiple stems and grow close to each other lead to canopy overlapping. In the segmentation process, these events were identified as having the same canopy cover with a large canopy area. These are the main factors that dropped the accuracy level for canopy delineation. Classification of segmented crown cover was done to distinguish crown distribution based on tree height. Three groups of crown distribution were classified, namely high (>15 m), medium (10-15 m) and low (<10 m) groups. Ideally, LiDAR technology can measure crown area, tree height and forest stand structure accurately. However, in subtropical forest many influencing factors such as terrain condition, species ecology reasons and vegetation structure as well as technical methods to delineate individual tree canopy need to be considered in order to enhance the result accuracy. This study is expected to be a stepping stone for future research and if tree crown delineation by LiDAR data could achieve reliable and good accuracy estimation, it would suggest that LiDAR is an alternative and effective approach for FRI practice, which indirectly helps in forest management and monitoring system in Okinawa Island.

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