MERCHANTABLE VOLUME ESTIMATION FOR MANGROVE STAND USING HIGH RESOLUTION SATELLITE IMAGE

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KEYWORDS: Tree volume, edge detection, segmentation, DBH

ABSTRACT: One of important aspect of mangrove forest management is an estimation of merchantable tree volume. It is a good indicator of the yield of a given stand. Various approaches have been used to calculate merchantable tree volume. This study utilized high resolution satellite images together with edge detection and segmentation methods to identify individual tree and measure tree height and crown area precisely. In addition, multi-source forest inventory techniques was applied to estimate merchantable volume characteristics in Matang Mangrove Forest Reserve (MMFR), Perak, Malaysia. The merchantable volume from national forest inventory was used as reference data for satellite image interpretation. The estimation produced by high resolution satellite image interpretation were tested by cross-validation between output model and ground data. The results show that the correlation (r^2) between Diameter at Breast Height (DBH) and tree canopy is 0.85, while the total stand volume was estimated at 119.03 m^3/ha. It indicates that the method for producing merchantable stand volume and high satellite image interpretation is feasible.

1. INTRODUCTION

Satellite imagery plays an important role in giving additional information of forest resource to compliment the fieldwork and ground surveys. It is generally acknowledged that digital remote sensing has the potential to provide information related to forest inventory, thus reducing the amount of field work involved in such tasks (Zaharul & Graciela, 2003). Khali, 2001 in his study concluded that forest management can be improve through the use of current technologies including remote sensing, Geographic Information System (GIS) and Global Positioning System (GPS). Therefore, this study focussed on remote sensing techniques to delineate mangrove tree crown to estimate merchantable volume of mangrove stand. The techniques used were edge detection and segmentation.

Generally, edge detection is a process to identify the boundary pixels that connect two separate regions, while image segmentation is a process of partitioning an image into homogenous groups based on similarity criteria i.e. digital number and texture. Edge detection and segmentation are fundamental tools in image processing, particularly in the area of feature detection and feature extraction (G.Samuel et al., 2003). Efficient image segmentation is one of the most crucial tasks in automatic image processing (Cheng et al., 2001). Apart from remote sensing, image segmentation has been interpreted differently for different application i.e. machine vision application, medical imaging and in statistical analysis (V. Dey et al., 2010). In remote sensing, it is often viewed as an aid to landscape change detection and land use/cover classification.

There are many methods for edge detection in image segmentation. Among them are Sobel operator methods, Kiresh methods, Laplacian of Gaussian methods, Canny methods, Roberts methods and Prewitt methods. But most of them may be grouped into either Gradient and Laplacian, Derivative approach and Pattern Fitting approach or Search based and Zero-crossing based (Kaylan et al., 2015). In term of software, there exists multiple software available with edge detection and segmentation function namely eCognition, Erdas Imagine, *Info*Pack, CAESAR and SPRING.

This study applied a two-staged approach with Laplacian of Gaussian edge detection followed by marker-controlled watershed segmentation. Erdas Imagine v2013 has been used to perform the image processing methods. The use of high resolution satellite imagery can accurately identify individual treetops and then to define the region in the vicinity of the treetop that encompasses the crown extent. Treetops are assumed to be represented by local radiation maxima and also located near the centre of the tree crown. As result, a marker image was created from the derived treetop to guide a watershed segmentation to further differentiate touching and clumping trees and a produce a segmented image comprised of individual tree crowns.

Watershed is one of the segmentation model that exists in satellite image processing. It is a mathematical morphological approach and derives its analogy from a real life flood situation (Beucher, 1992). The application of this model on remote sensing imageries is relatively recent than other models (V. Dey et al., 2010).

1.1 STUDY AREA

Matang Mangrove Forest Reserve (MMFR) is the biggest mangrove forest in Peninsular Malaysia covering a total area of 40,500 ha (Roslan & Nik Mohd Shah, 2013). It has been acknowledged as one of the best-managed mangrove in Malaysia. It is an exemplary sustainably managed mangrove forest and able to successfully balance the continuing demand for wood resources and preservation of the mangrove ecosystem. MMFR is the earliest forest to be gazetted as Permanent Forest Reserve, and subsequently managed on a systematic and sustainable approach since 1904 (Kamaruzaman et al., 2008). Timber from MMFR is primarily being used for manufacturing of charcoal which almost 80% of the total annual amount of charcoal produced was exported to Japan (Roslan & Nik Mohd Shah, 2013).

Images with the spatial resolution of 2.5m taken from SPOT-5 dated 8th of October 2013 (Figure 1a) was used to map the MMFR, while Pleaides imagery dated on 19th of April 2014 with a spatial resolution of 0.5m to estimate the merchantable volume of mangrove stand.

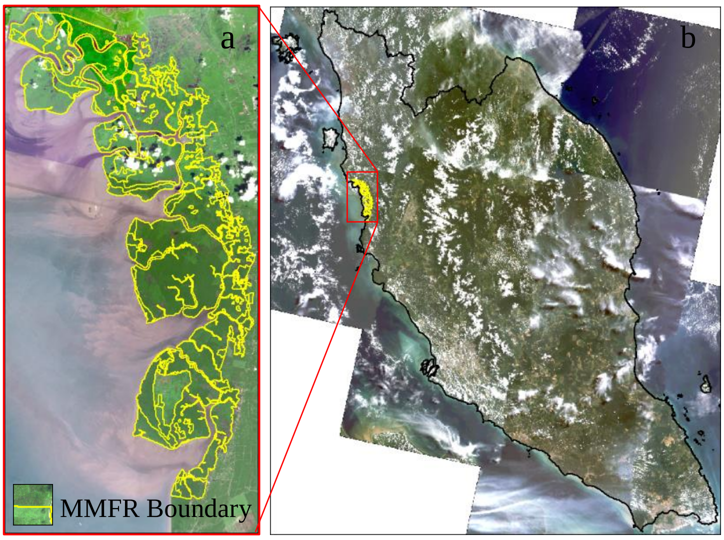


Figure 1: MMFR Boundary (a) and location of MMFR on west Malaysia (b)

1.2 OBJECTIVES

This study focuses on the application of remote sensing technologies for mangrove forest management. The aim of this study was to utilized high resolution satellite images together with edge detection and segmentation methods to identify individual tree and measure tree height and crown area precisely. Ultimately, the results was used as an input to estimate merchantable volume for mangrove stand. The traditional methods still prevailing in MMFR are labour intensive and time consuming.

2. MATERIALS AND METHODS

The study area was stratified base on feature on SPOT-5 imagery. Ten plots, each measuring 100 x 100 m^2 were established using stratified random sampling into different mangrove forest stratification. Stratification was carried out at two level which are at management zone level and at operational planning level. Both levels information were gathered from current MMFR working plan. Pan-sharpened Pleaides imageries of the plots area was used for further image processing.

Figure 2 is the Pleaides imageries of the plots at 1:1500 scale, while framework of this study is presented in Figure 3. It can be divided to three stages. The first stage utilizes an edge detection method to obtain initial closed objects (tree crown boundaries). While the second stage can be separated into two parts; marker-controlled watershed segmentation and treetop marker selection. Final stage was combining of second stage outputs to identify individual tree crown. Upon completion, GIS part took place from vector editing to final analysis which was calculations to estimate merchantable volume for mangrove stand.

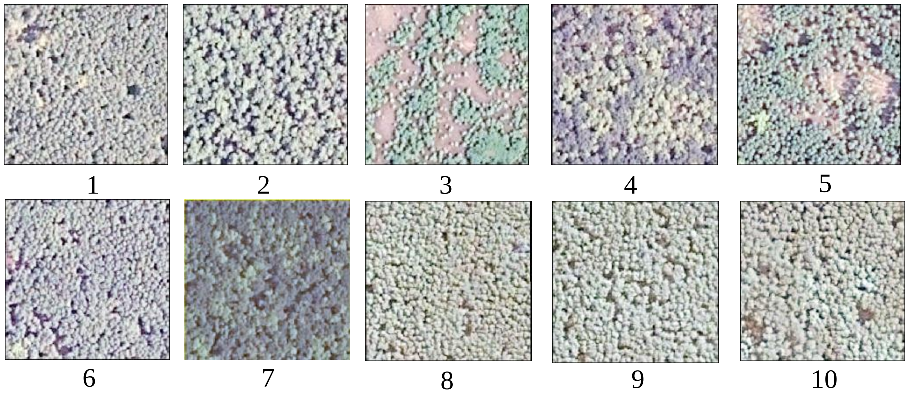


Figure 2: Pleaides imageries of the study plots

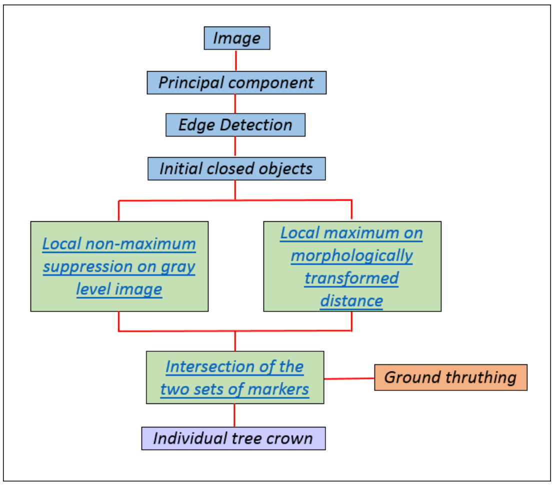


Figure 3: Framework of mangrove tree crown delineation

Before performing the edge detection and segmentation technique, the Pleaides images need to be pre-processed including radiometric and geometric corrections. Pre-processing of the various remote sensing data is important (Louis et al., 2001). Indeed, the quality of the pre-processing contributes substantially to the accuracy of final image processing. Before ready to be segmented through edge detection, the corrected images were converted to a single-band image using Principal Component Analysis (PCA). PCA transforms a set of image into a new set of image (components) with as little correlation between components as possible.

Edge detection was perform to PCA images. It contains three steps namely filtering, enhancement and detection. Filtering function is to reduce noise results in a loss of edge strength. Common types of noise are salt and pepper noise, impulse noise and Gaussian noise. Enhancement emphasizes pixels where there is a significant change in local intensity values and is usually performed by computing the gradient magnitude. Edge detection methods can be used to derive the initial boundary of the tree crown, then the non-tree area can be mask out. Tree crown objects can be retained for further segmentation and analysis.

Laplacian of the Gaussian (LOG) operator has been chosen as edge detection method. It can be divided into two steps. The first step, Gaussian smoothing (convolution) is applied to the image to remove noise as well as intensity variation due to the tree's internal structure. A second step is to find the zero of the second derivative of the smoothed image. In the final edge-detection step the dark background was masked out and the remaining edge pixels were labelled using an eight-connectivity scheme to generate a series of closed contours. However, to obtain the final individual tree crowns, further segmentation of these contours is needed (Le Wang et al., 2004).

Next steps performed were local non-maximum suppression method and local maximum-distance method. Both steps were done to obtain two set of treetop. Spatially, treetop is located at or near the centre of the tree crown when it was viewed from a near-nadir perspective. A treetop that was identified by these steps was labelled as marker. Final treetop markers were determined by integrating the results from local non-maximum suppression method and local maximum-distance method. These treetop markers then served as guides for the watershed segmentation so that all the individual tree crowns could be delineated. The segmentation results were converted into vector format (ArcMap shapefile) for the further analysis.

2.1 GROUND THRUTHING

The main objective of ground thruthing is to verify the information extracted from satellite image analysis. The study area was visited four times, five days each between April 2014 and September 2015. Stratified random of point sampling was carried out for this purpose. A total of 400 sampling trees (40 trees each plot) were established among the ten plots. The parameter recorded were mangrove tree species, DBH, tree height and tree crown diameter. DBH was measured using diameter tape that displays the diameter measurement when wrapped around the circumference of a tree. Ground-measured crown diameter for each tree obtained by taking the arithmetic mean of the horizontal crown diameter measured on the north-south axis and again on the east-west axis. Figure 4 is how tree crown diameter was measured. GPS was used to record the coordinate reading of the sampling trees, so that they can be compared with image analysis data. All those information were used as input in estimation of mangrove stand volume.

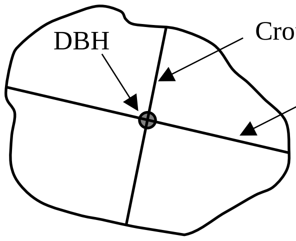
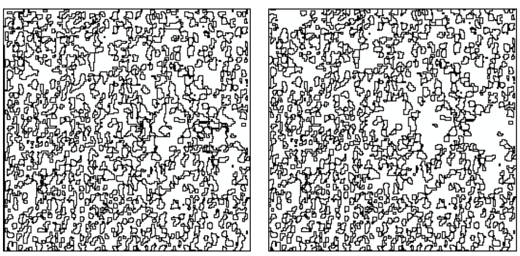


Figure 4: Ground-measured tree crown diameter

2.2 MERCHANTABLE VOLUME ESTIMATION

Volume is the most widely used measure of wood quantity and is usually estimated for the assessment of economic value or commercial utilization potential (www.fao.org). Merchantable volume refers to part of a tree that can be manufactured into a saleable product. It is closely related to merchantable height of a tree which is the length of usable tree and is measured from stump height to a cut-off point in the top of the tree. The general procedure in volume estimation of a tree is the establishment of a mathematical model where the independent variables can be estimated directly from satellite imagery (FAO, 1994). Tree height, tree crown and stand density are among the parameters used to estimate merchantable volume.

In this part, the converted vector from segmentation methods were used to estimate mangrove tree volume. The function to do raster-vector conversion was to make sure that the data can be edited/updated in GIS environment. The raw result from image analysis produced too many polygon which should represent tree crown each. Most of them were very small in size. Hence, the vector need to be generalize, where some polygon were merge to the adjacent reliable polygon and some were deleted. Generalize command on the advanced editing toolbar in ArcMap v10.1.3 was used to accomplish this editing. This generalization process used enhanced Pleaides image as reference. Figure 5 is an example of tree crown vector.



a b

Figure 5: Raw vector (a) and edited vector (b)

Once editing/updating were completed, tree crown diameter for each individual mangrove tree was counted base on input from attribute table of the vector data. Figure 6 is the example of how input from attribute table play its role in this step. Tree crown diameter was counted using following equation:

$$\text{Tree crown} = \sqrt{[(4A) / (\prod)]}$$

Where A = *area of vector polygon (m), and* $\prod$ = 3.142

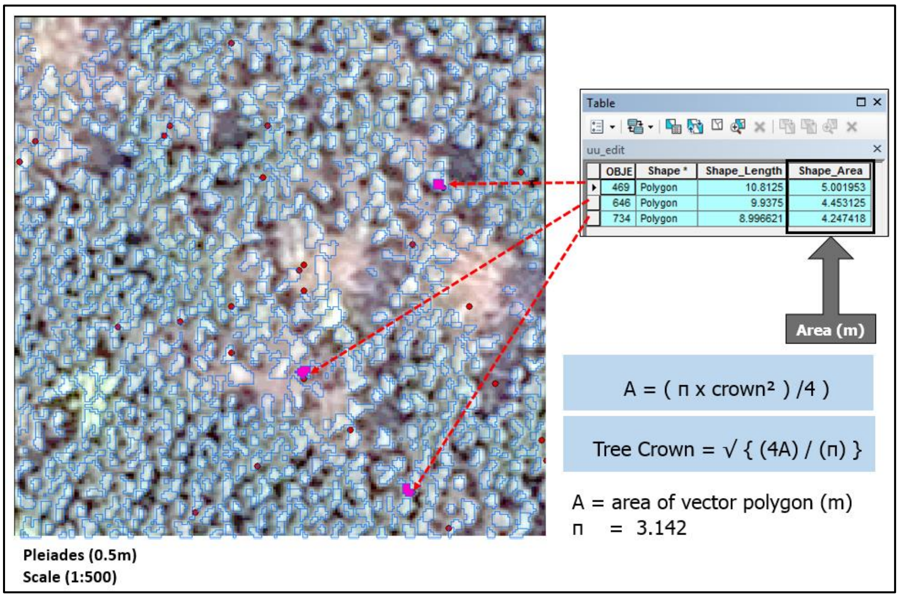


Figure 6: Edited vector overlay on Pleiades image

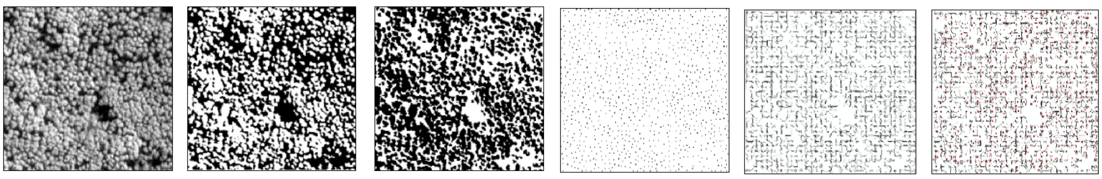
To see the relationship between DBH and tree crown diameter, linear regression model was developed. Linear regression is the most basic and commonly used predictive analysis. It was used to describe data and to explain the relationship between one dependent variable and one or more independent variables (www.statisticssolution.com). In this study, dependent variable was DBH while crown diameter was independent variables. DBH reading for individual tree was calculated based on the equation generated from the regression. Merchantable tree volume was calculated using the following formula (FAO, 1973):

$$V = 0.8602 - (0.03872 \times DBH) + (0.0013164 \times DBH^2)$$

Where DBH = DBH reading generated from image analysis

3. RESULTS AND DISCUSSION

Figure 7 is the image processing result for plot number 10. A is single-band image generated from PCA. B and C are result of two stages edge detection methods. D is mangrove treetop generated from treetop marker selection. E is tree canopy vector while F is overlay between treetop and canopy vector. From the result and other plot results, it can be concluded that, accuracy of the image analysis is dependent on human factor. Enhancement technique for example, knowledge and experience of the personnel who handle the technique is crucial. In addition to this, image enhancement can be classified in many ways i.e. contrast enhancement and spatial enhancement. The more knowledge and experience of personnel, the more precise the result. It is similar with watershed segmentation and vector editing/updating. In general, less accurate image processing will affect the vector result, thus effected the final result of this study – merchantable volume of mangrove tree.



A B C D E F

Figure 7: Example results of mangrove tree canopy extraction, where; A = principal component image, B & C = edge detection, D = local maxima, E = tree canopy vector and F = overlay between local maxima with canopy vector.

Figure 8 is the linear regression for this study. The results show that the correlation (r^2) between DBH and tree crown is 0.85 (r = 0.90). This result indicate that, correlation between the two variables is positive and strong. DBH growth is increases almost linearly as crown expansion increases. Tree with less DBH are more likely have small crown diameter.

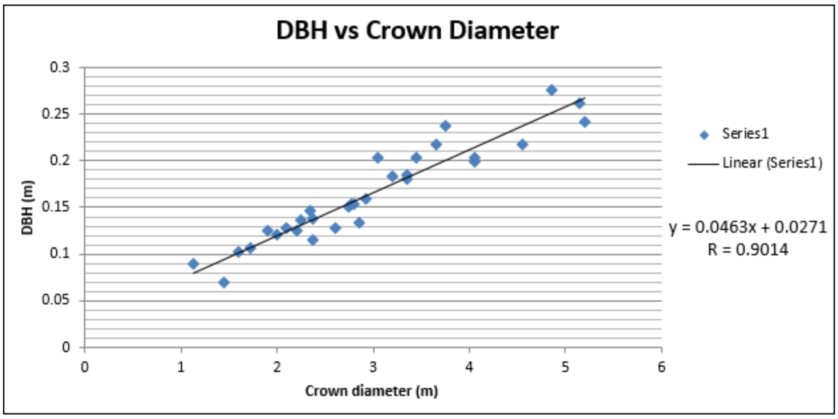


Figure 8: Relationship between between DBH and tree crown diameter

From the equation generated from this regression, DBH reading of the individual tree can be counted. Below is the formula used to count DBH:

$$Y = 0.0463x + 0.0271$$

Where Y = individual tree DBH and X = tree crown diameter

Merchantable volume of mangrove tree for the study area was estimated at 119.03 m^3/ha.

4. CONCLUSION

DBH is not a measurement that can be directly made on satellite imagery. However, a simple linear regression model that predicts DBH from tree crown diameters measured on high resolution satellite image can provide an indirect method of estimation. Predicted DBH can then be used to determine merchantable volume of individual mangrove trees. The equation developed in this study can be useful in predicting crown diameter for mangrove stand volume estimation. On the technical side, the result could serves as guideline in choosing the appropriate tools in the development of management plans for MMFR.

5. ACKNOWLEDGEMENT

This study is a joint project between Malaysian Remote Sensing Agency (ARSM), Forestry Department of Peninsular Malaysia (FDPM) and Perak State Forestry Department (PSFD). ARSM was responsible in term of remote sensing, GIS and ICT technical support. Meanwhile JPSM and PSFD covered forest inventories and technical resource assessment. We would like to express our appreciation to the Director General of ARSM, FDPM and PSFD who have consistently encouraged our effort to finish this study. We acknowledge the financial grants allocated for this study from the Ministry of Science, Technology & Innovation (MOSTI).

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