High Resolution Tree Height and Crown Mapping from Lidar in Malaysia: Preliminary Results

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HIGH RESOLUTION TREE HEIGHT AND CROWN MAPPING FROM LIDAR IN MALAYSIA: PRELIMINARY RESULTS

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ABSTRACT

Lidar measures accurate coordinates of tree on the ground and it provides useful method to estimate the individual tree canopy. Watershed segmentation by means of raster lidar image has potential to demarking the tree crown from the lidar image. Limited studies on lidar application to estimate tree crown in forest of Borneo motivated this study. This study focuses to estimate the tree crown using the watershed segmentation method from the measured lidar data over the Bukit Hitam Forest Reserve in Limbang, Sarawak. The tree crown extraction accuracy is about 5 meter radius and the tree height about 2.5 meter. Some recommendations are highlighted to increase the accuracy in the future.

INTRODUCTION

Remote sensing has been established as one of the primary tools for broad-scale analysis of forest management systems. Metrics relating to forest structure such as tree height, canopy cover and biomass can be estimated using remote sensing. More recently, as sensor technology has improved and expanded to yield higher resolution optical data as well as light detection and ranging (LiDAR) data, it has become increasingly possible to detect individual trees. Lidar measures the time return and determines the distance from the target. Location of each laser returns provides the target coordinates which are achieved from the differential GPS and others orientation parameters. The successful detection and delineation of individual trees is critical in forest science, allowing for studies of individual tree demography and growth modelling, understanding forest ecosystem, and more precise measures of biomass in forests. Lidar contributes a way to measure ground feature biophysical information and recently, this technology has been accepted as the potential measurement tool in which synoptic areal measurement and fast acquisition of measurement records can be achieved.

This study focuses on the application of LiDAR to measure the canopy size and distribution over the large area which is impossible to be accessible. LiDAR is known as the accurate measurement tool to measure the position of the object being sensed by the laser pulse returns. Yet, the irregular terrain topography with quick changes on the slope and elevation for bare earth permits misclassification of the last pulse return. It is therefore mistakenly represented the “true” ground surface height. Similar situation is also evident to the first return that would allow false presentation of the peak of the highest object when dealing with subtle, flat height and multi storey canopy layer. Interpolating the discrete lidar returns with both uncertainties to raster grid may impair the quality of digital elevation model (DEM) and digital surface model (DSM).

The treetop height of CMM helps in locating the potential canopy or crown of the individual tree. The isolation of individual tree with various canopy cover can be extracted by means of segmentation method. To begin, the all non-treetop minima has to be removed by segmentation method called geodesic erosion. Iterative searching for minima imposition is applied within the neighboring pixels. Changing the value of detected minima into smallest valley value is the final step.

Without non-treetop minima, it is easy and ready to apply the marker-controlled watershed segmentation to delineate the entire canopy and thus discriminate the potential individual tree. Watershed segmentation starts by denoting the CMM derived canopy cover as 1 and background as 0 in a binary form. The 1-binary image is then converted into the distance-transformed image (Chen, Q. et al., 2006). The distance-transformed image gives larger value at the centre of the crown and complete treetops is then determined by h-minima transformation that completely suppressed the all minima shallow than h value. The watershed segmentation is anticipated to be fully and iteratively implemented in Matlab. The complete canopy delineation is done and mapping of entire canopy can be undertaken for the whole lidar imagery

The applicability of raster lidar to estimate ITC of tropical forest using watershed segmentation is less documented especially in the Borneo. Forest inventory last updated since 1980s in reserved forest area of Limbang, Sarawak. Conventional method at higher labour and cost intensive. Tree crown & height inventory at the selected points in the designed forest plot. Typical lidar derived forest crown mapping is by using raster-based approach based on Crown Height Model (CHM). Local maxima is determined and watershed segmentation is typically used. Not straightforward in reserved forest canopy with close canopy condition.

Study area

The study area is located in Limbang Division, Sarawak, Malaysia. Bukit Hitam Forest Reserve is about 10 min (5.3 km) from the city of Limbang, Sarawak, Malaysia. Limbang which is the administrative town of Limbang Division in Northern Sarawak is located along the eastern bank of Sungai Limbang. Two Sarawak Nature Reserves located in Limbang division which are the Bukit Hitam Nature Reserves and the Bukit Sembiling Nature Reserves. The Sarawak Government gazette Bukit Hitam Forest Reserve on February 16, 1929 with 364 acres approximately but the latest gazette for Bukit Hitam Forest Reserve with effect from 20th April, 2000 covers 147 ha approximately. Thus, this study reports the preliminary results of accuracy assessment on raster based ITC in Bukit Hitam Forest Reserved of Limbang Sarawak. Bukit Hitam Forest Reserve is Hill Mixed Dipterocarp Forest. It's widespread covering a whopping 87 per cent of Sarawak's natural forest area. The Hill Mixed Dipterocarp Forest are richly diversified and contain the greatest number of economically important trees. These include Meranti (Shorea spp), Kapur (Dryobalanops spp), Keruing (Dipterocarpus spp) and Mersawa (Anisoptera spp) which are highly prized as timber.

Hill Mixed Dipterocarp Forest stand can be seen from the air looking like one huge, uniform emerald canopy. But it is non-homogenous and five canopy layers can be identified. The topmost layer comprises the biggest trees that shoot up to 60 metres in height, standing out singly or in clusters above a continuous second layer that reaches up to 45 m. Below this level is an under-storey of 23 to 30 m tall trees that sometimes intermeshes with the main canopy. Shorter woody tree-lets and shrubs form the fourth strata while the last layer is found on the forest floor which is carpeted with herbs and seedlings. Because of the very nature of forest dynamics, the canopy is very tightly knitted since gaps (resulting from lightning strikes or the falling and decay of over-matured trees) are rapidly filled with sprouts of saplings and seedlings.

Dipterocarps are the dominant tree species of the tropical forests of Southeast Asia. Borneo is the centre of diversity of this important timber-producing tree family, where at least 267 species are recorded (Ashton 2004). The northern part of Borneo is thought to be a refugium for plant species during the last ice-age (Corner 1960; Wong 1998). This is illustrated by the fact that Sarawak in northern Borneo alone harbours 247 or 92% of all species recorded from Borneo. The in-situ study plot covers about 24,0233.55m^2 or 24ha (16.33%) from total area. The standard field procedures by Forestry Department applied in this in-situ study plot. All plots were georeferenced with a geodetic GPS with differential correction capability and in each sample plot, individual trees were measured for DBH (diameter at breast height). Tree crown and height inventory at the selected points in the designed forest plot. Trees selected by random and each trees selected can be access. There's no inventory record found in Bukit Hitam Forest Reserve. Last forest inventory report for Limbang Valley Stateland Forest was recorded on July, 1979. Figure 1 shows the map of study area and the corresponding sampling points. This paper exhibits the preliminary result of accuracy assessment on the estimated tree height and tree crown derived by the lidar data at the 56 selected in-situ sampling points.

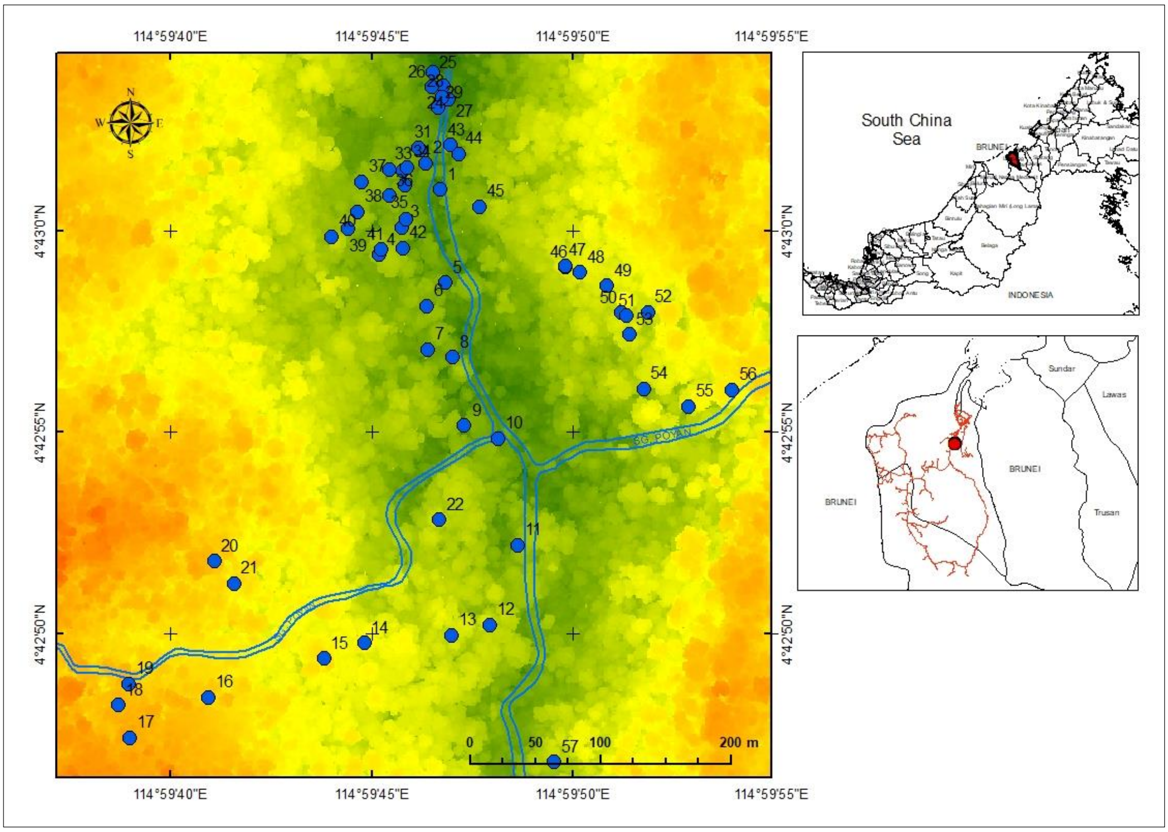


Figure 1. Map of the study area where the terrain elevation and sampling points are presented.

Data and Material

LIDAR systems are varied and flexible, and should be specified to match the intended target area and user requirements. Lidar cloud points were derived by the airborne measurement. Table 1 show specifications Technical description of airborne laser scanning (ALS) data acquisition.

Table 1. Specifications Technical description of airborne laser scanning (ALS) data acquisition.

Type	**Description**
Mode of operation	Airborne – Helicopter AS355
Date of acquisition	17 May 2017
Laser type	Riegl VQ 480i (Discrete pulse)
Laser Pulse Repetition Rate	Up to 550 kHz
Laser scan density (average)	At least 2 points/m2 (based on single-swath coverage)
Laser point measurement (average)	~ 4 points/m2 or greater (single-swath and 4 discrete returns per pulse)
Laser footprint	< 0.4 m
Flight altitude	~1050m (maximum)
Data format	LAS, ECW, GeoTIFF, KMZ, TXT, DWG & DXF
Digital cloud data (las)*	Generic Classified Lidar Point Cloud (Las) Vertical accuracy (0.15 m measured; 0.20m derived) Horizontal accuracy (<0.30 m measured)

Table 1. (Continued)

Type	Description
Digital intensity data	Colour Lidar Intensity Imagery (ecw) – 50 cm (Horizontal) Enhanced CLI – 25 cm (Horizontal)
Others generated data	Lidar accuracy assessment (ground survey) Tile layout (dxf) Data coverage and Void (kmz)
Aerial camera	Phase One 80 M Pixels
Aerial frame overlap	60% along-track & 30% across-track
Aerial digital photo	Frame-based camera system recording, at least 16M pixels (~4000x4000 CCD), 12-bit, GSD around 0.15m.

*Value represents standard error (68% confidence level or 1 sigma) in meters. Measured points are those observed directly & derived points are potential interpolated one from any terrain model.

METHODOLOGY

Methodology of this study is summarised in Figure 2. ArcGIS as the main processing tool provides extraction of watershed segmentation and lidar points generation in vector and raster. The accuracy determines the relative difference between the derived tree height and crown from lidar with the in-situ measurement taken on the site.

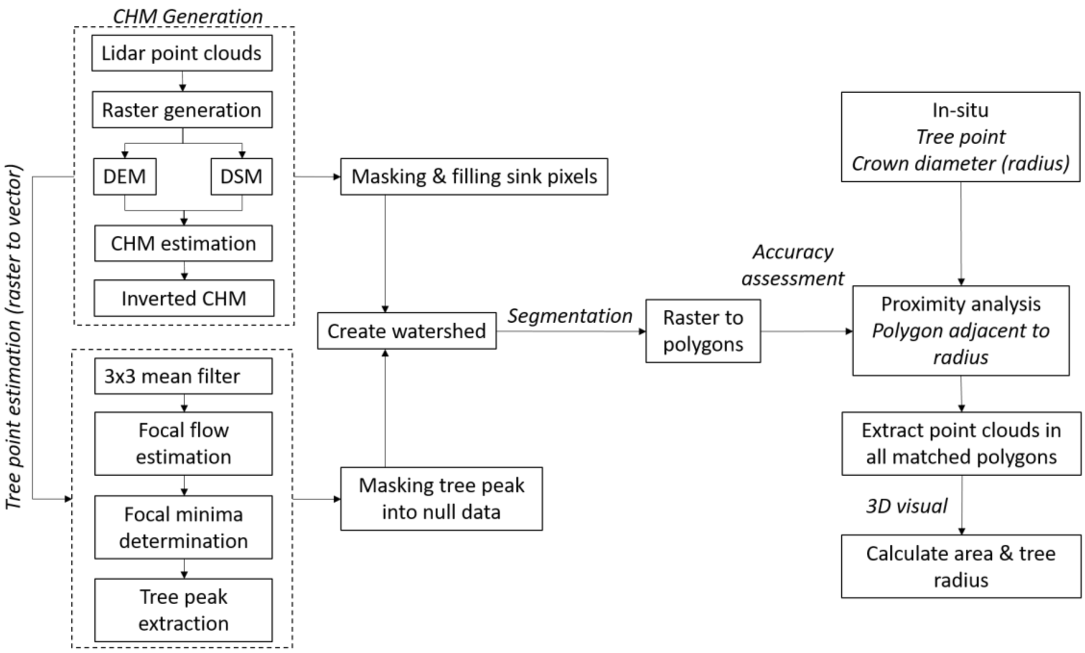


Figure 2. Flowchart of tree crown and tree height estimation from lidar cloud points in which watershed segmentation and in-situ measurement are used.

The Digital Terrain Model (DTM) and Digital Surface Model (DSM) were generated from the lidar cloud points. By subtracting the DTM and DSM at each pixel, the Canopy Height Model (CHM) is estimated and to minimise the extreme different height pixel induced on both images, the subtraction product must be normalised. The Gaussian mean filter at size 3x3 kernel window is applied to reduce some pronounced raster difference particularly at the abrupt height changes and this process generates the inverted and normalised CHM raster data. The CHM basically represents the above ground tree and is commonly used to distinguish between the ground and the above ground tree height.

To begin the watershed segmentation, the tree point must be estimated. The tree point may determine the starting point of the watershed flow. The idea of this process is to determine tree point based on the tree height from the local maxima of the CHM and the tree crown from the result of the watershed region being delineated. The raster CHM image was reversed to convert the maximum height of CHM pixel to become the lowest height in a way to naturally imitate the watershed flow going towards the lowest point on ground. Thus, the local minima is turned to present the tree peak and eventually converted into a vector. The tree peaks was masked out and assigned as null data and later, converted into the raster by filling the sink pixels. This process produces the tree crown at the end. By the flow direction surface generated by focal statitistics and the created watershed polygon, the tree crown and height were extracted.

The high precision handheld GPS provides coordinates of the tree planimetric position and the measuring tape give the crown radius of which the distance from the tree stem to the last edge of crown is determined. Yet the accuracy of 6 meters, at 12 GPS satellite visibility, need to be compensated in the final crown estimation as hypothetically presented in Figure 3 of how the tree crown position was measured on ground. The hypsometer measures the tree height at the same time. The radius, position and height of the tree are used to compare with the in-situ records for validating the results.

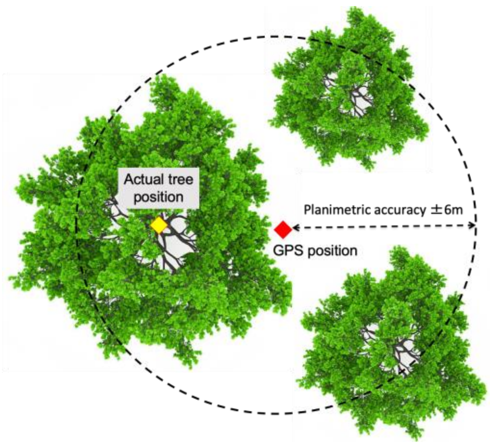


Figure 3. Measurement of the tree position and tree crown radius by GPS with the planimetric accuracy to be considered in the final estimation of tree crown.

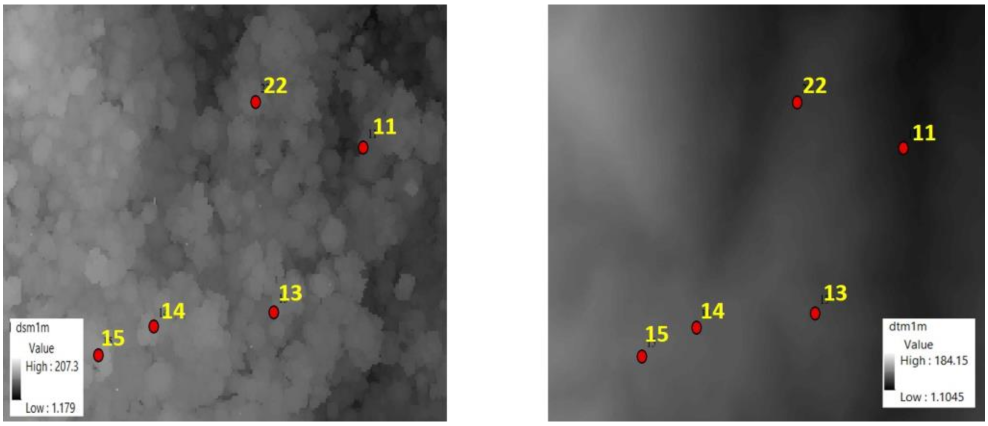
From the given tree position, any nearest segmented polygon is considered as the potential tree crown. All cloud points reside within the polygon are displayed in 3D visualisation in which the height and the crown diameter can be measured accordingly. The difference between in-situ and cloud points measurements for both parameters explains the total accuracy of this study through the root mean square error (RMSE) estimation as follows

$$RMSE = \sqrt{\sum_{i=1}^{N} \frac{(y_g - y_l)^2}{N}} \quad (1)$$

where y_g and y_l is the estimated parameter derived by ground and lidar measurement respectively from the number of samples, N.

Results and Analysis

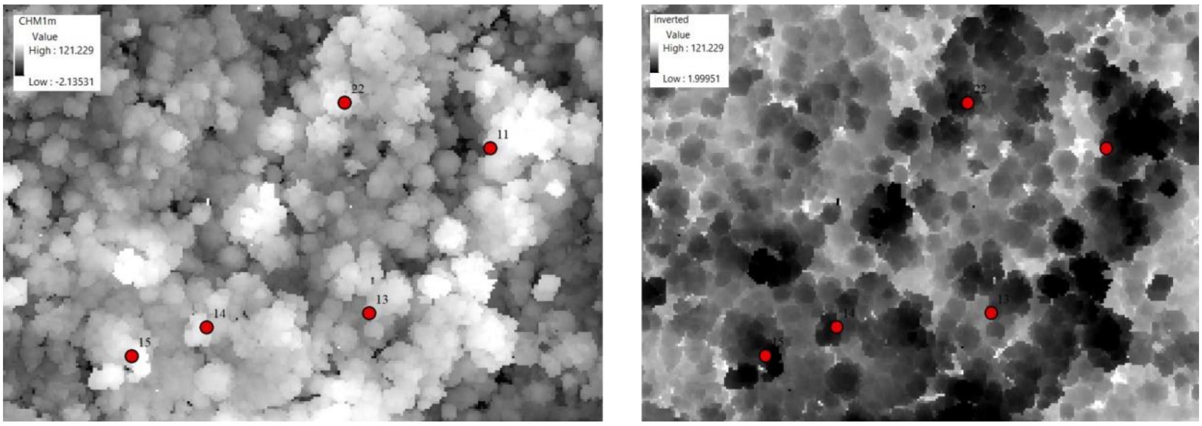
DSM and DTM produced from lidar clouds are shown in Figure 4(a) and (b) with the associates GPS points. Darker pixels present the lowest elevation and thus, the potential tree canopy is presented in bright pixels. The DTM presenting the terrain shows most of the potential tree crown are located at higher terrain elevation.



(a) **(b)**

Figure 4. DSM (a) and DTM (b) generated by the lidar cloud points and position of in-situ samping points are located on the potential tree crown.

Figure 5 shows the results of CHM generated from the DEM and DSM. Figure 5(a) is the normalised CHM and (b) is the inverted CHM. Lowest point of CHM becomes the higher pixel value in the inverted CHM image.

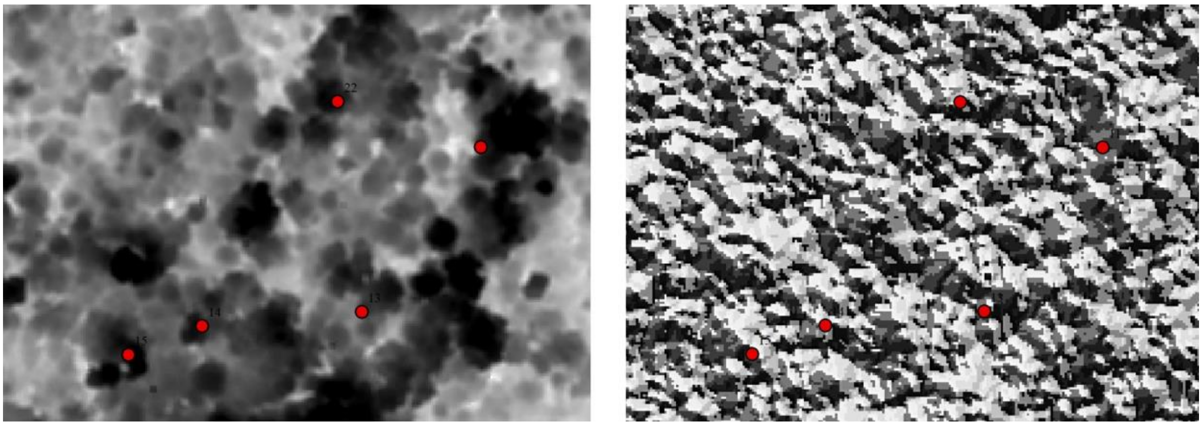


(a) **(b)**

Figure 5. The generated CHM images. (a) Normalised CHM and (b) the inverted CHM showing the tree canopy features and the elevation pixels.

Surface of watershed is presented by the inverted CHM where the highest pixel height is the local minima estimates. The local minima was assigned as the starting point in focal flow and the pixel below zero gives the position of the tree peak.

The focal statistics and the focal flow estimates are extracted from the inverted CHM and shown respectively in Figure 6. The local maxima was determined from the focal flow image. Position of the local maxima is estimated from the focal statsistics image and becomes the starting points to run the watershed segmentation processing.



(a) (b)

Figure 6. Focal statistics (a) and the flow flow (b) generated from the inverted CHM image.

To begin, the tree peak and others features is assigned as 0 and 1 respectively. Then, the void pixels were masked out from the raster image and potential tree peaks are determined. Fill sinks method is applied from the tree peak point and generate the flow direction surface and finally, the focal flow image is produced as shown in Figure 7.

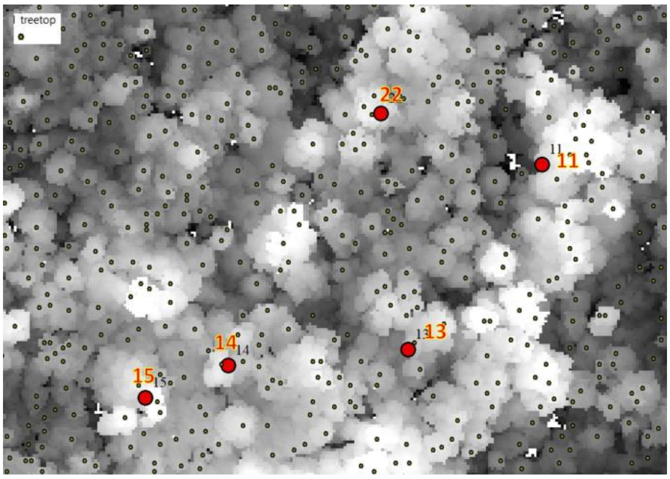
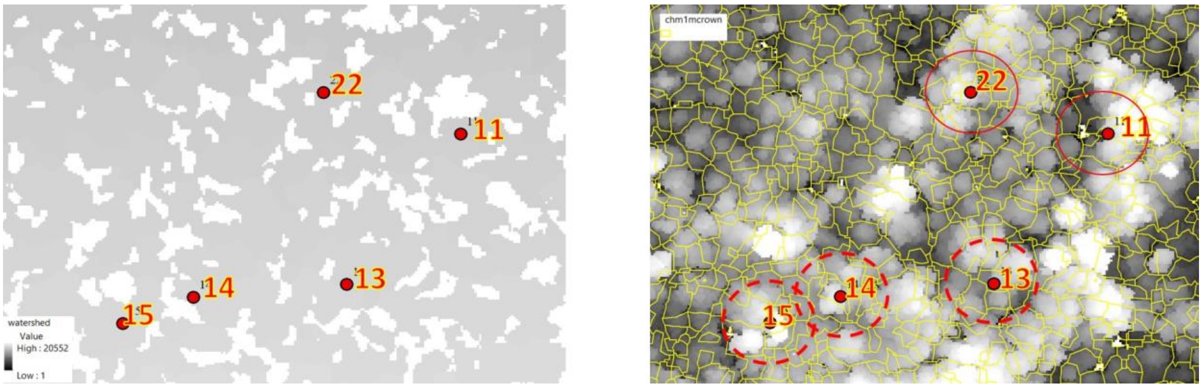


Figure 7. Tree peak points generated from the focal flow images.

The watershed segmentation determines the position of the tree crown from the inverted CHM images and all polygons are presenting the group of segmented pixels. Figure 8 presents the results of watershed segmentation. Based on the segmentation polygons, the lidar cloud points located within the polygon are chosen and extracted and being used to measure the size of tree crown. Watershed pixels represented in grey (a) and converted pixels into polygon (b). Watershed polygon displayed as the tree crown at associates actual tree crown positions on ground are nearly adjacent for points 13, 14 and 15 but the polygon were complicated to individually extract and assign to the actual position (marked in dashed circle) while points 22 and 11 were easily identified with the watershed polygons.



(a) **(b)**

Figure 8. Watershed segmentation on the lidar raster image (a) and potential tree crown size (b).

This study presents the 3D visualisation of lidar cloud points located within the watershed polygon and the results are presented in Figure 9. Figure 9(a),(b) and (c) shows three tree samples for tree at 46, 52 and 56 respectively. Based on the visualisation, it is clearly shown the emergent part of the tree canopies and completely determined the tree peak.

This allows the measurement of canopy size from the lidar cloud points. The under canopy features are visible from the lidar cloud points and this provides a way to delineate the terrain surface provided by the last lidar return points.

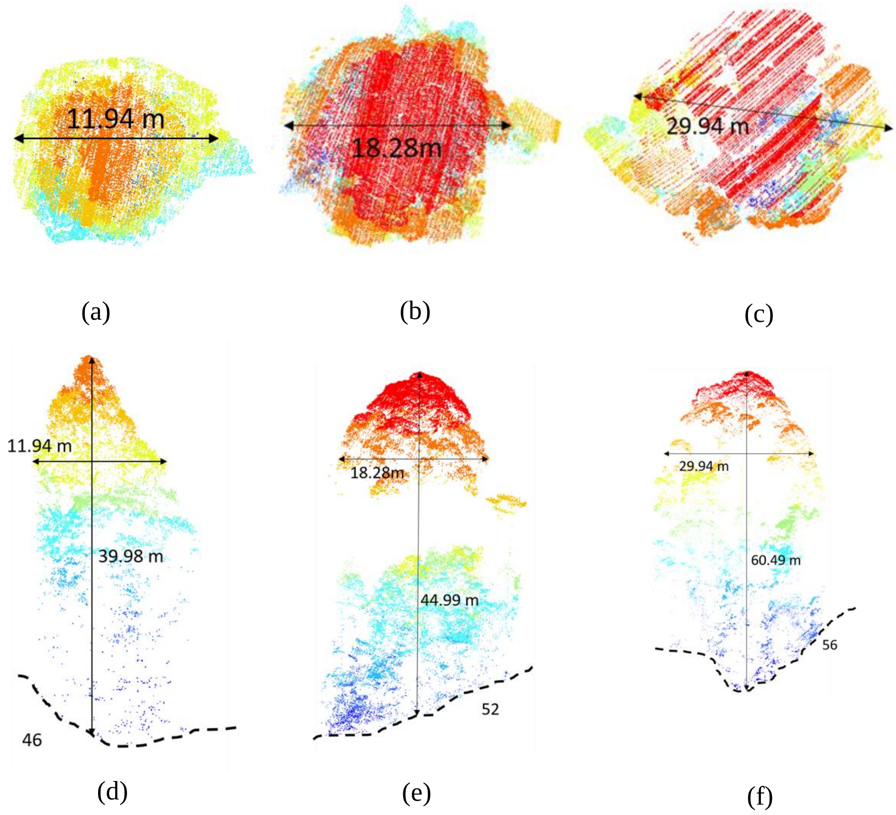


Figure 9. 3-D visualisation of lidar cloud points within the watershed polygon. Tree canopy dimension is presented by (a), (b) and (c) while the tree height is shown in (d), (e) and (f).

Comparison between the measured tree crown and tree height from the lidar cloud points with the in-situ record is presented in Figure 10. Yet, only few sampling points were used in this paper because a few samples were processed at the time of this paper produced. The accuracy of tree crown can be as high as 7 meter radius and this shows that the watershed segmentation has limitation to extract the smaller tree canopy particularly in the forest area where leaf overlapping is existed. The average RMSE of the tree crown is about 3 meter radius and this suggests that the RMSE is strongly related to the size of polygon generated by the watershed method.

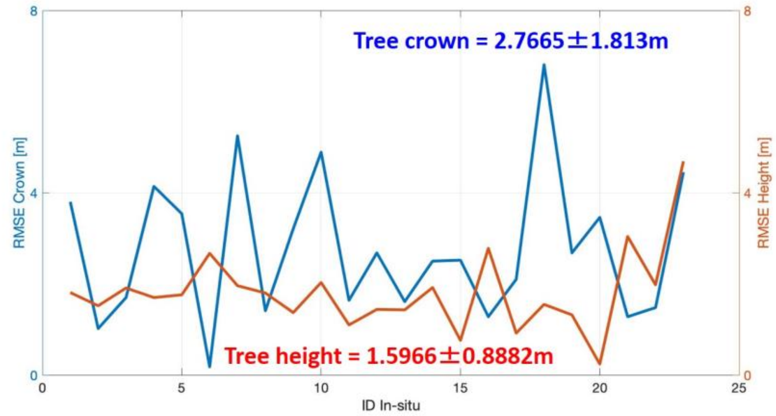


Figure 10. Validation results of tree radius and tree height

CONCLUSION

The application of watershed segmentation is presented in this study to determine the individual tree canopy and the tree height from the lidar raster data. The CHM plays the important role and contribute the estimation of polygon that representing the tree crown. This study also combines the use of lidar cloud points and results of watershed to finally determine the tree crown and height. The local maxima which present the tree peaks need to be carefully selected in order to achieve better accuracy. Leaf overlapping is one of the potential error sources of this results.

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