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ESTIMATING TREE HEIGHT BASED ON TREE CROWN FROM UAV IMAGERY

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ABSTRACT

Tree crown delineation is a significant measurement for forest inventory and management purposes. The increasing availability of high-resolution Unmanned Aerial Vehicle (UAV) data makes it possible to delineate the tree crown of a single tree. Currently, with the advancement in technology UAV has become one of the emerging technologies that offers an affordable, cheaper, and faster technology in acquiring data for numerous applications. More importantly, this technology is embedded with efficient approaches for real-time acquisition of high resolution to produce three-dimensional (3D) information. UAV images provide an accurate digital surface model for planting application. In this study, the UAV technology is explored by applying several algorithms approach to determine tree crown and tree height of a single tree canopy. As a result, this study has obtained the tree crown from the Digital Surface Model (DSM) that is filtered locally based on pixel size using the selected algorithms. Subsequently, the tree height has been calculated based on the tree crown extraction. As a conclusion, this study has contributed to the knowledge extension in this area and presented *the result of the tree height values according to the segmentation algorithm at the different flying height data.*

Keywords*:4 Unmanned Aerial Vehicle, Tree Height, Tree Crown*

INTRODUCTION

Forest inventory information is relatively important with respect to forest management, especially for the purpose of future planning and recording the status of the forest information by its areas. The forest information such as tree height, crown diameter, tree count is essential for several applications like forest regeneration, biodiversity assessment, tree growth modelling and others (Biging & Gong, 2007; Iizuka et al., 2018; Mohan et al., 2017; Jaafar et al., 2018). Those parameters are important in order to sustain better planning and monitoring of the forest values and its existence in our global environment. Moreover, tree canopy is important to reduce heat as it can provide the cooling effect to the environment (Yusof et al., 2019). Therefore, forest information is critical for an effective analysis and management of a forest. However, gathering forest inventory information in a faster and efficient manner has presently become one of the concerns and challenges in forest management (Iizuka et al., 2018).

The conventional method used in inspecting the tree parameters like in-situ measurement is relatively expensive. It involves labour-intensive forest inventories, encountering difficulties at location, supplementary work for data processing and data acquisition (Gatziolis et al., 2010; Kim et al., 2015; Iizuka et al., 2018). Moreover, the conventional methods are time-consuming and more applicable or suitable only for a small area (Biging & Gong, 2007). Other technologies like Light Detection and Ranging (LiDAR), remote sensing or Interferometric Synthetic Aperture Radar (InSAR) are currently used to obtain the forest information (Krause et al., 2019). Unfortunately, those technologies face more challenges, in particular, in the filtering of data processing at high area and a mixture of geographical features. Moreover, those technologies require well-trained individuals to perform data acquisition and these technologies are not appropriate for a small area by obtaining very high-resolution data (Zarco-Tejada et al., 2014; Salleh et al., 2015; Seul et al., 2015). Therefore, UAV becomes an advanced technology which is more cost-effective than airborne LiDAR and RADAR technologies (Mweresa et al., 2017), controllable, achievable to obtain the high resolution (Seul et al., 2015) and produce 3D images in data processing (Tuominen et al., 2015). Furthermore, UAV imagery, presently, has been used to systematically observe forest canopy height (Panagiotidis et al., 2017).

To the best of our knowledge, UAV has great potential to be used for various applications such as agriculture, forest inventory and mapping purposes. In fact, this technology has shown its ability to obtain a high-resolution image and 3D data besides being used to assess tree features and forest monitoring (Mohan et al., 2017). According to Nagendran et al, (2018) UAV is an important technology to extract the earth's surface information in a short time. The images from UAV are widely used in determining tree parameters such as crown diameter, canopy volume, tree height, and species types (Grznárová et al., 2019). Moreover, the images of UAV have emerged as suitable for 3D structure of forests and monitoring purpose (Strigul et al., 2015). Indeed, this technology has broadened the acquisition of 3D data as it is more affordable, perceived as a reasonable cost (Hung et al., 2012) and can remotely be operated from ground surface (Mohan et al., 2017).

Specifically, the aim is to determine the tree height based on tree crown using four different algorithms. The data of this study were obtained from a single tree which was captured at different flight heights. Therefore, the first objective of this study underlies an appropriate method for tree height estimation based on a single tree crown using UAV imagery. Second objective is to identify the best algorithm approach to determine tree height estimation. This study focused on the effect of using images of the same location, were captured under different flying altitude condition at 20 m, 40 m, 60 m, and 80 m. Previous study has analysed the measured values using UAV which captured at different flying height conditions (Domingo et al., 2019; Seifert et al., 2019; Torres-Sánchez et al., 2018 and Dandois et al., 2015).

Tree Height Estimation

Tree structural parameters mapping such as tree height and crown diameter provide the key indicators for planting growth, yield, biomass, estimated carbon stock and others (Kang et al., 2016; Castro et al., 2017; Panagiotidis et al., 2017). Tree height is an important ecological attribute, to determine the trees flourish with sunlight. Otherwise, the trees die because of no sun exposure. Some studies were conducted to estimate the tree height for a particular purpose such as estimation of forest biomass, forest assessment of planning and design (Ritter, 2014), 3D model of forest structure (Iizuka et al., 2018) and model the forest canopy surface (Lisein et al., 2013). Mweresa et al., (2017) estimated tree height using the basic calculation technique which is subtracting Digital Terrain Model (DTM) from DSM. In this study, the estimation of tree height will be based on tree crown delineation derived from DSM. In this case, four (4) appropriate algorithms are used to extract tree crown such as inverse watershed segmentation (IWS), object-based image analysis (OBIA), seed generation (SG) and watershed segmentation (WS).

Tree Crown Delineation

UAV imagery is preferably suited for assessing the structural form of tree crown using spatial resolution image (Johansen et al., 2018). Compared to other technologies, UAV images can be used for classifying plant species and estimating forest canopy (Stand, 2018). UAV has provided the expertise to visibly measure a single tree in forest as it provides a precision for forest applications like species mapping, inventory mapping, fire monitoring and disease mapping (Shin et al, 2019). In the literature, the tree crown extraction has been abundantly derived from the UAV image. The individual tree crown delineations have been developed based on horizontal slices crown concept (Jing et al., 2014) and using the bias field image by UAV imagery (Hongyu et al., 2018). As demonstrated in this study, the tree crown will be delineated using segmentation methods as previously done by other researchers (Ke et al., 2011; Okojie, 2017; Franklin, 2018; Grznárová et al., 2019).

METHODOLOGY

The data acquisition and processing were conducted using quantitative method. The method adopted in this study is arranged in four main phases which are relevant to the objective. It involves four phases which include preliminary study, data acquisition, data processing, and results and discussions as illustrated in Figure 1. The discussion starts with the elaboration of Phase 1 that concerns the preliminary study which deals with determining study area and flight planning using the DJI Go software. This is followed by an explanation of Phase 2 which addresses the data acquisition by using DJI Phantom 4 pro to capture a single oil palm tree. Phase 3 discusses data processing from raw data (UAV images) until the production of photogrammetric product such as DSM. In this phase, the DSM data is required to be used in applying the different algorithm to extract data from tree crown of single tree. Finally, phase 4 presents the results and data interpretations. From the tree crown extraction, the tree height value is determined by using equation.

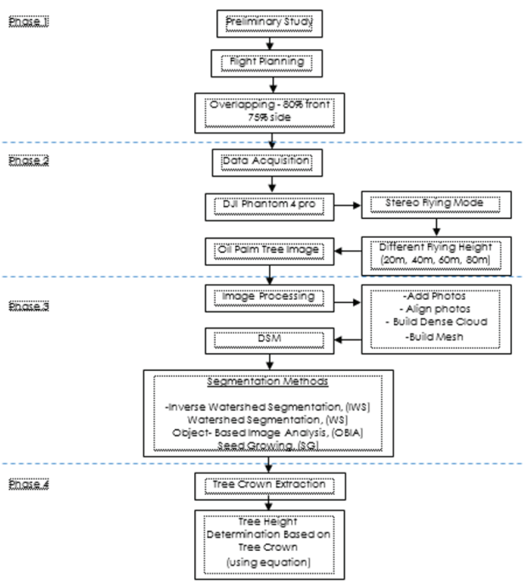

Figure 1. Overall Methodology Process

Source: Author

Study Area

The study focuses on a single oil palm tree as a case study. It is located at (4°22’50.60” N, 101°01’00.24” E) Kg Bali area within the area of a private oil palm plantation. The oil palm areas were selected due to the well-organized trees conditions and less tree canopy density. Other than that, oil palm is one of the important plants to take into consideration because it contributes to a major economics source in Malaysia (Marzukhi et al., 2020). This area is near Seri Iskandar new township – the capital city of Perak Tengah District. To meet the purposes of investigation, the total size of approximately 75m x 85m was delineated in the image acquisition to optimize on image processing (see Figure 2). In this study, a single tree canopy was used to conduct the data acquisition process. It was selected to see the effectiveness of tree crown based on algorithms approach to determine tree height value in different flying height.

Figure 2. A Single Oil Palm Tree as A Case Study Surrounded by Existing Physical Characteristics of the Selected Study Area

Source: GoogleEarth, 2019

UAV Flight Planning

The flights were conducted using a multirotor DJI Phantom 4 pro UAV fitted with a 12mp resolution camera and it can produce 4h UHD quality video. Phantom 4 pro has a terrific camera with a 1 inch 20-megapixel CMOS (Complementary metal–oxide–semiconductor) sensor which is capable of shooting 4k at 60 frames per second video. The DJI Phantom 4 pro UAV workings on the principle of on-board direct geo-referencing where the UAV component, equipped with a GPS that collects xyz of location data. This indicates that the acquired images have been directly geo-referenced by GPS capability during the flight mission.

In this study, the flight planning was designed by using DJI Go software. This software was interconnected with the UAV through wireless remote controller. The instruction was given by the DJI Go software on the ground and the information on location was sent to the UAV. Flight planning is the important process to ensure all parameters such as study area coverage, percentages overlapping of images and flying altitude are configured before data acquisition process. It is because these parameters affect the image acquisition result during flight mission. The flying altitude is configured based on user's requirement which is the flying time is dependent on the flight altitude and the percentage of image overlapping required. In this case, the image was captured every two seconds during data acquisition. Figure 3 shows the flight mission (with different altitude) during data acquisition process that emerged on the iPad attached to the UAV's remote controller.

Figure 3. Flight Mission from Different Altitude (a) 20m (b) 40m (c) 60m (d) 80m

Source: Author

Image Acquisition

As mentioned earlier, the data acquisition of single tree was captured at different flying height. The UAV was flown at an altitude of 20 meters, 40 meters, 60 meters and 80 meters with an image overlapping 80% front lap and 75% side lap. The image was captured in stereo mode flying view for each flying altitude as shown in Figure 4. Before the flight mission, the operator needed to check the functioning of UAV device thus, the UAV and camera were calibrated before the data acquisition was executed.

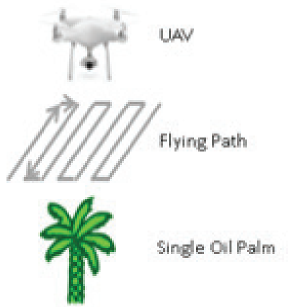

Figure 4. Camera Flying in Stereo View
Source: Author

In this study, as previously mentioned, only a single tree is taken into consideration in the estimation process. This tree is used at the same location at different flying altitude in data acquisition. All the images of single tree are used to estimate the tree crown by using four algorithms. The image was captured at a different flying height as shown in Figure 5.

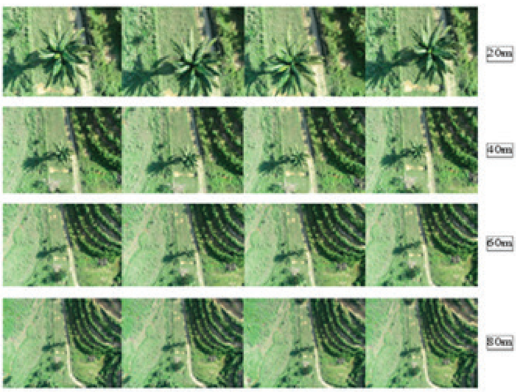

Figure 5. Image Acquired at Different Altitude (20m, 40m, 60m and 80m).
Source: Author

Image Processing

After the data acquisition, all acquired raw images data were processed using Agisoft Photoscan software. All processes were performed under the requirement settings and in a fully automated approach. Then, all images were used to generate dense cloud. Moreover, to complete the images processing, all the obtained images were processed in the Agisoft Photoscan software environment. At this stage, there were five processes to be accomplished (see Figure 6). Firstly, photos were aligned to find the orientation for each photo and camera position was set based on onboard positioning. Regarding this phase, the selection of the accuracy level was based on four scaling rates, namely the highest, high, medium, and low processes. It was followed by the process of building dense cloud which was to perform the image matching automatically.

In this situation, the algorithm was used to search the same point for each image before proceeding to the 3D generation. The next process was to build mesh which was to create the surface by using triangulation method. Finally, the researcher must generate a digital surface model (DSM) through which the tree crown could be extracted accordingly. The DSM data was used to extract the tree crown estimation by using the different algorithm.

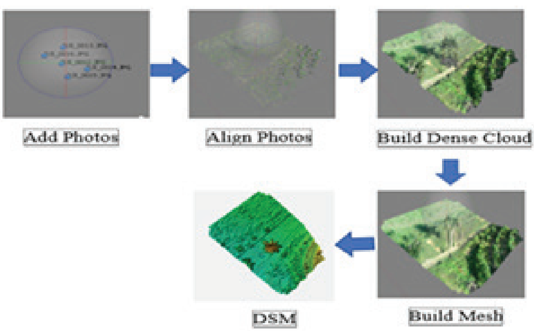

Figure 6. Flow of Image Processing using Agisoft

Source: Author

Tree Crown Delineation using Segmentation.

At this phase, the DSM data – the final output of the image processing is used to extract tree crown. Four (4) algorithms are used to determine tree crown, namely: inverse watershed segmentation (IWS), watershed segmentation (WS), seed growing segmentation (SG) and object-based image segmentation (OBIA). They are from the cluster of the segmentation approach. All segmentation has been tested from previous researchers as mentioned in section 1.2. The overall process of determining the tree height is illustrated in Figure 7.

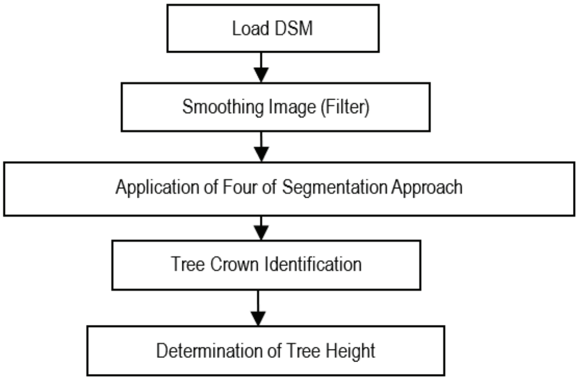

Figure 7. Tree Crown Identification Process

Source: Author

Previous researchers detected the tree crown of a single tree based on the canopy height model (CHM) (Tuominen et al., 2015; Wu et al., 2016; Birdal et al., 2017; Nevalainen et al., 2017; Ivanovs & Lazdins, 2018; Maschler et al., 2018). The segmentation techniques are required to determine the diameter of tree crown and tree height derived from canopy height model (Miranda, 2018). As mentioned above, to provide a strong validity to the tree crown delineation results, there are four segmentation methods (algorithms) that are used in this study. The DSM data of single tree was used to implement the segmentation process which consists of different algorithm. The implementation will be for every image at different flying height. At this stage, the System for Automated Geoscientific Analyses (SAGA) software is used to conduct the segmentation process. However, the final results of the tree crown delineation and tree height estimation will be obtained from ArcGIS software.

RESULTS AND DISCUSSIONS

As mentioned in section 2.5, four algorithms were utilized in this study, namely IWS, WS, OBIA and SG. All algorithms were used to determine the tree crown diameter. By accomplishing all processes that have been explained above, Figure 8 shows the tree crown extraction results by four algorithm segmentation methods at different flying heights. The results of single tree crown showed that the different algorithm methods offered different shape and outputs. As can be seen, the algorithm approaches gave different tree crown diameters for different flying altitudes.

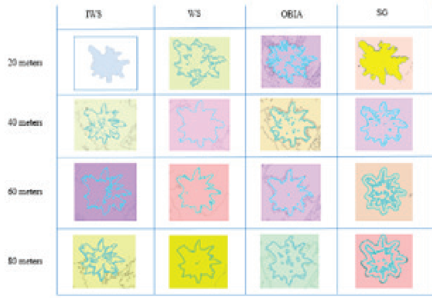

Figure 8. Tree Crown Delineation Results by Segmentation Methods and Flying Height

Source: Author

By having the extraction results, the diameter of each tree crown can easily be obtained from the field calculator process in ArcGIS software by applying Equation 1 (see (Krajicek & Brinkman, 1961; Zuhaidi, 2013).

$$CD = \sqrt{\left[\frac{4 * CA}{\pi}\right]} \qquad \text{Equation 1}$$

where: CD = Crown Diameter
CA = Crown Area
π = 3.14

Table 1 shows the tree crown diameter reading according to the four different segmentation algorithms and the different flying heights. From the results, it was found that the different crown diameter value is less than 1 meter for all the segmentation at different flying heights. The crown diameter values from OBIA are slightly different with a given range of 0.073m to 0.525m at different flying heights. However, the crown diameter values for SG segmentation produced between 0.002m and 0.016m reading at different flying altitudes. The reading value for IWS segmentation indicates that there are different crown diameters between 0.023m and 0.923m at different flying heights. Meanwhile, the WS segmentation presented the crown diameter between 0.058m and 0.892m. From the result shown, the algorithm is beneficial in estimating the parameters of single tree with high precision based on different flying altitudes.

Table 1. Crown Diameter Values

Flying Height (m)	Tree Crown Diameter (meter)			
	IWS	WS	OBIA	SG
20	8.037	8.912	8.321	9.473
40	8.960	9.746	8.561	9.471
60	8.937	9.048	8.634	9.457
80	8.301	8.854	8.846	9.473

Source: Author

Based on the tree crown diameter values as shown in Table 1, the tree height values can be calculated by using Equation 2 (see (Andersen et al., 2006; Larjavaara & Muller-Landau, 2013; Bragg, 2014). The results are shown in Table 2.

$$TH = (CD/2) * \tan\theta \qquad \text{Equation 2}$$

where: CD = Crown Diameter
TH = Tree Height

Table 2. Tree Height Values at Different Flying Height

Flying Height (m)	Tree Height (meter)			
	IWS	WS	OBIA	SG
20	8.877	9.843	9.190	10.462
40	9.896	10.764	9.455	10.461
60	9.871	9.994	9.536	10.445
80	9.168	9.779	9.770	10.462

Source: Author

As shown in Table 2, the four algorithm approaches succeeded in achieving the aim of this study. Clearly, the IWS algorithm has recorded a different reading between 0.025m and 1.019m at different flying heights. The WS algorithm has recorded a difference between 0.064m and 0.921m tree height value at different flying heights. For OBIA algorithm, the tree height values are recorded from 0.081m to 0.580m at different flying heights. Finally, the values of 0.001m to 0.017m is recorded for SG algorithm at different flying heights. As a critical summary for the findings, each algorithm has its own ability to provide acceptable values for the tree crown diameter and the tree height. In this case, the algorithm with a higher consistency in the generating value is considered as the most appropriate than others.

Therefore, among the four, it was found that the SG segmentation method becomes the most appropriate method due to a higher consistency values in both measurements. These four algorithms were selected for this study because they were identified based on previous research (Ivanovs & Lazdins, 2018; Grznárová et al., 2019; Holmgren & Lindberg, 2019).

However, other segmentation methods have also provided consistent results, but the values are greater than the SG segmentation method Besides that, previous researchers such as Wu et al., (2019); Naveed, (2019) and Qiu et al., (2020) had produced the individual tree crown by using the algorithm approach.

CONCLUSION

As a conclusion. this study has discovered the ability of the UAV technology in estimating the tree crown and tree height as required information in the multiple fields and future research applications regarding this forestry area. Therefore, the application of the four segmentation methods as testing work is appropriate thus shall contribute to the literature enlightened of both the UAV and forest as well as agricultural development. However, many things need to be done to make this exploration more valuable and acceptable. This will be further discussed in another paper. It is worthy to note, at this stage, this study has brought the UAV technology to the upfront success in this era, and it is at par with other popular technologies such as LiDAR and Radar in photogrammetry production. However, this study is only at a simulation stage, in which only a single tree is used as the parameter of measurements. Indeed, this exploration is still progressing to cover a cluster of tree canopy area. Moreover, these algorithms can also be applied to other canopy types.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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