Biosaintifika 14 (2) (2022): 168-179
p-ISSN 2085-191X | e-ISSN 2338-7610
Journal of Biology & Biology Education
https://journal.unnes.ac.id/nju/index.php/biosaintifika

Application of Unmanned Aerial Vehicle (UAV) For Estimation of Tree Height in Heterogeneous Forest

Francine Hematang[1*], Agustinus Murdjoko[1,2], Hendri Hendri[1], Max Tokede[1]

[1]Faculty of Forestry, University of Papua, Manokwari, 98314, West Papua, Indonesia
[2]Center for Biodiversity Research, University of Papua, Manokwari, 98314, West Papua, Indonesia

*Corresponding Author: chinex.hematang@gmail.com

Submitted: 2022-04-15. Revised: 2022-05-26. Accepted: 2022-08-31

Abstract. Tree height is one of the important indicators in forest management, then to collect data in the field including the tree height is costly. We applied Unmanned Aerial Vehicle (UAV) to measure the tree height and then produced the proper equation. This study aims to test the ability of low-cost UAVs in estimating tree height and the distribution of tree height classes on Mansinam island. The canopy height model (CHM) approach through aerial photography using UAV can be used to quickly estimate the height of large-scale trees combined with field measurements. CHM analysis was carried out using spatial statistics to get tree height value based on the canopy. Photogrammetry results show that the obtained CHM has a resolution of 11,8 cm/pixel with the results of the evaluation of tree height accuracy having an RMSE of 2,4 m, MAE 2,0 m, SDE 3,8 m. The Statistical test shows that the tree height estimation accepts H0 and there is a strong relationship between the observed tree height and the estimation through linear regression with an R2 value of 0,67. The broad estimation of height shows that Mansinam island has a tree height in the range of 7 – 66 m. This study shows that CHM obtained from aerial photography using low-cost UAVs is still able to estimate tree height well. Measuring tree height with a low-cost UAV can be another option for conducting a large-scale inventory. This research, tree height can be estimated quickly and can be carried out on a forest cover area.

Keywords: UAV; CHM; canopy; tropical forest; Mansinam

How to Cite: Hematang, F., Murdjoko, A., Hendri, H., Tokede, M. (2022). Application of Unmanned Aerial Vehicle (UAV) For Estimation of Tree Height in Heterogeneous Forest. *Biosaintifika: Journal of Biology & Biology Education*, *14* (2), 168-179.

DOI: http://dx.doi.org/10.15294/biosaintifika.v14i2.35637

INTRODUCTION

Tree height is one of the important pieces of information that can be used to assess and evaluate the economic and ecological value of tree stands (Krause et al., 2019). Tree height can also be used as several indicators such as to determine forest health conditions that can affect the stand growth process, and stand management for wildlife and timber businesses (Vaglio Laurin et al., 2019). The importance of knowing tree height information is not followed by calculation or estimation methods that can be used on a large scale efficiently (Dempewolf et al., 2017).

The extent of the forest, and still using conventional methods in the form of measurements using certain equipment such as laser range finders make calculating tree heights require a lot of time so it is still very limited to do (Zainuddin et al., 2016). Papua Island has the largest forest cover in Indonesia and in 2020 recorded a forest cover of 34.3 million hectares (PKTL, 2021). The forest cover is spread from mountainous areas to coastal areas and small islands. So far the forest inventory is to collect information In the context of forest management, it has not yet reached small islands due to several factors, one of which is accessibility. However, the existence of forests on small islands needs to be managed to ensure their sustainability so that it can provide sustainable benefits. For this reason, there is a need for a new breakthrough in collecting biophysical data on forest stands quickly, accurately, and cheaply.

The development of remote sensing technology today has made field data retrieval methods need to be adjusted to be more effective and more efficient. One method that has been developed and is starting to be used frequently is the application of remote sensing technology using a UAV The use of remote sensing technology (aerial photography) is one of the technologies that has long been used in the military field (Banu et al., 2016). Today aerial photography technology has been widely used in various fields including geoscience in the forestry sector. The use of aerial photography technology with low-cost UAVs and Structure from Motion (SFM) has now been widely used as well to assist in making natural resource management plans because it is considered to be able to save costs and time (Gülci, 2019). Reducing costs, time, producing high-resolution imagery, and being easy to use in a limited time and place are the advantages of using UAVs for remote sensing (Zhang et al., 2019).

Research on forest ecosystem assessment including tree height using UAV has been carried out by Iizuka et al. (2018). The results showed that low-cost UAVs and SFM can be used to estimate diameter at breast height and tree height inhomogeneous forests. Li et al. (2019) and Navarro et al. (2020) also used the UAV vehicle and the SFM method to estimate above-ground biomass in mangrove forests. Panagiotidis et al. (2017) and Krause et al. (2019) conducted a study on the extraction of the tree crown and tree height information using a high-cost UAV with a ground control point (GCP).

Estimation of tree height using the UAV approach was also carried out by Zarco-Tejada et al. (2014) who perform tree height calculations using passive sensors from low-cost UAVs and a CHM. All studies using UAV and SFM methods have concluded that the use of SFM through aerial photography has good potential to predict various information related to forest biophysics including tree height (Iglhaut et al., 2019). Besides, Birdal et al. (2017) stated that the calculation of tree height using remote sensing will improve accuracy and reduce time when compared to conventional approaches. However, mapping of small islands using UAVs to assess the biophysical conditions of islands is still relatively new or few in Indonesia (Ramadhani et al., 2015). This certainly illustrates that there are insufficient studies of natural resources in small islands of Indonesia, including the small islands of Papua.

This study focuses on forest types with various tree species using the CHM approach through aerial photography using low-cost UAVs. The relatively heterogeneous natural forest has several characters that can be used as information to help estimate tree height on a large scale based on UAV. One of the characteristics that can be used from heterogeneous natural forests to estimate tree height is the shape and color of the canopy that differs between individual trees. Thus, based on previous research, the use of low-cost UAVs without GCP is thought to still be able to produce a good Digital Terrain Model (DTM), Digital Surface Model (DSM), and CHM from aerial photography as an estimator of tree height in forests. heterogeneous. Based on these assumptions, the question is whether the technique of using aerial photography from UAVs can also be applied to estimate tree heights from relatively heterogeneous natural forests? What is the distribution of high-class trees in the mixed forest on Mansinam Island? This question is a research problem that will be answered. This study aims to determine the accuracy of tree height estimation using the CHM through the application of UAV remote sensing technology in a relatively heterogeneous natural forest area on the island of Mansinam.

This research, tree height can be estimated quickly and can be carried out on a wider forest cover area. In addition, this study provides information related to estimating tree height on Mansinam island which can be used by relevant agencies in forest management.

METHODS

Study Area

The research was conducted in a forest area of ± 400 ha on the island of Mansinam which administratively is located in Manokwari Regency, West Papua Province, Indonesia (Figure 1). This island is geographically located at coordinates 134° 5' 16,6” – 134° 6' 46,2” east longitude and 0° 53' 17,1” - 0° 55' 28,18” south latitude. The forest type is lowland tropical rain which is dominated by coastal vegetation types *Calophyllum inophyllum*, *Buchanania arborescens*, *Terminalia complananta, and Pometia coreaceae* scattered in the northern part and lowland forest vegetation types such as *Elaeocarpus* sp, *Palaquium amboinensis,* and *Artocarpus altilis* in the central to the southern part of the island (Hematang et al., 2021).

Acquisition and Processing Aerial Photo

Aerial photo acquisition using a quadcopter-type UAV vehicle, namely the DJI Phantom 3 Professional. This vehicle has a Sony EXMOR1/2.3 sensor with a resolution of 12,7 Mega Pixels, can fly for 23 minutes with a maximum flight altitude of 19,685 feet above sea level, weighs 1.280 grams, and has GPS/GLONASS installed (DJI, 2016). Acquisition of aerial photography at a cruising altitude of 150 m above ground level, carried out during the day with sunny weather and wind speed < 15 knots or 7,7 m/s (Navarro et al., 2020). The flight plan was designed using the Pix4Dcapture software installed on the smartphone device. The designed flight path is 80% front and side overlap, 90° camera angle, normal speed, and 2D grid

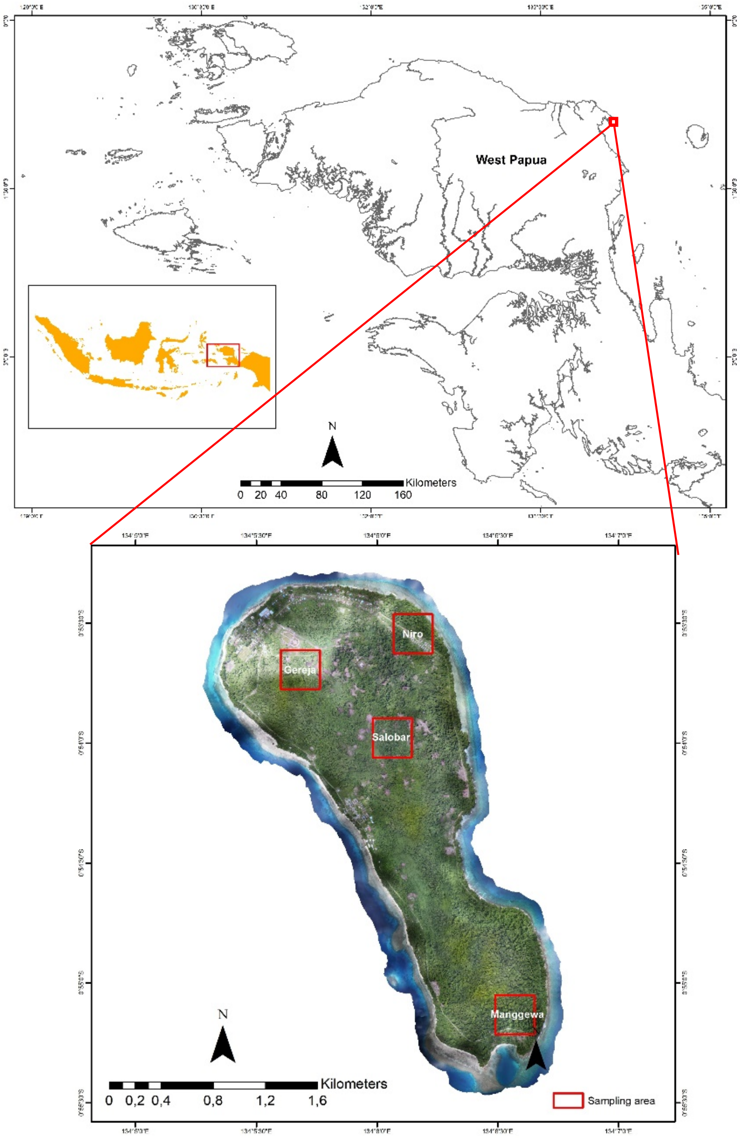

Figure 1. Study locations and distribution of sample area

flyway type. The coverage area on land photographed is 90.000 m² plus 20% to fulfill the side overlap of the resulting DEM and orthophoto.

Field observation sample plots for tree height data collection consisted of four plots with a plot size of 300 m x 300 m which were purposively adjusted based on consideration of the representation of the vegetation type and physical condition of the forest area (Figure 1). Analysis and interpretation of aerial photographs to extract data from both orthophoto and DEM were performed using Agisoft Metashape (Agisoft LLC St. Petersburg, Russia) (Agisoft, 2020). Agisoft software uses the structure from motion (SFM) method to extract point features from within the image file and match the point features to compose image mosaics and reconstruct objects from point features and camera positions (Iizuka et al., 2018). Orthophoto and DEM calibrations were not carried out using GCP but only using GPS information installed on the UAV. Photogrammetric parameters using Agisoft Metashape software as presented in Table 1 (Tomaštík et al. (2017); Dempewolf et al. (2017)).

Operational Research Variables

The research variables were the canopy area as the independent variable (estimating variable) and tree height as the dependent variable (yield variable). Tree crown extraction from orthophotos was carried out using the multiresolution segmentation algorithm software Ecognition. The multiresolution-based segmentation process is a grouping of certain areas that have similar adjacent pixel values into an object where

Table 1. Photogrammetric parameter settings using Agisoft Methashape software

Processing	***Parameters***	***Settings***
Align photo	Accuracy	High
	Pair Selection	Disabled
	Key Point Limit	40.000
	Tie Point	4.000-10.000
Build dense cloud	Quality	High
	Depth Filtering	Mild
Build DEM	Source Data	Dense Cloud
	Interpolation	Enabled
	Projection	WGS84/UTM Zone 53 S
Build Orthomosaic	Surface	DEM
	Blending Mode	Mosaic
	Color Correction	Yes
	Projection	WGS84/UTM Zone 53 S

homogeneous areas will become larger objects while heterogeneous areas will become smaller (Purba & Perwira, 2021). Yurtseven et al. (2019) stated that a quick delineation of the header can be done with the OBIA technique through object segmentation.

Making of Canopy height model (CHM)

Tree height can be estimated by reconstructing aerial photos captured using low-cost UAVs into a digital altitude model. Reconstruction of aerial photos was carried out to form a DTM, and a DSM using Agisoft metashape software. DSM is a representation of the height of all objects above ground level, while DTM represents the shape of the ground surface (Dong et al., 2020). The formation of DTM and DSM that will be used is a model from the analysis of aerial photographs using the SFM method. SFM can be used as potential data that represents tree height (Iizuka et al., 2018).

SFM performs point feature extraction from within the image file and matches the point features to compose the image then the camera position is estimated and the object is reconstructed from the point feature and camera position (Iizuka et al., 2018). Panagiotidis et al. (2017) stated that the CHM derived from the difference in elevations of DSM and DTM can be used to estimate tree height. The formation of CHM has been carried out with the help of ArcGIS 10.6 software through the process of reducing the elevation value from DSM and DTM data. CHM is mathematically formulated as in equation 1 (Panagiotidis et al. 2017; Sadeghi & Sohrabi, 2019).

$$CHM = DSM - DTM \quad (1)$$

Tree Height Extraction

The determination of tree height is based on the value of treetops from the results of the CHM analysis. To detect the value of treetops in CHM, it will be analyzed using ArcMap software with spatial statistical analysis methods in the form of identifying the maximum value based on area. The area that will be used in this tree height estimation is the area/polygon resulting from the delineation of the tree crown based on the identification orthophoto. Spatial statistical analysis used is zonal statistics on ArcMap. Statistical zones perform spatial statistical calculations from several data sets in certain zones/areas (ESRI, 2021). This study uses the maximum value in the zonal statistic to obtain the highest set of CHM values based on the canopy area. To determine the highest peak of the tree, the formula used is as in equation 2

Con = (“CHM Data” = “Zonal statistical data”, “CHM Data”) (2)

The conditional tool (Con) has the principle of evaluating if/else conditionally on each cell value from the entered raster data. The conditional statement used is if the cell in the CHM data is the same as the corresponding cell in the statistical zonal, then set the value of the cell in the CHM to the output raster. If the cell value in CHM is not the same as the value in the zonal statistic, it is set to “No Data” in the output raster (Panagiotidis et al., 2017).

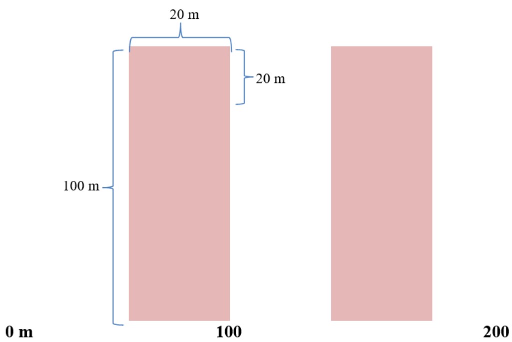

Figure 2. Sketch of the shape, size, and placement of the observation plots

Field Data Collection

The field survey is intended to collect empirical data on height, and real tree positions in the field. The observation plot is rectangular in shape, measuring 20 m x 100 m. Each observation sample plot was divided into 5 sub-plots, square in shape, and measuring 20 x 20 m. The number of sample plots made was 8 units which were placed purposively based on the consideration of representativeness of forest cover conditions and field topography. For each type of forest cover and field topography, two units of observation plots are placed in pairs with a distance of 100 m.

All woody plants at the tree level with a diameter of 20 cm up (≥ 20 cm) included in the observation sub-plot were measured for tree height. The assumption is that in the tree phase (DBH 20 cm) it is in the co-dominant to dominant class so that it will have a visible canopy when taking aerial photos. The tree height measurement is carried out using a hagameter, while the tree position will be calculated by recording the tree position measured in the observation subplot based on the x and y-axis distances in the measurement plot. The sketch of the sample plots and sub-plots for observations is shown in Figure 2.

Statistical Analysis

The Chi-square test tested the null hypothesis, namely h0 = The value of the tree height from the analysis was not significantly different from the tree height value from the field measurements if X^2 count < X^2 table. The value of X^2 count is calculated based on equation 3.

$$X^2\text{count} = \Sigma \frac{(\text{ho - he})^2}{\text{he}} \quad (3)$$

The root means square error (RMSE) explains the standard error between the value measured by estimation and the relative RMSE is the proportion between the RMSE value and the average observed value. A good RMSE and rRMSE is that it has a value that is low or close to a value of 0. The RMSE and rRMSE formulas use equations 4 and 5 (Krause et al. (2019); Zhou & Zhang, (2020); Li et al. (2019).

$$\text{RMSE} = \sqrt{\frac{\Sigma(\text{ho - he})^2}{\text{n}}} \quad (4)$$

$$\text{rRMSE (\%)} = \frac{\text{RMSE}}{\hat{\text{h}}} \text{ X } 100 \quad (5)$$

The mean absolute error (MAE) is used to see the distribution of the average error of the data and the relative mean absolute error (rMAE) is used to assess the proportion of the MEA to the average observed value. A good MAE and rMAE is a value that is low/close to a value of 0. The calculation of MAE and rMAE uses equations 6 and 7 (Panagiotidis et al. (2017); Krause et al. (2019).; Krause et al. (2019).

$$\text{MAE} = \frac{1}{\text{n}} \Sigma|\text{he - ho}| \quad (6)$$

$$\text{rRMSE (\%)} = \frac{\text{RMSE}}{\hat{\text{h}}} \text{ X } 100 \quad (7)$$

Test the coefficient of determination (R^2) with a high value. Calculation of R^2 value is obtained from the results of linear regression or follows the equation 8 (Li et al., 2019)

$$\text{R}^2 = 1 - \frac{\Sigma\,(\text{ho - he})^2}{\Sigma\,(\text{ho - }\hat{\text{h}})^2} \quad (8)$$

Standard deviation error (SDE) and relative SDE have a low value/close to 0. SDE and rSDE calculations use equations 9 and 10 (Krause et al., 2019).

$$\text{SDE} = \sqrt{\frac{1}{\text{n-1}}\sum(he - ho - MAE)^2} \quad (9)$$

$$\text{rSDE}(\%) = \frac{\text{SDE}}{\hat{h}} \text{ X } 100 \quad (10)$$

Where **he** is the tree height value from the CHM estimation (Estimated), **ho** is the tree height value from the field measurements (Observation), $\hat{\mathbf{h}}$ is the average tree height value from the field measurements, and **n** is the number of samples.

RESULTS AND DISCUSSION

Orthophoto and Canopy Height Model (CHM)

A total of 373 aerial photography taken using UAVs were spread over four sample areas, each with 74 photos of the *Gereja* sample area, 100 photos of the *Manggewa* area, 101 photos of the *Niro* area, and 98 photos of the *Salobar* area. The results of the photogrammetric analysis show that the average total error of orthophoto formation in the 4 sample areas is 4.36 m, with details of the average x error: 2.33 m, y error: 1.64 m, z error: 2.67, and xy error: 3.13 m. The resulting orthophotos have different resolutions between sample areas where the *Gereja* area has an orthophoto resolution of 5.9 cm/pixel, the *Manggewa* area of 8.2 cm/pixel, the *Niro* area of 7.7 cm/pixel, and the *Salobar* area of 8.1 cm/pixel with the average orthophoto resolution in the sample area is 7.4 cm/pixel. The canopy Height Model resulting from DTM and DSM analysis has an average resolution of 14.9 cm/pixel. The CHM resolution generated from each sample area is different where the Church area has a CHM resolution of 11.8 cm/pixel, the *Manggewa* area of 16.4 cm/pixel, the *Niro* area of 15.4 cm/pixel, and the *Salobar* area of 16.2 cm/pixel as shown in.

Estimation of tree height through CHM was carried out using the software SFM algorithm. The SFM algorithm is software that performs point feature extraction from image files (orthophoto) and then rematches the point features to reconstruct the image of the camera position object (Iizuka et al., 2018). Yi et al. (2014) further explained that the basic principle of the SFM algorithm is to extract object information from the image, then reconstruct the object to position the appropriate object points from two or more same images. The more that overlap, the better. In this research, Agisoft metashape software is used to reconstruct the elevation model on orthophoto so that it can be analyzed to produce a more detailed elevation model in the form of a DTM and a DSM. DTM and DSM data are used to build the CHM. The quality of CHM is highly dependent on the quality of the DSM and DTM data generated. The factor that affects the quality of DTM and DSM data sourced from low-cost UAVs is the density of the tree canopy. Low-cost UAVs generally have passive sensors so that they are not optimal in recording the value of the height of the ground under a dense tree canopy. Tree canopy density is highly dependent on the heterogeneity of the studied forest.

Sample tree height extraction

From the four locations of the sample units, 90 sample trees were selected whose height was measured. At the *Gereja* area, sample locations were taken 38 sample trees with a tree height range of 20 – 27 m, at the *Manggewa* location 15 sample trees with a tree height range from 19 – 36 m, the *Niro* location as many as 20 sample trees with a height range from 18 – 37 m, and the *Salobar* location. as many as 17 sample trees with a tree height range between 17 – 38.7 m. Each sample location has a different number of samples for measuring tree height where this is because the tree selection is done by considering the presence of a sample tree canopy that is easy to identify when interpreting the canopy through orthophoto aerial photography.

The results of a spatial statistical analysis based on the values of DTM, DSM, and CHM at each sample location show that the range of tree height values for the *Gereja* location has a minimum height (hmin) of 21 m and a maximum height (hmax) of 29 m, the *Manggewa* area has a hmin of 21 m and hmax of 32 m, the *Niro* area has a hmin of 21 m and hmax of 32 m, and the area *Salobar* have a hmin of 16 m and a hmax of 35 m. The estimated tree height values of individual sample trees at each location will then be statistically tested with the same individual tree heights measured in the field. Table 2 shows a comparison of statistical descriptions of the height of the observed and estimated trees. The results show an insignificant difference between the height of the observation and the estimate, but the difference must be tested statistically to obtain the level of accuracy.

Table 2 shows that numerically there are differences in tree heights estimated based on CHM and tree heights from observations. To find

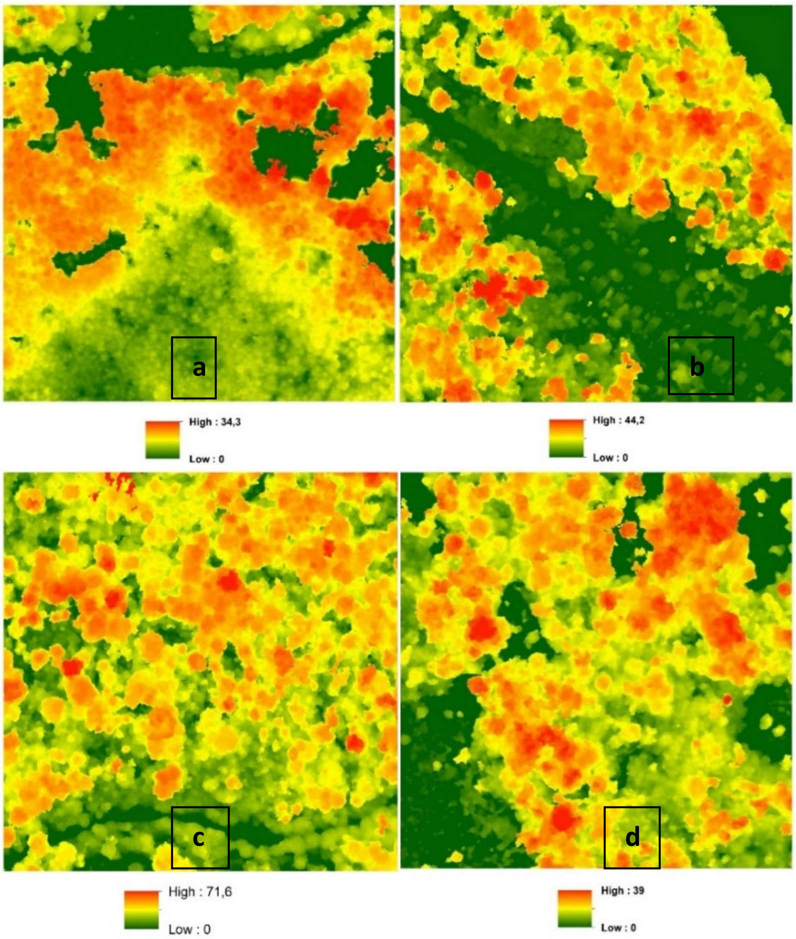

Figure 3. Canopy height model in the sample area a: Gereja, b: Niro, c: Manggewa, d: Salobar

out whether the two groups of data were statistically significantly different, a chi-square statistical test was carried out, and to find out whether the estimated tree height based on CHM could be used as an estimator of the actual tree height, a correlation test was carried out based on a simple regression procedure which was followed by a test of the accuracy of the estimation based on the value. the coefficient of determination (R2) and the average value of the estimated error, as well as the value of the standard deviation at the 95% confidence interval.

Crown Segmentation

Tree crowns covered in orthophoto are delineated to form polygons for each tree at each sample location. The number of delineated crowns at the Church location was 1,041 crown polygons, *Manggewa* 616 crown polygons, *Niro* sample locations 585 header polygons, and *Salobar* sample locations 629 crown polygons. Figure A2 in the appendix shows the results of the delineation of the tree canopy on the orthophoto of each sample location marked by a red line polygon border.

Table 2. Comparison of height (h) of measurement and sample estimates

Sample Area	Measurement (m)			Estimated height from CHM (m)			Number of samples
	Min	mean	Max	Min	mean	Max	
Gereja	20.0	23.6	27.0	21.0	24.0	29.0	38
Manggewa	19.0	27.6	36.5	21.0	27.0	32.0	15
Niro	18.0	27.3	37.0	21.0	29.0	32.0	20
Salobar	17.0	25.1	38.7	16.0	25.0	35.0	17

Table 3. Results of statistical analysis of tree height estimation accuracy with CHM

X^2 Count	X^2 Table : 0.05	RMSE (m)	rRMSE (%)	MAE (m)	rMAE (%)	R^2	SDE (m)	rSDE (%)	n
19.18	112.02	2.41	9.48	2.01	7.92	0.67	3.83	15.10	90

Based on the segmented tree canopy polygons at each sample location, 90 polygons were selected purposively to be used as the header of the sample tree. The header polygon is then used as an auxiliary variable in extracting the estimated tree height based on CHM.

Estimation Accuracy Statistical Test

The results of the chi-square test showed that accepting h0 or the tree height estimated by CHM was statistically not significantly different from the tree height from field measurements at the 95% confidence level. Thus, the null hypothesis (ho) states that if X^2count < X^2table is acceptable (Table 3). The data in Table 3 also shows that the equation of the relationship between tree height based on CHM and tree height from field measurements is linear with an RMSE value of 2.41 m, and an rRMSE value of 9.48%, and an R2 of 0.67. This means that statistically, the tree height diversity according to CHM can explain 63 percent of the tree height diversity in the field with an average estimation error rate of 9.48%. The linear regression equation formed as presented in Figure 4 can statistically be used to estimate tree height based on CHM. Zainuddin et al. (2016) explained that the magnitude of the R^2 value could indicate the results of estimating tree height using CHM were close to the actual value based on the results of measurements in the field. MAE means that the average error in the estimation of tree height using the CHM method is 2,01 m or 7.92% of the average value of the actual tree height.

Panagiotidis et al. (2017) used CHM from UAV to estimate tree height and the results of accuracy evaluation obtained RMSE of 3 m, and MAE of 2.88 m. This fact illustrates that the use of CHM can be used as a parameter to estimate tree height in the field quickly and relatively accurately. The level of accuracy of the application of the CHM approach to estimate tree height can be influenced by several factors, including the remote sensing vehicle used, data acquisition methods, data analysis, and other required supporting data (Ganz et al., 2019). Another factor that is thought to influence the accuracy of tree height estimation using CHM is the delineation of the tree canopy area. Automatic

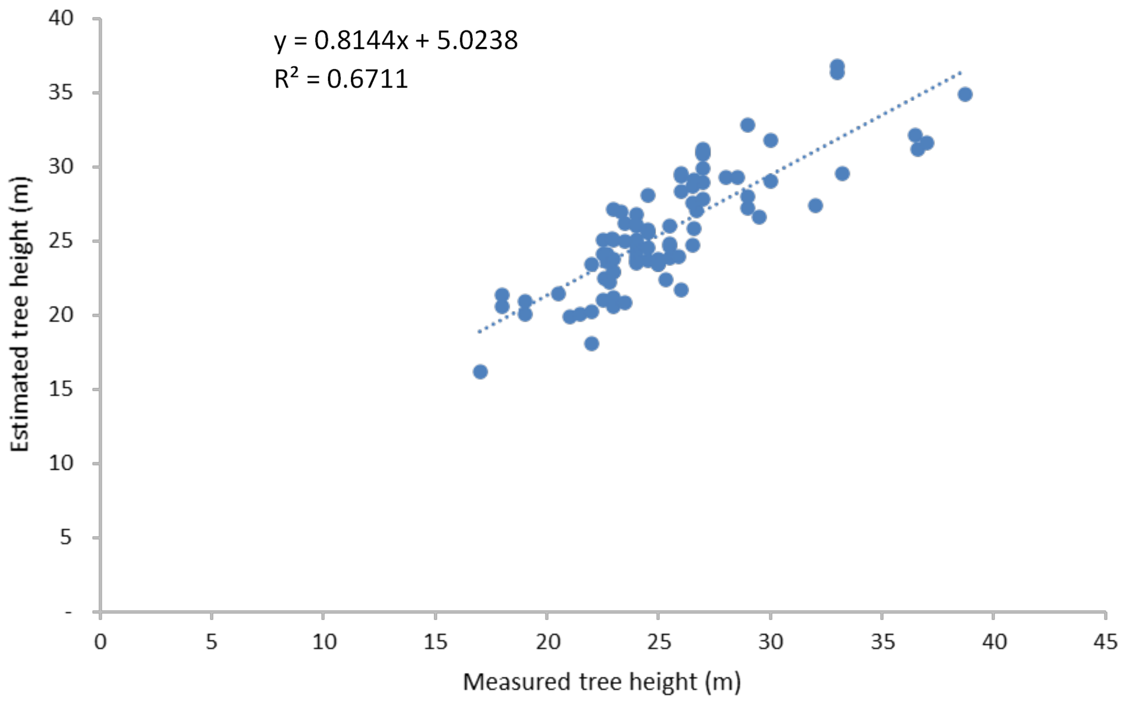

Figure 4. Equation model of the relationship between the estimated tree height based on CHM and the tree height measured in the field

Table 4. Distribution of the height class of the estimated tree

Class Tree Height (m)	Number of Trees	Class Average Tree Height (m)
7 - 18	472	15.52
19 - 30	1877	25.06
31 - 42	514	33.73
43 - 54	8	44.23
55 - 66	1	63.03

delineation using simple segmentation is very dependent on the color and shape of the header in the image so that it affects the delineated header. Homogeneous tree crowns in both shape and color can give segmentation results that underestimate or overestimate the actual crown. Errors in the header segmentation are thought to have contributed to the occurrence of estimation errors. Likewise, in heterogeneous forests, it is assumed that the color and shape of the canopy in the image are more varied so it is likely to provide varying levels of accuracy as well.

The application of remote sensing technology with UAV vehicles and with the help of software using the SFM method can quickly and relatively precisely obtain tree height data in heterogeneous natural forests. The results of the Chi-Square statistical test showed that between the tree heights estimated with CHM and the tree heights from field measurements, there was no significant difference at the 95% confidence level. This fact shows that statistically, tree height obtained using CHM from orthophoto from low-cost UAV sensing can provide tree height data faster than measuring tree height in the field which takes a long time and costs a lot of money. The results of the statistical analysis also prove that the equation of the relationship between tree height according to CHM and the measured tree height shows a coefficient of determination (R2) of 67% and an average error value of 2,01 m (Table 3). This means that CHM can be used as an estimating parameter for tree height through a linear relationship equation model (Figure 4).

Using Canopy Height Model (CHM)

This study utilized CHM and tree canopy in four sample areas covering an area of 36 ha to estimate tree height extensively on Mansinam island. The results of the analysis show that the tree height on Mansinam island is estimated to be between 7 – 66 m with an average tree height of 24 m. To make it easier to understand the distribution of the height and diameter estimation, a tree height interval was made in 5 classes. The results of the classification based on the height interval made show that the tree height class 19-30 m is the tree height interval that is expected to be the most encountered with the number of trees reaching 1,877 trees.

The research location forest is a small island that is included in the type of tropical rain forest which is a combination of coastal forest vegetation types and lowland forest vegetation. The combination of these vegetation types causes the composition of woody plant species and topographic conditions to be relatively heterogeneous. This fact can be seen from the number of individual woody plants found in the sample area as many as 1,877 individuals, dominated by tree height classes between 19 - 30 m.

Through this study, we also suspect that the dominant tree height on Mansinam island is in the 19 – 30 m class. The results of field measurements also showed that 87% (79 sample trees) of the 90 sample trees were between 19 – 30 m (Table 2). This dominant class is environmentally influenced by edaphic conditions on the island of Mansinam. Almost all parts of Mansinam island have a thin soil solum because it is dominated by coral rock types so it is poor in nutrients. Another thing that affects the distribution of tree height on Mansinam Island is logging activities. The structure and species composition of tropical rainforests can change if there is a disturbance (Murdjoko et al., 2016).

The advantages of using SFM and UAV technology in forest inventory activities to assess forest wealth such as canopy density, canopy diameter, canopy height, and tree diameter. Tree height, tree distribution, stand structure, and various other information has been disclosed by several researchers. Research on the estimation of tree dimensions in an area of 36 ha takes approximately 24 hours starting from the preparation of the vehicle, taking aerial photos, photogrammetry, data analysis, and field sampling (Hematang et al., 2021). Analysis of stand dimensions from aerial photographs with an area of 27 ha takes 23 hours (Iizuka et al., 2018). From the aspect of the vehicle used for sensing, it has also been carried out to determine the speed of completion of activities. An example of using UAV researched by Li et al. (2019) showed that the UAV was able to fly and record over an area of 85 ha for 40 minutes with the help of 3 people, compared to a field survey conducted by 6 people for an area of 0,25 ha it took 8 days by Otero et al. (2018) in mangrove forest inventory activities. The results showed that the speed of completing an inventory of 2 ha requires less than 7 hours/day with 3 surveyors. Němec (2015) stated that conducting a field survey covering an area of 200 ha required 14 workers and was carried out for 25 days. The ability of UAVs in assisting fieldwork for data collection has been proven to save time and costs.

Low-cost UAVs generally do not have capabilities comparable to high-class UAVs but with the results of this study create a new alternative to using the latest inexpensive technology to quickly collect all plant biophysical information including tree height. With the results of this study, the use of low-cost UAVs can be used to estimate tree height quickly and over a wider area. The use of cheap, fast, and appropriate technology is one solution to complete data collection related to the size of the area and the number of research objects such as in the field of environment and forestry.

This application of the research seems to be efficient in supporting forest inventory, particularly in Papua where some areas of forest are still inaccessible. Therefore, we are proposing this validated method to contribute to the data collecting process in which the height measurement of trees could be executed efficiently and effectively. However, this finding can be only used for trees in more or less similar ecological conditions as this research. To complete the method, future researches are necessary to focus on other lifeforms of vegetation such as tree ferns and tree palms. Moreover, the measurement of tree height using this method could be systematically developed in forest inventory like biomass of vegetation.

CONCLUSIONS

Low-cost UAVs can still be used to estimate tree height with accuracy test results having an RMSE 2.41 m and an average error value of 2.01 m. In addition, the dominant tree height on Mansinam island is in class 19 - 30 m. This study has not implemented a ground control point (GCP) through the reconstruction of a three-dimensional (3D) model to improve the accuracy of UAV image acquisition. Therefore, it is necessary to conduct research by reconstructing 3D models using GCP in image acquisition.

ACKNOWLEDGMENTS

We would like to thank the head of Mansinam village and all the people on the island of Mansinam for assiting in data collection and research permits that have been given to researchers.

REFERENCES

Agisoft. (2020). Agisoft Metashape User Manual. *Agisoft Metashape*, *September*, 160. https://ww w.agisoft.com/pdf/metashape-pro_1_5_en.pdf

Banu, T. P., Borlea, G. F., & Banu, C. (2016). The Use of Drones in Forestry. *Journal of Environ mental Science and Engineering B*, *5*(11), 557–562.https://doi.org/10.17265/21625263/ 2016.11.007

Birdal, A. C., Avdan, U., & Türk, T. (2017). Estimating tree heights with images from an unmanned aerial vehicle. *Geomatics, Natural Hazards and Risk*, *8*(2), 1144–1156. https://doi. org/10.1080/19475705.2017.1300 608

Dempewolf, J., Nagol, J., Hein, S., Thiel, C., & Zimmermann, R. (2017). Measurement of with in-season tree height growth in a mixed forest stand using UAV imagery. *Forests*, *8*(7), 1–15. https://doi.org/10.3390/f8070231

DJI. (2016). *Phantom 3 Profesional : User Manual*. 3–6. https://dl.djicdn.com/download s/phantom _3/User Manual/Phantom_3_Pro fessional_Use r_Manual_v1.8_en.pdf

Dong, X., Zhang, Z., Yu, R., Tian, Q., & Zhu, X. (2020). Extraction of Information about Individ ual Trees from High-Spatial-Resolution UAV-Acquired Images of an Orchard. *Remote Sensin g*, *12*(1), 133. https://doi.org/10.3390/rs120101 33

ESRI. (2021, 24 September). Con. Diakses pada 22 Mei 2021, dari https://desktop.arcgis. com/en/arcmap/latest/tools/spatial-analyst-to olbox/con-h tm

Ganz, S., Käber, Y., & Adler, P. (2019). Measuring tree height with remote sensing-a comparison of photogrammetric and LiDAR data with differe nt field measurements. *Forests*, *10*(8). https://doi.org/10.3390/f1008 0694

Gülci, S. (2019). The determination of some stand parameters using SfM-based spatial 3D point cloud in forestry studies: an analysis of data pro duction in pure coniferous young forest stands. *Environmental Monitoring and Assessment*, *191* (8). https://doi.org/10.1007/s10661-019-76 28-4

Hematang, F., Murdjoko, A., & Hendri. (2021). Model Pendugaan Diameter Pohon Berbasis Citra Unmanned Aerial Vehicle (Uav) Pada Hutan Hujan Tropis Papua: Studi Di Pulau Mansinam Papua Barat. *Jurnal Penelitian Kehutanan FALOAK*, *5*, 16–30.

Iglhaut, J., Cabo, C., Puliti, S., Piermattei, L., O'Con nor, J., & Rosette, J. (2019). Structure from Mot ion Photogrammetry in Forestry: a Review. *Cur rent Forestry Reports*, *5*(3), 155–168. https://doi.org/10.1007/s40725-019-00094-3

Iizuka, K., Yonehara, T., Itoh, M., & Kosugi, Y. (2018). Estimating Tree Height and Diameter at Breast Height (DBH) from Digital surface models and orthophotos obtained with an unmanned aerial system for a Japanese Cypress (Chamaecyparis obtusa) Forest. *Remote Sensing*, *10*(1). https://doi.org/10.3390/rs10010 013

Krause, S., Sanders, T. G. M., Mund, J. P., & Greve, K. (2019). UAV-based photogrammetric tree height measurement for intensive forest monitoring. *Remote Sensing*, *11*(7), 1–18. https://doi.org/10.3390/rs11070758

Li, Z., Zan, Q., Yang, Q., Zhu, D., Chen, Y., & Yu, S. (2019). Remote estimation of mangrove aboveground carbon stock at the species level using a low-cost unmanned aerial vehicle system. *Remote Sensing*, *11*(9). https://doi.org/10.3390/rs11091018

Murdjoko, A., Marsono, D., Sadono, R., & Hadisusanto, S. (2016). Population Dynamics of Pometia for The Period of Post-Selective Logging in Tropical Rainforest, Southern Papua, Indonesia. *Biosaintifika: Journal of Biology & Biology Education*, *8*(3), 321. https://doi.org/10.15294/biosaintifika.v8i3.6309

Navarro, A., Young, M., Allan, B., Carnell, P., Macreadie, P., & Ierodiaconou, D. (2020). The application of Unmanned Aerial Vehicles (UAVs) to estimate above-ground biomass of mangrove ecosystems. *Remote Sensing of Environment*, *242*(November 2019). https://doi.org/10.1016/j.rse.2020.111747

Němec, P. (2015). Comparison of modern forest inventory method with the common method for management of tropical rainforest in the Peruvia n Amazon. *Journal of Tropical Forest Science*, *27*(1), 80–91.

Otero, V., Van De Kerchove, R., Satyanarayana, B., Martínez-Espinosa, C., Fisol, M. A. Bin, Ibrahim, M. R. Bin, Sulong, I., Mohd-Lokman, H., Lucas, R., & Dahdouh-Guebas, F. (2018). Managing mangrove forests from the sky: Forest inventory using field data and Unmanned Aerial Vehicle (UAV) imagery in the Matang Mangrove Forest Reserve, peninsular Malaysia. *Forest Ecology and Management*, *411*(October 2017), 35–45. https://doi.org/10.1016/j.foreco .2017.12.049

Panagiotidis, D., Abdollahnejad, A., Surový, P., & Chiteculo, V. (2017). Determining tree height and crown diameter from high-resolution UAV imagery. *International Journal of Remote Sens ing*, *38*(8–10), 2392–2410. https://doi.org/10.1080/01431161.2016.1264028

PKTL. (2021). Statistik Bidang Planalogi Kehutanan dan Tata Lingkungan Tahun 2020. Direktorat Jenderal Planologi dan Tata Lingkungan, Kementerian Lingkungan Hidup Dan Kehutanan, Jakarta. Indonesia

Ramadhani, Y. H., K, A. P., & Susanti, R. (2015). Pemetaan Pulau Kecil dengan Pendekatan Berbasis Objek Menggunakan Data Unmanned Aerial Vehicle (UAV) Studi Kasus di Pulau Pramuka , Kepulauan Seribu. *Majalah Ilmiah Globe*, *17*(2), 125–134.

Sadeghi, S., & Sohrabi, H. (2019). The Effect Of Uav Flight Altitude On The Accuracy Of Individual Tree Height Extraction In A Broad-Leaved Forest The Effect Of Uav Flight Altitude On The Accuracy Of Individual Tree Height Extraction In A Broad-Leaved Forest. *The International Archives of the Photogramm etry, Remote Sensing and Spatial Information Sciences*, *XLII* (November). https://doi.org/10.5194/isprs-archives-xlii-4-w18-1168-2019

Tomaštík, J., Mokroš, M., Saloš, S., Chudỳ, F., & Tunák, D. (2017). Accuracy of photogramm etric UAV-based point clouds under conditions of partially-open forest canopy. *Forests*, *8*(5). https://doi.org/10.3390/f8050151

Vaglio Laurin, G., Ding, J., Disney, M., Bartholomeus, H., Herold, M., Papale, D., & Valentini, R. (2019). Tree height in tropical forest as measured by different ground, proximal, and remote sensing instruments, and impacts on above ground biomass estimates. *International Journal of Applied Earth Obser vation and Geoinformation*, *82*(June), 101899. https://doi.org/10.1016/j.jag.2019.101899

Yi, G., Jianxin, L., Hangping, Q., & Bo, W. (2014). Survey of structure from motion. *Proceedings of 2014 International Conference on Cloud Computing and Internet of Things, CCIOT 2014*, *Cctot*, 72–76. https://doi.org/10.1109/CCIOT.2014.7062508

Yurtseven, H., Akgul, M., Coban, S., & Gulci, S. (2019). Determination and accuracy analysis of individual tree crown parameters using UAV based imagery and OBIA techniques. *Measure ment*, *145*, 651–664. https://doi.org/10.1016/j.measurement.2019.05.092

Zainuddin, K., Jaffri, M. H., Zainal, M. Z., Ghazali, N., & Samad, A. M. (2016). Verification test on ability to use low-cost UAV for quantifying tree height. *Proceeding 2016 IEEE 12th Internatio nal Colloquium on Signal Processing and Its Applications, CSPA 2016*, *March*, 317–321. https://doi.org/10.1109/CSPA.2016.7515853

Zarco-Tejada, P. J., Diaz-Varela, R., Angileri, V., & Loudjani, P. (2014). Tree height quantification using very high resolution imagery acquired from an unmanned aerial vehicle (UAV) and automatic 3D photo-reconstruction methods. *European Journal of Agronomy*, *55*, 89–99. https://doi.org/10.1016/j.eja.2014.01.004

Zhang, Y., Wu, H., & Yang, W. (2019). Forests Growth Monitoring Based on Tree Canopy 3D Reconstruction Using UAV Aerial Photogram metry. *Forests*, *10*(12), 1–16. https://doi.org/10. 3390/f10121052

Zhou, X., & Zhang, X. (2020). Individual tree parameters estimation for plantation forests based on UAV oblique photography. *IEEE Access*, *8*, 96184–96198. https://doi.org/10.1109/ACCESS.2020.2994911