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Performance Analysis of Forest Canopy Height Model Generated from UAV and InSAR

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Abstract – Forest canopy height is a crucial parameter in ecosystem process modelling, yet research on generating canopy height models (CHMs) using photogrammetry method from UAV data remains limited compared to methods such as light detection and ranging (LiDAR). This study investigates the performance of accuracy and effectiveness of CHM generated from low-cost Unmanned Aerial Vehicle (UAV) via the photogrammetry method together with the well-known long-established Interferometric Synthetic Aperture Radar (InSAR). Leveraging advancements in UAV technology for three-dimensional land surface modelling, this research focuses on the Pasoh Research Station (nearby the Arboretum area) of Pasoh Forest Reserve in Negeri Sembilan, Malaysia. A series of images were captured at ten different UAV flying altitudes ranging from 120m to 500m above the mean sea level. Subsequently, CHMs were derived from both UAV and InSAR data, and compared against field measurements of tree height. The results indicate that UAV with a flying height below 200m can generate much more accurate results (with average height difference less than 10m) than InSAR (average height difference of 10.532m). It is noticeable that when comparing the InSAR-generated CHM to field measurements at lower altitudes (below 150m), the canopy height obtained from InSAR data is less accurate (more than 10m difference with field measurement) than the CHM obtained via UAV photogrammetry processing (only 5.353 m difference with field measurement). However, when UAV flying height is above 200m, InSAR data is performed more reliably. A 120m UAV flying height has a good potential to generate canopy height that is closer to the field measurement.

Keywords – *Unmanned Aerial Vehicle (UAV), Forest Canopy Height Model (CHM), Interferometric Synthetic Aperture Radar (InSAR), Flying Altitude*

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1.0 Introduction

Sustainable forest management requires an understanding of the emergence of macroscopic forest patterns. Forest canopy height is important in indicating forest biomass, diversity of species, site quality, and several other functions of the ecosystem (Dinca & Zhiyanski, 2023; Tao et al., 2016; World Bank, 2019). Forest canopy structure and forest stand attributes are increasingly recognized in understanding and managing forest ecosystems as being of theoretical and practical importance. The canopy height as the primary attribute of the vertical structure is essential information for many forest management activities and is a crucial parameter in ecosystem process models (Lu et al., 2016; Norby et al., 2021).

Forest canopy height refers to the height of the highest vegetation components above ground level, and is essential for studying micrometeorological phenomena over forests and forest-atmosphere interaction. Forest canopy height is also required in estimating forest biomass and carbon pools (Berninger et al., 2019). According to Zhang et al. (2016), forest canopy height which acts as a product and driver in the ecosystem mechanism has significant effects on the distribution of biomass, carbon accumulation, forest productivity together with plant and animal diversity. Canopy height shows a high variation in geographic location. The ranges of height are from more than 50 m in Asian dipterocarp forests, Australia's eucalypt forests and North American west coast temperate conifer forests to less than 20 m in many boreal forests (Mitchell et al., 2021)。

Forest canopy height can be extracted by using remote sensing techniques. As remote sensing techniques are efficient methods because of their fast data acquisition, processing and analysis, numerous studies have attempted to estimate forest height by these data such as Light Detection and Ranging (LiDAR), optical images, and Synthetic Aperture Radar (SAR) (Hao et al., 2023). The rapid developments in UAV technologies have made them an attractive alternative for acquiring high-resolution data at local scales. Compared to the resolution of aerial images (1m resolution) or satellite data (2–30 m resolution), UAV images tend to have spatial resolutions of 5 - 15 cm due to a lower altitude of acquisition (Zhang & Zhu, 2023). Besides, UAV offers the ability to control the image acquisition process and timing and can obtain overlapping images to the user's specifications. Similar to aerial- and satellite-based spectral data, UAV images can be used for classifying vegetation types and estimating forest canopy cover (Shin et al., 2018). In forestry, these small autonomous machines can be remotely operated from the ground and can fly below the cloud cover. Low-altitude imagery can be obtained from UAV to characterize forest ecosystem structure through a Canopy Height Model (CHM) (Valluvan et al., 2023).

According to Berninger et al., (2018), SAR sensors also allow forest structural variables estimation as microwave signals can penetrate vegetation and are less attenuated by clouds, smoke, and solar illumination effects relative to LiDAR. He also stated that L-band backscatter is the most widely available spaceborne SAR and has been useful for characterizing tropical forest structures due to its relatively long wavelength (23 cm). Non-forest vegetation usually exhibits lower L-band backscatter compared to well-structured forests, facilitating the mapping of forest/non-forest areas. InSAR with L-band has also shown utility for estimating canopy height in a range of forest types (Fagua et al., 2019).

The study of forest canopy height is an essential part of the broader data needed to maintain biodiversity. The Forest canopy height model can help in collecting forest inventory data such as tree height, diameter, biomass, site quality, and others. The project's goal is to compare the different methods to retrieve forest canopy height. The methods used include UAV imagery and Interferometric SAR (InSAR) data. UAV imagery is obtained from different flying altitudes which are 120m, 150m, 180m, 200m, 250m, 300m, 350m, 400m, 450m and 500m. All the data will be compared to the field measurement to find out which is the most suitable to use in the study forest canopy height in the study area.

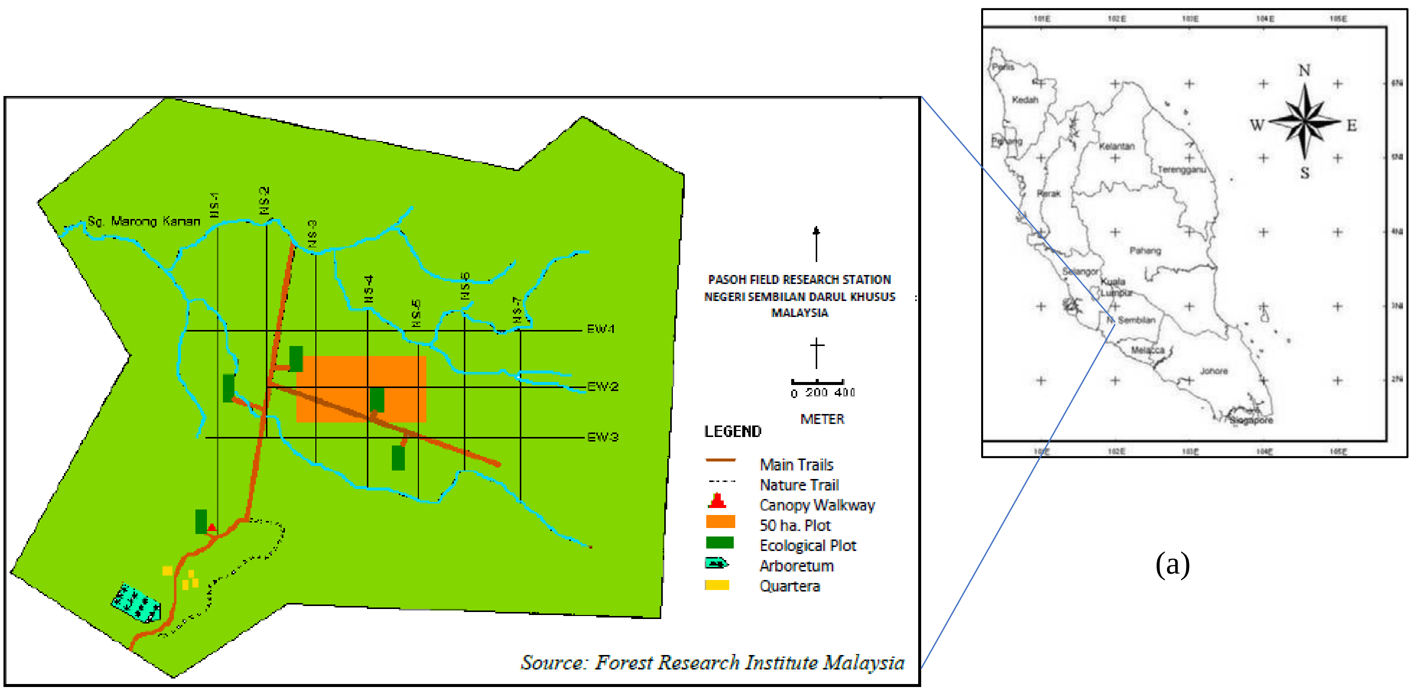
2.0 Materials and Methods

The project consists of five phases. In the first stage, based on reading and extracting literature information, the project problem statement, purpose, objective and research field are planned and defined. In the second stage, data acquisition of the RGB images of the UAV at different flight altitudes, and a set of airborne NEXTMap™ InSAR dataset which covers the study area with DSM and DTM (as by-products) in 1-meter spatial resolution. In the third stage, UAV data preprocessing and orthomosaic of UAV RGB image data was performed and tree canopy height was calculated. In the fourth stage, the tree canopy height data measured in the field were used to verify the accuracy of the tree canopy results obtained from UAV RGB images at different flight heights and

InSAR images. In the fifth stage, the results of each data in the previous stages were analysed and compared, the best selection method for measuring tree canopy height is then suggested.

2.1 Study Area

Pasoh research plot (2°59′ N, 102°18′ E) (as illustrated in Figure 1) is an ecological research site that was established on 1994 in Pasoh Forest Reserve. Pasoh Forest Reserve is in the centre of Peninsular Malaysia and is located in the district of Simpang Pertang, Negeri Sembilan. Pasoh Forest Reserve is a nature reserve. It is located about 8km from the town of Simpang Pertang and 70 km southeast of Kuala Lumpur (Okuda et al., 2003; Alyousifi et al., 2020).



(a)

(b)

Figure 1. Study area; (a) location map, (b) the detailed plan of Pasoh Forest Reserve.

Pasoh Forest Reserve is a lowland dipterocarp forest, a type of evergreen tropical moist forest. It is categorized as a tropical rain forest. Pasoh Forest Reserve has a total area of 2450 hectares. In the reserved forest, there are more than 800 tree species (Kochummen et al, 1990, Manokaran et al, 1991). Pasoh Forest Reserve has an average of 1800 mm of rainfall each year (Marryanna et al, 2017), which is comparably low in Malaysia. However, the low rainfall does not affect the development of the forest because of the fairly even distribution of the rain throughout the year. According to Burgess (1972) and Numata et al (2013), the inland dipterocarp forest in Pasoh Forest Reserve is relatively dry compared to both east and west sides of Peninsular Malaysia (Okuda et al., 2003; Kochummen et al., 1989).

2.2 Data Acquisition

Two remotely sensed datasets, namely NEXTMap ™ InSAR and UAV RGB data were used to calculate canopy height using the Canopy Height Model (CHM). The DSM data came as a by-product with NEXTMap InSAR data and contains elevation of natural features including vegetation and man-made features such as buildings etc while the DTM data provides elevation of the bare earth where surface features such as vegetation and man-made features such as buildings etc have been removed.

RGB UAV images of the study area (Pasoh Research Station office and nearby the Arboretum area) were acquired using DJI Phantom 4 PRO V2 at multi-altitudes, namely 120 m, 150 m, 180 m, 200 m, 250 m, 300 m, 350 m, 400 m, 450 m and 500 m. The DJI Phantom PRO V2 onboard camera features a 1-inch 20MP CMOS sensor and a mechanical shutter, which eliminates rolling shutter distortion.

2.3 Data Processing

2.3.1 Data Pre-processing and Orthomosaic of UAV images

Commercial software was used to pre-process the UAV images acquired (Figure 2). Pre-prosessing steps performed (Figure 3) include (1) Loading of UAV photos, (2) Photo Alignment, (3) building of dense point cloud, (4) Building DEM, and lastly (5) orthomosaic of the final images.

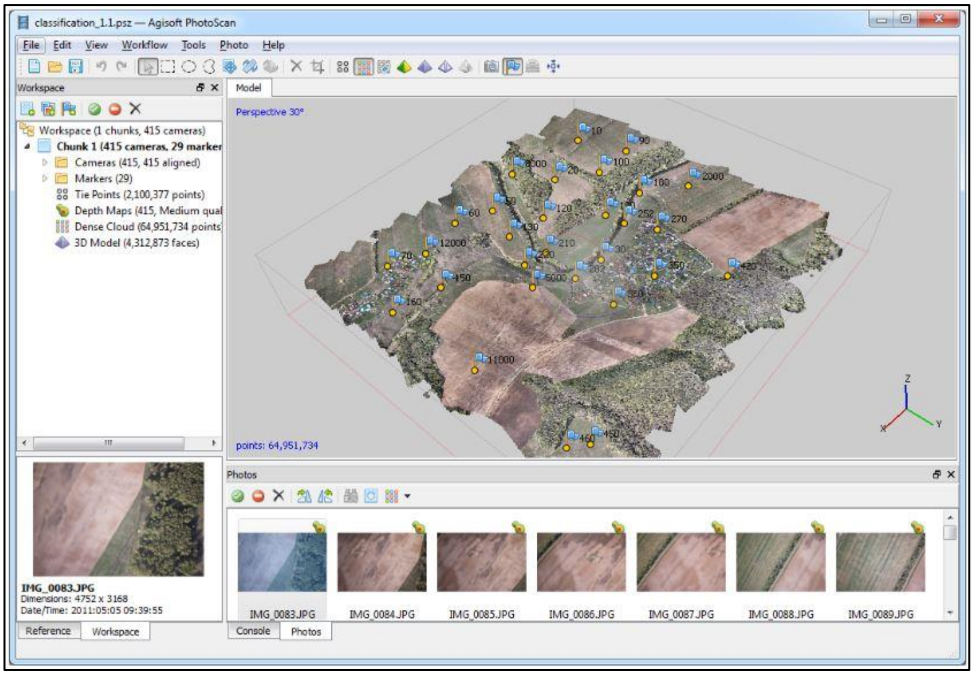


Figure 2. Commercial software used **(**Agisoft Metashape Professional)

UAV images taken were used as a source for 3D reconstruction. Once all the photos were loaded and aligned, the camera position and orientation for each photo were used to build a sparse point cloud model. Based on the estimated camera positions in the earlier stage, the program calculates the depth information for each camera so that the information in each photo to be combined into a single dense point cloud. A dense point cloud was then edited and classified and used as a basis for following processing stages such as Build Mesh, Build DEM, and Build Tiled Model (Pahari, 2023). DEM generated earlier was then rasterized from a dense point cloud, a sparse point cloud or a mesh. A DEM represents a surface model as a regular grid of height values. Most accurate results are calculated based on dense point cloud data (Polidori & El Hage, 2020). Digital elevation models (both DSM and DTM), as well as tiled models, were generated according to the user requirements (Burnham, 2019).

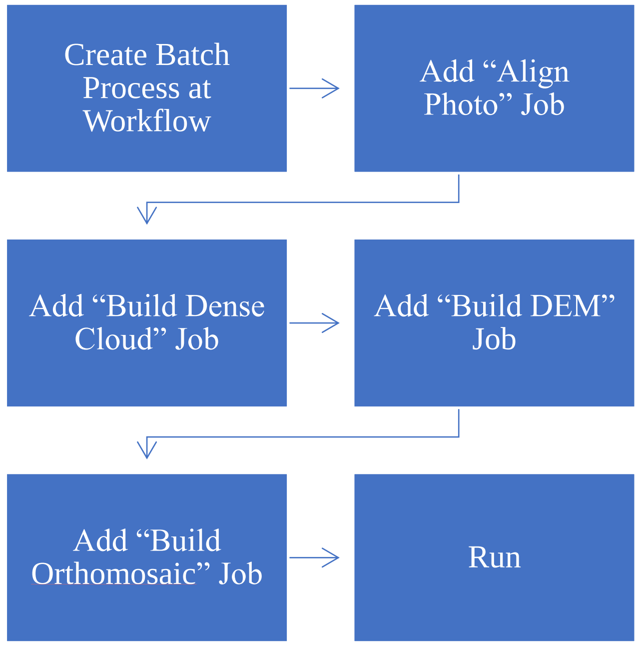
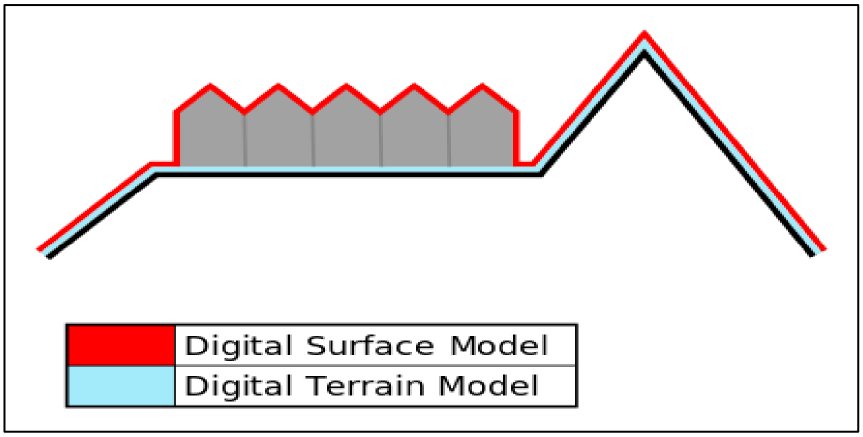


Figure 3. Steps in pre-processing of UAV images

2.3.2 Canopy Height Modeling (CHM)

To determine canopy height, the bare earth surface (DEM) is needed to subtract from DTM (Schlund et al., 2023). After adding all the necessary layers, the "Raster Calculator" in ArcGIS Spatial Analyst tool was used. "Raster Calculator" built and executed a single Map Algebra expression using Python syntax in a calculator-like interface. Map Algebra expression was composed by specifying the inputs, values, operators, and tools to use to calculate the canopy height.

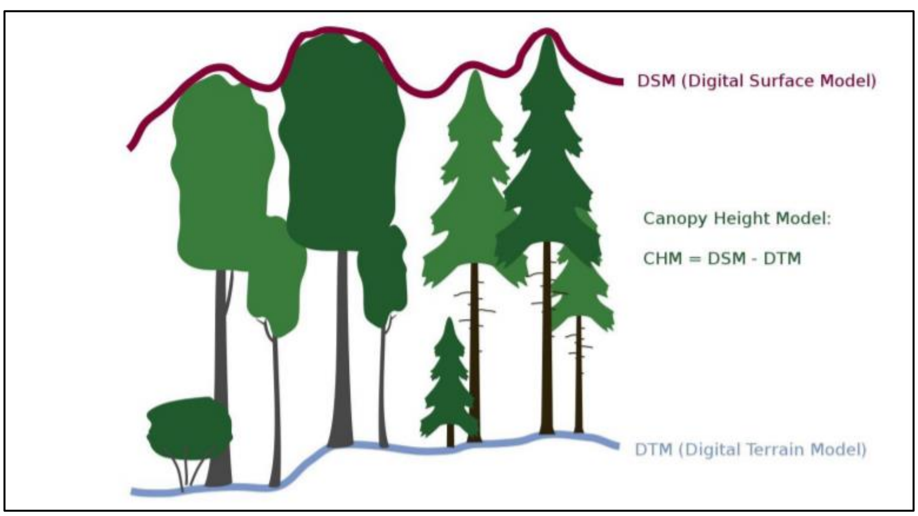
The Digital Surface Model (DSM) describes the height of trees, buildings, and other features above the bare ground. It can be said that DSM is an elevation model of bare ground terrain with features on it. It is important to distinguish between DTM and DSM (Watson, 2020), one is to use a suitable model in the study. As DSM contains the elevation data of features on the Earth's surface, it is useful in landscape modelling, city modelling and visualization applications (see Figure 4).



(Source: Wikipedia, 2024)

Figure 4. Different between DTM and DSM in 2D view

CHM describes the height of the trees. It is not an elevation value, but the height or length from the bare ground to the top of the trees (see Figure 5). CHM can be derived by subtracting the bare ground elevation which is DTM from the elevation of the top of the surface which is known as DSM (Liu et al., 2021).



(Source: Ahmad et al, 2017)

Figure 5. Relationship between DTM, DSM and CHM

2.4 Field Data Validation

Validation of the forest canopy height was done by comparing field measurements of the heights of trees with the canopy height generated from aerial images. Trees that are easy to recognise crowns on the aerial images were selected and their height was measured. The tool Nikon Forestry Pro (Figure 6) was used for measuring canopy height in the field and a total of 40 sampling points were collected from the field campaign.

(Source: Nikon Website, 2011)

Figure 6. Nikon Forestry Pro

3.0 Results and Discussion

3.1 Results Obtained from UAV and InSAR

The forest canopy height produced from UAV and InSAR data were in the raster image. Figure 7 shows the forest canopy height generated from a UAV with 120m flying altitude in a raster image after going through the filtering process. The colours in the image represent the value of height. Each colour has its value. The green colour gradient represents the height value from lowest (dark green) to highest (dark green). As we can see in the image, there are blank spaces. The blank space shows that there are no trees in that area. It is because when we subtracted DTM from DSM, the result did not show positive values in that area.

Figure 7. Forest canopy height generated from UAV with the flying altitude of 120 m in the raster image

Figure 8. shows the overlay of forest canopy height generated, the location of trees and the orthophoto of the study area. We can see that the blank spaces are mostly open spaces which include roads and buildings. The red colour dots represent the trees. The canopy height of each tree in every different UAV flying altitude and InSAR data are recorded in a table.

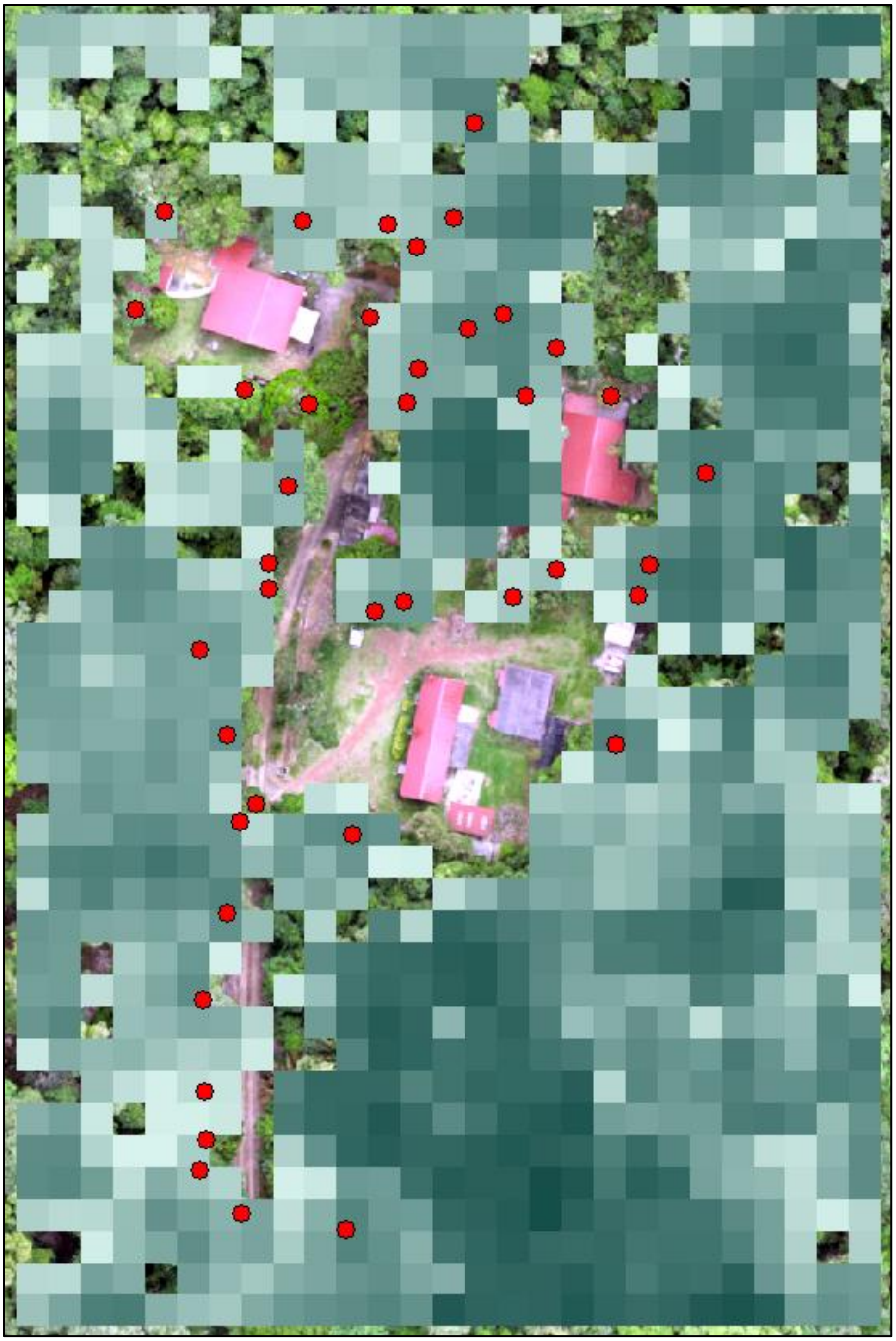


Figure 8. Overlay of forest canopy height generated, location of trees and orthophoto of study area

Table 1 and Table 2 show the canopy height extracted from UAV (flying at various altitudes from 120 m to 500 m) and InSAR data respectively.

Table 1. Canopy height extracted from UAV at 120m, 150m, 180m, 200m, 250m, and 300m flying altitude.

Tree	120m	150m	180m	200m	250m	300m
1	17.030	15.552	16.093	13.298	13.715	10.823
2	16.603	12.768	16.093	13.298	13.715	10.823
3	8.344	5.948	4.310	3.312	2.547	2.958
4	8.724	4.285	4.538	2.165	2.152	1.360
5	14.676	14.391	12.646		10.837	4.623
6	20.649	21.202	18.062	11.526	16.676	12.751
7	24.255	20.558	20.437	17.542	18.742	17.139
8	14.268	12.988	11.953	9.811	11.559	9.497
9						
10	21.728	20.065	20.826	18.312	17.900	16.976
11	20.842	17.058	16.633	15.575	1.833	14.725
12	18.235	11.754	10.156	9.173	4.990	8.606
13						
14	18.115	11.166	7.043	8.793	9.131	9.200
15	19.057	15.860	7.220	4.174	13.635	12.006
16	19.744	14.319	16.922	14.408	13.985	13.528
17	3.825		0.656			
18	6.865		1.132	1.266	1.505	
19	8.463		5.478	5.727	2.929	2.744
20	14.834		11.662	9.263	9.702	6.568
21	21.694		17.435	15.724	15.737	14.851
22	15.471	12.842	12.280	10.328	11.204	9.849
23	6.596	5.391	2.135		2.000	
24	14.187	10.348	11.589	8.748	10.008	8.520
25						
26						
27	13.639	12.606	10.932	7.652	12.158	11.664
28						
29	8.450		2.863		1.551	
30	12.042	7.444	8.388	6.715	6.984	6.029
31	20.080	18.390	16.497	14.296	13.904	13.218
32	13.539	11.636	10.501	8.513	9.818	7.909
33	6.827	4.934	4.874	2.227	3.032	1.554
34	11.934	6.529	5.902	2.099	3.908	4.913
35	15.555	13.059	11.851	11.024	10.435	9.385
36	22.811	20.243	17.331	17.890	12.738	15.137
37	21.824	18.219	17.742	16.510	16.153	15.120
38	4.714					
39	6.596		2.135		2.000	
40	22.618	12.772	19.556	17.436	17.431	15.848

Table 2. Canopy height extracted from UAV at 350m, 400m, 450m, 500m UAV flying altitude and InSAR data

Tree	350m	400m	450m	500m	InSAR
1	13.918	10.099	8.922		12.107
2	13.918	12.064	8.922	6.920	7.759
3	3.995	1.036			9.538
4	1.083	0.365			8.783
5	15.972	13.734	14.441		10.729
6	16.815	15.393	14.072	7.469	13.952
7	17.075	15.493	14.076	10.798	9.362
8	10.951	10.110	6.742	3.951	6.142
9					9.554
10	16.166	15.269	10.535	9.556	4.695
11	12.406	13.652	12.136	9.065	10.834
12	4.411	10.353	2.589	1.894	9.780
13					
14	2.814	11.241	3.983	4.783	12.396
15	13.592	11.318	0.793	8.602	14.966
16	14.426	12.217	11.056	7.475	14.465
17	0.066				13.508
18					4.883
19	4.424	3.293	0.650		6.293
20	5.641	6.060	3.501	1.892	11.690
21	13.758	14.320	12.052	9.853	9.289
22	10.573	8.955	7.501	4.057	10.958
23		0.359			11.180
24	8.251	7.641	4.775	2.445	7.161
25					6.339
26					7.795
27	15.540	9.241	16.459	9.138	5.595
28					5.248
29					1.883
30	5.521	4.261	2.208		12.136
31	13.540	12.954	10.771	7.594	4.473
32	8.101	7.230	3.878	2.117	3.917
33	3.140	0.757			13.390
34	6.270	3.953	3.850		9.538
35	12.089	10.416	9.044	3.688	11.026
36	15.109	14.229	11.267	8.659	12.573
37	13.576	13.131	9.111	8.152	4.267
38					2.361
39		0.359			11.180
40	17.265	15.583	12.953	5.865	7.325

3.2 Discussion

The canopy height generated from UAV and InSAR data were then compared to the field measurement to validate the result. Figure 9 shows the canopy height (in m) measured from field measurement, UAV and InSAR data.

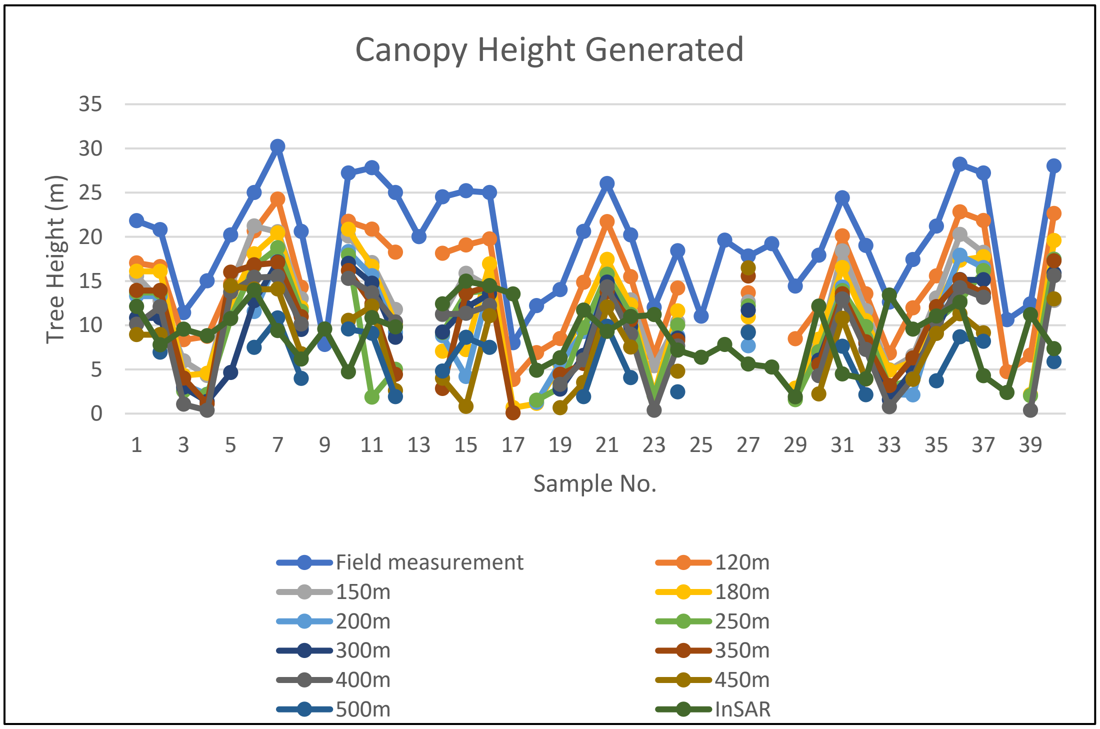


Figure 9. Canopy height obtained from field measurement, UAV and InSAR data

From the graph above (Figure 9), the highest line (blue colour) is the canopy height obtained from field measurement. It is noticeable that the orange colour which is the canopy height generated from 120 m UAV flying altitude is closer to the field measurement. The pattern of the graph of this line is very similar to the one collected from field measurement.

There are some missing canopy height data from those canopy height generated from UAV data due to those trees being located at the roadside where the information may be lost during the processing step. UAV data is collected in raster form and during the processing, the value assigned to the pixel is replaced by one of its surrounding pixels. It can be further explained that for those missing canopy height data, the road data had been wrongly assigned to the canopy pixel and therefore, the height for some canopies cannot be retrieved.

It is noticed that more individual canopy heights were generated from InSAR data compared to UAV data. However, when comparing to the field measurement, canopy heights generated from InSAR are quite different from the data collected from field measurement and the graph pattern is slightly different too (see Figure 9).

3.2.1 Difference in Canopy Height between UAV and InSAR Data to Field Measurement

From the canopy height generated, the difference between every canopy height retrieved and their respective field measurement was calculated. Table 3 shows the average height difference obtained from every UAV flying altitude and InSAR data relative to the field measurement.

From the table, it can be said that canopy heights obtained from UAV flying altitudes of 200m to 400m do not have much difference (see Figure 10). All of them are about 11m lower than the canopy height from field measurement. Canopy height extracted from UAV flying altitudes of 450m and 500m have 14.419m and 17.539m difference from the field measurements respectively. Hence, we can conclude that the accuracy drops when the UAV flying altitude increases.

Canopy height obtained from UAV flying altitudes 120m, 150m and 180m having low height difference. This shows that the result is closer to the field measurement and the canopy height extracted is more reliable.

Table 3. Average height difference obtained from every UAV flying altitude and InSAR data to the field measurement

Type of Data	Average Height Difference (m)
UAV 120m	5.353
UAV 150m	8.580
UAV 180m	9.345
UAV 200m	11.303
UAV 250m	11.181
UAV 300m	11.872
UAV 350m	11.006
UAV 400m	11.997
UAV 450m	14.419
UAV 500m	17.539
InSAR	10.532

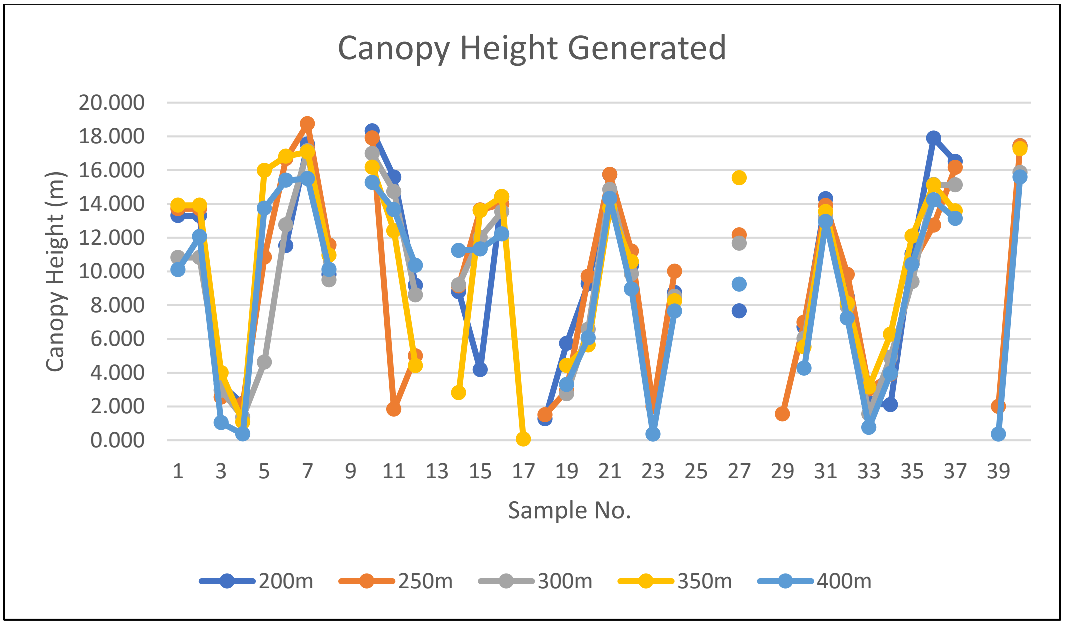


Figure 10. Graph of canopy height generated from UAV 200m to 400m flying altitude

3.2.2 Comparison Canopy Height Obtained from UAV at 120m, 150m, 180m flying Altitude and InSAR Data

When comparing InSAR data to UAV data (Figure 11), UAVs with a flying height below 200m can generate much more accurate results than InSAR. However, when UAV flying height is above 200m, InSAR data is somehow more reliable.

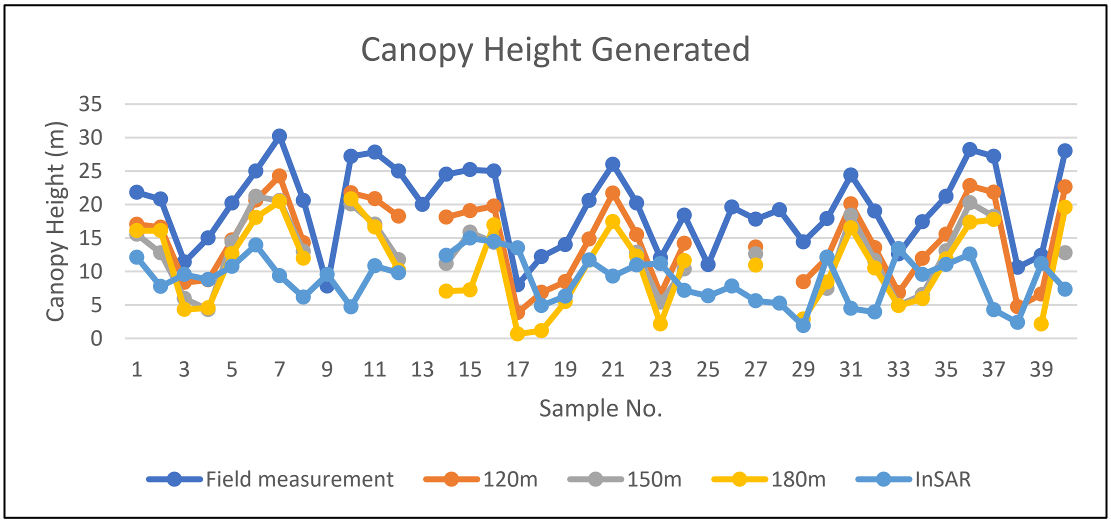


Figure 11. Graph of canopy height generated from UAV flying altitude of 120m, 150m, 180m and InSAR data

By comparing all the UAV data collected from 120m, 150m and 180m UAV flying heights (the lower the UAV flying height, the higher accuracy at the spatial resolution), every detail in the imagery can be seen and this enables more accurate canopy height result to be generated compared to other flying altitude when validated the result with field measurement.

4. Conclusion

This study has made a fair comparison and analysis of the canopy heights generated from UAV and InSAR data. From the results obtained, it was proven that UAV at 120 m flying height has a good potential to generate canopy height which is comparable to the field measurement. As the canopy height is the primary attribute of the vertical structure, it is important information for many forest management activities. Therefore, to obtain more precise canopy height, UAV and photogrammetry technologies can be used at low flying altitudes. The approximate height of the trees available in the study area needs to be considered too during the flight planning phase to avoid UAV flies lower than the trees. For this study area, it is suitable to use a flying height of 120 m (60–80-meter gap between the highest canopy and UAV).

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