TREE HEIGHT DERIVED FROM POINT CLOUDS OF UAV COMPARED TO AIRBORNE LASER SCANNING AND ITS EFFECT ON ESTIMATING BIOMASS AND CARBON STOCK IN TROPICAL RAIN FOREST O F MALAYSIA

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ABSTRACT: Forests occupy about one-third of the land area of the earth and have been playing crucial role in regulating the adverse effect of increased emission of greenhouse gasses. Tropical rain forests have higher capacity to sequester carbon dioxide and hence play a role in stabilization of the concentration of greenhouse gasses in the atmosphere. Forest inventory parameters require accurate information for biomass and carbon stock estimation. However, acquiring of forest inventory parameters data especially tree height for estimation of biomass and carbon stock is often a major challenge in tropical forest. A conventional method that is data acquisition using handless tool is tiresome, labor intensive, not applicable in large area and cumbersome approach due to the complexity of tropical forest. On the other hand, data collection using LiDAR technology, is expensive and therefore not readily available. However, rapid advancement in photogrammetry technology in both hardware (i.e., Unmanned Aerial Vehicle) and software (i.e., image matching algorisms) led on data acquisition of fine spatial resolution imagery of less than a meter with notably improved revisit time at affordable cost. Therefore, this study aimed to assess the accuracy of measuring tree height using drone in comparison to that of Airborne LiDAR and assessing its effect on estimating forest biomass and carbon stock.

1.0 INTRODUCTION

1.1 Background

Forests occupy about one-third of the land area of the earth and play crucial role in regulating the adverse effects of increased emission of greenhouse gasses in the atmosphere. Trees and forests play an important role in human livelihoods, as well as in ecosystem services and health. Among ecosystem services offered by the forest include regulation of hydrological cycles, mitigation of global climate change, recreation and biodiversity conservation. Therefore, sustaining these services under increasing community demand depends on effective forest management, which is in turn based on concrete scientific understanding of the natural processes of carbon cycling. Forests play a crucial role in the global carbon cycle, and forest vegetation and soils comprise about 60% of the total terrestrial carbon stock. Furthermore, Gibbs et al. (2007) emphasized that forests sequester and store more carbon than any other terrestrial ecosystem and therefore play potential role in regulating the effect of climate change.

The role of tropical forests in global climate change, especially the carbon cycle and its relation to the greenhouse effect, has increased interest in estimating the biomass density (Henry et al., 2011). Because of their high carbon density, tropical forests are increasingly viewed as the place for mitigation of climate change. In an effort to reduce deforestation and degradation by creating monetary value for the carbon in forests, the United Nations Framework Conversion on Climate Change (UNFCCC) introduced Reduce Emission from Deforestation and Forest Degradation (REDD+) program in developing countries as strategy to regulate the effect of greenhouse gasses in the atmosphere (Gibbs et al., 2007). One important component of REDD+ is Measuring Report and Verification (MRVs). This mechanism refers to prolonged measurement and collection of data on the anthropogenic forest related greenhouse gas emissions. In addition to that Henry et al. (2011) argued that because of interest in the global carbon cycle, estimating aboveground biomass with the required accuracy to establish the increase or decrease of carbon stored in forests is very important. However, they stated that the largest errors in estimates of the terrestrial carbon balance are believed to result from uncertain rates of tropical deforestation.

According to Angelsen (2009), global initiative aimed to reduce the impact of climate change through establishing reducing emissions from deforestation and forest degradation, and enhancing forest carbon stocks in developing countries

(REDD+) which involve payment for environmental services (PES). The UNFCCC signed by 150 countries to conventionally commit to have an update, publish and make available their national assessment of the forests, however, the current review indicated that very few countries meet the minimum ability needed for MRVs (Angelsen, 2009). Most of developing countries have limited capacity to assess accurately their biomass and carbon stock. Nabuurs et al. (2008) explained that for biomass and carbon estimation, the inventory-based approach is conducive and reliable. Therefore, REDD+ established measurement report and verification (MRVs) as a way to quantify biomass pools in which above ground biomass is the part of it. In order to assess above ground biomass and carbon stock REDD+ through MRVs require accurately data measurements of the forest parameters, which is important for accurately estimation of the AGB and carbon stock (IPCC, 2014). The accurate methods on estimating AGB in REDD+ scheme especially on evaluating the baseline for national carbon has been stated by (Gibbs et al., 2007; Chave et al., 2014).

1.2 Research Problem

Tree height and Diameter at Breast height (DBH) are important parameters of the forest that used as input in the allometric equation for quantification of forest biomass and carbon stock. Andersen et al. (2006) reported that tree height is one of essential variable in the quantitative assessment of forest biomass and carbon stocks. The estimation of biomass and carbon stock, inclusion of tree height in the model can significantly improve the accuracy of estimating carbon stock. Tree height can be estimated in forest stand, however, the activities would be tedious, time-consuming and costly. Previous work has shown that the inclusion of height in biomass allometries, compared to the sole use of DBH, would significantly improve biomass estimation (Hunter et al., 2013). Several studies have been carried out to measure or estimate tree height. These techniques range from traditional field work using hypsometers to the more advanced approaches of using remote sensing. In the traditional field work, measuring tree height is generally more cumbersome and time consuming due to intermingling of the crown of the trees. Direct measurement of forest parameters for estimation of aboveground biomass is expensive and therefore the measurements are limited to 10-year intervals (Houghton, 2005). In the controlled field experiment which was done prior to this research where observers were measuring tree height at different distance from the tree, it was revealed that there were variations in tree height measurements reported by different observers. The error was attributed to the increase in the distance from the tree, obscured of tree top due to occlusion of the crown of the tree.

In remote sensing, Airborne LiDAR System (ALS) has been used as a fundamental remote sensing technique to estimate tree height and consequently carbon stock. ALS and space satellite are remote sensing technique which has been used to estimate aboveground biomass and subsequently carbon stock. Sadadi (2016) reported that ALS was considered the most accurate and efficient way of assessing field measured tree height and subsequently biomass and carbon stock. His results revealed that RMSE of the field measured tree was 4.2 m (21.45%) when compared to ALS estimated tree height and coefficient of determination was 0.61. The fact that ALS is the most accurate and efficient way of assessing tree height provided reliable DTM is available, but LiDAR is an expensive tool and therefore not readily available.

Recently, advances in photogrammetry image matching of UAV 3D point cloud extraction technology from very high-resolution images potentially offer a cheap and flexible alternative for ALS. Fritz et al. (2013) stated that, compared to other platforms such as airborne sensors, UAV shows comparatively low costs for acquisition of information and high flexibility with Unmanned Aerial Vehicles (UAVs) devices led to intense research in this field. Currently, UAVs have developed to off the shelf platforms for remote sensing applications and photogrammetric data acquisition (Fritz et al., 2013). UAV provide extremely fine resolutions and thus allow the identification of previously undetected object details, and images are rarely affected by cloud cover because flying altitudes are usually low. Flight missions can be timed very flexible and they are very cost-effective (Getzin et al., 2012; Fritz et al., 2013). UAV imagery is characterized by a high image overlap and therefore, has the potential to accurately model the canopy surface and tree height at a very high spatial and temporal resolution (Lisein, et al., 2014). Many types of research have been done in estimating AGB using UAV in temperate forest and very little in tropical forest. Limited numbers of research have been comparing UAVs from ALS and assess its accuracy in AGB estimation, especially in tropical forest. The main objective of this research is to investigate the accuracy of tree height extracted from 3D point clouds of photogrammetry image matching or Structure from Motion (SfM) of UAV images in comparison to tree height measured with ALS data and assessing its effect on estimation of biomass and carbon stock.

1.3 Study Area

This research was carried out in Ayer Hitam Tropical Forest Reserve which is located in the state of Selangor, Peninsular Malaysia (Figure 1). The study area was selected in order to demonstrate the applicability of the Structure from Motion technique in comparison with LiDAR in estimation of tree height and consequently biomass and carbon stock in tropical forest. This is because of the fact that many study have been conducted in the temperate forest. Limited researches have been conducted in tropical forest. Additionally, availability of ALS in Ayar Hitam Forest Reserve was important for area consideration. Geographically Ayer Hitam Forest Reserve lies between Latitude of 2°56'N - 3°16'N and Longitude of 101°30'E - 101°46'E. It is 20 km and 45 km away from University Putra Malaysia (UPM), and from the city of Kuala Lumpur respectively (Hasmadi et al., 2008). According to Nurul-Shida et al., (2014), Ayare Hitam Forest Reserve is among three left lowland dipterocarps tropical forest reserve in Klang valley. It is currently surrounded by residential buildings and modern infrastructures which make it isolated and hinder ecological connectivity with another forest. Since 1996 the forest has been leased to the Faculty of Forestry, University Putra Malaysia by Selangor State Government. Initially, Ayare Hitam Forest Reserve was logged. The main reason was encroaching forest area for other development activities such as building residential areas, new township, factories highways, agriculture activities and over exploitation of forest resources for social economic development projects (Nurul-Shida et al., 2014) . Ayare Hitam Forest Reserve was logged-over forest, however, now is yet to attained its restoration state. It is the only lowland forest reserve found in Selangor state so far, at the beginning the forest area was 4270.7 ha in 1906, however, the remaining forest is 1248 ha which has 6 administrative compartments (Nurul-Shida et al., 2014).

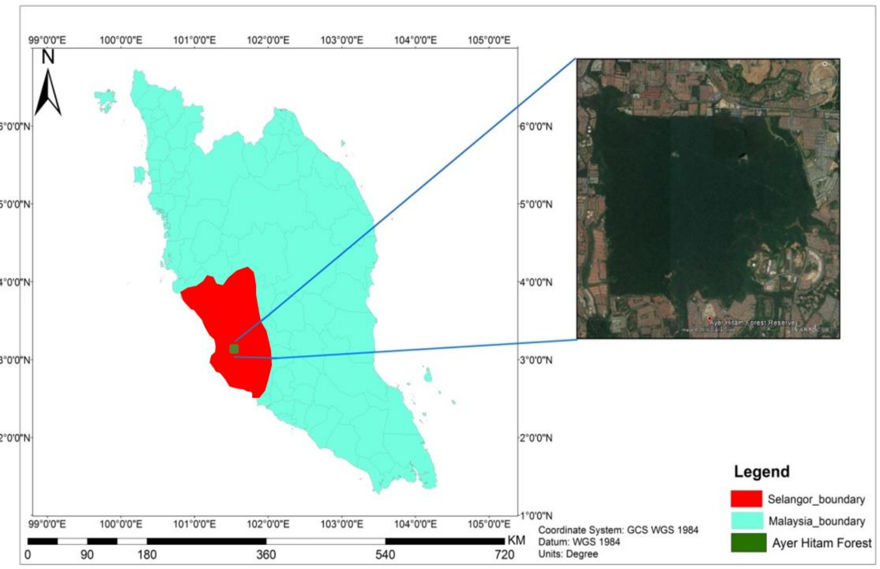

Figure 1. Location map of the study area

2.0 MATERIALS AND METHODS

2.1 Data Used

In this study, three main datasets were acquired, which include UAV, Airborne LiDAR and biometric datasets. The UAV data were acquired by using Phantom-4 DJI, after placing ground control points. The acquired UAV stereo images were used to generate photogrammetric products such as digital surface model, digital terrain model and ortho-mosaic images. The available airborne Lidar Dataset was also used to generate height canopy model from subtraction of DTM from DSM. The biometric dataset was collected by using field equipment such as diameter tape, Leica DISTO 510, global position system and measuring tape.

2.2 Methods

The methods in this study consist of four parts (Figure 2) namely:

1. UAV data acquisition and processing
2. LiDAR data processing
3. Field data collection and process
4. Comparing results and sensitivity analysis

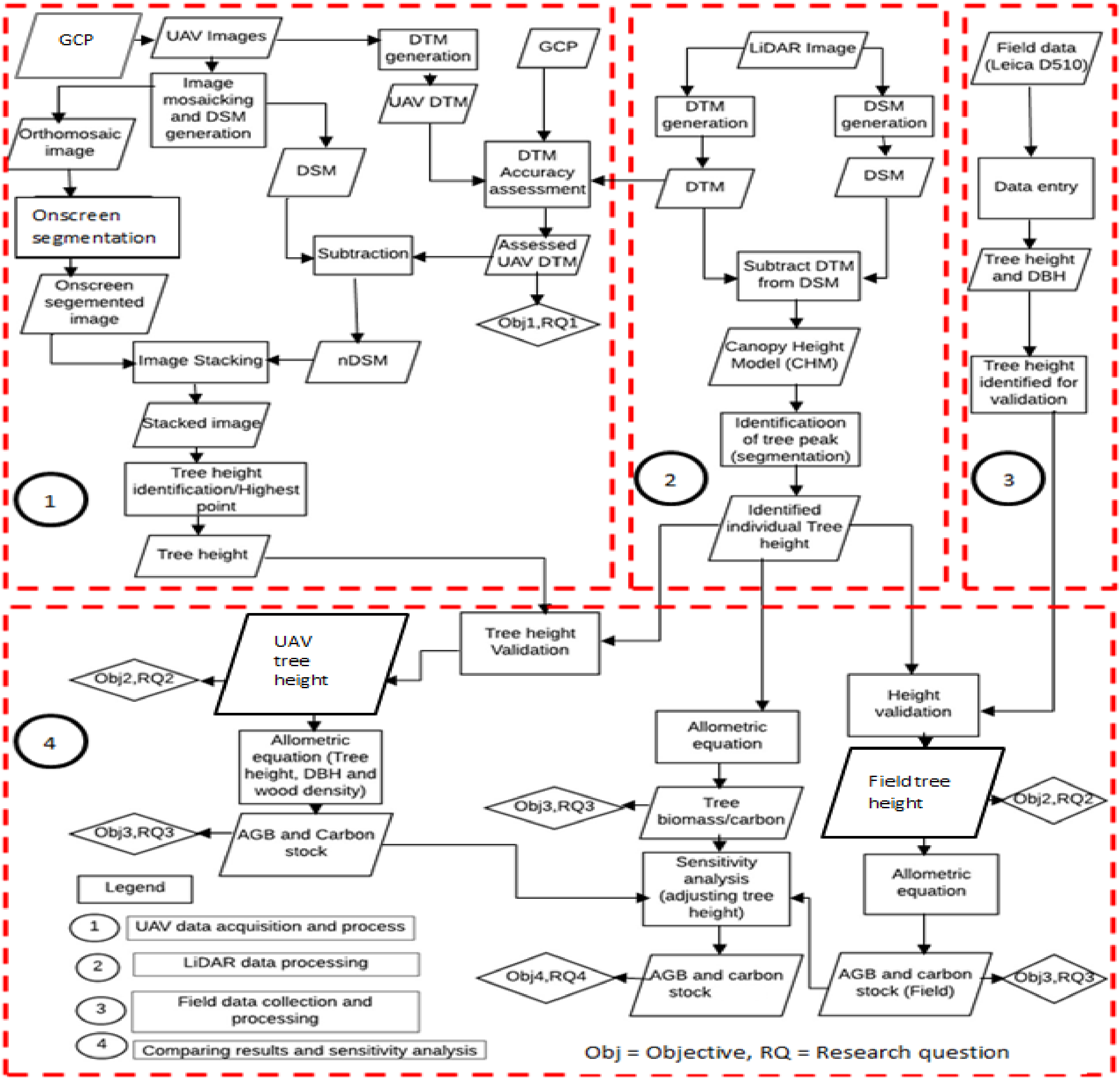

Figure 2. Flowchart of the methods used in this research

The UAV dataset used in this study consists of the imagery acquired in six areas in Ayare Hitam Forest Reserve. The flight areas were identified based on the availability of open space for placing ground control points and the time the UAV can be airborne in relation to the battery capacity. The Pix4D (capture and Pix4D Ctrl DJI) smartphone based software was used for preparation of UAV flight plan. For all six flights, the parameters used in collecting the images are listed in Table 1. Figure 3 shows the UAV flight planning areas and UAV settings.

A Ground Control Point (GCP) is a marking on the ground where x, y and z were measured with high precision using Differential Global Position System (DGPS). Accurate GCP are required for the geometric correction of the UAV images. In this study UAV flight areas were identified in such a way that all areas have had enough open spaces at its corner point for placing ground control. Ground control points were marked on the ground using white and black spray paint to provide good contrast and ensure visibility in the UAV images when it was flying at 80 m altitude. The GCP were marked in every corner of the identified flight areas, four points were marked in each flight.

Table 1. Parameter used for UAV data collection

Parameter	Value
Speed	Moderate
Angle	90 (Nadir)
Overlap	80%
Side Overlap	60%
Altitude Area 1 till 4 and 6	80 m
Altitude area 5	90 m (to avoid collision with surrounding buildings)

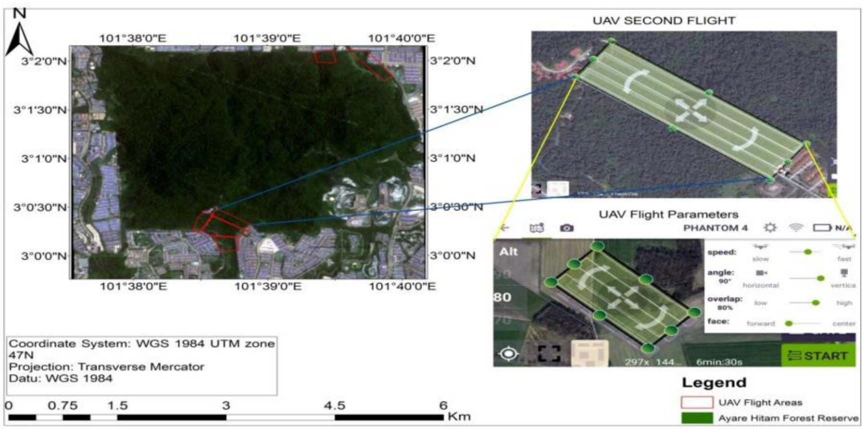

Figure 3. UAV flight mission and parameters set in the study area.

Processing of images with Agisoft PhotoScan consists of the following steps:

- loading photos into PhotoScan, inspecting uploaded images, removing unnecessary images,
- aligning photos,
- building dense point cloud,
- building DSM,
- building, ortho mosaic
- building DTM

The building of dense point clouds allows calculation of depth information, which is required for the generation of ortho-mosaic images, DSM and DTM. In order to achieve the best possible geometric accuracy the “high quality” setting of the software was applied. After building the dense point clouds and 3D polygonal model the software can generate a Digital Surface Model (DSM), Orthomosaic image and Digital Terrain Model (DTM) (Figure 4 a,b&c). A DSM represents a surface model as a regular grid of height values. DSM can be rasterized from a dense point cloud, a sparse point cloud. A software enables to perform DSM based point, distance, area, volume measurements as well as generate cross -sections for a part of the scene selected by the user. The building up of ortho-mosaic image was important because mosaic image was used in onscreen segmentation process and matching of individual trees. This was possible because the ortho mosaicked image had very high resolution.

AGISOFT software allows for the automatic generation of a digital terrain model (DTM). In this process, dense point clouds were classified into two classes viz “ground” and “the rest”. The technique of identifying ground points from 3D point clouds is often referred to as ground filtering or bare-earth extraction (Wang et al., 2009).

Figure 4. DSM (a), Orthomosaic (b) and DTM (c) for first flight

3.0 RESULTS AND DISCUSSION

3.1 DTM and Tree Height Assessment

The relationship between Airborne Lidar and photogrammetric image matching DTM were established in order to assess the influence of photogrammetric image matching error in tree height estimation. This was done by comparing tree height measured by ALS and tree height estimated by photogrammetric image matching at a point where photogrammetric image matching DTM was close in height (RMSE = ±0.19 m and RMSE% = 0.5%) to Airborne LiDAR DTM. At this point, 93 trees were used to evaluate the effect of differences in tree height. The relationship was explained by correlation coefficient and coefficient of determination which was 0.89 and 0.799 respectively. The RMSE of the tree height to UAV estimated tree height was 1.56 m and 8.7%. The summary of the relationship and comparison of the estimated tree height based on the area where photogrammetric image matching and Airborne LiDAR DTM had small difference was indicated in the Table 2 and Figure 5.

Table 2: Comparison of UAV and ALS tree height where UAV and ALS DTMs have slight difference in height

Statistics	ALS and UAV close altitude	ALS and UAV tree height
Correlation Coefficient	0.995785479	0.894274068
R Square	0.99158872	0.799726108
Adjusted R Square	0.991496288	0.797525296
Standard Error [m]	1.008903101	1.505570224
Root Mean Square Error [m]	0.190367513	1.561653393
RMSE%	0.539068939	8.707791154
Observation	93	93

The t-test assuming equal variance was done to compare the mean of the DTM height (altitude) of ALS and photogrammetric image matching. The results revealed that at ($p < 0.05$) there was no significant difference between height of ALS DTM and UAV. Likewise, in the same area t-test results revealed that at ($p < 0.05$) there were no significant difference in the mean of tree height measured by ALS and that estimated by UAV in the point where UAV DTMs had RMSE and RMSE % of RMSE = ±0.19 m and RMSE% = 0.5 respectively.

3.2 Tree height Accuracy Assessment

In this study, the total number of 388 matched trees was used to assess the relationship between Airborne Lidar and UAV estimated tree height. The model of fit was developed. Airborne Lidar and UAV derived tree height was considered to be independent and dependent variable respectively. Then Airborne Lidar was used to predict photogrammetry image matching estimated tree height. The coefficient of determination (R^2) of 0.785, standard error of 1.72 and RMSE of ±1.71

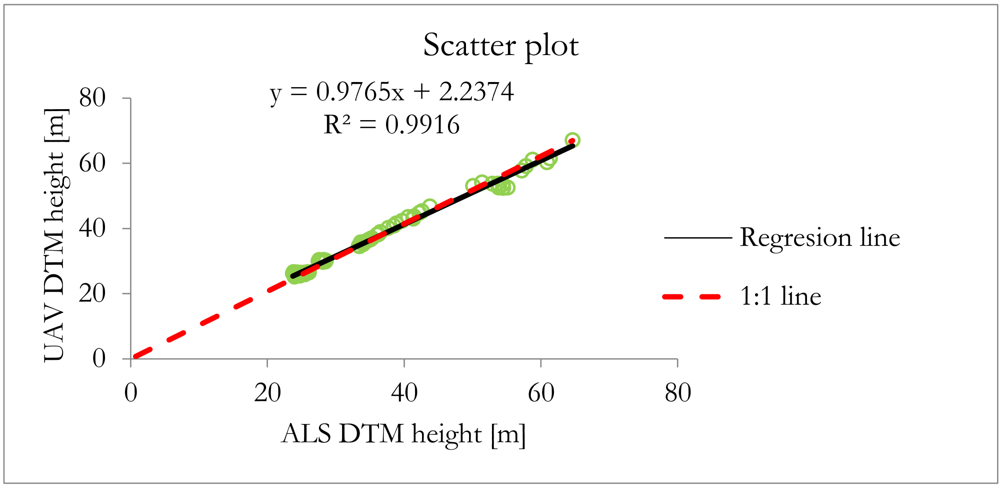

Figure 5. Relationship between ALS DTM height and UAV DTM height

m was obtained (Table 3). The model indicated that when the independent variable was zero (0 m) the dependent variable was 1. 22 m (intercept). In addition to that the linear equation showed that the regression coefficient (slope) for Airborne LiDAR was 0.8678 m. This coefficient indicated that for every additional 1 meter in Airborne LiDAR estimated tree height we expect photogrammetry image matching of UAV estimated height to increase by the average of 0.8678 m (Figure 6).

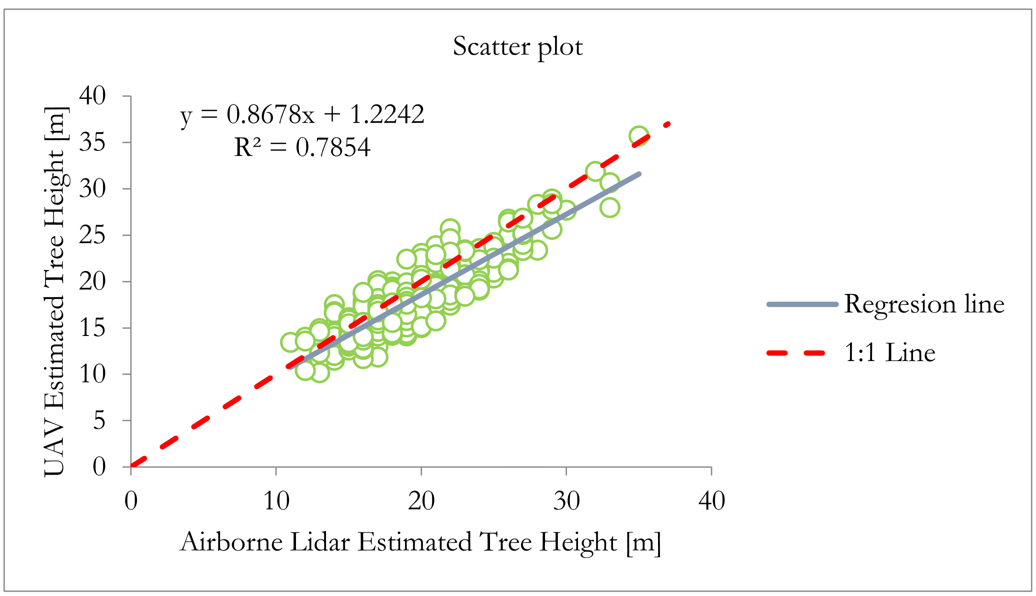

Figure 6. Scatter plot of the relationship between UAV and Airborne LiDAR

Table 3. Descriptive statistics for Lidar and UAV tree height

Statistics	Airborne LiDAR Estimated Tree Height [m]	UAV Estimated Tree Height [m]
Mean	19.07989691	17.78212556
Standard Deviation	3.781678666	3.703073032
Minimum	11	10.15921021
Maximum	35	35.70339203
Count	388	388

In total, 388 trees were estimated by photogrammetry measurements. The mean tree height estimated was 17.78 with the standard deviation of ±3.7 m and trees height was ranging from 10.16 m to 35.7 m minimum and maximum respectively. Then, photogrammetry measured tree height was validated using ALS. Thus when UAV tree height was regressed with ALS derived tree height, R^2 of 0.78 was obtained. This indicated that the variation in tree height estimated by UAV was explained by ALS tree height by 78%. This implies that there was strong relationship between height derived from ALS and that of UAV.

The accuracy assessment of UAV tree height was evaluated by using tree height derived from ALS and the RMSE of ±1.7 m (RMSE=9.6%) was obtained. This study is comparable to the study conducted by Wallace et al. (2014) in Australia native forest stand in which in their study 112 trees out of 136 measured trees which had spatial detailed on the upper canopy where captured by UAV. The study revealed that when photogrammetry tree height was regressed against field measured tree height showed R^2 of 0.63 and RMSE was ±1.30 m (Figure 40). The small difference existed was attributed to the difference in the complexity of the forest. On the other hand this study was comparable to the study done in Maryland USA by Dandois & Ellis (2013) which stated that accuracy of field tree height and photogrammetry measured tree height had coefficient of determination ranging from 0.63 to 0.84 with 155 points/m^2 while in his study the point cloud density was ranging from 50 to 254 points/m^2.

This result is comparable with the results obtained by Lisein et al. (2014) done in a mix of uneven-aged broadleaved stands with a predominance of Oaks (*Quercus robur* and *Quercus petraea*) and some even-aged coniferous stands where tree height ranged from 10.5 to 29.4 m, with an average of 22.3 m. The error was attributed to the fact that point clouds of UAV could not penetrate to the ground. This result is comparable to the study done by Balenovi et al. (2015) in temperate forest where they reported that RMSE and RMSE % range from ±0.31 to ±5.27 m and 10 to 28.5% respectively for sub-compartment 16a, 17a, 17b, 18a, 18b, 20a, 20b, 20c. Likewise in the study done by Lisein et al. (2014) revealed that regression model performed quite well, it predicted individual trees height with an RMSE of 4.7% (±1.04 m, R^2 of 0.91) based on photo-CHM (Table 4), the RMSE was less than that obtained in this study because they studied temperate forest (more point clouds at the ground because forest was opened). Unlike this study which was done in tropical rain forest.

Table 4. Comparison of individual tree height models (n = 86) based on photo-CHM and LiDAR-CHM metrics.

CHM	R^2 Adjusted	RMSE [m]	RMSE %
Photo-CHM	0.91	1.04	4.7
LiDAR-CHM	0.94	0.83	3.7

Source: Lisein et al. (2014)

3.3 Biomass and Carbon Stock Assessment

The above ground biomass of the measured tree height, estimated tree height of UAV was computed and compared with that of Airborne LiDAR. The equation used to compute AGB was developed by Chave et al. (2014), the equation utilizes DBH, average wood density as suggested by Reyes et al. (1992) and tree height as input parameters. This is because of the fact that using the local equation of Yamakura et al. (1986) and Kenzo et al. (2009) which utilize only DBH as input in allometric equation to calculate AGB yield low value. Additionally Gibbs et al. (2007) suggested that the uses of local and regional allometric equations are not appropriate. However, the uses of generic equations is suitable because the development of trees were based on large number of trees (Gibbs et al., 2007; Chave et al., 2014). Extensive studies have been done to assess the accuracy of estimating tree height which provided superior results in forest (Wallace et al., 2014; Popescu, 2007).

In this study the accuracy assessment of the biomass of UAV and field measurements was done by using AGB computed from ALS. When AGB computed from UAV validated by AGB of ALS the results revealed that coefficient of determination (R^2=0.99), RMSE was 0.06 Mg and RMSE% was 13%. The R^2 indicated that, 99% of AGB of UAV was explained by ALS. Also RMSE of 13% Mg showed average error of predicting AGB in UAV. On the other hand the validation of field biomass revealed that R^2, RMSE and RMSE% was 0.96, 107 Mg and 24% respectively. The coefficient of determination (R^2) indicated that 96% of variability in estimating of AGB of field was explained by ALS estimated AGB. The average error of modeling of AGB of the field was 24%. For the total of 388 matched trees, the total amount of biomass computed from ALS was 189.49 Mg, 177.13 Mg for UAV and 172.97 Mg for measured tree height. This result is comparable to the results of Sadadi (2016) which reported the AGB of ALS, TLS and field were 179.85 Mg, 170.86 Mg and 146.33 Mg respectively for 312 total trees. Furthermore t-test indicated that at $p<0.05$ there was no significant difference in biomass estimated by ALS and that of field and UAV.

The computation of carbon stock was based on the amount of biomass which was calculated. The carbon stock is approximated to 50% of the biomass in the tree. The mean carbon stock for tree derived from Airborne LiDAR was 0.229 Mg, 0.215 Mg for UAV and 0.209 for measured tree height. This implies that there was loss in carbon stock. This result is comparable to the study done by Sadadi, (2016) who reported 0.27 Mg , 0.26 Mg and 0.22 Mg for LiDAR, TLS and Field respectively. However, most of the study reported the carbon stock for the whole study area.

4.0 CONCLUSIONS

- The tree height estimated from UAV data and field measured tree were regressed with ALS derived tree height for validation and accuracy assessment. When tree height derived from photogrammetry matching of UAV was regressed against ALS measured tree height the coefficient of determination (R^2) obtained was 0.78 and tree height derived was accurate by 90.37% (RMSE = ±1.7 m, RMSE%= 9.63), this implies that 90.37% of the tree height derived from UAV data was accurately estimated.

- The ANOVA revealed that there was variation in the means of tree height derived from the CHM of ALS, UAV and measured tree height. Following up the ANOVA test the t-test found that there was a significant difference in the means of the tree height derived from ALS, UAV and measured trees from field.

- The amount of AGB estimated by the ALS was 189.49 Mg of AGB derived from Airborne LiDAR. On the other hand, the AGB of estimated UAV total matched sampled trees were 177.13 Mg for UAV while the AGB which was estimated by field was 172.97 Mg. This implies that UAV and field approaches underestimated biomass and carbon stock. Furthermore t-test revealed that there was no significant difference in the means of the AGB and carbon stock derived from ALS, UAV and field measured trees.

- ALS approach to estimate biomass was considered to be more accurate in estimating AGB because it was able to see the trees at the top and had accurate DTM. Tree height estimated by photogrammetry image matching point clouds or SfM and tree height measured from the field were adjusted based on RMSE obtained when validated by ALS derived height. The results revealed that biomass was sensitive to the differences in tree height measurements.

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