COMPARISON OF FOREST TREE PARAMETERS EXTRACTED FROM UAV OPTICAL AND TLS DATA IN BOTH TROPICAL RAIN AND TEMPERATE FORESTS

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ABSTRACT: There is a great need for a cost-effective and accurate method to assess the parameters for estimating above-ground biomass (AGB)/carbon stock, both in complex multi-layered tropical rain-forest and in temperate forests. The tree height and Diameter at Breast Height (DBH) are important forest parameters required as inputs for biomass estimation equation and can be obtained through various methods such as direct field measurement. However, measuring tree height and DBH by field surveying is time-consuming, limited to inaccessible areas and rather expensive. With the advancement of remote sensing technology, various datasets have been used to assess AGB including airborne LiDAR or sometimes called Airborne Laser Scanner (ALS) but this data is not always available and expensive to acquire for regular monitoring. The emergent of Unmanned Aerial Vehicle (UAV) and Terrestrial Laser Scanner (TLS) technologies, which operate from air and ground respectively, can provide accurate information of upper and lower canopy layers at a reasonable cost for regular monitoring of carbon stock. However, both are associated with the limitation of foliage coverage in the complex multi-layer tropical forest which can underestimate AGB when used separately. This study aimed at establishing a cost-effective method that ensures reasonable accuracy for regular assessment of tree parameters in tropical rain-forest and temperate forests for AGB/carbon estimation for REDD+ and its MRV system by complementing UAV imagery and TLS data. Furthermore, a comparison between the techniques and modeling approach in both the tropical and temperate forest are discussed. Moreover, a comparison is made of the effect of the structure and the condition of both tropical rain and temperate forests on the results extracted from UAV and TLS.

1.0 INTRODUCTION

1.1 Background

Forests play a major role to sequester and store large amounts of carbon which act as a natural control of climate change and important global carbon budget (Gibbs et al., 2007). On the other hand, deforestation and forest degradation lead to carbon emissions. The main carbon pools in the forest ecosystems are the living biomass of trees and undergrowth vegetation, the dead mass of litter, dead wood and soil organic matter. The carbon reserved in the aboveground living biomass of trees is typically the largest pool and the most instantly impacted by deforestation and degradation (Gibbs et al., 2007).

The United Nations Framework Convention on Climate Change 2007 UNFCCC report as cited by (Patenaude et al., 2004) direct human-induced emissions and removals of carbon dioxide to be reduced from Land Use Change and Forestry activities, which include deforestation, afforestation, and reforestation activities. In order to control the impact of climate change, the range of initiatives have been established, one of such program is Reducing Emissions from Deforestation and Degradation (REDD+) with its measuring reporting and verification (MRV) mechanism. REDD+ was designed to provide incentives to developing countries to reduce deforestation and forest degradation rates and support conservation measurements which reflect the value of the carbon sequestered and stored in trees (Angelsen et al., 2012).

The opportunity for tropical countries such as Malaysia to benefit from REDD+, required a cost-effective method for providing accurate and timely information to determine forest parameters for estimating AGB and carbon stock (Angelsen et al., 2012). Karna et al., (2015) stated that the tree canopy height and diameter at breast height (DBH) or crown projection area are important forest inventory parameters for estimating Above Ground Biomass (AGB). The precise and unbiased biomass can be obtained through a destructive method which involves cutting trees, weighing, labor intensive as well as time- consuming and rather expensive. However, biomass estimation through a non-destructive method using an allometric equation which needs a direct measurement of DBH and Height as input parameters also can be expensive and time-consuming, therefore we need remote sensing technology. Remotely sensed data can be used as a cost-effective source of secondary information to improve the precision and timelines for generating the inputs forest parameters of an allometric equation for estimation of AGB and carbon stocks stored in the tropical rainforest (Mohren et al., 2012).

In case of a forest developed country like Germany, climate change the carbon sink function of forests has become an important function to reduce the emission of greenhouse gases (GHGs) and their impacts since the sequestered carbon is removed from the system. International treaties like the Kyoto Protocol take forests and their functions as one of the key factors in mitigating emissions of GHGs (Rosenqvist et al. 2003).

Assessing the forest resources and their contained biomass is therefore an important task for many stakeholders from sub-national to international levels. To quantify this resource in terms of biomass and carbon stock information in forest inventories on an ever more detailed level, down to the individual trees, is a challenge also for researchers. Different methods are being used for the determination of biomass and carbon stocks. The most exact approach being destructive sampling for which the tree is cut down, measured and weighed. This approach gives detailed information about the biomass and the stored carbon. Nevertheless, this approach does not only limit the biomass determination to only once in time because of its destructive nature but is also highly impractical for large stands.

Remote sensing is an important tool for the estimation and measurement of large forest areas and several methods have been developed over time. Space based platforms carrying optical sensors and technologies like synthetic aperture radar (SAR) sensors and Light Detection and Ranging (LiDAR) systems are used for large scale forest estimations. They have been identified as being highly important tools also for the monitoring of forests for national and international carbon balances in order to comply with the Kyoto Protocol (Rosenqvist et al. 2003).

Remote sensing data can be used to extract important tree parameters which can be used with the appropriate models to estimate the forest biomass. These parameters, needed as model inputs, can, amongst other methods, be derived from aerial or satellite images. Using the CPA extracted from such an image the DBH can be estimated with reasonable results (Laar & Akça 2007). Even the height of trees can be extracted, for example through photogrammetric methods (Laar & Akça 2007; Dandois & Ellis 2010).

When coming to very high resolution information down to individual tree levels satellite remote sensing technologies are reaching their spatial limit. The spatial resolution provided by satellite images is often not enough for the recognition of detail, for example when delineating tree crowns in a forest canopy. Cloud cover and shadows lead to occlusions and are a problem, especially in some geographical regions. Other limitations are the revisiting time which restrains the possible time interval of image acquisition for a specific area and the maximum possible obtainable spatial resolution of approximately 0.5 m.

The emerging of Unmanned Aerial Vehicles (UAVs) which are lightweight, low-cost aircraft platforms operate from the ground that can address some of these operational issues. The UAVs' offer a promising way for timely, cost-effective and approachable way for monitoring of natural resource at spatial and temporal resolutions that are appropriate to overcome the limitation related to satellite and airborne based research (Anderson & Gaston, 2013). There is a possibility to produce accurate canopy height model with UAV images by providing a close view of the upper canopy which assists in the retrieval of vertical forest structural parameters by subtracting with existing DTM see **Error! Reference source not found.** (Paneque-Galvez et al., 2014). Ota et al.,(2015) reveal that applying the Structure from Motion (SfM) approach can support the derivation of high spatial resolution 3D point cloud model from the photograph taken by UAV, similar to those derived from airborne LiDAR.

1.2 Research Problem

To mitigate climate change the Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (REDD+) and its MRV mechanism under the UNFCCC was initiated. MRVs is calling for the use of the cost-effective method for providing accurate and timely information of the forest parameters across the complex multi-layered lowland tropical rain forest for estimation of forest biomass and carbon stock which is essential to boost the opportunity for tropical countries to benefit from REDD+ (FAO, 2010).

The tropical rainforest is characterized by three layers of trees which are emergent trees, continuous canopy (main stratum) and understory canopy (Nurul-Shida et al., 2014). The accurate and cost-effective method for assessing the AGB by taking into consideration trees in all canopy layers of the tropical forest complex structure is required. Tree canopy height and DBH are common forest parameters for developing allometric equations for estimating AGB. Measuring tree height and DBH by field surveying are time consuming, limited to inaccessible areas and rather expensive.

A prominent technology like Unmanned Aerial Vehicles (UAVs') which are lightweight, low-cost aircraft platforms operate from the ground, offer a promising way for timely, cost-effective and approachable way for monitoring natural resource at high spatial and temporal resolutions that are appropriate to overcome the limitation related to satellite and airborne based research (Anderson & Gaston, 2013). Previous studies have shown that using the UAV image through automatic image matching technique a photometric digital surface model (DSM) can be generated. Once the DTM is available it can remain constant for a long time while DSM needs to be up-to-date and accurate to generate accurate forest canopy height model that would assist in the retrieval of tree canopy height (Lisein et al., 2013). The limitations associated with this method compared to LiDAR is that they cover a small area and sometimes impossible to acquire the lower canopy information from the aerial view for assessing understory trees as well as DTM. Therefore, the CHM is applicable for upper canopy biomass estimation only. However, UAV imagery can be acquired regularly at low-cost compared to Airborne LiDAR and reduce the field survey cost significantly which give it value approachable way to replace LiDAR on regular monitoring purpose.

Terrestrial laser scanners (TLS) is a very useful and robust method for measuring forest structure through non-destructive technique particularly in a tropical forest, where the direct method is often tough, labor intensive, prone to human measurement error and expensive. TLS can accurately assess DBH and height of lower canopy trees and the DBH of upper canopy trees while UAV 3D image matching data can assess the height of upper canopy trees.

UAVs on the other hand can cover and deliver data for larger areas. No extrapolation of the measured parameters is needed, which is one advantage of the use of UAVs and sensors for data acquisition. The use of UAV images for remote sensing purposes has become quite popular in the forestry domain and is also economically highly attractive since commercial type UAVs with RGB cameras as sensors are much cheaper than other technologies (Dandois & Ellis 2010; Schiffman 2014). Large areas can be covered in comparatively short time and at lower costs. To decide on how useful information derived from commercial type UAV is, it is important to investigate how accurate the parameters extracted from UAV images are compared to technologies with as high accuracy like a TLS data.

This study aimed at establishing a cost-effective method that ensures reasonable accuracy for regular assessment of tree parameters in tropical rain-forest and temperate forests for AGB/carbon estimation for REDD+ and its MRV system by complementing UAV imagery and TLS data. Furthermore, a comparison between the techniques and modeling approach in both the tropical and temperate forest are discussed. Moreover, a comparison is made of the effect of the structure and the condition of both tropical rain and temperate forests on the results extracted from UAV and TLS. Ayer Hitam Tropical Forest Reserve near Kuala Lumpur, Malaysia and a temperate forest plantation at Amtsvenn, close to the city of Gronau, Nordrhein-Westfalen, Germany are the test sites of this research. Phantom-4 UAV and RIEGL VZ-400- TLS were used in both tropical and temperate forests to collect the data.

2.0 MATERIALS AND METHODS

2.1 Study Areas

The first study site of the tropical forest was in Ayer Hitam Forest Reserve (AHFR). It is a tropical rainforest covers an area of 1,248 hectares and located in Puchong, the state of Selangor, Peninsular Malaysia (03° 01' N, 101° 39' E), and approximately 45 kilometres from the city of Kuala Lumpur (Hasmadi et al., 2008). AHFR is surrounded by residential and other economic development activities which isolate the forest from another forest (Figure 1). The study area was selected based on the logistic support of the University of Putra Malaysia who managing this forest for the purpose of teaching, research and extension activities since October 1999. The logistical requirements include the local knowledge for navigation, tree species identification, and availability of Airborne LiDAR data. The Ayer Hitam Forest Reserve is tropical rain forest with an average temperature of 27.8°C where a maximum and minimum temperature is 32.6°C and 24.6°C respectively while the relative moisture is 83% and average annual rainfall is 2178mm. The landscape of the study area is undulating with several different topographical characteristics such as hillsides, ridge, and valley. The terrain is moderately steep with a slope of up to 34° and elevation ranges from 15-233m (Hasmadi et al., 2008). The Ayer Hitam Forest Reserve is classified as logged-over lowland mixed dipterocarp tropical forest with a dense, multi-layered vegetation structure which is still regenerating with 430 species in 203 genera and 72 families found in this forest (Hasmadi et al., 2008). The forest is dominated by a high density of small and medium size trees with the forest floor covered by seedlings and saplings as well as herbs, climbers, creepers, palms and ferns (Nurul-Shida et al., 2014).

The second study area of the temperate forests locate about 0.5 Km^2 consists of patches of forest with mixed tree species. It is located on the border of the Netherlands and Germany, by Amtsvenn, close to the city of Gronau, Nordrhein-Westfalen, Germany (: 32558395 m E, 5782262 m N, UTM 32 N, ETRS89). This research area consists of several forest stands within an agricultural area (Figure 2). These stands are managed on an informal basis and show different densities, stand compositions and growing stages. The most common tree species were Beeches (*Fagus sylvatica)*, Scots pines (*Pinus sylvestris*), Oaks (*Quercus robur*, *Quercus petraea*), Alders (genus *Alnus*) and Birches (genus *Betula*). The identification was done on a common name basis and not distinguishing sub-species.

A stratified random sampling method was employed to select plot sites within in the second research areas. A relatively high number of potential plot sites were generated. In the field, some of these plots had to be skipped because of inaccessibility. Dense and thorny undergrowth of up to 2 m height inhibited the access with the TLS and would also have occluded large parts of the plot. This lead to some bias for some forest patches. While a purposive sampling method was used in locating the TLS plots. The plot selection aimed at covering the variation across the dense, complex forest vegetation structure and due to the weight of the TLS (23 kg), taking accessibility (slope steepness, the penetrability of the undergrowth and distance to the road) into account. This sampling design is non-probability method where the sample plots choice is based on the researcher judgment. In both research study areas a circular sample plots of 500 m^2 with a 12.62 m radius on flat terrain were used for the measurement of the forest parameters DBH, Height and CPA. The circular plots are easy to establish and less exposed to errors in the plot area than square plots. Since the length of the boundary of the circular plot is smaller than in square plot, there may be few trees located on the edge.

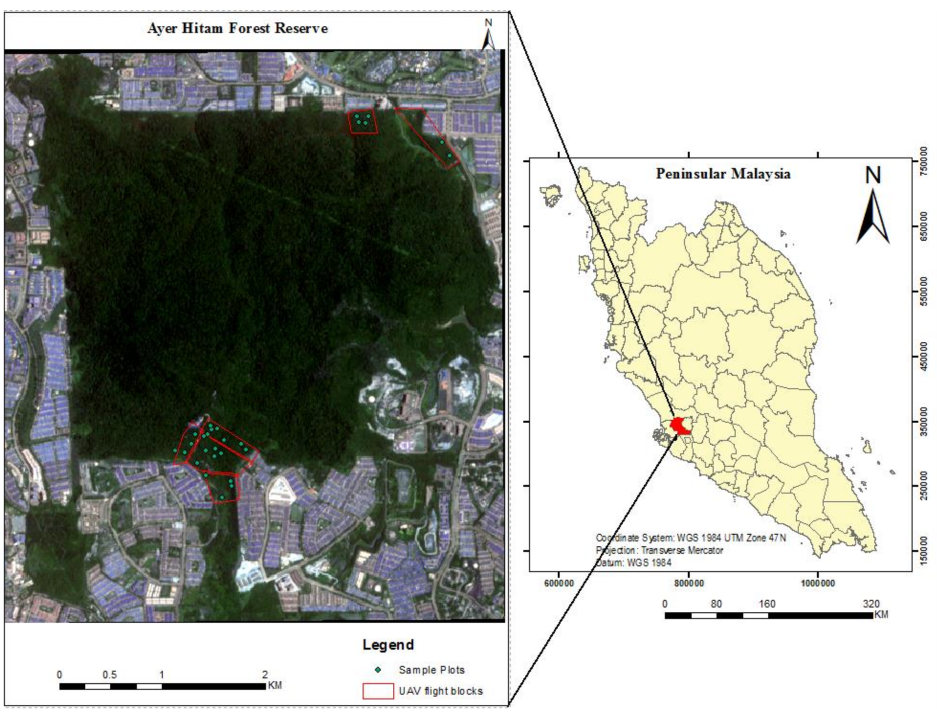


Figure 1. Location map of the first study area of Ayer Hitam Forest Reserve (Tropical Forest).

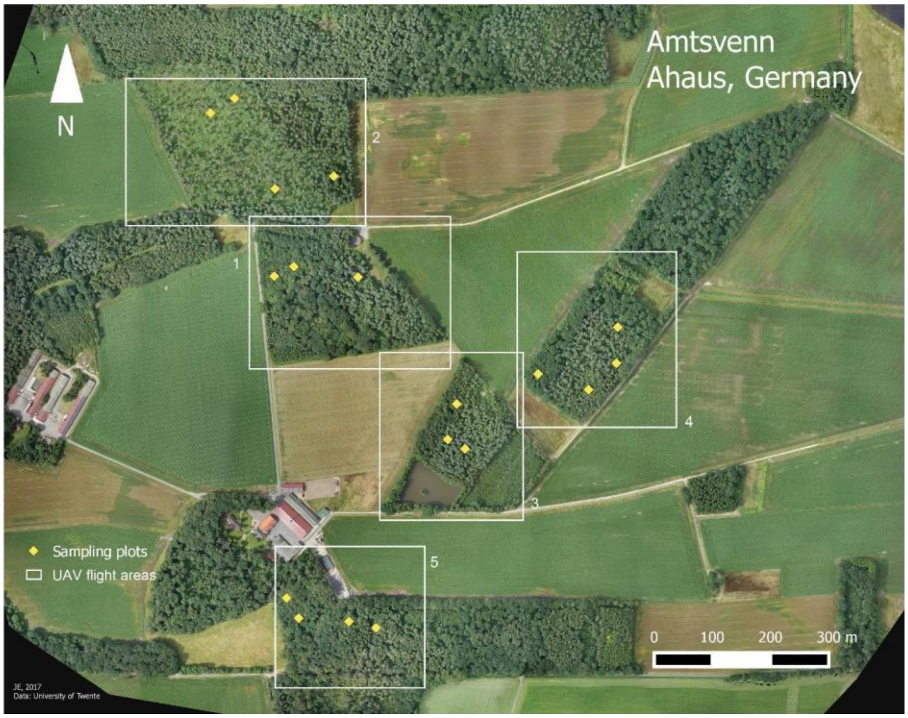


Figure 2. Location map of the second study area of Amtsvenn, Ahaus, Germany showing the UAV flight areas (white line, white numbers) and sampling plots for TLS and field measurements (Temperate Forest).

Mission Planning

In both study areas the mission planning software (PIX4D Capture) was used to define the parameters (Table 1) to guide the UAV to perform the flight on the six (6) blocks where the sample plots were located. The flight height depended on the terrain of the flight block and the starting point was located in the area with high elevation to avoid crushing of the UAV on the tall trees in the hills.

Table 1. Technical parameters to guide UAV data acquisition

UAV Speed	9m/s
Front overlap	80%
Side overlap	60%
Flying height	80 and 90 meters
Resolution	4000x3000

GCP's allocation

The Ground control points (GCP's) were allocated to assist spatial referencing of the 3D model generated from the images. These points were pre-marked on the ground in a position that can be viewed by the UAV and can clearly be seen in the images *(*Figure 3).The GCP's locations were measured with high accuracy using Differential GPS.

Data acquisition

Based on the defined parameters during mission planning (position, altitude and flight line) the UAV recorded the digital images (Figure Error**! No text of specified style in document.**). All the images were stored on the UAV memory card and the qualities of the images were assessed after every flight.

Figure **Error! No text of specified style in document.**. The UAV flying (left) and GCP's maker (right).

2.2 Methods

A general overview of data processing steps for the different data sets for the two study areas can be seen in Figure 4. It includes 4 lines of data analysis i.e. UAV, TLS, ALS and field data.

3.0 RESULTS AND DISCUSSIONS

3.1 Tropical Forest Results

The UAV-based Canopy Height Model (CHM) was developed by subtracting the LiDAR Digital Terrain Model (DTM) from the UAV-DSM. The upper canopy tree height derived from CHM generated from 3D image matching of UAV imagery compared with the tree height derived from ALS-CHM achieved an R^2 of 0.81 and RMSE of 2.1m (11%) and statistically, significance difference was observed. The UAV-based CHM overestimated the tree height by 1.26m when the overall mean tree height difference for 30 plots was calculated. The DBH derived from TLS point clouds when compared to field measured DBH achieved an R^2 of 0.986 and RMSE of 1.4cm (7%). The DBH derived from the TLS point clouds was underestimated by 0.28cm of the overall mean tree DBH difference for 30 plots and no statistical significance different was observed.

The derived AGB from the upper and lower canopies were combined. The accuracy of the forest AGB/carbon stock on plot base estimated by the developed method when compared to reference method achieved an R^2 of 0.98 and RMSE of 536.25Kg per plot (6.23%) for 30 plots. Also, a t-test shows no statistical significance difference between the AGB/carbon estimated by the two methods.

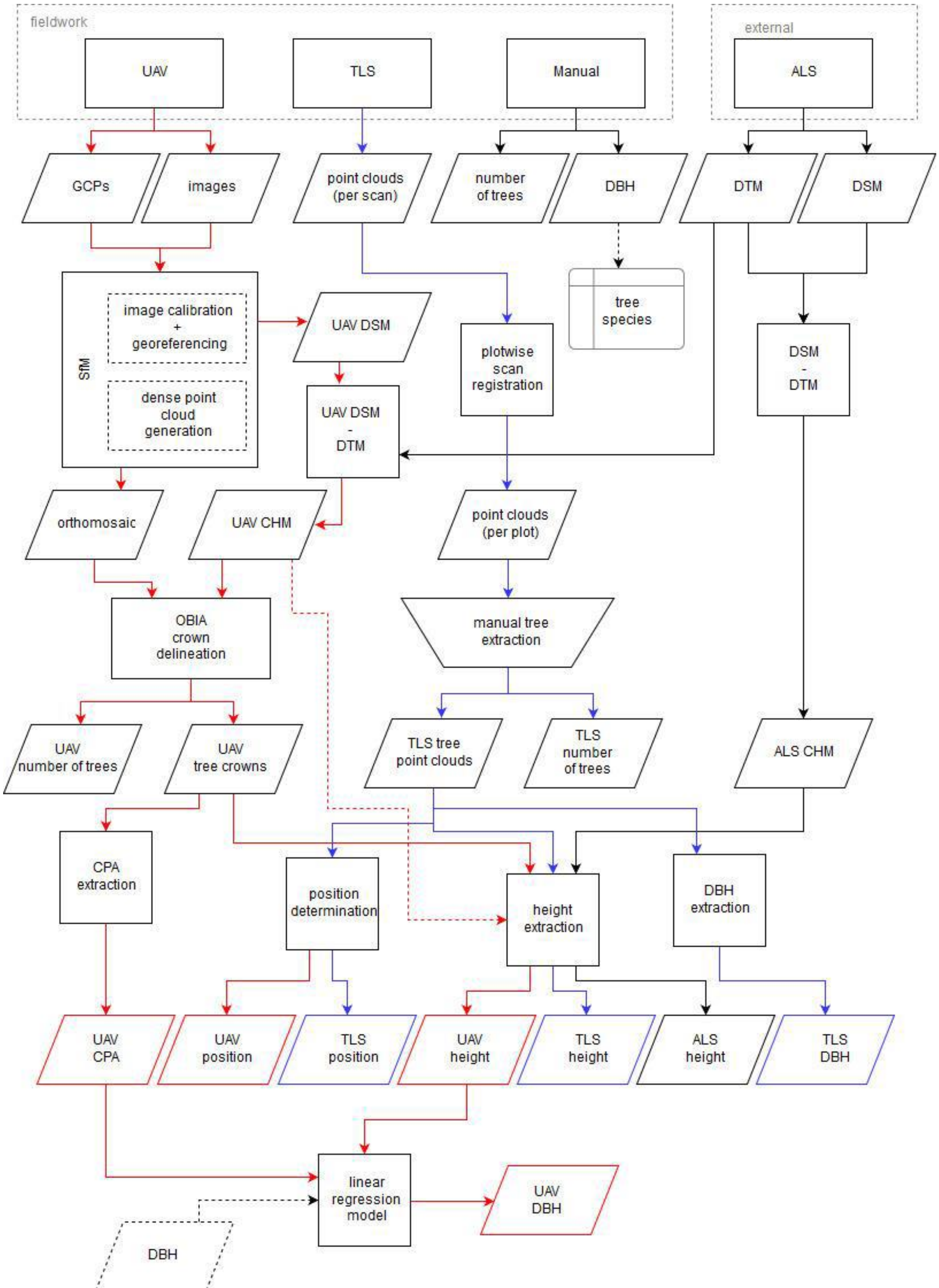
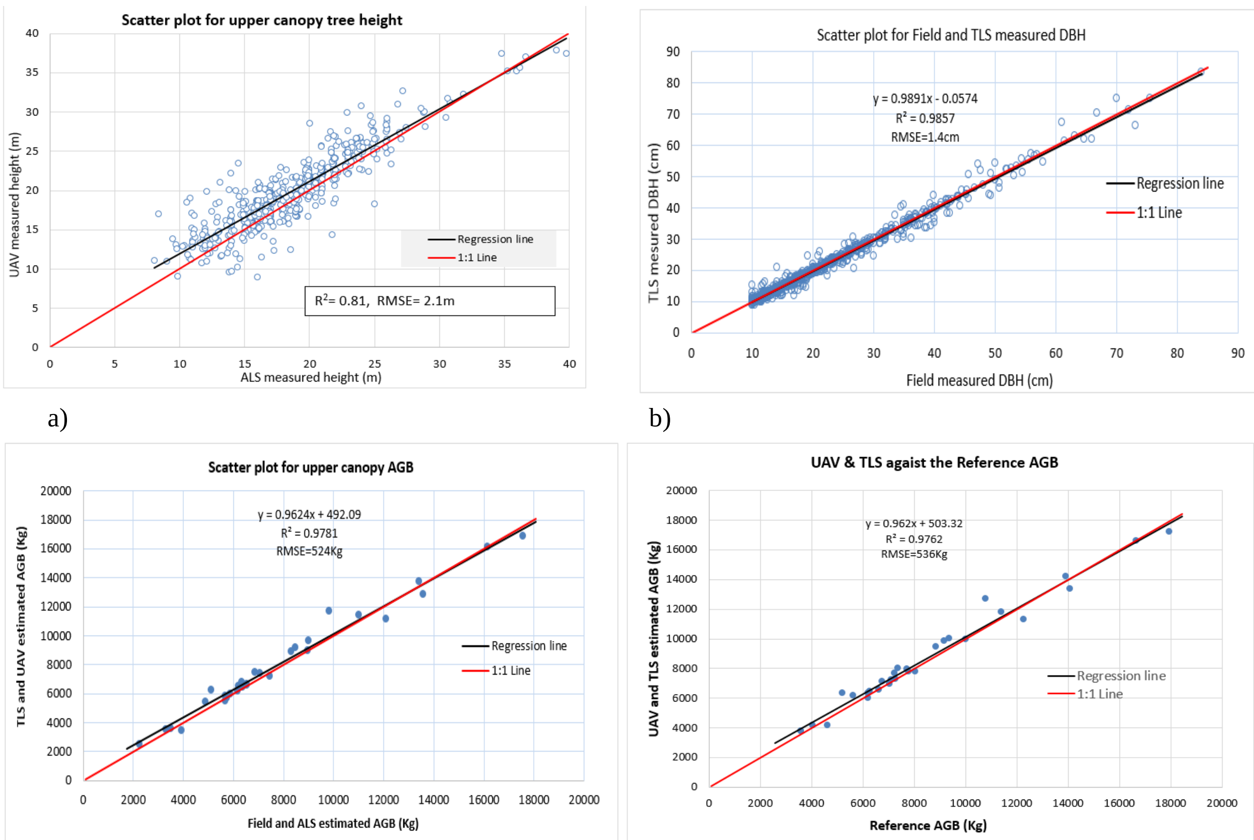


Figure 4 Flowchart of the general methods for the two study sites.



c)

d)

Figure 5. Regression Analysis of the relationship of (a) UAV and TLS trees height, (b) TLS and field DBH, (c) AGB of UAV and TLS and the field, and (d) AGB of UAV and TLS and Reference field.

As far as the results of the research in the tropical forest is concern, the accuracy of the upper canopy tree height derived from UAV-CHM upon comparing with the tree height derived from ALS-CHM achieved an R^2 of 0.81 and RMSE of 2.1m (11%).This means 89% of the tree height was accurately estimated by the canopy height model developed using the DSM generated from 3D image matching of UAV imagery and the LiDAR DTM. The accuracy of the DBH derived from TLS point clouds when compared to field measured DBH achieved an R^2 of 0.986 and RMSE of 1.4cm (7%). This means the 93% of the DBH was accurately measured from the TLS point cloud. The accuracy of the forest AGB/carbon stock on plot base estimated by the developed method when compared to reference method achieved an R^2 of 0.98 and RMSE of 536.25 Kg per plot (6.23%). This means the 93.77% of the AGB/carbon stock was accurately estimated by integrating TLS information and upper canopy tree heights from Canopy height model generated from 3D image matching of UAV imagery. The UAV may contribute to a dramatic cost reduction of repeated monitoring of tropical forests by replacing the LiDAR for upper canopy tree height estimation. However, once a LiDAR DTM is used and the DSM generated from images acquired by UAV with strong overlap condition, reasonable accuracy for AGB estimation is guaranteed. On the other hand, these results demonstrated that TLS under multiple scans approach can be practically used for collecting forestry parameters (DBH and lower canopy tree height) in sample plots accurately for AGB and carbon stock estimation as long as the ground vegetation are cleared to minimize the occlusion for the tree trunk to be viewed properly by the TLS scanner.

3.2 Temperate Forest Results

As far as the results in the temperate forest, a general problem of the regression analysis of the influence by stand composition and density is that more than half of the matched trees are from high density deciduous stands (Table 2). For combined stand density and composition classification there were very few or no trees for a sound analysis. The low number or non- existence of trees in classes like the high density coniferous class did skew the analysis further. The skewed sample size of the classes did also result in critical values of collinearity between some classes (Table 3). The analysis shows low R^2 values and mostly p-values clearly higher than α.

As Figure 6 shows the results in the temperate forest is highly affected by the the UAV data from one flight area could not be calibrated and therefore further processing and analysis could not be done for that area. Problems in the UAV flight planning and data acquisition lead to incomplete or inaccurate results in the UAV data processing.

Table 2. Composition class, density class and number of matched trees per plot.

Plot	Number of matched trees	Density	Composition
0908_1	9	Medium	Mixed
0912_1	17	Medium	Mixed
0912_2	22	High	Deciduous
0922_1	7	Low	Coniferous
0922_2	5	Low	Coniferous
0923_1	7	Low	Coniferous
0923_2	19	High	Deciduous
0923_3	14	Medium	Deciduous
0924_1	12	Medium	Deciduous
0924_2	22	High	Deciduous
0926_1	12	High	Mixed
0926_2	12	High	Deciduous
1024_1	8	Low	Mixed
1026_1	18	High	Deciduous
Total	184	-	-

Table 3. Results of regression analysis combining density and composition classes.

p-values ->		R^2 adj.	Mix.	Dec.	Med.	High
Tree det.	UAV	0.474	0.126	0.329	0.814	0.341
	TLS	0.098	1	0.739	0.158	0.336
	pos.	0.069	0.016	0.008	0.565	0.660
Height	UAV-ALS	0.179	0.003	0.012	0.825	0.042
	TLS-ALS	0.117	0.886	0.838	0.016	0.225
	UAV-TLS	0.139	0.035	0.066	0.163	0.234
DBH	UAV-field	0.124	0.049	0.104	0.688	0.177
	TLS-field	0.019	0.330	0.243	0.018	0.036
	UAV-TLS	0.059	0.781	0.560	0.016	0.013

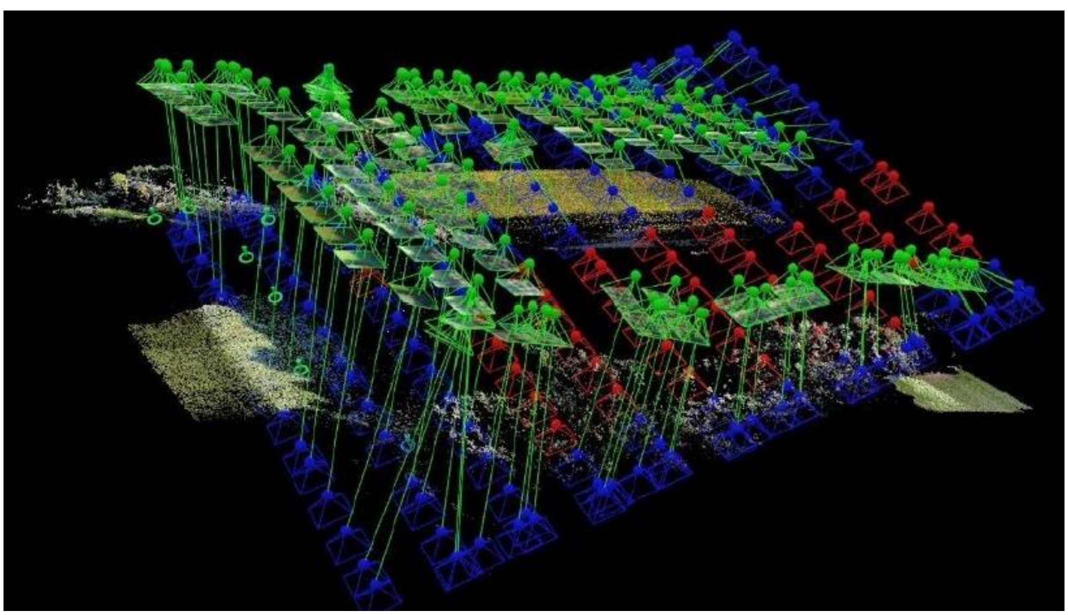


Figure 6. Results of the image calibration attempt of the 5th UAV flight. Blue pyramids represent the recorded UAV GPS position when the picture was taken. Green pyramids show the calculated position after the Pix4D calibration (with additional manual tie points (green circles with pin) and GCPs (blue circles with pin)). Red pyramids signal images that could not be calibrated.

In general the tree detection rate from the TLS data was very high (95 %). The number of trees delineated from the UAV data was slightly lower (87.4 %) and decreased further to just over half (56.3 %) of the number of trees counted in the field. The recognition rate of individual trees from the UAV data was lower than in comparable studies. The UAV data from one flight area could not be calibrated and therefore further processing and analysis could not be done for that area. Problems in the UAV flight planning and data acquisition lead to incomplete or inaccurate results in the UAV data processing. There was a significant difference between height values from the reference ALS data and the height values extracted from UAV and TLS data sets. Height values from both data sets, UAV and TLS, were higher than the reference height values from the ALS data set (RMSE UAV 5.5 m, RMSE TLS 6.6 m). UAV and TLS height values were not significantly different from each other. The UAV accuracy of both tree detection and DBH extraction accuracy were both significantly (negatively) influenced by higher density in stands and in stands with higher deciduous tree content. TLS tree detection and DBH value extraction was not influenced by stand composition but partly by stand density. Height values from both data sets were significantly influenced by stand density and composition.

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