TERRESTRIAL LASER SCANNING TO SUPPORT CARBON ESTIMATION IN NATURE CONSERVATION AREA: A CASE STUDY OF HAAGSE BOS AND SNIPPERT FOREST, NETHERLANDS

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ABSTRACT: Forests have the ability to sequester and store carbon in the living biomass. This make forests play a crucial role in climate change. Thus, estimating aboveground forest biomass and carbon stocks is one of the most important element for measuring and monitoring carbon stock under the REDD+ mechanism. This study aims to estimate above-ground biomass (AGB) and carbon stock based on allometric equations in the temperate forest of nature conservation area of Haagse Bos and Snippert Forest, the Netherland. Terrestrial Laser Scanner (TLS) in a multiple-scan design to measure diameter at breast height (DBH) and tree height of all trees within 500 m^2 sample plots was used. Results of this study show that TLS can detect trees correctly with a success rate of 97% compared with field measurement. The highest success rate of trees detection are 98.3% for evergreen forest followed by 98% for broadleaf forest and 91.9% for mixed forest. Very strong relationship was found between the DBH measured with the TLS data and field measurements of plot values with R^2 of 0.96 and RMSE of 2.42 cm. However, comparing tree height of TLS data and field measurement, a reasonable relationship with R^2 of 0.61 and RMSE of 3.66 m were found. The above ground carbon (AGC) stocks in study area estimated from field measurement was 103.7 ton/ha., while the AGC stocks estimated from TLS data was 104 ton/ha. The result of mean AGC stock from field measurement and TLS data in evergreen forest were 61 ton/ha and 65 ton/ha, respectively. In broadleaf forest were 145 ton/ha and 151 ton/ha, respectively. However, in mixed forest were 106 ton/ha and 117 ton/ha, respectively. The results show that TLS data are very suitable and had a high agreement with ground truth for estimation of aboveground biomass and carbon stock.

1. INTRODUCTION

Under the UNFCCC all signatory Parties have to report on their carbon emissions and removals, including the LULUCF sector. Carbon estimation plays a key role in national carbon management schemes, such as the national reporting of emissions and sinks under the UNFCCC and in carbon trading (CIFOR et al., 2009) as well as meeting Kyoto obligations by signatory countries. At the beginning, when conference of the parties (COP) 11 Montreal was held in November 2005, REDD only covered an effort of emission reduction. Then in further development at COP 13 Bali in December 2007, the convention takes into account efforts in maintaining and keeping the amount of carbon in certain land that has maximum biomass composition, such as undisturbed natural forest. Beside an action of carbon stock enhancement or emission reduction, conservation activity is also covered by the REDD schema, with adding Bali action plan into LULUCF, which is called REDD+ (Sulistyo, 2012). The process should meet international standards and, at the same time, be manageable in a cost-effective manner within the local context. REDD+ programs require reliable, accurate, and cost-effective methods for measurement and monitoring of forest carbon storage.

Forest inventory methods have developed and been implemented over a long period, and are available for application in all forest ecosystems. They may require detailed and intensive sampling schemes to reduce uncertainty and to provide unbiased estimates. Any forest management planning requires reliable and consistent estimates of relevant stand characteristics, notably tree volume and stand structure. For carbon accounting the figures provided by forest inventories can be expanded to forest biomass and forest carbon stock. In the specific situation of REDD+ schemes, sound measurement, reporting and verification (MRV) schemes need to be implemented. In Durban COP 17 agreement, it was concluded that all countries would participate in the development of a new universal greenhouse gas reduction protocol that would replace the Kyoto Protocol (UNFCCC, 2011). This protocol should be completed by 2015 and put into effect in 2020. For presenting REDD+ in the new framework, methodologies and rules for implementing REDD+ are to be developed by 2015. Therefore, there is a need for development of new inventory methodology for the framework.

Various methods of remote sensing based Above Ground Biomass (AGB) and carbon stock estimation have been developed. However, most of the existing methods have considerable uncertainties and thus reliable methods are required. In this regard, TLS combined with automatic data processing techniques, may provide an alternative for the permanent sample plot method for ground-based forest inventory. TLS find rapidly growing interest in photogrammetry as efficient tools for fast and reliable 3D point cloud data acquisition. They have opened a wide range of application fields within a short period of time. Beyond interactive measurement in 3D point clouds, techniques for the automatic detection of objects and the determination of geometric parameters form a high priority research issue.

This research aims to assess the carbon stocks in different types of forests in part of Netherland using TLS. Apart from aforementioned, the Dutch government has pledge to UNFCCC commitments of reducing greenhouse gas emissions. As part of its commitment the country needs to undertake inventories of the sources of carbon sinks and emissions, reliable baseline statistics on national forest carbon stocks is required. Moreover, greater uncertainties over the role of Dutch forests, forest soils, wood products and management and land use options on carbon sequestration are prevalent calling for the need of methods that combine remote sensing technique and field measurements (Nabuurs et al., 2000). Thus, this research developed a relatively new and robust method to assess carbon stock using TLS with improvement in the assessment. With the quality of 3D point clouds generated by laser scanners and the automation potential in data processing, TLS is also becoming a useful tool for forest inventory.

2. MATERIALS AN METHODS

2.1 Study Area

The study area is located about 7 km North Easter away of Enschede, in Haagse Bos and Snippert forest (Figure 4) in East Netherlands. The forest consist of partly private and partly natural monument or conservation area. Formerly, most of the area were managed for timber production, wood from coniferous trees as a commodity. Nowadays, the forest has gradually been changed into mixed forest, and designated for nature conservation and recreation area. Total area of Haagse Bos and Snippert forest are 294 ha. In this area there are three types of forest cover according to a land cover map from TOP10NL, broadleaf and coniferous trees, and mixed forest, of both exotic and native species.

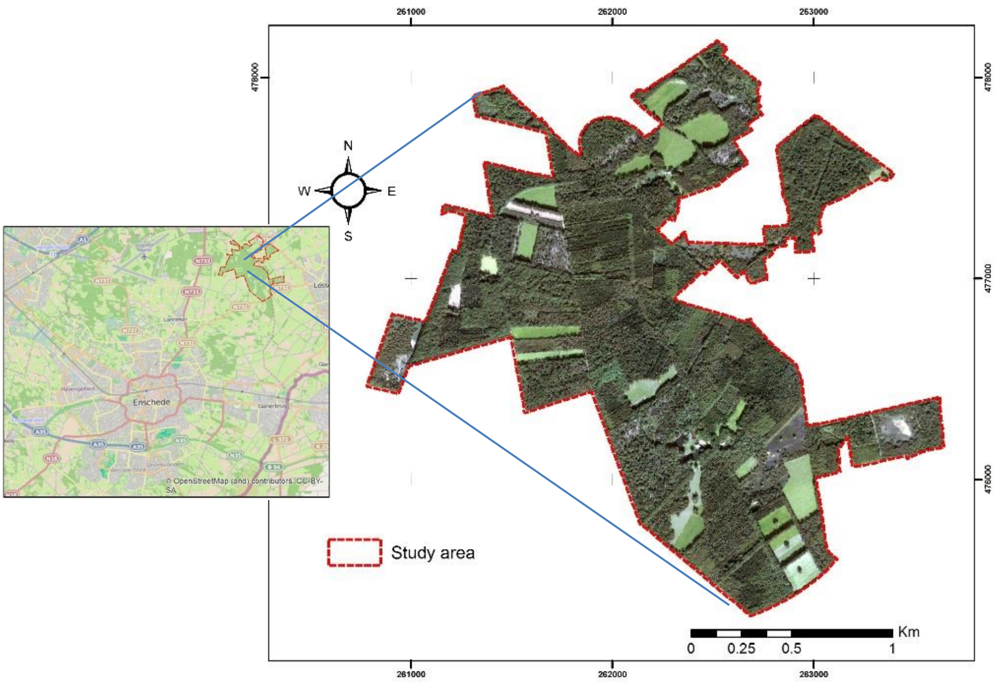


Figure 1. Study area location map

Generally, forest in the Netherlands have mostly recreational and nature conservation function, some also production, so even with Haagse Bos and Snippert forest. Some part of this forest are protected, so no logging or only controlled logging. The Nature Monument part is managed without human intervention. Part of Haagse Bos forest was previously a production forest. Coniferous trees were planted for timber production. The old production forest with hard labour has been transformed into a natural forest with more mixed stand, undergrowth, and more diversity. Also less of even aged tress, natural process of undergrowth development and re-establishment of local species for wildlife habitat.

The forest is open for public for serving as tourism and recreational areas. This forest constitutes of tree species such as, European beech (*Fagus sylvatica*), Oak (*Quercus robur*.), Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*), Eastern hemlock (*Tsuga Canadensis*), European larch (*Larix decidua*), European White Birch *(Betula pendula)*, Alder *(Alnus glutinosa)*, etc.

2.2 Data

TLS point cloud data were collected in the field. Riegl VZ-400 laser scanner were used for the collection of the data. Topographic map and other thematic map were used for study area delineation and sampling design. Very high resolution imagery was used to identify the trees in the field and which were used as reference points in data analysis.

2.3 Field instruments and software used

Field instruments needed for the study are Riegl VZ-400, GPS, Silva Compass, Sunnto Clinometer, Spherical densitometer, Leica Disto D5 laser ranger height measure, Diameter tape (5m), Measuring tape (30m) and Data recording sheet were used to measure and record the tree parameters in forest. The list of equipment is shown in Table 1.

Table 1. List of equipment used in field work.

Instruments	Purposes
Riegl VZ-400	Terrestrial laser scanning
GPS Garmin	Navigation and positioning
Leica DISTO D5	Tree height measurement
Haga altimeter	Tree height measurement
Silva compass	Plot delineation and locating TLS
Sperical densitometer	Forest canopy density measurement
Diameter tape (5m)	DBH measurement
Measuring tape (30m)	Plot delineation
Quickbird image	Sample plot identification

Different software was used for point cloud processing and analyzing. The software used in the study and its specific purpose are listed in the Table 2.

Table 2. List of software and its use purposes.

Software	Purposes
RiScan Pro	Multiple-scan registration, pre-processing
Computree	Creating DTM, automatic DBH and tree height measurement
ArcGIS 10.3	Vector analysis and map layout
Erdas Imagine 2014	Image processing
SPSS	Statistical analysis
MS Office 2013	Data analysis and thesis writing

2.4 Methods

The method of this research mainly cover of three parts: 1) field data collection, 2) tree parameters data analysis, and 3) carbon estimation. In the field data collection, biometric and point cloud data in each plot were collected at same time. Biometric data were recorded based on direct observations consist of tree species, DBH, height, and plot canopy density. These kind of data were measured in the field as a ground truth. Point cloud data were collected using TLS by Riegl series VZ-400. For pre-processing and registration of multiple-scans, the RiSCAN PRO software was used. For tree detection, and automatic measurement of tree parameters from registered point cloud data, Computree software was used. This is an open source software to processing platform for 3D point clouds in forestry developed by Office National des Forêts (ONF). Digital terrain model (DTM) generation, horizontal slicing of trees, and cylinder fitting are major steps for automatic extraction of tree parameters. The carbon stock in Haagse Bos and Snippert forest was calculated based on the above ground biomass from allometric equation from both field and TLS derived DBH and height. Comparison among tree detection, DBH and tree height, AGB and AGC derived from field measurements and TLS data were done in SPSS. A schematic flowchart of research is presents in Figure 2.

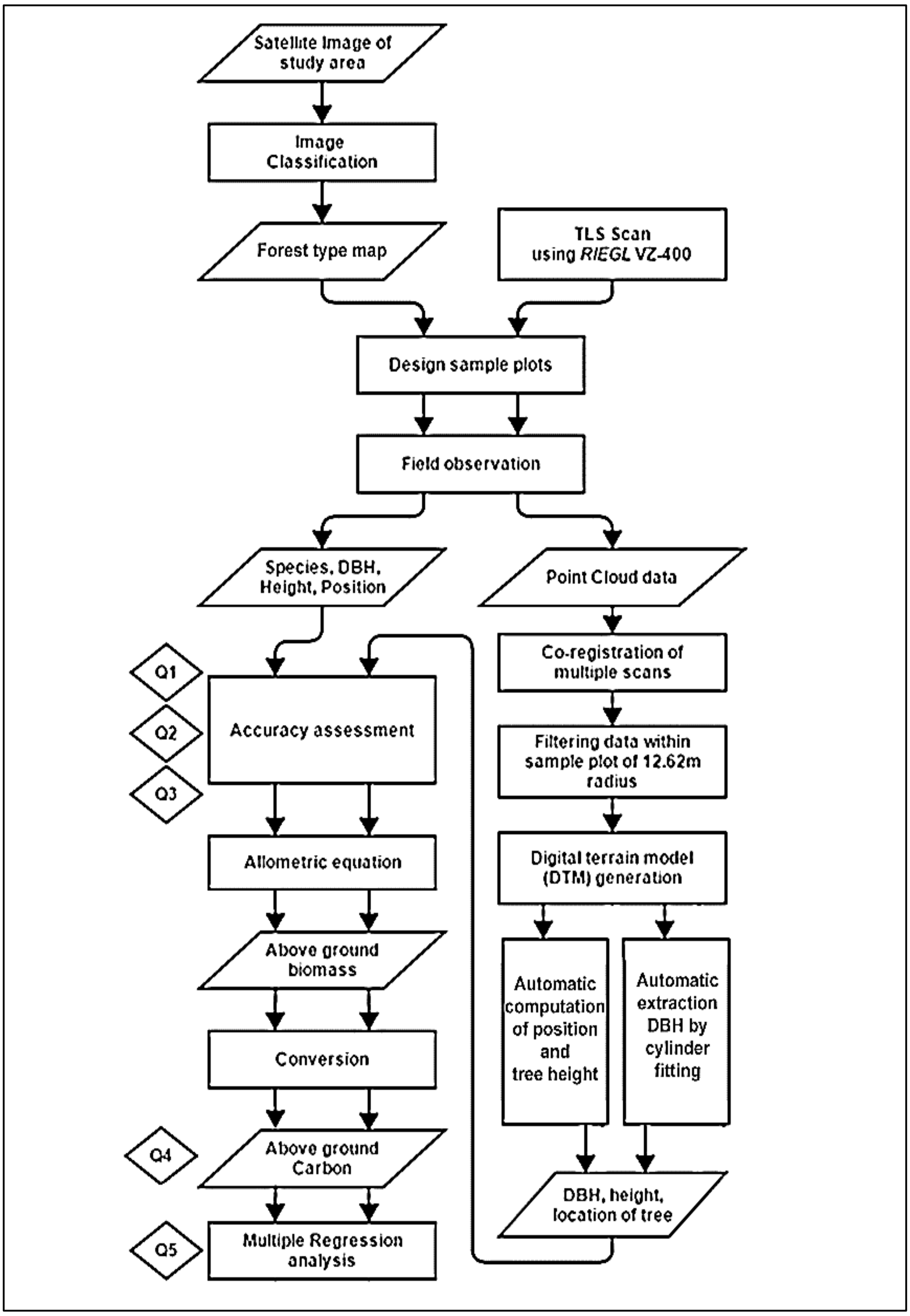


Figure 2. Flowchart of the methods

The Quick-bird image, acquired in September 2006, was geo-referenced and registered with UTM 32 N projection, WGS 84 spheroid and WGS 84 datum. The panchromatic image (spatial resolution 0.61m) was pan sharpened using the Quick-bird MSS image (2.4 m) to obtain a multispectral image with 0.61 meter spatial resolution. Next, the segmentation results were reclassified into land cover classes. For land cover classification system, this study used a land cover classification from the Eurostat Land Use/Land Cover Area Frame Statistical Survey (LUCAS) classification and land cover classification of the TOP10NL map.

Collecting point cloud data using TLS should consider the suitable plot size. If a plot is large occultation problem occurs, and if plot is small representative data cannot be acquired. According to Trochta et al. (2013) stated that 95% tree can be successfully detected within 15 m distance from the TLS. Similarly, Ruiz et al. (2014) argued that minimum plot size for forest inventory parameters estimates from TLS data should be 500-600 m2. Therefore, this study a circular plot of an area of 500 m2 and radius ~12.62 m was used.

In forest inventory stratified sampling is reported to yield a better precision than simple random sampling. This can be achieved if the established strata have greater homogeneity. Therefore stratification based on forest types was done as mentioned above to obtain homogeneous strata. Then in each forest class plots of 500 square meter circular plots were used and data were collected.

A total of 24 samples plot were distributed in a stratified random sample technique (Figure 3). From the sample plot centres 12.62 m radius buffer was created to establish the sample plots area of 500 m^2. The shape file of the sample plots was overlaid on Quick-bird image and a print out of the image of the sample plots was prepared for the annotation and measurements of biophysical characteristics of the sample trees in the field.

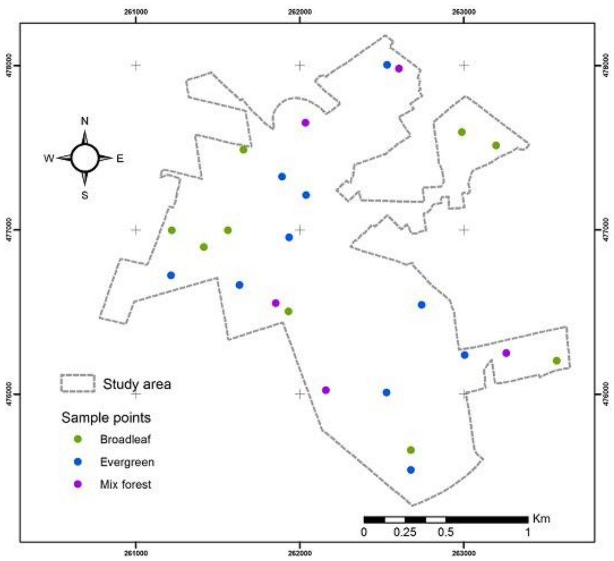


Figure 3. Position of 24 sample plots in the study area.

In this study a circular plot of 500 m^2 as a sampling unit with 12.62 m radius was delineated in the forest. Firstly, we identified the species of each marked tree. Secondly, trees with DBH 10 cm or more within the plot were only measured. This is because it is assumed that trees with DBH < 10 cm contribute little to the total biomass (Brown, 2002). DBH of tree measured with diameter tape at 1.3 m height above the ground. A diameter measuring tape had millimeter accuracy. Then, the tree height of marked tree also measured. Haga altimeter and Laser range finder was used to measured height of tree. Finally, estimating crown cover density using Spherical Densitometer was carried out.

Each forest sample plot was scanned with Riegl VZ-400 TLS. Within the plot 3-5 circular retro-reflectors were placed and 12 cylindrical retro-reflector as identifiable targets to aid in the merger as tie point for the point clouds from 4 individual scans into a single point cloud. Then, the sample plot was scanned in multiple mode (Figure 4) to avoid possible occultation from surrounding vegetation. In comparison to single scan mode, multiple scan mode gives much more details of the scene but it takes more time for data acquisition and processing. The scanning resolution of approximately 1 cm at a distance of 10 m was selected, because this is enough to distinguish small vegetation features like small branches and leaves.

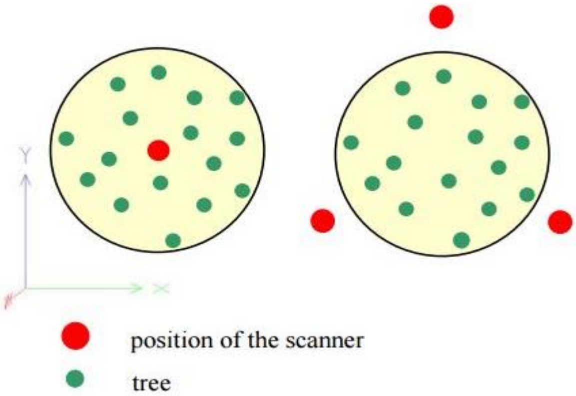
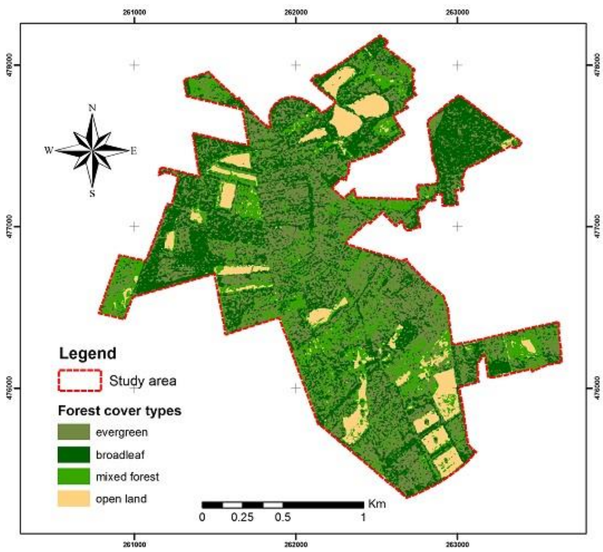


Figure 4. TLS scan positions

3. RESULTS AND DISCUSSIONS

3.1 Forest cover types

Digital image classification techniques group pixels to represent land cover features. Land cover could be urban, agricultural, forested, and other types of features. Hence, to overcome this variability, the forest was classified as coniferous, broadleaf trees, and mixed forest, based on LUCAS classification and land cover classification of the TOP10NL map. The classification was done in a supervised technique using maximum likelihood classifier. The boundary of the study area (Haagse Bos and Snippert) was also digitized and the image area of interest (AOI) was extracted out by clipping. The result of the classification of Quick Bird image is forest cover types map of year 2006 of the study area (Figure 5). The accuracy of the classified images was assessed. For the classification accuracy assessment image 64 validation points were used, which achieved 76% as an overall classification accuracy.



Figures 5. Forest cover types map

3.2 TLS trees detection

The point cloud data of 24 plots have been processed in Computree software. Total 414 trees were detected by TLS in three different types of temperate forest of Haagse Bos. In general, the tree extraction percentage was 96.95%. All trees in 15 plots were recognized and extracted. In addition, the lowest percentage of trees detection is 73% in plot 11. Trees which are not detected mainly caused by failing the classification criteria or occlusions. In the evergreen forest, plot 6 and 9 got the value of trees detection percentage 95% and 93% respectively. While all trees in the rest plots of evergreen forest were recognized and extracted. The overall success rate of trees detection in evergreen forest is 98.3%. In the broadleaf forest, similar condition of trees detection like evergreen forest also seen.. Plot no. 8 and 12 had the value of trees detection percentage 93% and 92% respectively. The overall success rate of trees detection in broadleaf forest is 98%. By contrast, mixed forest had the lowest percentage of trees detection. The overall success rate of trees detection in mixed forest is 91.9%.

3.3 Trees DBH and height measurements

The overall comparisons of DBH derived by automatic methods with field measurements are shown in Figure 6. The R^2 values for automatically estimated DBH is 0.96, i.e., 96% variability in field measured DBH are explained by DBH from TLS data. The RMSE values is 2.42 cm for automatic DBH extractions. This value shows that there is high agreements between the DBH derived from TLS and field measurements. Paired t-test has been performed to compare the DBH of the tree in the field and derived from TLS. The result shows that value of P (|T| > |t|) = 0.75 which is bigger than confidence interval value 0.05.

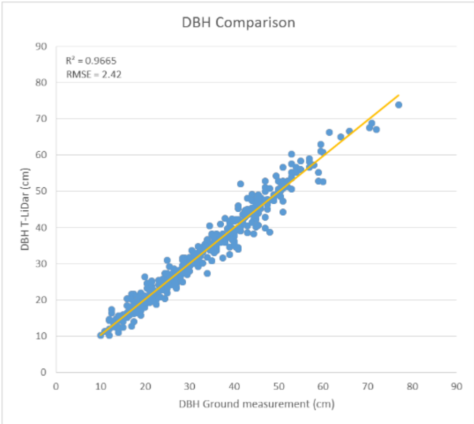


Figure 6. Comparison of DBH field measurements and DBH derived from TLS.

Regression analysis was done to compare the relationship between field observations and measured DBH from TLS in different types of forest. The relationships analyses of each forest cover are shown in Figure 7 by scattered plots and T-test. The highest value of R^2 of DBH comparison is 0.959 in evergreen forest with the value of RMSE is 1.95 cm, followed by broadleaf forest with the value of R^2 is 0.955 and value of RMSE is 2.71 cm, and the lowest value of R^2 is mixed forest 0.951 with the value of RMSE is 3.17 cm. The value of R^2 in all plots of study area was above of 0.95, which is reasonably high and a very close estimate between the field measurements and TLS derived DBH. These make DBH derived from TLS are very suitable for AGB and AGC estimation. Paired t-test has been performed to compare the DBH of the tree in the field and derived from TLS in each forest covert types. The results shows that value of P (T<=t) two-tail in evergreen forest is 0.17, in broadleaf forest is 0.20, and in mixed forest is 0.75.

The overall comparisons of tree height derived by automatic methods with field measurements are shown in Figure 8. The R^2 values for automatically estimated height is 0.523, i.e., 52% variability in field measured tree height are explained by height from TLS data. The RMSE values of 3.66 m for automatic tree height extractions. This value show that there is moderate agreements between the height derived from TLS and field measurements. Paired t-test has been performed to compare the tree height in the field and derived from TLS. The result shows that value of P (|T| > |t|) = 3E-10 which is lower than confidence interval value 0.05.

Regression analysis was done to compare the relationship between field observations and measured tree heights from TLS in different types of forest. The analyses of each forest cover are shown in Figure 9 by scatter plots. The highest value of R^2 for Height comparison is 0.585 in mixed forest with a value of RMSE of 3.71 m, followed by broadleaf forest with the value of R^2 is 0.538 and a value of RMSE of 4.12 m, and the lowest value of adjusted R^2 is evergreen forest -0.123 with the value of RMSE of 3.43 m. Two forest types, mixed and broadleaf forest, had the value of R^2 above of 0.5 while in evergreen forest had the negative value of adjusted R^2 which means tree height from TLS in evergreen forest cannot explain the variance of tree height of field measurement and this value considered to be 0. This happened due to outliers which caused of occlusion and the high number of trees in one plot. Paired t-test has been performed to compare the tree height in the field and derived from TLS in each forest cover types. The result shows that in all forest cover types of Haagse bos value of P (T<=t) two-tail are under 0.05.

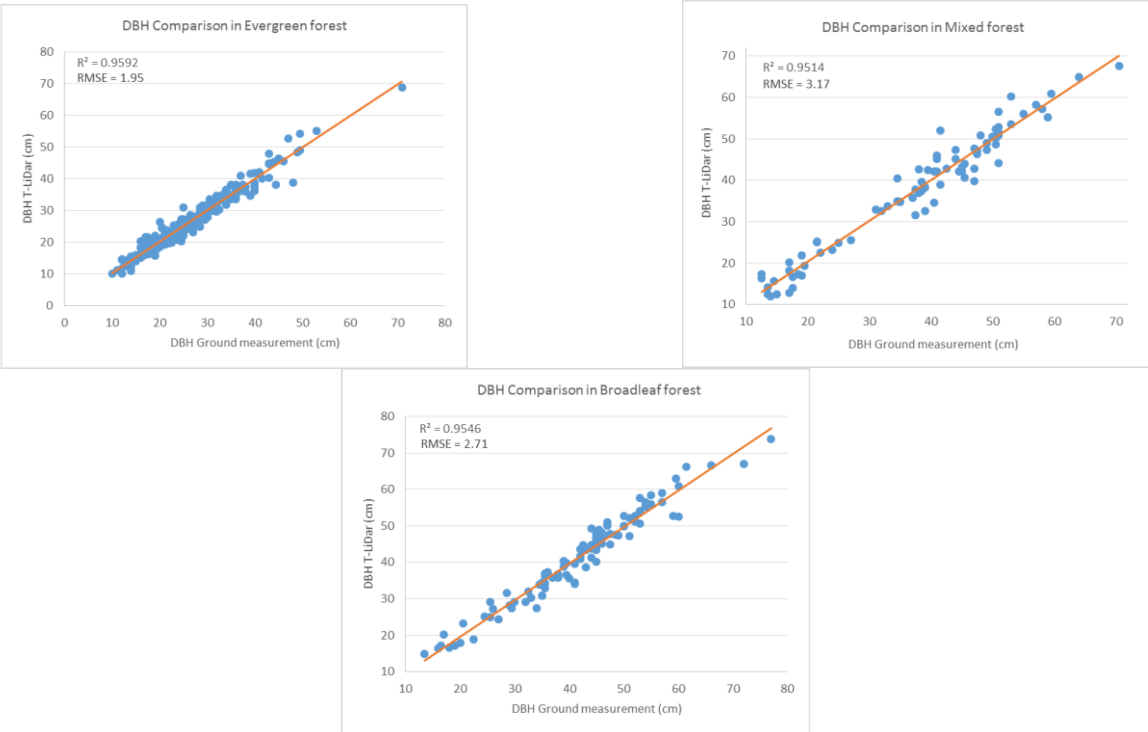


Figure 7. Comparison of DBH form field and DBH derived from TLS in three different forest cover types.

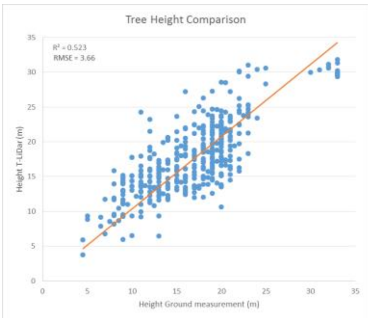


Figure 8. Comparison of tree height from field measurements and tree height derived from TLS.

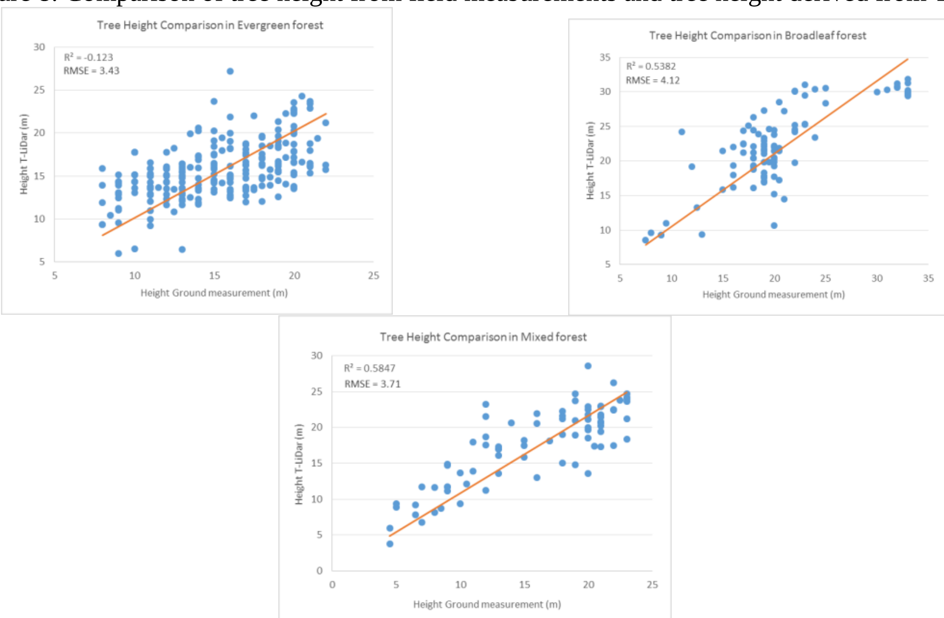


Figure 9. Comparison of tree height form field measurements and TLS in three different forest cover types

3.4 Comparison between AGB and AGC stocks and accuracy

The average per hectare estimate of biomass and carbon are 220.6 ton and 103.7 on the basis of field observation while 221.2 ton and 104 ton on the basis of TLS estimation. AGB and AGC derived from TLS were compared with estimated field measurements (Figure 10). The R^2 values for both the estimated AGB and AGC is 0.97 and the corresponding RMSE values are 24.6 and 11.6 ton per hectare. These values indicate that AGB and AGC can be estimated with high accuracy using manually derived DBH and tree height from TLS data compared to field measurement.

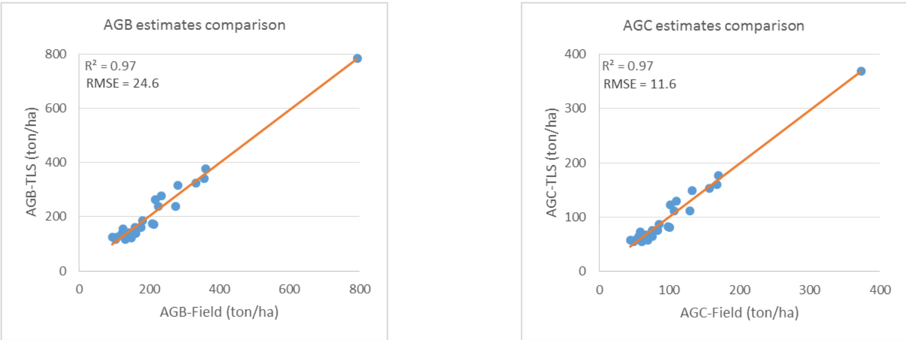


Figure10. Comparison of AGB and AGC stocks, estimated from field measured and TLS.

AGB and AGC derived from field and TLS for evergreen forest were compared with estimated field measurements (Figure 11). The adjusted R^2 values for both the estimated AGB and AGC is -0.63, the negative value of adjusted R^2 which means AGB and AGC measured from TLS in evergreen forest cannot explain the variance of AGB and AGC of field measurement and this value considered to be 0. While the corresponding RMSE values are 17.3 and 8.1 ton per hectare.

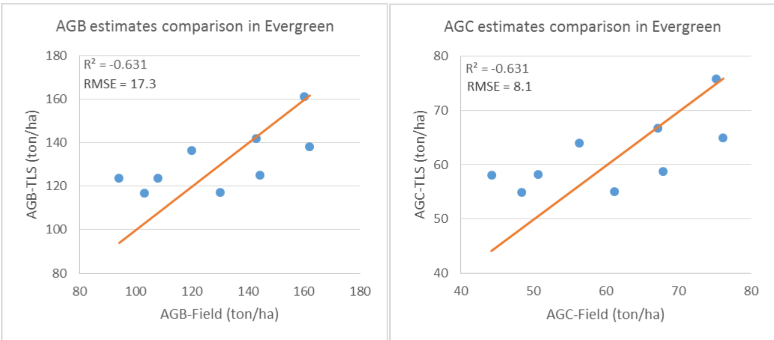


Figure11. Comparison of AGB and AGC stocks, estimated from field measured and TLS in evergreen forest.

AGB and AGC derived from field and TLS for mixed forest were compared with estimated field measurements (Figure 12). The R^2 values for both the estimated AGB and AGC is 0.93. While the corresponding RMSE values are 26.6 and 16.7 ton per hectare.

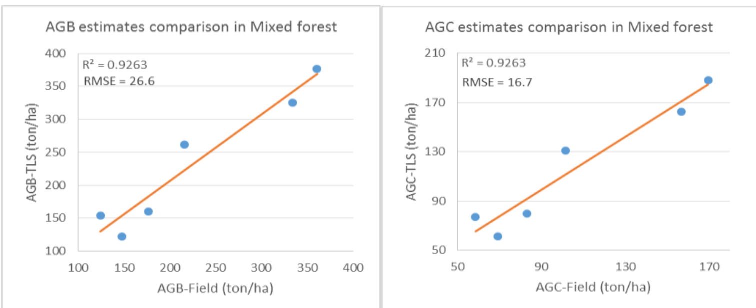


Figure12. Comparison of AGB and AGC stocks, estimated from field measured and TLS in mixed forest.

This study investigates the ability of TLS to retrieve above-ground biomass from allometric equations at Haagse Bos temperate forest based on retrieval of stem count, tree DBH, and tree height. Recent technology advancement suggested that, automation and accurate retrieval of the mentioned parameters would be valuable for research needs because AGB biomass is a crucial forest parameter for many carbon balance studies. Total AGB of each species was calculated using DBH and height based on best available models developed by previous research. 97.9% of all trees, from 5 species, in this study area using allometric equation with combined DBH and height as a parameters (i.e. spruce, scots pine, larch, oak, and beech). While, 2.1% trees from 2 species (alder and birch) using the equations that uses only DBH as a parameter. The allometric equation are developed for one specific area may introduce error when it is used for different environments.

The result of mean AGB and AGC stocks from tree parameters derived from TLS of the study area were approximately 221.2 ton/ha and 104 ton/ha, respectively. Meanwhile, the value of AGB and AGC stocks from field measurement were 220.6 ton/ha and 103.7 ton/ha. These results show a slight difference compared to the general carbon stocks estimates made for the Netherlands, which is made based on standing stock approach (Annual increment-harvest) (Nabuurs et al., 2000). This estimate has about twice the general estimate for the Netherlands be about 59 ton/ha.

A scatter plot was established between the total AGB/AGC in ton per hectare derived from TLS vs. total AGB/AGC in ton per hectare using allometric equation. The R^2 value is 0.97 and RMSE value of AGB and AGC were 24.6 ton/ha and 11.6 ton/ha, respectively. These values indicated that AGB and AGC can be estimated with high accuracy using manually derived DBH and tree height from TLS data compared to field measurement. T-test was done to test the significance of AGB and AGC estimated from field measurement and TLS data. The result shows that in AGB and AGC comparison value that value of t-stat (-0.11) it is in range between t critical two-tail (-2.1 up to 2.1) and the value of P (T<=t) two-tail (0.91) is higher than confidence interval value (0.05) which means null hypothesis are accepted, so there is a no significant difference between the AGB/AGC measured in the field and AGB/AGC derived from TLS data. With this analysis it is shown that TLS data are very suitable and had a high agreement for estimation of aboveground biomass and carbon stock.

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