Print : ISSN 0970 – 7662
Online : ISSN 2455 – 7129

Journal of Tree Sciences

online available at www.ists.in

Volume 39 No. 2 December, 2020

Tree biophysical parameter retrieval using close range photographs

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DOI: 10.5958/2455-7129.2020.00015.1

ABSTRACT

An approach to generate the 3D model of individual standing trees and retrieve their biophysical parameters has been presented in this paper. The technology requires little user intervention and allows full or semi-automated external orientation of images, camera calibration and creation of 3D models based on image correlation techniques. Close range photographs of isolated trees taken from multiple angles were used. The 3D models generated were used to obtain measurements on tree height, crown base height and crown diameter. Accuracy and precision of the results were tested, and validated using conventional ground based measurements. It was found that the field observed and model estimated parameters were in good agreement and the error in measurement was 4.64% for height and 13.75% for crown diameter. The correlation coefficient between phytomass based on the field data and 3D modeled data was 0.7 for *Eucalyptus* sp. and 0.56 for *Tectona grandis* (Teak). More repetitive experiments and methodological studies particularly in forest ecosystem are required using very high-resolution close range digital photographs to understand the rate of growth, carbon pool assessment and carbon sequestration in forests with higher accuracies.

Key Words:

Biophysical parameters, close-range photographs, digital camera, 3D model

INTRODUCTION

Forest ecosystems are one the most important carbon sinks and the major storehouses for above ground and below ground biomass. Forest biomass assessment has essential contributions to the global carbon budget, measurement of ecosystem productivity (Galidaki, 2017), management of forests and climate change modeling studies. The sustainable management of these forest ecosystems requires accurate and timely information on the dynamics of their various structural attributes. The primary tree-level attributes to characterize the forest ecosystems include tree height, diameter at breast height (dbh), crown diameter and crown to base height. The conventional methods of acquiring information on tree parameters have relied upon direct field-based measurements (for which various instruments like poles, level rods, hypsometers for tree height measurements and diameter tapes for crown diameter measurements have been developed) for forests biomass and carbon assessment using optical and microwave satellite data (Husch et al. 1982,; Kale et al. 2002; Kale et al. 2004; Korhonen et al. 2006, Dadhwal et al. 2009). Satellite data-based methods have shown promising results in obtaining forest variables over larger areas for several decades (Korpela and Takola 2006,). Forest stand-level attributes derived from medium spatial resolution optical satellite data have also been estimated but with variable accuracy (Hyyppa and Hyyppa 1999; Kumar et al. 2011; Patil et al. 2012; Singh et al. 2012; Devagiri et al. 2013; Salunkhe et al. 2014; Kumar et al. 2014; Upgupta et al. 2015; Salunkhe et al. 2016). The transition from medium to high resolution remote sensing imagery opened up new vistas for a semi-automatic computer based analysis of aerial or satellite images on an individual tree crown basis (Key et al., 2001; Gougeon and Leckie 2006). Data from both airborne and space-borne Synthetic Aperture Radar (SAR) have also shown capabilities in retrieving forest attributes (Fransson et al. 2004; Izzawati et al. 2006; Kumar et al. 2017a,b). In the last few decades, airborne laser (Persson et al., 2002; Leckie et al. 2003) and terrestrial laser (Thies and Spiecker 2004) scanning data have been found to be highly efficient for the estimation of forest biophysical parameters but it has high operational costs which limits its repeat collection frequency. Field surveys are by far the most accurate means of acquiring forest parameter information in tropical and subtropical forest ecosystems.

With the advancement in digital technology, digital cameras were used as a new tool of communication. Hengl et al. (1998) calculated the stem volume from stereo-photogrammetry of mature trees surrounded by a cubic array of survey points, photographed with a non-metric digital camera, and followed by edge detection analysis. From terrestrial photographs of seedlings, relationships between biomass, basal diameter and silhouette area have been developed (Ter-Mikaelian and Parker 2000). Pyysalo (2004) measured tree crown dimensions on lateral photographs captured from two different directions. Lee et al. (2003) presented automated methods of tree boundary extraction and Clark et al. (2001) used digital terrestrial photogrammetric methods for tree stem analysis. Mat et al. (2014) determined the age of a tree by measuring tree diameter using close range photogrammetry technique.

In close-range photogrammetry (CRP) a hand held or standard camera is used to take multiple, overlapping images from different perspectives, and produce measurements that can be used to create accurate 3D model of objects. Using a digital camera with known characteristics (lens focal length, imager size and number of pixels), it requires a minimum of two images of an object and if the same three object points in the two images can be specified manually along with a known dimension, the other 3D points in the images can be determined automatically (Atkinson 1996).

Digital photogrammetry has been applied in agriculture and forestry for crop quality monitoring, crop growth monitoring (Ying et al. 1999), modeling of trees and forest inventory *etc* but the applications are limited. However, new technologies that can refine the method of forest inventories and improve the process of measuring and monitoring forests are continuously being developed. The objective of the present study is to develop a robust photogrammetric method to generate the 3D model of a tree and measure its parameters based on terrestrial close range photographs, which can further be developed and demonstrated for applications in larger forest area.

MATERIALS AND METHODS

Study Area

The present study was carried out in the forest plantations of Bhakra forest range in Nainital district of India (Fig.1). The geographical extent of the study area is 29°04' to 29°13' N and 79°21' to 79°24' E and has an average elevation of 285m above mean sea level. The topography is nearly flat to very gentle. The highly fertile soils here were once covered by extensive moist deciduous tree species, mainly Sal (*Shorea robusta*) in the past. The government converted the entire area of natural forests into plantations of different tree species like *Eucalyptus sp., Tectona grandis, Acacia catechu, Populus* sp. *Dalbergia sissoo, Holoptelia integrifolia*, *Bombax ceiba, Mallotus philippensis* and *Cassia fistula* under production forestry. The age group of the plantations varies from 5–48 years for *Tectona grandis* and 4–7 years in case of *Eucalyptus.* Climate is tropical with a mean temperature of 22.8°C. The total annual rainfall is 2095 mm.

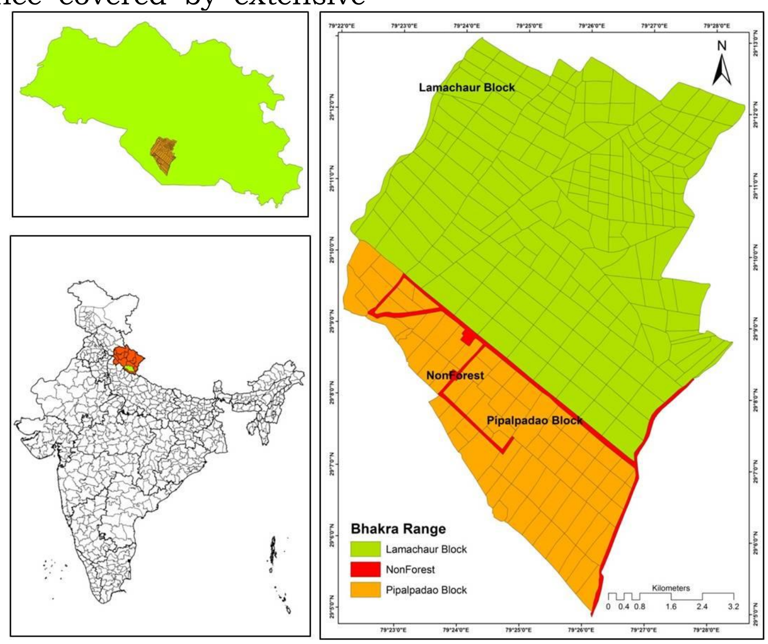

Fig.1: Study area location

Close Range Photography

The approach and methodology was first tested and developed on *Cinnamomum camphora* which, is an evergreen tree reaching a height of 20-30 m at maturity. The tree produces a bright green and dense foliage with a dome shaped crown which makes it quite suitable tree for 3D modeling. The tree was photographed from multiple angles using Nikon D80 Digital Single Lens Reflex (DSLR) camera (Resolution-10 MP) with convergent optical axis at a single focal length setting of 18 mm. Reference markers and reference scales were used. The captured photographs were then processed to generate a 3D model in Photomodeler scanner software. The methodology thus established (Fig.2) was implemented on the selected plantation trees of Bhakra Range in Haldwani. A total of 40 field photographs were acquired and trees of different age groups were targeted. The stepwise procedure for acquiring the digital photographs is detailed as: (a) The image capturing locations were chosen at a distance of 10-20 meter from the tree, (b) Reference scale bar of 0.5 meter was placed to the tree trunk, (c) Reference markers were placed around the tree on the ground and wherever possible on the tree branches, (d) optical axis of camera was kept horizontal and images were captured, (e) tree height was measured with a Laser Dendrometer and crown width in different directions were measured with a tape and (f) Distance of camera from the tree was also measured. A total of 18 trees (10 Teak, 7 Eucalyptus) were photographed accordingly. The diameter at breast height (dbh), tree height and crown diameter of all the photographed trees was measured. Wherever photography from all angles was not possible the trees were captured from only two angles which is sufficient to generate the 3D model and obtain the measurements. Tree parameters like tree height and crown diameter were estimated from the 3D models and validated with ground measurements.

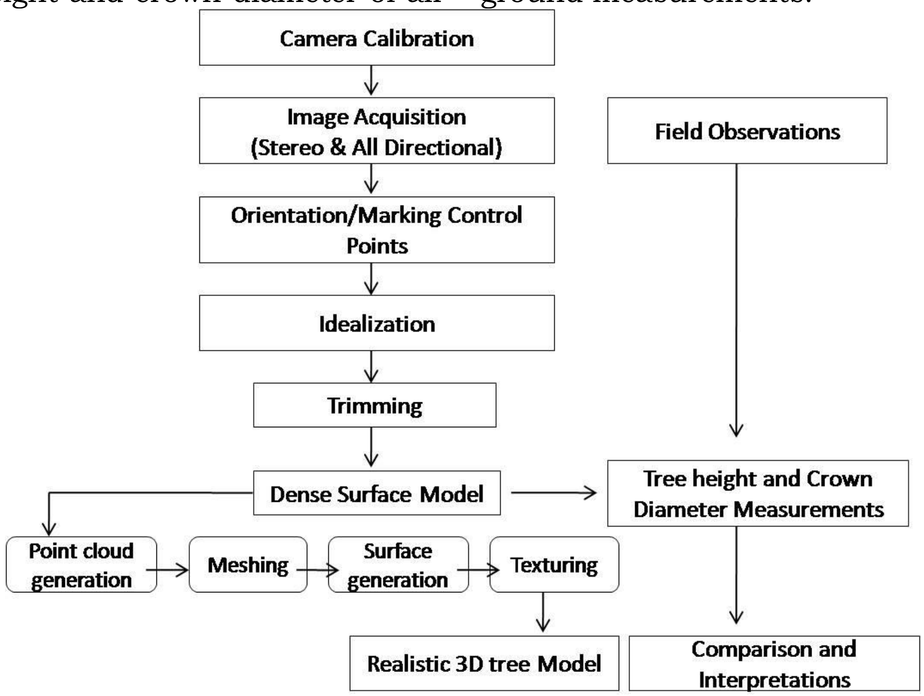

Fig.2: Methodology for the study

Processing of field photographs

The photographs acquired in the field were processed in PhotoModeler Scanner as follows:

(a) Camera Calibration: Camera Calibration is the process of determining the characteristics of a camera so that it can be used as a measurement device. The calibration parameters such as focal length, principle point X, principle point Y, Lens distortion parameters were derived in the software. The camera was then calibrated for 18mm focal length using the self-calibration option and calibration sheet provided in the software package.

(b) *Orientation/Marking Control Points*: This was done by marking control points in the first and then identifying and marking the same points in the next or adjacent photograph (Fig.3).Well distributed and sufficient number (>7) of points were marked to orient the photographs. Greater the number of points lesser is the residual error. All the photographs were processed to orient and rectify them to a plane parallel to the tree trunk.

(c*) Idealization:* The photographs were then idealized to account for lens distortions. Since a non- metric camera was used and had some lens distortions at the fringes of the image, the photographs were idealized using the in-built module for idealization in the software (Fig. 3).

(d) *Trimming:* Trimming was performed to consider only the area of interest, tree in this case, as it reduces the time for dense surface model generation. Hence to define the actual processing extent in the entire image, the tree boundary in images were digitized.

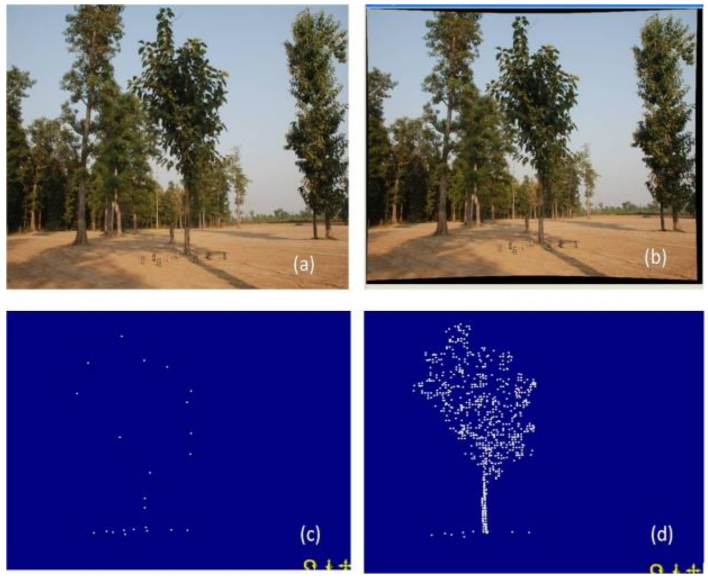

Fig.3: Processing in PhotoModeler (a) distorted photograph, (b) idealized photograph, (c) control points marking and (d) dense point cloud creation.

Generation of 3D model and parameter retrieval

After trimming the area of interest, a dense surface model was generated. The scale was first set to meters and a dense point cloud was derived using the image based scanning algorithm in the software (Fig.3). Dense point cloud algorithm is a search algorithm that uses an existing pre-oriented project and pairs of photos from that project to search for image patches that 'look' alike. This search is done in a regular grid-like manner so a grid of 3D points is computed. When a good match is found between two photos, the orientation and camera data allows the program to compute the correct 3D location of the surface point corresponding to the image patch. Dense point clouds thus generated were converted into a triangulated mesh surface to get the surface model and give a shaded look to the tree model. The dense surface model thus created was used to measure the dimensions of the tree. Any two points selected within the dense surface model provided distance between those two points. Tree surface texture was draped using the original oriented photographs to give a realistic look. For good texturing the maximum residual value should be less.

Assessment of Biophysical Parameters

The parameters measured in the field were compared with the estimates from 3D model and plotted on graphs for comparison. A multiple linear regression model was run with the field measured parameters to develop a relationship between diameter at breast height (dbh) and tree height. The generated regression model coefficients were used to establish dbh and height equations for the Teak and Eucalyptus trees separately. The tree height measured from the 3D models were then input into these equations to obtain the dbh derived through 3D modeling. The dbh and height measurements (both from field as well as from 3D models) were used to calculate the tree volume using volume equations for Teak (*Tectona grandis)* ($V=0.08847-1.46936*D+11.98979*D^2+1.970560*D^3$) and for Eucalyptus sp. ($V= -0.0015+0.2401*D^2*H$) (FSI, 1996). The biomass was estimated by multiplying volume with specific gravity (0.57 for Teak and 0.875 for Eucalyptus). Finally the biomass estimated from field data were compared with the biomass estimates from 3D models and plotted for comparison and interpretations.

RESULTS

The 3D model generated for *Cinnamomum camphora* from 6 photographs is shown in Fig.4. The model measured a mean tree height of 8.5 m and crown diameter of 8.0 m as compared to the field measured tree height and crown diameter of 7.85 m and 8.34 m, respectively. The measurements show that there is an error of 0.65 m for tree height and 0.34 m for crown diameter measurements. The generated model was rotated in 3D to study the crown dimensions from multiple angles.

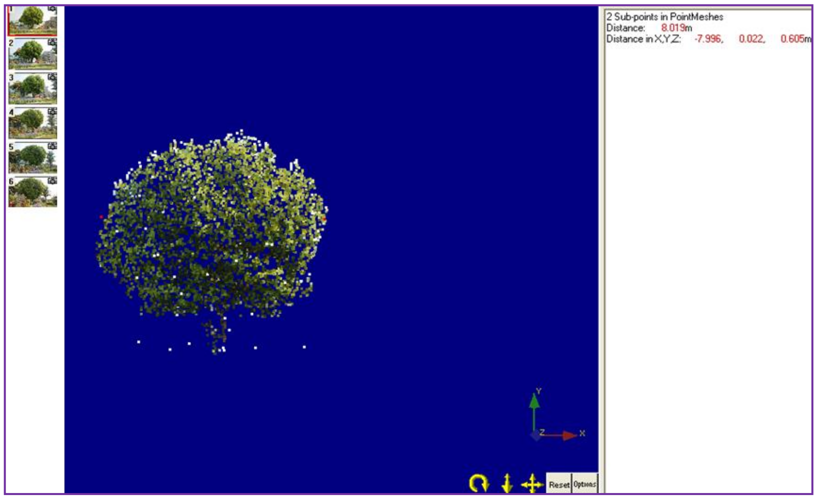

Fig.4: Measurements from the 3D model (*Cinnamomum camphora*)

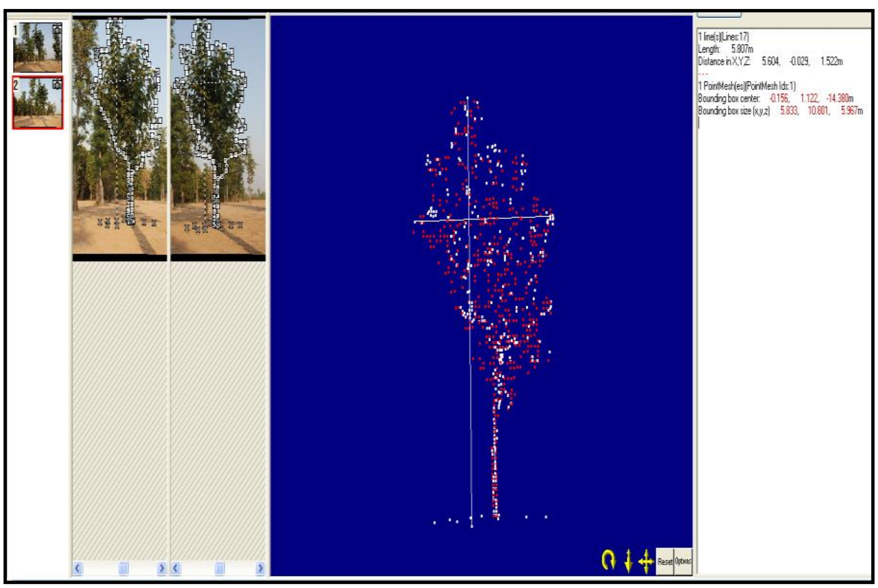

Fig.5: Measurements from the 3D model for *Tectona grandis*

Modeling and Measurement of forest plantation trees

The measurement of parameters from the 3D model of images of teak trees captured from plantations is depicted in Fig.5. The dbh of plantation trees ranged from 8 to 52.3 cm for Teak and 5.1 to 22.8 cm for Eucalyptus while the tree height ranged from 7.0 to 23.9 m for Teak and 6.2 to 17.12 m for Eucalyptus. Also the field measured crown diameter ranged from 3.16 to 9.72 m for Teak and 2 to 3.46 m for Eucalyptus. The measurements obtained from the 3D models are shown in Table 1.

Table 1: Observed and modeled tree height and crown diameter

Sl. No.	Species Name	DBH (cm)	Tree height (Field) (m)	Tree height (3D model) (m)	Crown Diameter (Field) (m)	Crown Diameter (3D model) (m)
1	*Cinnamomum* sp.	-	7.85	8.5	8.34	8.00
2	*Tectona grandis*	14.6	9.0	11.43	4.66	5.33
3	*Tectona grandis*	28.3	20.7	19.25	5.16	5.64
4	*Tectona grandis*	50.9	23.9	21.60	9.72	11.56
5	*Tectona grandis*	26.5	14.7	10.62	5.16	6.35
6	*Tectona grandis*	50.1	15.7	15.06	9.72	11.56
7	*Tectona grandis*	8.00	7.0	7.57	3.16	4.77
8	*Tectona grandis*	52.3	20.0	18.20	9.72	9.87
9	*Tectona grandis*	36.4	11.3	11.15	7.02	5.69
10	*Tectona grandis*	48.2	14.2	12.60	9.72	7.39
11	*Tectona grandis*	31.4	19.75	17.54	7.02	8.71
12	*Eucalyptus* sp.	16.9	17.12	13.50	3.46	4.01
13	*Eucalyptus* sp.	8.8	10.58	10.45	2	2.17
14	*Eucalyptus* sp.	22.8	16.6	14.12	3.16	5.20
15	*Eucalyptus* sp.	21.3	15.3	12.4	3.16	4.62
16	*Eucalyptus* sp.	17.5	10.9	13.1	3.46	4.47
17	*Eucalyptus* sp.	5.1	6.2	5.98	2.0	3.15
18	*Eucalyptus* sp.	8.3	10.58	11.28	2.0	3.9

The measurements from the 3D model were in close proximity with the field measured values. However, the error observed was less in the measurement of tree height and greater in the measurement of crown diameter. Nearly 4.64 % error observed in tree height measurement with a R^2 of 0.879 and RMSE of 5.83 while 13.75 % error in crown diameter measurement with R^2 of 0.84 and RMSE of 8.625 (Fig.6).

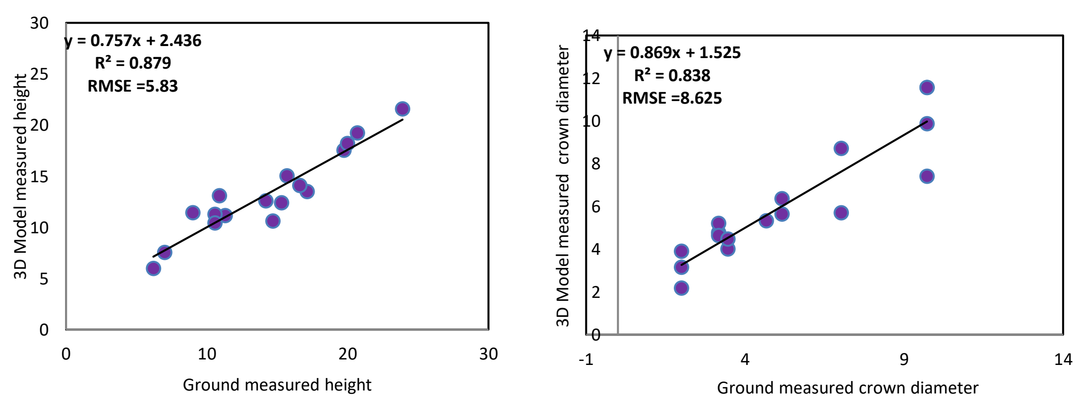

Fig.6: Regression between field-measured and 3D modeled parameters

Biomass Assessment

Biomass values ranged from 0.005-1.64t for Teak and 0.005-0.18t for Eucalyptus trees as estimated from the field data. The correlation between observed biomass and the predicted biomass was found to be 0.7 with an RMSE of 0.22 for Eucalyptus (N=7) and 0.64 with an RMSE of 2.80 for Teak (N=8). The regression plots generated are shown in the Fig.7.

The correlation found was less in case of Teak due to some single scattered trees that were not having normal growth pattern. These trees had not attained height growth in proportion to the growth in their dbh. As a result the dbh-height relation was not so good and hence the predicted biomass was less accurate. Initially the correlation (R^2) was very poor 0.429 but after removing some of the unusual trees the correlation improved to 0.638.

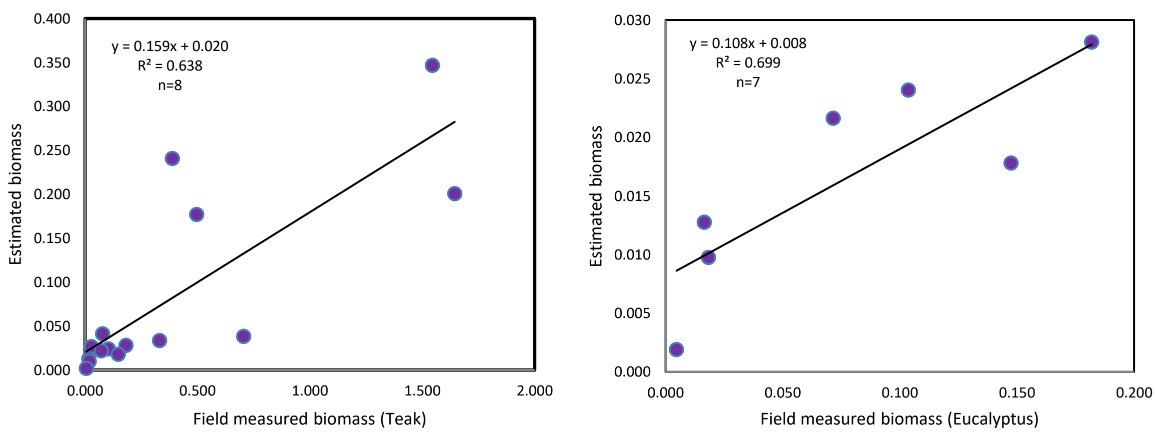

Fig.7: Regression plot between field and model measured biomass

DISCUSSIONS

Digital cameras have been used to measure individual tree parameters from digital images in the field (Juujarvi *et al.* 1998). The cameras are used to generate 3D model of buildings, engineering structures, volume estimation, forensic, accident scenes, etc. Several close range photogrammetric packages allow creating a dense surface model (DSM) using photo-matching algorithm in the same way as digital laser scanning does. But the instruments used for laser scanning such as laser scanners are very expensive and difficult to use. The approach used in this study is fairly inexpensive and easy to use. The method also requires little user intervention as after the initial data capture and manual point marking, the image orientation and model generation steps are semi-automated.

The measurement of tree height as well as crown diameter was more accurate as compared to the biomass estimates. This is because tree height and crown diameter are directly measured variables while biomass is a derived estimate from allometric equations based on an indirect relation with the tree parameters. With increasing dbh, the error for biomass estimate using allometric equations also increases exponentially (Calders *et al.*, 2015). Hence removal of the biomass estimate for the high dbh values improved the R^2 from 0.429 to 0.638 in teak trees. Further research is needed to look into the issues to improve accuracy of the assessments.

Approaches to model the morphology of plants and trees have been roughly classified as either rule-based or image based. Rule-based methods apply rules for creating models of plants and trees (Quan et al. 2006) but are not user-friendly to a non-expert. The image-based methods directly model the plant using image samples which range from a single image (Han and Zhu 2003) to multiple images (Sakaguchi 1998; Shlyakhter et al. 2001; Quan et al. 2006). Sakaguchi (1998) and

Shlyakhter et al. (2001) used the visual hull of the trees computed from silhouettes to represent irregular shapes. However, the methodology of terrestrial photography used here largely depends on a clear view of the tree. It is most effective in open and medium density forest for measurement of tree dimensions and in scattered trees for 3D model generation. It may not be very effective in case of undisturbed and dense forests where canopies overlap and will reduce accuracy in measurement because images cannot be captured from all directions. Even in the case of scattered trees the direction of light limits image capture from certain positions. The realistic look of the 3D tree model can be improved further by increasing the number of stereo-image captures. Photogrammetry is a very good tool if there is a limited access time to the object to be modeled. This method is very fast and does not require special instruments. The trade-off is that it can take a lot of time to process the images.

CONCLUSIONS

In this study we investigated the potential of digital cameras in generating accurate 3D model of individual standing trees and estimating biophysical parameters like tree height and crown dimensions from them. The generated 3D models of trees produced acceptable measurements comparable with the field data. Overall, this study indicated that close-range photography combined with specialized photogrammetric software packages have immense capability of measuring and modeling tree species for forestry applications. It may be concluded that close-range photogrammetry based image analysis techniques can be applied to assess the bio-physical parameters of trees and the above-ground biomass for larger areas. This methodology is also applicable for studying the morphology and growth phenology of trees for forest management purposes.

ACKNOWLEDGEMENT

This study was supported by Indian Institute of Remote Sensing as part of National Carbon Project under IGBP (ISRO Geosphere Biosphere Programme). The authors are grateful to Mr Vishal Malave for his initial support in establishing the methodology for data capture and analysis.

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Received: 14th October, 2020 *Accepted: 18th December, 2020*