© 2020 Kwame Nkrumah University of Science and Technology (KNUST)
http://dx.doi.org/10.4314/just.v38i1.3

RESEARCH PAPER

MEASUREMENT OF TREE VOLUME BY MEANS OF NON-METRIC 35MM PHOTOGRAPHY AND PHOTOGRAMMETRIC APPROACH

A. B. Agyemang[1], **J. A. Quaye-Ballard**[2*], **S. G. Godwin** and **K. Fumey-Nassah**
Department of Geomatic Engineering, Faculty of Civil and Geo-Engineering,
College of Engineering, KNUST, Kumasi
[1]*abagyemang.coe@ knust.edu.gh;* [3]*gsulvester@gmail.com;* [4]*KafFum65Nas@gmail.com*
[*]Corresponding author: *quayeballard.soe@knust.edu.gh*[2]

ABSTRACT
Forest Mensuration employs certain measurement principles to obtain quantifiable information about the forest for sustainable decision making. In this paper, a photogrammetric alternative employing 35mm non-metric photography has been suggested and used in the preparation of a Standard Volume Table (SVT) for Forest Mensuration. The forester is afforded volume information about trees in less time and at lower cost, without sacrificing accuracy. Comparisons are made between the photogrammetric and traditional methods used by foresters in measuring tree-volume. From the three methods – use of the Spiegel Relaskop, measuring tape on felled tree, and the photogrammetric technique developed in this work, volumes were determined using the Huber formula and a regression equation. The use of measuring tape on felled tree to determine tree volume has been known to provide the most reliable volumetric determinations and commonly serves as a standard for such measurements. Results from the photogrammetric technique compared very well with those obtained using measuring tape on felled tree indicating that , photogrammetric technique herein devised proves a more effective means for deriving Tree Volume Tables, if factors like speed, cost, and convenience are considered.

Keywords: *Tree-Volume, Pinus Hinduransis, Standard Volume Table (SVT), Photogrammetry, Zeiss Topocart D*

INTRODUCTION

Forest mensuration helps to determine the volume of logs, trees and stands and also facilitates studies of increment and yield (Graves, 1906). It is one of the keynote foundations of forestry and is the application of measurement principles to obtain quantifiable information about trees for decision making. Recently, researchers are focusing on using 3S technologies - Geographic Information Systems (GIS), Global Positioning Systems (GPS) and Remote Sensing (RS) - in forest mensuration as they are important aspects of science and technology of Land and Environmental Surveying. Such technologies have many advantages such as in quantifying the areal extent and spatio-temporal aspects of the forest in addressing climate change for sustainable decision making (Quaye

-Ballard *et al*., 2013). Many researches have been conducted to overcome the problems associated with the traditional methods based on time and extent of area required for decision making by using photogrammetric techniques in estimating tree and forest volumes as well as tree heights from LiDAR (Korhonen *et al*., 2013; Muller *et al.*, 2014; Popescu *et al*., 2003; Strother *et al*., 2015), laser altimetry (Holmgren, 2004, 2012; Hyyppä *et al*., 2004; Popescu *et al*., 2003; Tansey et al., 2009); aerial photographs (Miller *et al*., 2015; Straub *et al*., 2013) and 3D image analysis technique in assessing tree structure (Miller *et al*., 2015; Morgenroth and Gomez, 2014). Forestry, in a broader sense, manages activities involving forestland, the plants and animals on the land, and humans as they use land. As has aptly been said, "one cannot efficiently make, manage or study anything one cannot locate or measure".

Traditional methods for forest mensuration include the measurement of tree diameter and height. Some equipment used for diameter measurements include tree calipers, diameter tape, Biltmore Stick, etc. The Clinometer is also used for determining tree height. Diameter measurement is important because it is one of the directly measureable dimensions from which the tree cross-sectional area, surface area and volume can be computed. Tree calipers can conveniently be used for timber with diameter not exceeding 36 inches. However, for bigger diameters it is clumsy and impractical. The diameter tape is often used instead of calipers for scientific records on permeant sample plots. This is because, readings taken with the diameter tape are not subjected to the variations incurred in using the calipers. However, the diameter tape cannot be used to measure ends of logs except on the exposed ends of the logs; the tree calipers are preferable for this purpose. The Biltmore Stick is good for circular cross-section measurements but has inaccuracies in estimating diameters of tress due to the difficulty of holding the Stick exactly at a precise distance from the eye, difficulty with keeping the eye at breast height level and the eccentricity of the cross-sections. In addition to the above, climbing and felling of trees must be done for measuring tree volume by determining diameter at various heights. The climber climbs the tree and takes diameter and height measurements at various sections of the tree. Standing trees are felled before the height of the tree can be determined. After the trees are felled, the tape is used to measure the height. Thus, from the above, before a SVT can be prepared, trees need to be felled and so a sizeable portion of a whole plantation is destroyed before a Standard Volume Table is derived. With the felling of trees method, trees can be measured with any degree of accuracy. Tree volume increases with diameter and height. However, this increase is not regular for individual trees due to differences in tree forms. Tabulated values obtained from such measurements of felled trees are known as the Standard Volume Table (SVT). Other Volume Tables exist – examples include Local Volume Table (LVT) and Form Class Volume Table (FCVT).

Photogrammetric procedures are used to determine the volume of trees as against the traditional methods of climbing, felling the trees or using the Spiegel Relaskop. These methods are employed to measure the diameter and heights to enable the tree volumes to be determined, and from this a SVT is prepared. The SVT helps in the management of the tree species. Considerable research has been conducted using Remote Sensing as well as Laser Scanning Altimetry in estimation of tree volume (Maltamo *et al.,* 2004). Husch *et al*. (1982) have demonstrated that photogrammetric measurements provide better means for measuring the growing space of a tree since it is correlated to tree and stand volume. Making use of new technology is one of the challenges facing foresters since resource information must usually be obtained with limited budget and this justifies use of geospatial technology as exemplified by the photogrammtric method herein presented for tree volume measurements with non-metric 35mm. The aim of the research was to use 35mm non-metric photography in the Zeiss Topocart D for derivation of a Tree Volume Table of a pine plantation. The trees which were to be estimated for volume were photographed and the negatives used, instead of the positives, in order to reduce cost without sacrificing accuracy.

MATERIALS AND METHODS

Study area and field work

The study area is located at the Forest Research Institute of Ghana (FORIG) plantation at Mesewam near Kumasi on the Kumasi-Accra road. It extends between latitudes 6° 42′ 25.23″ N to 6° 42′ 13.36″ N and longitudes 1° 32′ 05.75″ W to 1° 31′ 54.16″ W (Fig. 1). The research was carried out on a Pine tree (*Pinus Hinduransis)* plantation. The size of the plantation is about 99m by 100m. In order to get clear view of the lower portions of the trees, the plantation was cleared of weeds. The pine trees on the edges of the plantation were dominant in growth whereas those within were suppressed due to competition for sunlight and soil nutrients. The growth patterns of the pine trees paved way as to the order with which the exposures should be taken. The exposures were taken in such a way that the SVT Table would be fair representation of the plantation. A careful consideration was given to the type of film, focal length of the camera lens, shutter speed, field of view and lighting conditions the plantation.

For traditional methods, the volume of a standing tree is determined by measuring the diameter and the heights of logs. The points at which the diameter is measured vary with circumstances. In the case of standing trees, standard position for diameter measurement has been established as 1.3m above ground level. The diameter taken at this height of 1.3m above ground is usually referred to as the Diameter at Breast Height (DBH). Height determination for the estimation of the volume of tree starts from the DBH. It is important, therefore, to consider the tree stem as made up of logs. The various portions of the tree stem take different geometric forms. In other words, it is very important to consider the stem of any tress to be a composite of geometric solids. In this research, the volume of a tree was regarded as equal to that of an equivalent cylinder. To obtain the diameter of the equivalent cylinder, several diameter readings were taken on the stem using the Zeiss Topocart D and the mean of these was used. The volume of the tree was then calculated as product of the mean diameter and the corresponding merchantable height of the tree/log.

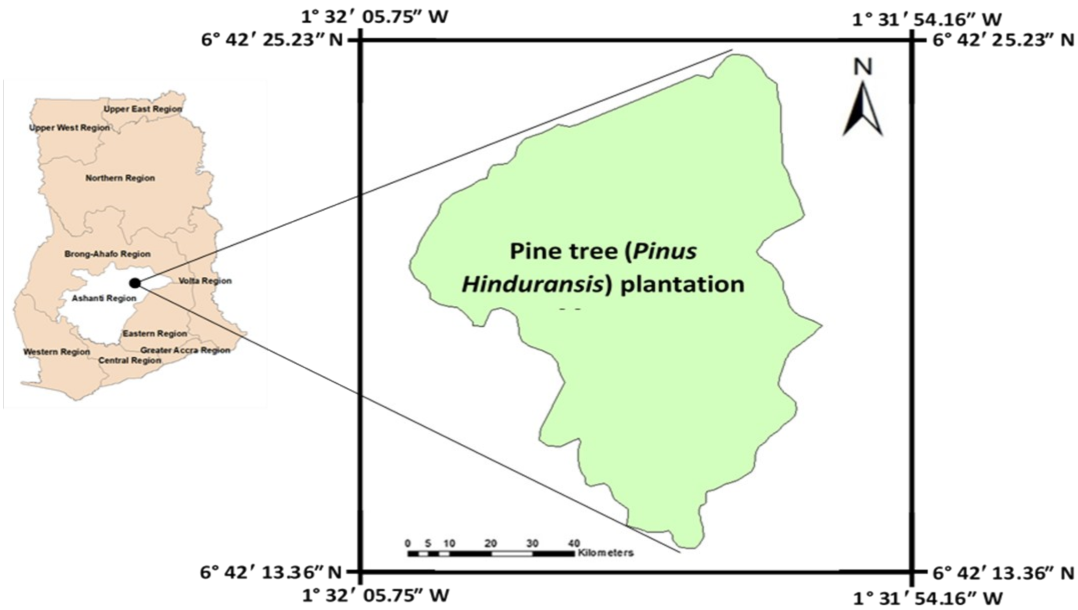

Fig. 1: Location map of the study area

Data and equipment
A Pentax ME Super camera was used to take 35mm photographs. Negatives were developed and used for observation in the Zeiss Topocart D for the photogrammetric measurements. The Zeiss Topocart D (Fig. 2) is a stereoplotter for topographic mapping at large, medium and small scales and is located at the Department of Geomatic Engineering of the Kwame Nkrumah University of Science and Technology (KNUST), Kumasi. Its main use, by design, is in plotting from individual aerial photo models for compilation of maps. It accommodates photo formats of up to 230mm square and camera principal distances in the range of 45mm to 310mm, and so is capable of plotting from Super Wide Angle, Wide Angle and Normal Angle photograpghs without the need for time-consuming conversions of original photo formats into other formats.

The Spiegel Relaskop is a traditional method in Forest Mensuration and fulfills all the principles of forest mensuration requirements throughout the world. It has five purposes - estimating height, slope, diameters at heights normally out of reach, basal-area per unit area of an extensive stand (not of a small plot) and basal-area density or crowding at a single point. The Spiegel Relaskop was used to measure horizontal distances (as it automatically corrected for the angle of inclination), the total tree height and height to a particular upper stem diameter, and stem diameters at particular heights.

Photography and scale
The choice of the appropriate film depends on

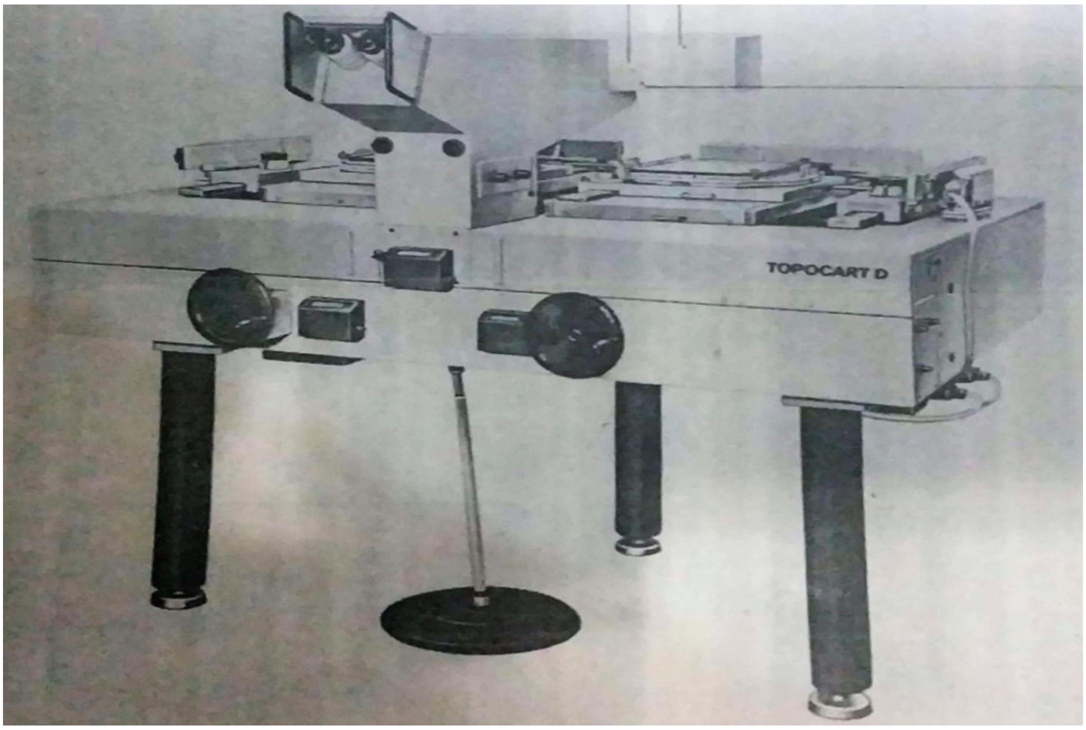

Fig. 2: The Zeiss Topocart D located Department of Geomatic Engineering of the KNUST

the type of work and lighting conditions. For this research, Kodak Gold colour (instead of black-and-white) film was used to ensure better delineation of tree edges against the usual greyish sky background in the photographs. The camera used was a non-professional off-the-shelf camera. It was therefore uncallibrated and had a lens of nominal focal length 50mm. The film speed used was 100ASA, which implied a fine-grained slow emulsion. The shutter speed was set at 1/60th to minimise image movement. The above-mentioned parameters, coupled with aperture setting of f/5.6 ensured adequate exposure for the photographs in the normally dark environment of the plantation. The negatives of the photographs were stored in an air-conditioned environment to prevent any photo format dimensional change which could, in turn, affect the scale of the particular photograph. The scale of the *vertical* photograph of a tree can be modeled as illustrated in Equation 1.

$$Scale = \frac{f}{H} \quad (1)$$

where *f* is the camera principal distance (or, in this case, the nominal focal length of the camera lens), and *H* the horizontal distance from the camera to the tree. It is worthy of note that the camera was non-metric and was not calibrated; modern lens surfaces are very well machined to specified curvatures and therefore produce little distortions. It was with this in mind that the research was carried out to evaluate, inter alia, the efficiency with which ordinary off-the-shelf cameras could be used for jobs traditionally the preserve of purpose-designed metric photogrammetric cameras.

Computing cubic volume

Various equations exist for computing cubic volume of solids. Table 1 outlines some the geometrical solids and the equations for computing the volume. The Huber formula was used for calculating the tree volumes. Regression equations were derived by considering Volume as the dependent variable and a combination of DBH, height and artificial form factor (DBH^2H) and their transformations were examined for their significance, correlation coefficients and standard errors. These were used as

Table 1: Equations for computing cubic volume of solids (where: h = height; A_b = cross-sectional area at base; A_m = cross-sectional area at middle; and A_u = cross-sectional area at top)

Geometric Solid	Equation for volume V (cubic units)
Cylinder	$V=A_b h$
Paraboloid	$V= \frac{1}{2}(A_b h)$
Cone	$V= \frac{1}{3}(A_b h)$
Neiloid	$V= \frac{1}{4}(A_b h)$
Paraboloid Frustrum	$V= \frac{h}{2}(A_b + A_u)$, Smalian's formula
	$V=h(A_m)$, Huber's formula
Cone Frustrum	$V= \frac{h}{3}(A_b + \sqrt{A_b^2} + A_u)$
Neoloid Frustrum	$V = \frac{h}{4}(A_b + \sqrt{A_u^2}A_u + \sqrt{A_u^2}A_b + A_u)$
Neoloid, Cone or Paraboloid Frustrum	$V = \frac{h}{6}(A_b + 4A_m + A_u)$, Newton's formula

criteria for the optimum variables and equation types.

The following are the four equations that were subjected to least squares regression analyses and the best-performing selected for preparation of the SVT:

$$V = b_0 + b_1 D^2 H \quad (1)$$

$$V = b_0 + b_1 D^2 + b_2 H \quad (2)$$

$$V = b_0 + b_1 D^2 H + b_2 D \quad (3)$$

$$\log V = b_0 + b_1 \log D + b_2 \log H \quad (4)$$

where D is DBH; H the height of the tree; V represents any of the volume measurements, and the logarithms are to base 10; and b_0, b_1, and b_2 are coefficients.

The correlation coefficient (R) values and the "residual standard deviation", from which the standard error is obtained are useful for the comparison of regression. The higher the correlation coefficient the more precise the relationship between the dependent and independent variables. Also, the closer the residual standard deviation approaches zero, the more precisely the regression predicts the variables. Consequently, the equation which yielded the highest correlation coefficient and lowest standard error, was selected for the construction of the SVT. The standard error suggested how close the results were to the parameter estimated. A computer program was written in BASIC to calculate the parameters required for the preparation of the SVT. In the preparation of the SVT, random tree sampling was done to ensure that reliable volumes of other tree forms of the same tree species could be estimated from Table 1, given the DBH, and the height. A computer program in BASIC was written to compute the parameters required for the preparation of the SVT. In the preparation of the SVT, tree sampling was randomly done to ensure that adequate volume of other trees of the same tree species can be estimated from the Table, knowing the DBH, the height and the form. The flowcharts for volume computation and regression analysis in the BASIC program are respectively depicted Figs 3 and 4. N is number of trees, DBH is diameter at breast height, H is height, MD is mean diameter, R is correlation coefficient and RSTD is standard error.

RESULTS AND DISCUSSIONS

Volumes were determined using three methods – use of the Spiegel Relaskop, use of measuring tape on felled tree, and the photogrammetric technique.

Traditional techniques - Spiegel Relaskop and measuring tape on felled tree

Table 2 shows results from the traditional techniques - the Spiegel Relaskop and measuring tape on felled tree - at 2m height intervals. Using the Huber's formula in Table 1, the volume of one particular tree was determined using the Spiegel Relaskop, and measuring the same tree with a linen tape after the tree had been felled. The results were $0.79483m^3$ and $0.87183m^3$ respectively. The volume of the tree using the Regression Equation 2 for Spiegel Relaskop and measuring tape on felled tree techniques were $0.78099m^3$ and $0.86079m^3$ respectively.

Photogrammetric technique

The results obtained by the Photogrammetric technique involving use of the Zeiss Topocart D is shown in Table 3. The first and second height readings in the Y-direction taken at Diameter (D) using the he Zeiss Topocart D are 6846.30units and 6948.80units respectively. The difference between the two readings yield 102.5units which converted from instrument units to photo distance is 102.5/4mm (or 25.6mm). Applying scale in converting to the actual height of the tree yields 18.6m.

Using the Huber's formula in Table 1, the volume of the same tree (that was felled) was determined with the Photogrammetric technique to be $0.89118m^3$, with a DBH of 0.334m and merchantable height, H, of 18.6m. The volume of the tree as determined from the Regression Equation was $0.87305m^3$.

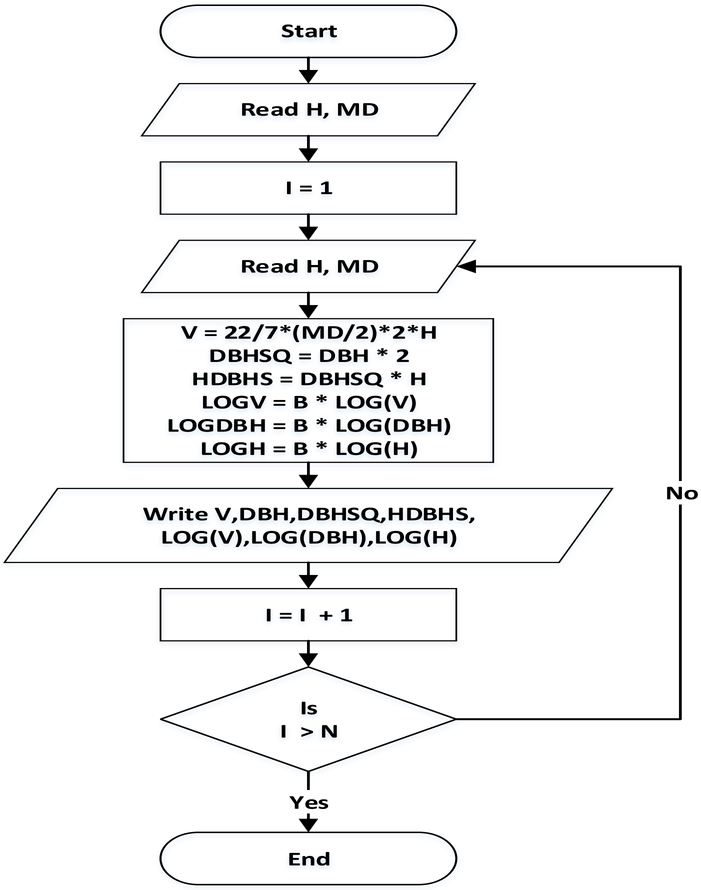

Fig. 3: Flowchart for volume computation

Volume of tree

Table 4 shows the volume obtained using the Spiegel Relaskop, measuring tape on felled tree and the photogrammetric techniques. From Table 4, the results obtained using the Photogrammetric technique compared favourably with the traditional techniques. That is, the volume obtained using the photogrammetric technique is in close agreement with that obtained using the measuring tape. The volume obtained by the measuring tape is the *Standard* upon which the results of the Spiegel Relaskop and the Photogrammetric techniques were evaluated. Since its results compared favourably with the measuring tape results, the Photogrammetric technique was proved to be usable for preparation of SVT for foresters. The results of equations 2, 3, 4 and 5 are tabulated in Table 5.

Comparison is made on the equation which yields the highest correlation coefficient and lowest standard error for the construction of the SVT (Table 5). From Table 5, equation 2 satisfied the criteria for the selection of best equation for the construction of the SVT. Hence, the “Standard Merchantable Volume” Table (Table 6) was constructed using equation 2

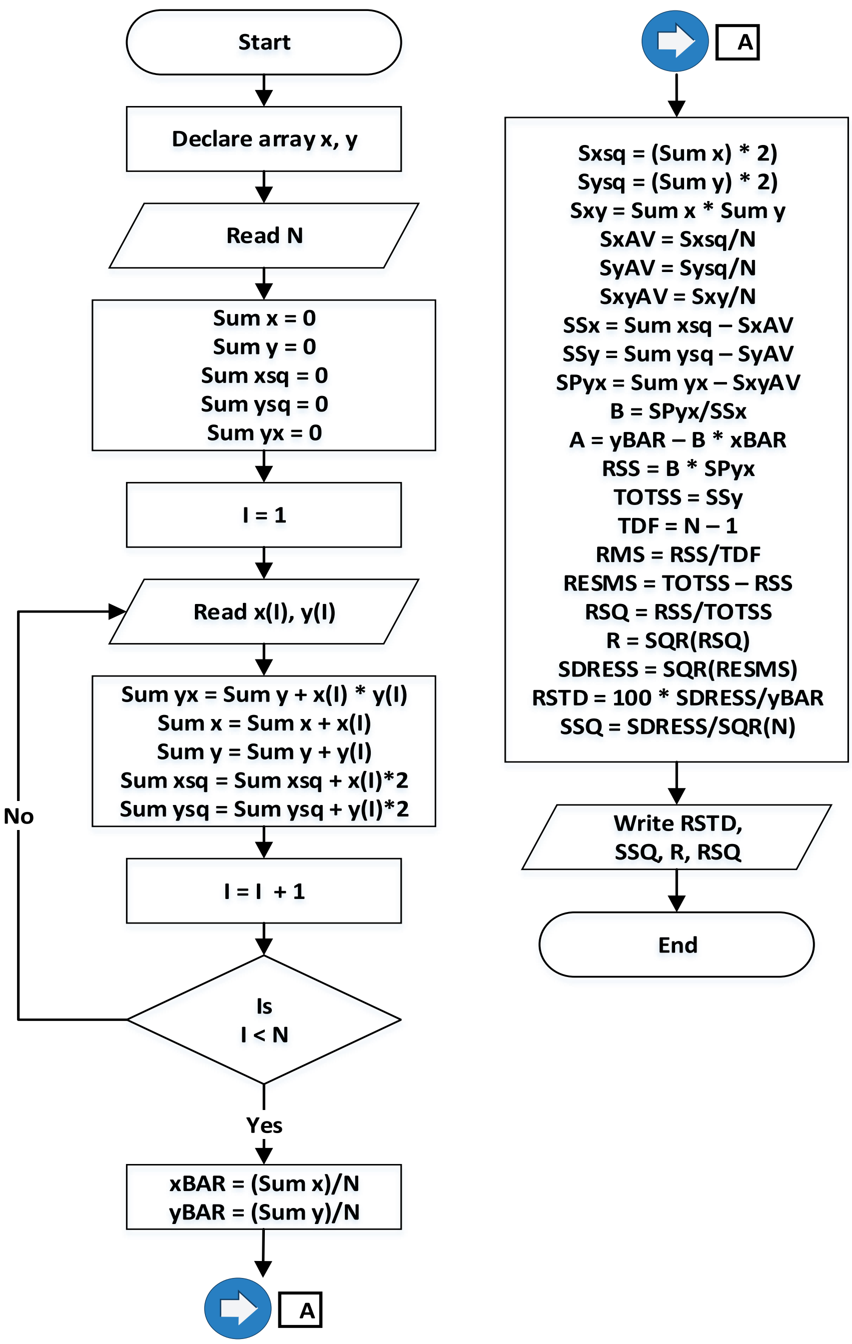

Fig. 4: Flowchart for regression analysis

Table 2: Measurements using Spiegel Relaskop and measuring tape on felled tree techniques

Height (m)	Diameter (m) using measuring tape on felled tree	Diameter (m) using Spiegel Relaskop
0	32.0	32.8
2	30.0	30.1
4	28.0	27.1
6	26.0	25.8
8	22.0	23.6
10	20.0	19.4
12	16.0	16.0
14	15.0	14.5
16	12.0	12.4
18	10.0	9.6

Table 3: Diameter measurements using photogrammetric technique

Reading in X-direction (units)		Difference (units)	Converting from instrument units to photo distance (mm)	Applying scale to convert to the actual diameter (cm)
1st Observation	2nd Observation			
1916.48	1914.64	1.84	0.46	33.4
1916.73	1915.05	1.68	0.42	30.5
1916.94	1915.37	1.57	0.39	28.3
1917.07	1915.55	1.52	0.38	27.6
1917.27	1916.07	1.20	0.30	21.8
1917.78	1916.76	1.02	0.26	18.9
1918.17	1917.21	0.96	0.24	17.4
1918.20	1917.26	0.94	0.24	17.4
1918.47	1917.43	1.04	0.26	18.9
1918.76	1918.91	0.85	0.21	15.2
1918.90	1918.26	0.64	0.16	11.6
1918.98	1918.42	0.56	0.14	10.6

because it gave the highest correlation coefficient and lowest "residual standard deviation" between the dependent and independent variables.

The Zeiss Topocart D has the merit of facilitating movement in the X-direction without movement in the Y-direction, and this makes measurements of tree diameter and height very easy. Furthermore, with the Photogrammetric technique, the negatives can be stored and used again in case of mistake in any measurement.

Table 4: Comparing results from Spiegel Relaskop, tape on felled tree, and photogrammetric technique

Technique	Volume from Huber's formula (m^3)	Volume from Regression Equation (m^3)
Spiegel Relaskop	0.79483	0.78099
Measuring tape on felled tree	0.87183	0.86079
Photogrammetry	0.89118	0.87305

Table 5: Results yielded by equations 2, 3, 4 and 5

Equation	Residual Standard Deviation (RSTD)	Sum of Squares (SSQ)	R	R^2 (RSQ)	Coefficient b_0	Coefficient b_1	Coefficient b_2
Equation 2	0.1307	0.0169	0.8827	0.7792	0.0488	0.3973	-
Equation 3	0.2680	0.0718	0.3221	0.1037	-0.3821	-2.2075	0.0750
Equation 4	0.2504	0.0627	0.4666	0.2177	-0.3250	-0.2592	0.2177
Equation 5	0.2663	0.0708	0.7376	0.5440	-3.1294	-2.2074	2.5842

Such mistakes are not so easily rectified with use of the Spiegel Relaskop because any mistake made in the measurement requires revisiting the field. Locating the actual level where the DBH is measured was tricky with the photogrammetric, but this was resolved by tying colour bands around the trees at breast height. The size of the bands also needed to be such as would render them visible on the photographs.

CONCLUSIONS AND RECOMMENDATIONS

The photogrammetric technique provides an easy means of storing information. Repeat observations can be made on the negatives used whenever so required, without the need to revisit the field. From the measurements made on the same tree using the three different techniques - photogrammetric, Spiegel Relaskop and Tape measurement of felled tree - the volume of the tree obtained from the photogrammetric technique compared favourably with the use of tape on felled tree, which provide the standard for the other. Consequently, the photogrammetric technique should provide a very efficient technique for preparation of Tree Volume Tables.

REFERENCES

Graves, H.S. (1906). Forest mensuration. J. Wiley & sons, New York. 368-374

Holmgren, J. (2004). Prediction of tree height, basal area and stem volume in forest stands using airborne laser scanning. *Scandinavian Journal of Forest Research*, *19(6): 543–553*.

Holmgren, J. (2012). Estimating wood volume and basal area in forest compartments by combining satellite image data with field data. *Examensarbete i ämnet Fjärranalys*. ISRN SLU-SRG-AR-47-SE

Husch, B., Miller, C. I. and Beers, T. W. (1982)

Table 6: Standard merchantable volume table (volumes are in m^3)

Height (m) / DBH (m)	3.0000	5.0000	7.0000	9.0000	11.0000	13.0000	15.0000	17.0000	19.0000	21.0000	23.0000
0.105	0.0620	0.0707	0.0795	0.0883	0.0970	0.1058	0.1145	0.1233	0.1321	0.1408	0.1496
0.135	0.0706	0.0850	0.0995	0.1140	0.1285	0.1430	0.1574	0.1719	0.1864	0.2009	0.2154
0.165	0.0813	0.1029	0.1245	0.1462	0.1678	0.1894	0.2111	0.2327	0.2543	0.2760	0.2976
0.195	0.0942	0.1244	0.1546	0.1848	0.2150	0.2452	0.2754	0.3056	0.3359	0.3661	0.3963
0.225	0.1092	0.1494	0.1896	0.2298	0.2701	0.3103	0.3505	0.3907	0.4310	0.4712	0.5114
0.255	0.1263	0.1780	0.2297	0.2813	0.3330	0.3847	0.4363	0.4880	0.5397	0.5913	0.6430
0.285	0.1456	0.2102	0.2747	0.3393	0.4038	0.4683	0.5329	0.5974	0.6619	0.7265	0.7910
0.315	0.1671	0.2459	0.3248	0.4036	0.4824	0.5613	0.6401	0.7190	0.7978	0.8766	0.9555
0.345	0.1907	0.2853	0.3798	0.4744	0.5690	0.6635	0.7581	0.8527	0.9473	1.0418	1.1364
0.375	0.2164	0.3282	0.4399	0.5516	0.6634	0.7751	0.8868	0.9986	1.1103	1.2220	1.3338
0.405	0.2443	0.3746	0.5050	0.6353	0.7656	0.8959	1.0263	1.1566	1.1869	1.4172	1.5476
0.435	0.2744	0.4247	0.5751	0.7254	0.8757	1.0261	1.1764	1.3268	1.4771	1.6275	1.7778
0.465	0.3065	0.4783	0.6501	0.8219	0.9937	1.1655	1.3373	1.5091	1.6809	1.8527	2.0245
0.495	0.3409	0.5355	0.7302	0.9249	1.1196	1.3143	1.5090	1.7036	1.8983	2.0930	2.2877

Forest Mensuration. John Wiley & Sons, NY. 402.

Hyyppä, J., Hyyppä, H., Litkey, P., Yu, X., Haggrén, H., Rönnholm, P., Pyysalo, U., Pitkänen, J. and Maltamo, M. (2004). Algorithms and methods of airborne laser scanning for forest measurements. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, 36(8): 82–89.

Korhonen, L., Vauhkonen, J., Virolainen, A., Hovi, A. and Korpela, I. (2013). Estimation of tree crown volume from airborne lidar data using computational geometry. *International journal of Remote Sensing*, *34: 7236–7248*.

Maltamo, M., Eerikäinen, K., Pitkänen, J., Hyyppä, J. and Vehmas, M. (2004). Estimation of timber volume and stem density based on scanning laser altimetry and expected tree size distribution functions. *Remote Sensing of Environment*, 90(3): 319–330.

Miller, J., Morgenroth, J. and Gomez, C. (2015). 3D modelling of individual trees using a handheld camera: Accuracy of height, diameter and volume estimates. *Urban Forestry and Urban Greening,* 14(4): 932–940.

Morgenroth, J. and Gomez, C. (2014). Assessment of tree structure using a 3D image analysis technique—A proof of concept. *Urban Forestry and Urban Greening,* 13(1): 198–203.

Muller, M., Kersting, A.P.B., Nakajima, N.Y., Hosokawa, R.T. and Rosot, N.C. (2014). Influence of Flight Configuration Used for Lidar Data Collection on Individual Trees Data Extraction in Forest Plantations. *Floresta*, 44(2): 279–290.

Popescu, S.C., Wynne, R.H. and Nelson, R.F. (2003). Measuring individual tree crown diameter with lidar and assessing its influence on estimating forest volume and biomass. *Canadian Journal Of Remote Sensing*, *29(5): 564–577.*

Quaye-Ballard, J. A., An, R., Andam-Akorful, S. A. and Quaye-Ballard, N. L. (2013). Role of Geoinformatics for Ghana oil and gas industry. *International Journal on Recent and Innovation Trends in Computing and Communication*, *1(6): 539-546*.

Straub, C., Stepper, C., Seitz, R. and Waser, L.T. (2013). Potential of UltraCamX stereo images for estimating timber volume and basal area at the plot level in mixed European forests. *Canadian Journal of Forest Research*, *43(8): 731–741*.

Strother, C.W., Madden, M., Jordan, T.R. and Presotto, A. (2015). Applications Paper: Lidar Detection of the Ten Tallest Trees in the Tennessee Portion of the Great Smoky Mountains National Park. Photogrammetric Engineering & Remote Sensing, 81(5): 407–413.

Tansey, K., Selmes, N., Anstee, A., Tate, N.J. and Denniss, A. (2009). Estimating tree and stand variables in a Corsican Pine woodland from terrestrial laser scanner data. *International Journal of Remote Sensing*, *30(19): 5195–5209.*