COMPARISON OF STANDING VOLUME ESTIMATES USING OPTICAL DENDROMETERS[1]

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Abstract—This study compared height and diameter measurements and volume estimates on 20 hardwood and 20 softwood stems using traditional optical dendrometers, an experimental camera instrument, and mechanical calipers. Multiple comparison tests showed significant differences among the means for lower stem diameters when the camera was used. There were no significant differences among the methods for volume or height.

INTRODUCTION

Digital technology is being utilized more and more to facilitate the collection of forest inventory data. Satellites that scan the earth's surface on a periodic basis provide affordable data for various forms of regional analyses. Digital aerial cameras and positioning systems can be directed to capture more detailed information quickly and with little manual processing. Technologies are reducing data collection costs and changing the way we can model and analyze these data. Regardless of methodology and scale, at some point this macroscale data must be combined with a more detailed subsample on the characteristics of the individual trees that make up the regional forests. For metrics such as volume or biomass, current methods of collecting this individual stem data are cost prohibitive, and some metrics such as crown dimension are highly error prone. There is hope that the digital camera system can aid in the affordable and accurate collection of individual stem data.

Since the 1950s, cameras have been used in various ways to collect tree stem data (Bradshaw 1972; Crosby and others 1983; Juujärvi and others 1998). In 1998, the USDA Forest Service funded a study to examine the feasibility of using a digital camera to collect data from individual standing trees (Clark 1998). While the method was feasible, several improvements—including increased focal length, digital range, and inclination—were needed before it could be considered practical. The main advantages of using digital cameras over film cameras are the elimination of film and development costs and the capability of direct integration with digital image processing software. These things greatly reduce the costs of using camera systems, propelling them into competition with traditional methods. This paper will examine how use of the camera instrument compares to standard and felled-tree methods of measuring diameter, height, and volume.

METHODS

Twenty hardwood and 20 softwood trees were selected from a mature, mixed oak-pine stand at the Bent Creek Experimental Forest near Asheville, NC. The trees were approximately distributed by 1-inch classes from 4 to 24 inches in diameter at breast height (d.b.h.). Diameter measurements were made at heights of 0, 0.5, 1, 2, 4.5, 17.3 ft, and every 4 ft from 8 ft to the top of the tree (excluding 16 ft). The locations of the measurement points along the tree boles were not marked, and thus were measured independently by each method. However, to minimize extraneous variability, a vertical paint mark was made on each stem to ensure that measurements were taken from the same side of the tree by each method. Occasionally, due to thick underbrush or tree crowns, some of the crew members taking optical measurements may have deviated from the directional control in order to observe the diameter at the desired height. Total tree height was also recorded along with live crown ratio. Truth data were collected by felling each stem, then measuring diameters with a mechanical caliper and heights with a nylon tape.

The Standard Method

Four four-member crews collected diameter and height data using sectional aluminum poles for height determination and pentaprism calipers for diameters. In some cases, McClure pentaprisms were used on diameters exceeding 24 in., which was the limit of the pentaprism calipers. Five hardwood and five softwood trees spanning the diameter ranges were systematically assigned to each crew.

The standard method deviated from the previously described protocol in two ways. First, whenever a fork or other drastic diameter change occurred, a new base was established above the anomaly from which diameters were again collected in 4 ft intervals. Second, diameter tapes or mechanical calipers were sometimes used for the measurement of d.b.h. in order to verify the size class of the stem. In some instances, these measurements were recorded in lieu of the optical dendrometer measurements.

The Camera Method

The camera-rangefinding instrument (fig. 1) used in this study was a prototype model built by Laser Atlanta, Inc., which incorporates a Panasonic GP-CX161, 480 x 720 output pixel, color, CCD (charge coupled device) video camera into their Advantage® CIL laser rangefinder (Clark 2000). Camera data were output to a Sony GV-D300

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Figure 1—Camera rangefinder prototype used in this study.

portable digital video (DV) cassette recorder, and the range data were output to a memory card. Each mini DV cassette was capable of storing 60 minutes of video data. The 2Mb memory card was capable of storing approximately 36,000 range/bearing/pitch records. The instrument was set to record 30 frames per second of video data and 3 ranges per second (derived from 238 ranges measured per second).

Each stem was scanned with the camera-rangefinding instrument from two or more visible vantage points, with at least one of these points aligned with the vertical paint mark on the stem. Redundant data were collected from the additional vantage points to increase the probability that a given height was visible. In general, a close-range (10 to 30 ft) distance was used to view the lower portion of the stem and a >30 foot range for the upper portions in order to avoid severely acute perspective angles.

The camera data were post-processed back at the office, using customized software written in C++ for the Windows platform by Neil Clark. The following procedure was used to calculate the diameters:

1. Range data were filtered in order to determine the actual range to the stem and to filter out ranges from occluding objects.

2. Heights were calculated using ranges and inclination angles.

3. Video frames were manually correlated with the range data, extracted from the videotape, and saved as digital images.

4. Image coordinates representing the diameters were collected by on-screen digitizing and the resultant diameters were calculated, then output to a digital file.

Differences, defined as method measurements minus felled tree measurements, were analyzed for total height, volume calculated by Smalian's formula, and outside bark diameters at d.b.h., 17.3 ft, and in the clear bole and crown. The clear bole and crown diameters were determined using total height and live crown ratio. Graphical analysis and descriptive statistics were used to compare the methods. A randomized block design analysis was also performed to test for differences between the two instruments and the "true" value for each taxonomic division. Trees were considered blocks, which contained three treatments defined as Camera, Standard, and True. Overall significance tests were performed, least square means computed, and Bonferroni multiple comparisons performed using an experimentwise error rate of 0.05.

RESULTS AND DISCUSSION

Figure 2 and table 1 show the results of diameter errors by category. Due to procedural errors, four softwood stems were not matched and were left out of the comparison for the camera method. A 17.3 ft diameter measurement from one stem was also excluded from comparison because it was missing in one of the data sets. Differing sampling methods also created different sample sizes among the other diameter categories; therefore, only diameter measurements taken at heights corresponding with the truth data were compared.

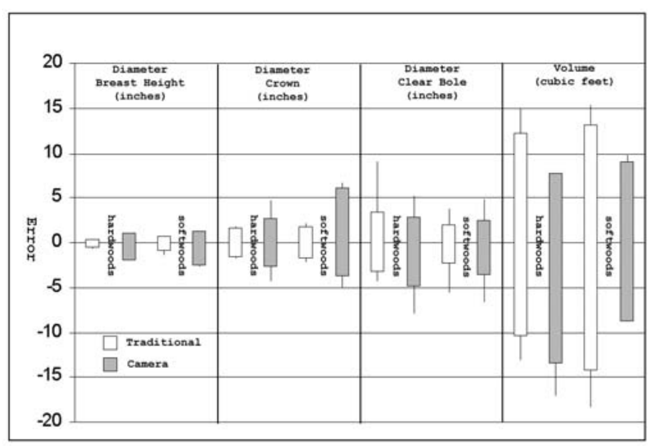

Figure 2—Errors for camera and standard methods for varying stem characteristics. The box indicates a 95 percent confidence interval about the mean (assuming normal distributions), and tails indicate the maximum and minimum observations.

Table 1—Difference statistics (method – felled tree) by category for hardwoods and softwoods

Division	Method	n	Mean	Stnd.Dev.	Minimum	Maximum
		- - - - - - - - - - - *Diameter at breast height (inches*) - - - - - - - - - - -				
Hardwood	Standard	20	-0.08	0.19	-0.80	0.10
	Camera	20	-.46	.77	-1.90	1.00
Softwood	Standard	20	-.12	.44	-1.40	.80
	Camera	16	-.71	.97	-2.70	1.00
		- - - - - - - - - - - - - *Clear bole diameters (inches)* - - - - - - - - - - - -				
Hardwood	Standard	159	.10	1.66	-4.30	9.00
	Camera	166	-.96	1.98	-7.90	5.30
Softwood	Standard	173	-.15	1.11	-5.60	3.70
	Camera	145	-.54	1.60	-6.70	4.80
		- - - - - - - - - - - - - - *Crown diameters (inches)* - - - - - - - - - - - - - -				
Hardwood	Standard	69	-.03	.84	-1.80	1.80
	Camera	151	.03	1.40	-4.40	4.60
Softwood	Standard	81	.01	.95	-2.10	2.10
	Camera	93	1.15	2.52	-5.00	6.60
		- - - - - - - - - - - - - - - - - - *Height (feet)* - - - - - - - - - - - - - - - - - - -				
Hardwood	Standard	20	.94	3.22	-5	9
	Camera	20	-2.32	7.26	-15	9
Softwood	Standard	20	.11	5.79	-7	15
	Camera	16	.04	9.41	-14	16
		- - - - - - - - - - - - - - - - *Volume (cubic feet)* - - - - - - - - - - - - - - - -				
Hardwood	Standard	20	.88	5.78	-13.16	14.94
	Camera	20	-2.90	5.39	-17.04	3.20
Softwood	Standard	20	-.50	6.98	-18.39	15.31
	Camera	16	.12	4.57	-8.65	9.79

Diameters at Breast Height

For diameters at breast height the standard method is more accurate for all taxonomic divisions (fig. 3). Within this category there is a concern that contact dendrometer (mechanical caliper or diameter tape) measurements, acquired to determine tree size class, were substituted as the optical dendrometer measurements for the standard method. The existence and severity of this operator bias could not be documented, but is mentioned as a possibility.

Discrepancies greater than 1 in. using the camera method were all negative and occurred primarily on larger stems (fig. 3). A number of probable causes exist for the variability of the d.b.h. errors. A high frequency of understory vegetation can cause improper range data collection. The range filter used in the diameter processing software is not sensitive to occlusions within a certain threshold (5 ft) of the estimated stem face range. Correction for measuring range to the stem face instead of the stem axis may have a

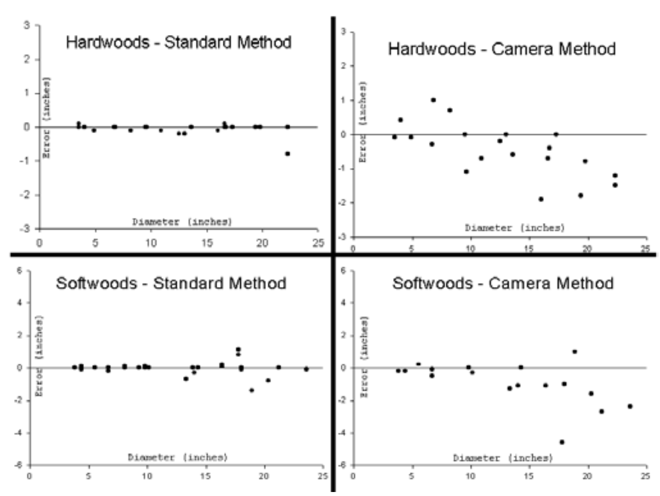

Figure 3—Diameter at breast height errors.

slight effect. Difficulty in locating stem edges due to foreground occlusion or background obfuscation may have been caused by the understory vegetation. Observations made on unimpeded open field targets indicate an instrument bias correlated with the inclination angle.

Clear Bole Diameters

Multiple comparison tests (table 2) demonstrated no significant differences among the softwood means for diameters on the clear bole, but the camera was significantly lower than the two other methods for hardwoods. Extreme negative values are present predominantly for large diameters (fig. 4) and low heights (fig. 5). All values greater than 24 inches were situated below breast height and are subject to the same error explanations as d.b.h. These lower height measurements had small effects on the volume determination (especially if useable volume was to be considered), due to the short lengths with which these measurements were associated. Some extreme

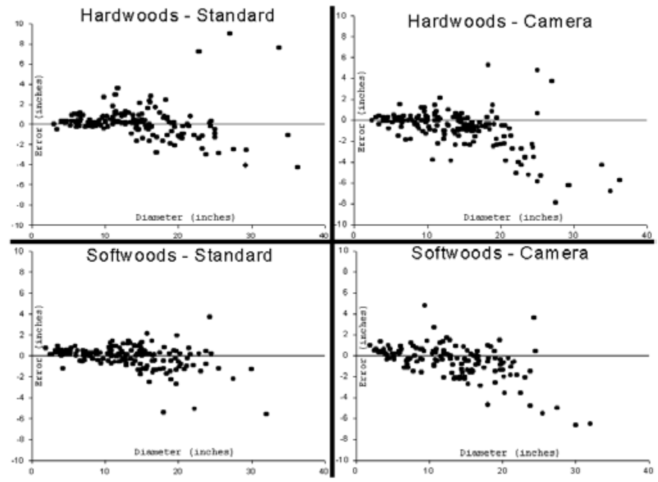

Figure 4—Clear bole diameter errors.

Table 2—Bonferroni Multiple Comparision test results from a randomized block design analysis on the inventory attributes

		Least squares means		
Division	P-value	Camera	Standard	Fell
	- - - - - - - - *Diameter at breast height (inches)* - - - - - - -			
Hardwoods	0.0045	12.22 a	12.60 b	12.68 b
Softwoods	.0103	12.23 a	12.74 ab	12.94 b
	- - - - - - - - - - - - *17.3 diameter (inches)* - - - - - - - - - - - -			
Hardwoods	.0009	10.68 a	11.53 b	11.32 b
Softwoods	.1852	10.44 a	10.86 a	10.75 a
	- - - - - - - - - *Clear bole diameters (inches)* - - - - - - - - -			
Hardwoods	.0026	12.34 a	13.27 b	13.19 b
Softwoods	.0668	11.67 a	12.11 a	12.25 a
	- - - - - - - - - - - Crown diameters (*inches*) - - - - - - - - - - -			
Hardwoods	.8162	6.83 a	6.68 a	6.58 a
Softwoods	.4271	7.27 a	6.58 a	6.73 a
	- - - - - - - - - - - - - - - - *Height (feet)* - - - - - - - - - - - - - - -			
Hardwoods	.1102	65.60 a	68.85 a	67.92 a
Softwoods	.981	67.31 a	66.94 a	67.28 a
	- - - - - - - - - - - - - *Volume (cubic feet)* - - - - - - - - - - - - -			
Hardwoods	.0185	36.38 a	40.16 b	39.28
Softwoods	.3663	41.52 a	39.70 a	41.40 a

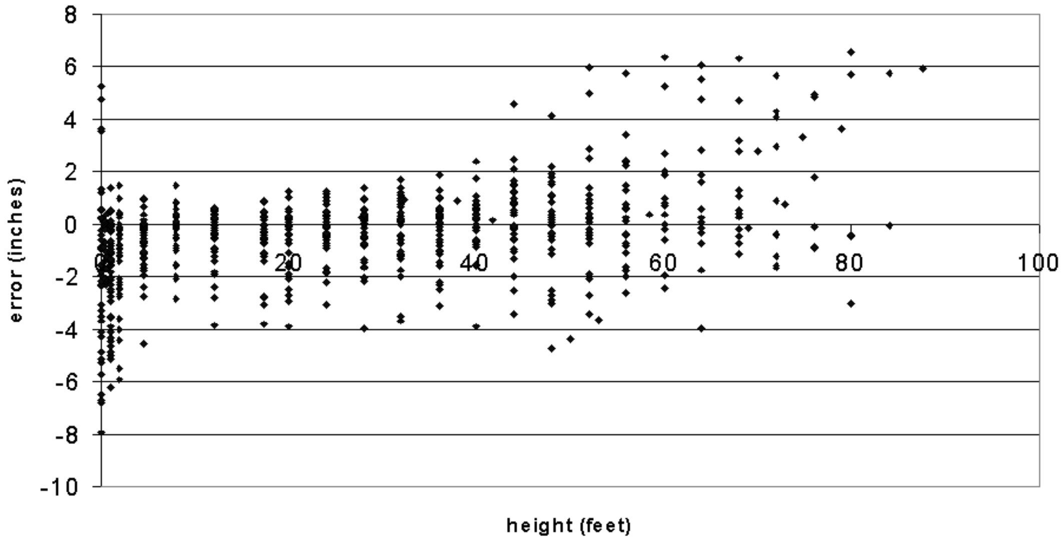

Figure 5—Camera diameter errors by height.

positive values in the hardwoods using the standard methods may have been the result of estimation due to exceeding the range of the pentaprism.

Crown Diameters

Using the standard method, variance (fig. 6) seemed to be independent of dimension in the crown measurements. The multiple comparison tests (table 2) did not indicate significant differences among the means, though standard errors (fig. 6) were less for the standard method. Camera mean errors were positive for both hardwoods and softwoods, and extreme positive errors can be found in the softwoods. Twenty of the 22 camera errors >4 inches (fig. 6) were from three stems, so there is a potential for the camera estimates to have a correlated error. Especially among the hardwood crown diameters, the differing data collection protocol of the standard method greatly influenced the number of samples that could be compared.

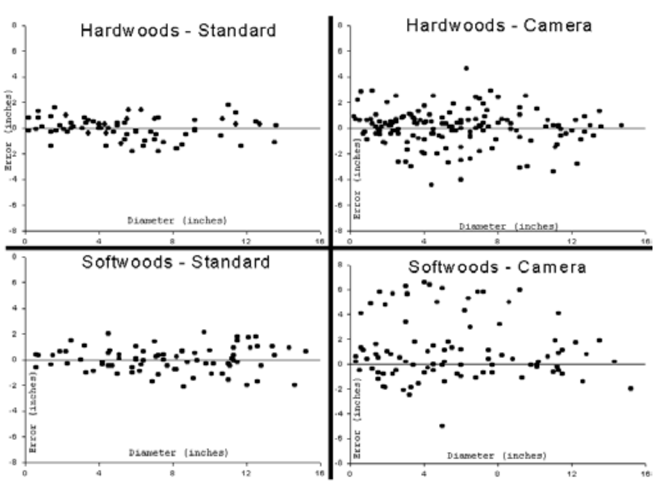

Figure 6—Crown diameter errors.

Height

Total tree heights (actually stem length) ranged from 23 to 93 ft. Table 1 reveals that the camera variance is greater; however, the multiple comparison tests (table 2) do not reveal any significant differences among the means. It is thought that the camera method may improve for the hardwoods in a leaf-off condition if a better range to the top can be achieved. Then, by taking this length from ground to highest tip and projecting it back over to the plumb stump axis, a more accurate total tree height can be calculated.

Volume

The hardwood least squares means between the camera and standard methods are significantly different from each other based on the multiple comparison tests (table 2), though neither method is significantly different from the true mean. Although the results using the standard method were better for each separate category previously mentioned, the volume results were slightly less satisfactory than the camera measurements. The camera and felled-tree methods used the 4 ft incremented diameters in order to calculate volume, whereas the standard method used shorter segments in places where forks or significant taper changes were exhibited. This may provide a partial explanation of this unexpected outcome. On the camera side, the negative trend still exists in the hardwoods. However, on some softwood stems the negative lower diameter errors are offset by positive upper-stem errors.

CONCLUSIONS

For heights or diameters alone, the camera method was not quite as accurate as the standard method. For volume, the camera method was marginally better than the standard method. A summary of the multiple comparison tests (table 2) shows that the standard method least squares means do not differ significantly from the felled-tree method least squares means in any category. Camera method diameters on the lower portion of the stem are generally lower than the true diameters. It is evident that extreme diameter measurement errors are related to their position on the stem. Negative errors occur predominantly below breast height, and most of the extreme positive errors occur in the crown. Sources of instrument and methodological bias are being investigated. If the biases present at the two extremities of the stem can be removed, this instrument can produce some results comparable to the standard methods with considerable timesavings in the field.

FUTURE WORK

A few hardware improvements are needed, including the integration of the ranging and video data streams and incorporation of the video tape recorder into the ruggedized unit, before the camera can be considered a reliable production instrument. The information extraction suite of algorithms needs to be expanded to provide increased automation. Image matching can be implemented to photogrammetrically determine heights, providing greater accuracy for spatial measurements, and edge detection can be used to eliminate manual coordinate capture. Algorithms can also be developed to incorporate more variables of interest, such as crown characteristics, biomass models, and stem quality.

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