USE OF A NON-METRIC DIGITAL CAMERA FOR TREE STEM EVALUATION

Neil Clark, Graduate Research Assistant
Randolph H. Wynne, Assistant Professor
Department of Forest Biometrics
Virginia Tech, Blacksburg, Virginia, U.S.A.

Daniel L. Schmoldt, Research Forest Products Technologist
Philip A. Araman, Research Forest Products Technologist/Project Leader
Matt Winn, Forest Technician
Southern Research Station
USDA Forest Service
Brooks Forest Products Center
Virginia Tech, Blacksburg, Virginia, U.S.A.

ABSTRACT

We are investigating the use of a commercially-available solid-state matrix camera as a dendrometer for tree stem measurements. Thirty-two images of four hardwood stems were used to measure 54 diameters at various heights on the stems ranging from 1.4 m to 21 m. These measurements were compared to caliper measurements taken at the same heights. The percent inaccuracy between diameters derived using the camera and caliper measurements was 6.9 percent, which falls within the range of other dendrometers commonly used. The advantage of this system is the additional stem form, defect, and vigor information that can be instantaneously captured. We found that this method is accurate and efficient for collecting a large amount of data for a single stem.

INTRODUCTION

Forest biometricians are constantly seeking ways to gather data in the most efficient manner possible. Measurements of trees are taken to provide data on growth, yield, health, and economic or ecological value. These data are needed to make sound, informed management decisions. In addition, advertised timber sales often report volume and quality of timber being sold. While a single diameter and a single height measurement may suffice for most volume estimation, more intensive forest inventories (e.g., Cost 1979) require multiple height and diameter measurements as well as evaluation of sweep, crook, cull estimation, log grading, and crown ratio. This detailed information can be very expensive to collect using conventional methods.

Currently, optical dendrometers are used to obtain stem measurements visually, one measurement at a time. Avery and Burkhart (1983) define an ideal upper-stem dendrometer as one that would be "simple to use, portable, relatively inexpensive, accurate at all tree heights, and operable independently of distance from point of measurement." A good review of optical dendrometers, though not very current, can be found in works such as Grosenbaugh (1963) and Ashley and Roger (1969). Since that time there seems to have been a stagnation in development, as is evidenced by recent reports exploring some of the same instruments (e.g., Williams, et al. 1994, Parker 1997, and Garrett, et al. 1997). Errors for these instruments are generally found to be in the range of 5-12.5% for height (Williams et al.1994) and 2-11% error in diameter.

Using a camera as a dendrometer has only become useful and economical as technology has improved. Marsh's study in 1952 did not show a great deal of promise for the use of photography for forest mensuration. Furthermore, Grosenbaugh (1963) sites dubious visual clarity, camera orientation with the tree axis, slowness, and expense as limitations of photography for measurement purposes. Ashley and Roger (1969) developed a photographic device which produced diameter measurements with a standard error of about 0.3 inch and heights with a standard error of about 0.5 percent of the height in laboratory tests. Bradshaw (1972) proposed another method taking larger scale photos at certain points of the stem. His diameter errors were comparable to those of Ashley and Roger. Tree lean was a problem for this method however since slope distance was calculated based on horizontal distance, angle of inclination, and the assumption of a right triangle. The other drawback is that only one measurement can be obtained per photo, which is comparable to other optical dendrometers. Crosby et al. (1983) propose another method using a long focal length camera. They use a measuring pole to lift a scale of known length up to a determined height. The scale is used to determine the photo scale. This method is restricted, however, to the height of the pole, which in their experiment was 10 m. Minolta Camera Co., Ltd. has produced a prototype measuring camera that utilizes the auto-focus as a range finder and features a scale mark that can be used much in the same way as the external scale in Crosby et al. (Takahashi 1997). Results from this camera after corrections for bark, false diameter, and oblique view were very good (2-5% for diameter and 2-11% for height). This device seems to make the job of obtaining specific diameters much easier; however, the result is still one singular measurement per photo.

Most of the literature about forestry applications of terrestrial photography has focused on obtaining upper stem diameters and perhaps tree height. Expense is put forth as a drawback to multiple photographs. Recent advances in the field of microelectronics expand the opportunity for terrestrial photography of trees. The invention and development of charged-coupled devices (CCDs) allow the capture of light rays at resolutions almost comparable to film emulsion methods. The output of the CCDs is an image in digital format. The advantages are: (1) expense and time delay for developing and printing is eliminated, (2) storage is much more convenient, (3) organization can be much easier, and (4) digital image manipulation allows operations that could never be accomplished with standard film technology.

In this study we describe the mathematical derivations necessary to obtain tree measurements from digital photography. Furthermore, we propose a preliminary protocol for collecting digital images in a forest setting, and test this procedure and image analysis methods on a small sample of standing trees.

METHODS

In order to overcome some of the problems with conventional photography we propose the use of multiple images of the same stem. For this study images were acquired of the whole face of the stem from four camera stations, each rotated 90 degrees around the stem (Figure 1). This provides four measurements of diameter at each height. This method should greatly reduce the effects of tree lean.

Camera Factors

The camera used was a Kodak DC-120, which is a commercially available, reasonably priced (<$800), solid-state matrix camera. Incoming light is captured by an 850 x 984 element charge-coupled device (CCD). Each element is 7.8 x 5.0 microns in dimension (Kodak 1997). Filters are used such that each element only detects the intensity of a single wavelength (e.g., red, green, or blue). In order to convert the information from 836,400 analog measurements to 3,686,400 digital output values (1280 x 960 (pixels) x 3(colors)) interpolation is necessary to fill in both the spectral and spatial gaps. The details of this procedure are proprietary, which hinders us from being able to determine the actual camera resolution.

We determined the virtual size of the now square image pixels by imaging a rectangular light post (assumed to be plumb) with the camera axis horizontal (measured with the clinometer) at various distances from .3 to 21.6 m. Scale was then calculated using equations 1 and 2 where $\boldsymbol{s}$ is scale, d equals a distance measured on the image, D is the same corresponding distance measured in object space, f is the focal length of the camera, and L_o is the horizontal distance between the lens and the object. The pixel dimension was adjusted iteratively until the scales were approximately equal. This pixel dimension was used in all subsequent calculations.

$$s = \frac{d}{D} \qquad (1)$$

$$s = \frac{f}{L_o} \qquad (2)$$

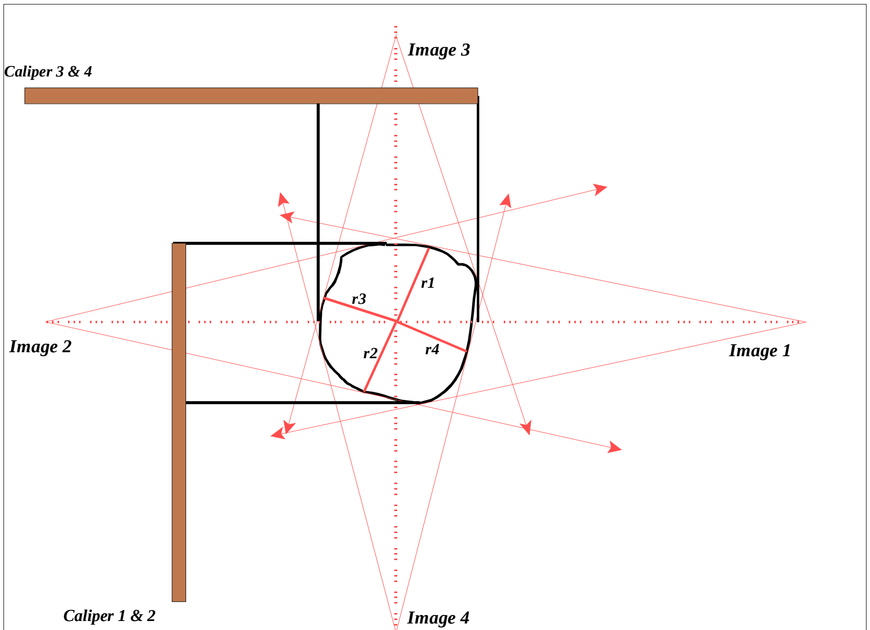

Figure 1. Diagram of relationship between caliper measurements and camera stations.

Measurement Derivation from Images

In the office, images were transferred to a computer and converted to TIFF files. This step "explodes" them to their final output image size and makes them compatible with many software packages. Image Tool, a digital image processing package developed in the Department of Dental Diagnostic Science at The University of Texas Health Science Center, San Antonio, Texas, was used to obtain the image measurements for this study. The images were indexed and their ID numbers and ancillary data (side ID, distance to the base of the tree (B_o), and angle of inclination (θ)) were recorded in a spreadsheet.

Before taking measurements from the digital images, we needed to determine the image locations corresponding to the caliper measurement locations. To do this we located B_i (Figure 2) on the image and recorded the y-value. This value was assigned an object space height. For the base image we used the value of 0, however, for cases of extreme slope the value of the uppermost B_i (of the four images) should be defined as 0 and the others given appropriate values based on the location of that point in other images. This follows the standard convention of measuring tree height from the uphill side.

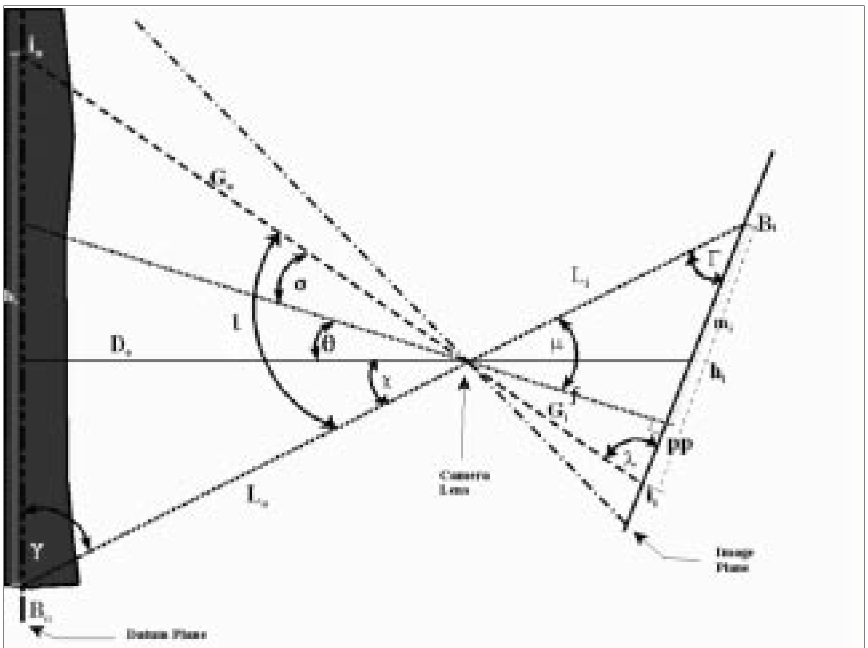

Figure 2. Identification of the variables used in the calculations. Angles are indicated by Greek letters corresponding to the variable name of their opposite side. The subscripts **o** and **i** reference object and image space measurements, respectively.

The angles μ, χ, and γ (Figure 2) were calculated by equations 3, 4, and 5 respectively. Desired stem heights were entered into the same spreadsheet file, and their image y-values were solved according to equation 6, where h_o is the desired stem height and L_o is the measured distance to B_o. Image measurements were taken at the appropriate y-values with the resulting tree diameter measurements determined by equation 7.

$$\mu = \arctan\left(\frac{m_i}{f}\right) \qquad (3)$$

$$\chi = \mu - \theta \tag{4}$$

$$\gamma = 90^\circ - \chi \tag{5}$$

$$h_i = \frac{\sin\left[\arcsin \frac{\sin\gamma h_o}{\sqrt{L_o^2 + h_o^2 - 2L_o h_o \cos\gamma}}\right] \cos\mu f}{\sin(180^\circ - (\iota + \Gamma))} \tag{6}$$

$$treediameter_{h_o} = 2G_o(\sin(\arctan \frac{measurement_{td_i}}{2G_i})) \tag{7}$$

Field Data Collection

Images were acquired and data was collected on four hardwood stems in the Middle Mountain in the Monongahela National Forest, West Virginia, USA. The species consisted of black cherry (*Prunus serotina),* red maple (*Acer rubrum),* and sugar maple (*Acer saccharum),* though species composition was not a criterion for selection.

Preceding image acquisition, four faces were marked on the stem using spray paint. This was done in order to ensure proper orientation when “actual” measurements were collected after felling. Diameter measurements were obtained from the felled stem using metal tree calipers, and height measurements were determined using a steel tape. For trees with merchantable heights of less than 15.2 m, diameters were measured at breast height (1.4 m) and then every 1.2 m up the stem starting at 2.4 m and continuing until a diameter measurement of less that 10.2 cm was reached, or until the end of the central stem. For trees taller than 15.2 m, diameter was measured at breast height, every 1.2 m from 2.4 to 6 m, then every 3 m until the central stem ended or reached a diameter of less than 10.2 cm. For each height (h_o) two caliper measurements were taken perpendicular to image directions 1 & 2 and 3 & 4 (Figure 1).

The process of collecting the images, while awkward at first, became easier with practice. First a general assessment is made in order to determine the placement of camera stations around the stem. Unlike some single measurement procedures, tree lean need not be determined. However, major impediments, like landforms or water bodies, should be taken into consideration as well as adjacent stems or undergrowth that may interfere with viewing the stem.

For our study we situated the camera so that the widest direction of the image plane was in the vertical direction. This was done in order to minimize the number of exposures required to image the vertical extent of the stem. If only one diameter at a particular height is desired, camera orientation is unnecessary. In fact, given the specifications of the CCD arrangement compared to the output pixel matrix this "regular" orientation should be more precise. This will be discussed later in more detail.

The inclination angle of the camera was set so that the base of the tree could be seen near the bottom of the view finder, again to maximize stem coverage. The steel tape was secured to the ground or to the stem near the point B_o (Figure 2). We used a retractable steel tape with a metal pin attached to the end that could easily be pressed into the ground. It is important that the tape be secured so that this same point can be used for both opposing images. B_o represents a point in the datum plane of the object space. For our purposes a point representing the center of the stem perpendicular to our camera station was chosen. We then measured the distance between this point and the front center of the lens to the nearest half inch. This length is used to calculate all of our object distances.

The angle of inclination of the camera was determined by using a Sunnto™ clinometer placed on the camera body. A digital inclinometer, if built into the camera, would allow the angle to be recorded into the image's header file. This angle is essential to derive accurate measurements from oblique imagery.

We manually set the focus at one point on the stem in order to reduce the chance that a closer object would interfere with the auto-focus of the camera. In addition we needed to know the principal distance of the camera. The principal distance is the "perpendicular distance from the perspective center of the lens system to the image plane" (Karara 89). Focused at infinity the principal distance is equal to the focal length of the camera. If the tree was more than a few feet away the focus was assumed to be at infinity.

We had heuristically determined that, within limits, the exposure time did not greatly affect diameter measurement results. For this reason we opted to go with the auto exposure setting on the camera to determine our shutter speeds. The auto-flash setting was activated as well. By using auto-exposure, we obtained relatively consistent image intensity regardless of ambient lighting (cloudy vs. sunlight) or background light (sky vs. forest). The aperture and shutter speeds were automatically stored by the camera in the images header files. The DC-120 also has a picture quality setting which compresses the images to varying degrees. We selected quality setting 2 out of the possible 4, with 4 being no compression and 1 being the greatest degree of compression. Reduced resolution in areas of low contrast was the main drawback at the lower picture quality settings.

After the camera station was set up and the settings adjusted the image was captured. Then we located an identifiable point on the stem in the view finder, and with care not to move the tripod, readjusted the inclination angle so that the same point could still be viewed in the view finder for the next image up the stem. The second image was captured and the process repeated until the entire stem was imaged on one side.

Before moving the camera station we walked to the opposite side of the stem in order to locate the position of the next station. The previous camera station and the stem were aligned with the proposed new station and the location marked before moving the previous station. Once the spot was marked, the

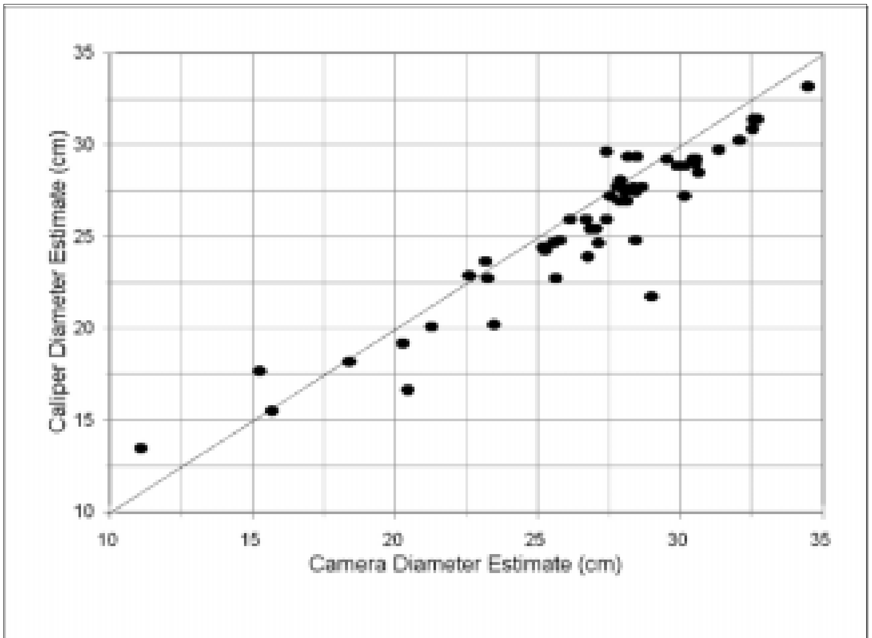

Figure 3. Relationship between camera and caliper estimates of diameter at various heights for four stems.

camera station was moved to the new spot without moving the point where the tape was fixed. The data collection process was repeated at this new station. After completion of the second station the third station was located by approximating a line perpendicular to the first two lines of sight. For the third and fourth images the tape was moved to a new location representing the new datum for images 3 and 4 and images were acquired in the same way as images 1 and 2.

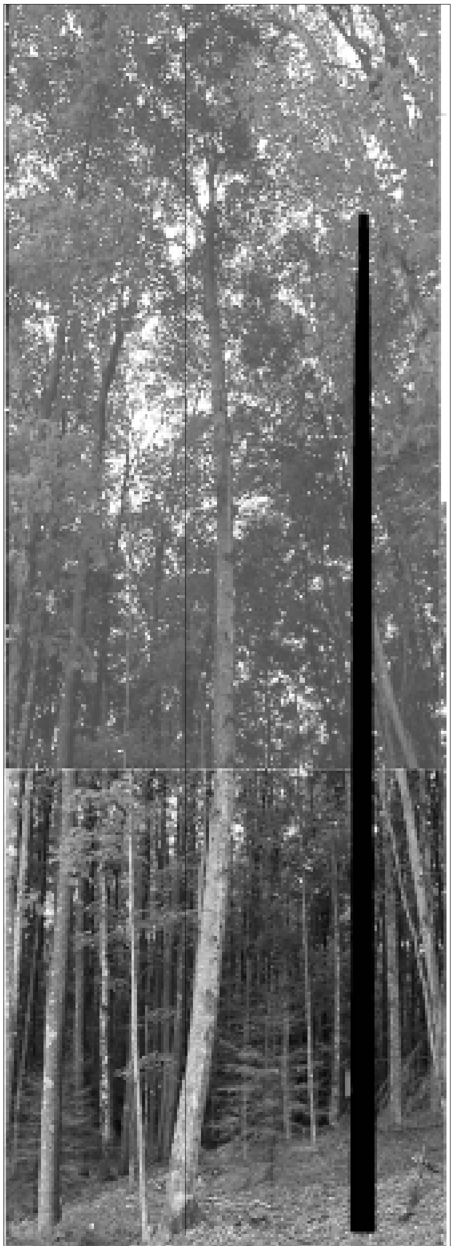

Figure 4. Overlapped images of stem showing offset between datum plane and the actual stem axis. black silhouette represents information derived from a volume model assuming correct taper function is used.

RESULTS AND DISCUSSION

In total, 190 diameter measurements were taken from 32 images (4 trees, 4 sides, 2 images/side). These measurements ranged from approximately 10-38 cm at distances ranging from 6-21 m with camera inclination angles from 3 to 63 degrees. The average error of these individual measurements from the caliper measurements was 9.7 mm, ranging from -58.4 mm to 83.8 mm(Figure 3). This does not account for tree lean. As Figure 4 shows, tree lean can often be quite an issue. In theory, this lean problem should cancel out if the images are captured in opposite directions using the same datum plane. The actual results did not support this theory because the heights were determined from the assumption that the stem axis was in the datum plane. Tree lean causes one height to be overestimated and one height to be underestimated. Using the perpendicular photos in order to locate the identical stem height on the opposing photos should reduce the error due to tree lean.

Fifty-four diameters representing the assumed circular cross-section were calculated and compared for both the camera and caliper measurements by averaging the diameter measurements of the four measurements for the camera and the two measurements for the calipers. In many cases there were less than four image estimates because of obscured visibility. On average the camera measurements were 11.1 mm larger than the caliper measurements, with 39 of the 54 measurements within 13 mm of this mean. The percent bias, calculated by dividing the difference between the camera and the caliper means by the caliper mean (e.g., Garrett et al. 1997) was only 0.2 percent. The percent inaccuracy, calculated from the square root of the average of the sum of squared percentage differences of the estimated diameters, was 6.9 percent. This result compares well with the percent inaccuracies of other dendrometers reported in Garrett et al. (1997), which range from 5 to 11 percent.

The bias can be attributed to camera resolution, lighting factors, cross-sectional abnormalities of the stem, and incorrect horizontal positioning. Differences between semi-major and semi-minor axes were as much as 33.0 mm. This may be a factor for some of the bias, though in a large enough sample with images taken in random directions of the eccentricity of the stem, it should be negligible.

The horizontal position may not have been correctly determined, particularly in the upper portions of the stem. Height is calculated to the datum plane, which coincides with the center of the base of the stem perpendicular to the camera axis. As the stem leans toward or away from this plane the height may be under or over estimated. The largest positive measurement deviation (83.8 mm), was from a fork in the stem, while the diameter just slightly lower was much nearer to the caliper measurement.

The pixel resolution is approximately 7 mm per 10 meters from the object plane. Error thus increases with distance (Figure 5). This error could be reduced by utilizing software that will allow sub-pixel measurement. The variance of the error increases as well, which is due to the fact that the bottom of the stem is where the datum is defined. The probability that the stem axis deviates from the assumed datum increases as height up the stem increases. Utilization of the perpendicular images to factor in this deviation could reduce this error.

Lighting factors affected these measurements in several ways. In areas of low contrast, the edges blurred due to the interpolation techniques of the camera. Adding to this problem was the compression scheme that was selected for this study. In one particular image tree lean was exacerbated by a low contrast condition where a section of the stem was distorted by the compression algorithm. In some cases it was hard to distinguish the stem from the background. Some of this effect can be avoided if the exposure time is increased. The DC-120 has an LCD display on which the image can be viewed seconds after its capture. This can be used to determine whether or not the exposure settings produce good images, so that adjustments can be made and the stem re-imaged.

CONCLUSIONS

The procedures used in this study can be used to collect multiple height and diameter measurements from a stem in a relatively short period of time without felling the tree. In addition to this primary information, there are some ancillary advantages:

- Crown shape and size can be captured in the image providing information on the health and vigor of a stand.
- Knots, splits, lightning scars, and other blemishes may be detected.
- Sweep and crook can be measured from the imagery.
- The image can be stored as a permanent record.
- Exact volume estimates can be calculated accurately and quickly without resorting to generalized taper equations.

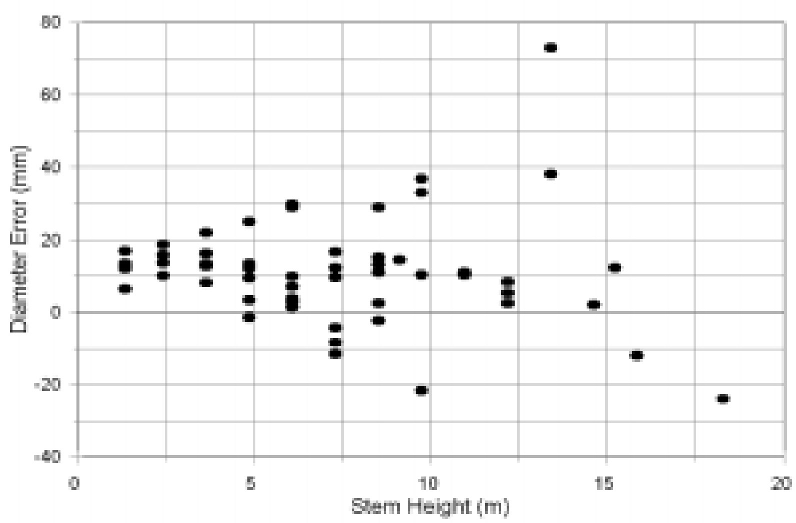

Figure 5. Distribution of errors of diameter measurements as a function of distance.

This method is not without drawbacks however. As previously noted, there is a small positive bias using these methods. Either a correction factor can be applied to the current method, or ways can be found to eliminate or reduce this bias.

As with other optical dendrometers there is the problem of not being able to sight the measurement point. Flexibility is built into this procedure in that the distance and orientation around the stem are flexible so that the best vantage point can be selected or, alternatively, a nearby diameter (either higher or lower on the stem) can be selected instead. There are some locations that may still be obscured by foliage during leaf-on periods. These points could be estimated rather well on the imagery by interpolating between obtainable measurements below and above the desired location.

This study shows that a digital camera can be an effective multi-measurement dendrometer to collect a great deal of information about a single stem in a short amount of time. To collect the same amount of data at this accuracy would require many hours of tedious, difficult, and error-prone field work. Instead, a few minutes of careful imaging in the field, followed by digital analysis in the office, are all that is required by this procedure. Further work and software development may reduce the error and time needed to extract the measurements, and image resection techniques may be used in order to more accurately determine height, branch positions, etc.

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