Ground-based digital imagery for tree stem analysis

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Abstract

In the USA, a subset of permanent forest sample plots within each geographic region are intensively measured to obtain estimates of tree volume and products. The detailed field measurements required for this type of sampling are both time consuming and error prone. We are attempting to reduce both of these factors with the aid of a commercially-available solid-state matrix camera. This device, along with clinometer angle measurements and distance, can be used to rapidly capture data of an entire tree stem. Subsequent analysis can generate bole heights, diameters, and form measurements. We have found the diameter measurements taken from digital images to be nearly equal to caliper measurements on felled trees. We are developing specifications for both the camera system and data collection protocol. This includes potential sources of error that may adversely affect diameter measurements, which we enumerate in this paper.

Keywords: Digital camera, forest inventory, mensuration, dendrometers

1 Introduction

Inventory and monitoring activities have become more important in recent years. Forest resources are being stretched and strained as more resource uses are sought for an increasing population of users. Therefore, knowledge of what resources exist, where they are located, what their condition is, and how they change over time are critical pieces of management information. To accommodate these management needs, inventory information needs to be more detailed and accurate and must be collected with maximum efficiency to extent fixed budget dollars (Peterson et al. 1994).

In the USA, intensive forest inventory plots are used to collect very detailed information about tree volume and timber products (Cost 1979). While a single diameter and a single height measurement may suffice for most volume estimation, more intensive forest inventories require multiple height and diameter measurements as well as evaluation of sweep, crook, cull estimation, log grading, and crown ratio. Consequently, such plots are only measured at a very low sampling rate relative to regular forest inventory plots. However, field conditions (e.g., climate, insects, terrain) are not conducive to accurate and detailed measurements. Additionally, quality assurance and quality control procedures are difficult to monitor and verify. Accurate measurement systems are needed that can provide this same information quickly and with greater reliability.

Theoretically, the activity of data collection occurs in two stages: (1) data acquisition and (2) mensuration. Traditionally, these two tasks are conducted simultaneously, for example when a diameter tape is place around a tree. To expedite and improve the data collection process, however, it is important to disengage these activities, with the latter being performed in the office where conditions lend themselves to accurate and repeatable measurement. This methodology has been used for years in photogrammetry and remote sensing, where 2-D images (containing raw data) are acquired remotely and laboratory analyses generate the refined data desired (mensuration). We postulate that the same approach can used in terrestrial digital imaging to obtain large amounts of highly accurate data quickly.

Most of the literature about forestry applications of terrestrial photography has focused on obtaining upper stem diameters and perhaps tree height (Ashley and Roger 1969, Crosby et al. 1983, Takahashi 1997). Expense is suggested as a drawback to multiple photographs (Grosenbaugh 1963). Recent advances in the field of microelectronics, however, expand the opportunity for terrestrial photography of trees to digital imaging. 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) image organization can be much easier, and (4) digital image manipulation allows operations that could never be accomplished with standard film technology.

This study compares tree stem diameter measurements obtained using digital imaging to corresponding caliper measurements. Benefits of this approach and potential sources of measurement errors are enumerated and examined.

2 Methods

For this study, images were acquired of the whole face of the stem from four camera stations, each rotated 90 degrees around the stem (Fig. 1).

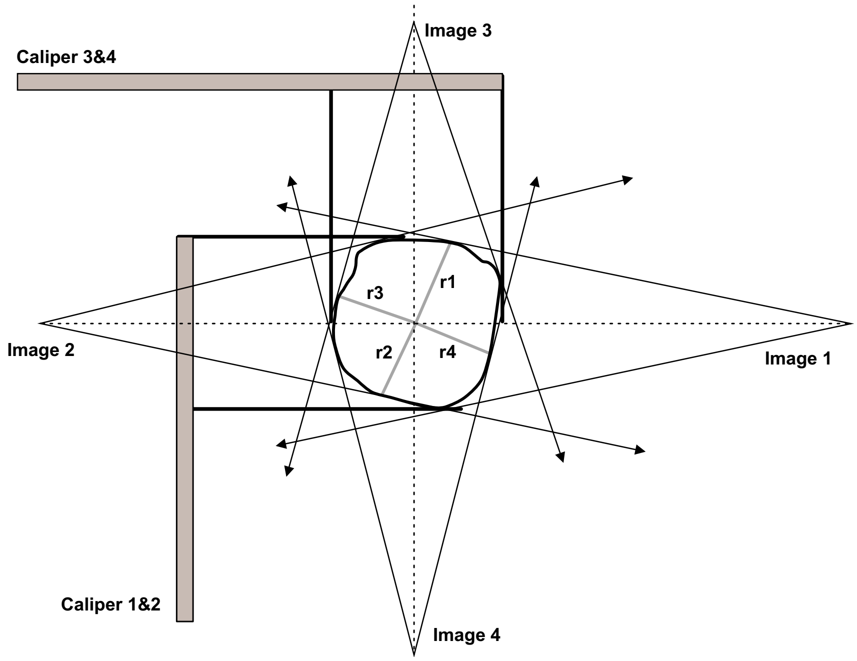

Figure 1. A top-view of data collection for an individual tree stem depicts the relationship between camera images and caliper measurements. At each imaging station, multiple views (images) were captured vertically up the stem to acquire the entire stem.

This provided four measurements of diameter at each height. Typically, two images per side were obtained to acquire the entire length of the stem. Diametrically opposed diameter measurements were later compared to the caliper measurement in the same plane.

2.1 Digital imagery

The camera used was a Kodak[1] DC-120, which is a commercially available, reasonably priced (< 800 US$), solid-state matrix camera. An 850 x 984 element charge-coupled device (CCD) captures incoming light. 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). 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, filling in both the spectral and spatial gaps. Details of this procedure are proprietary, which hinders us from being able to determine the actual camera resolution. Virtual pixel size is distance dependent and was determined by measuring objects of known dimension (Clark et al. 1998).

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, and angle of inclination) were recorded in a spreadsheet.

2.2 Data acquisition

Images were acquired and data was collected on four hardwood stems on Middle Mountain in the Monongahela National Forest, West Virginia USA. Species consisted of black cherry (*Prunus serotina*), red maple (*Acer rubrum*), and sugar maple (*Acer saccharum*), though species 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 true diameter 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, two caliper measurements were taken perpendicular to image directions 1 & 2 and 3 & 4 (Fig. 1).

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, 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. By using auto-exposure, we obtained relatively consistent image intensity regardless of ambient lighting (cloudy vs. sunlight) or background light (sky vs. forest). Aperture and shutter speeds are 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 forest conditions of low contrast was the main drawback at the lower picture quality settings.

3 Results and conclusions

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 1.76 mm, ranging from –67.9 mm to 74.4 mm. In a previous report (Clark et al. 1998), an average error of 9.7 mm was reported. This earlier value did not correct for pixel overlap. Because one pixel on each side of the tree is often counted even though the true tree diameter does not extend the full width of each pixel, an extra pixel's width is included in the diameter estimate, on average. By subtracting one pixel width for the average overlap, the average error is reduced substantially.

Fifty-four diameters representing the assumed circular cross-section were calculated and compared between camera and caliper measurements. Diametrically opposed camera diameters were arithmetically averaged. Then, a geometric average was calculated for each pair of caliper measurements and each pair of camera measurements at each height. In some cases, four camera images were unavailable because of obscured visibility. On average, the

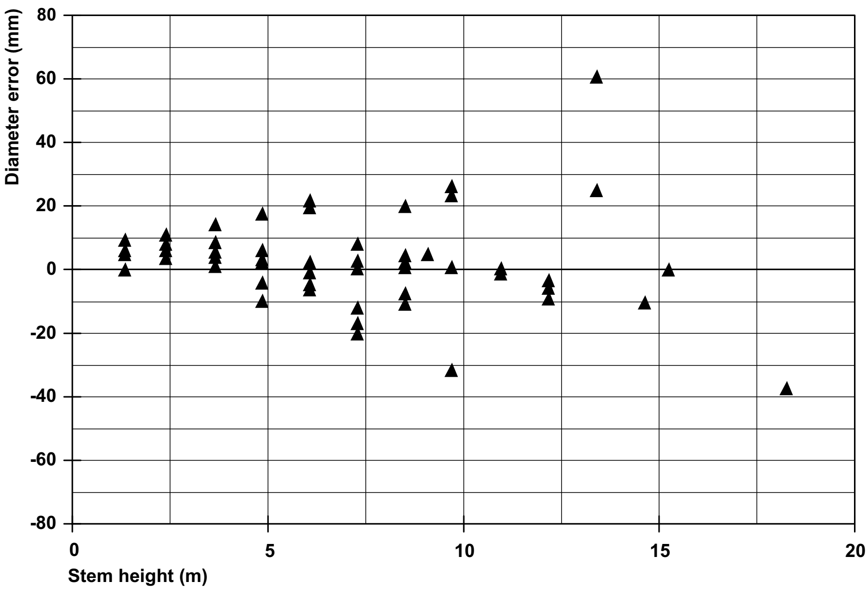

Figure 2. Diameter errors vary by the camera distance to the datum.

camera measurements were 3.4 mm larger than the caliper measurements, with 39 of the 54 measurements within 13 mm of the mean (Fig. 2). As noted above, this bias is much smaller than previously reported due to pixel-overlap correction. Errors increase, however, as stem height increases due to the larger, virtual pixel size that results from greater camera-to-datum distance.

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 0.8 percent. The percent inaccuracy, calculated as 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.

We can plot camera-estimated diameters versus caliper-measured diameters (Fig. 3). From these data, we estimated a regression line to predict caliper-derived tree diameters from camera-estimated diameters. If we assume no bias, i.e. force the regression line through the origin, then we find that the coefficient of the independent variable is very close to unity. In fact, a 95 % confidence interval for this coefficient just includes 1. Therefore, our camera diameters agree very closely with caliper diameters.

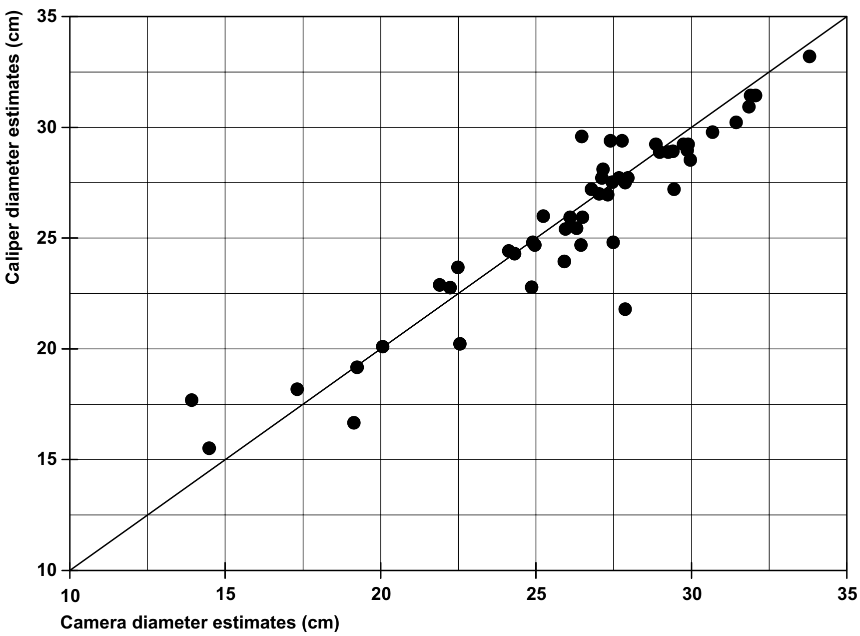

Figure 3. We can treat the diameter measurements calculated with the camera as a way to predict caliper-derived tree diameters. The diagonal line has a slope of 1 beginning at the origin.

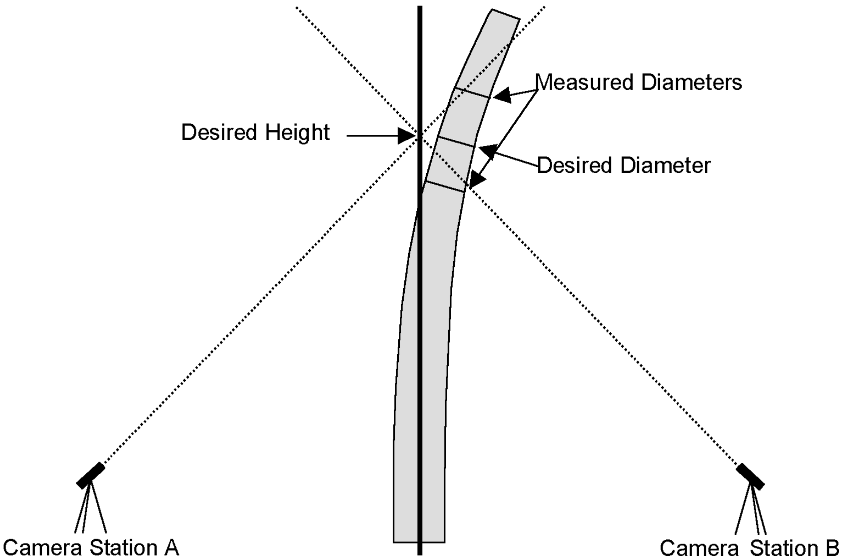

Figure 4. Leaning trees can create significant errors in measurement.

4 Discussion

The above camera measurements do not account for tree lean. As Fig. 4 shows, tree lean can often be quite a significant source of error. It is particularly noticeable in the smaller diameter measurements of Fig. 3. In theory, lean errors partially offset if images are captured in opposite directions using the same datum plane. Tree lean causes one height to be overestimated and the other height to be underestimated. These mis-estimations, however, do not cancel each other exactly. Still, by using a perpendicular photo to locate identical stem heights on opposing photos it should be possible to reduce the error considerably.

Measurement errors from digital images can occur in several other ways. For example, in Fig. 5 an enlarged portion of a digital image shows how tree edges can be difficult to determine under varying background contrast. When the image

Figure 5. An enlarged portion of an image shows that the tree stem on the left of the image does not have a clear, unambiguous, and straight boundary, which introduces errors into diameter measurements.

background is sky, tree boundaries are clear. When the background includes forest, stem delineation is more subjective. Because each pixel can represent 10–20 mm (depending on camera distance), single pixel errors become significant.

As noted above, virtual pixel size – and consequently, error – increases as one measures diameters farther up the stem. Smaller diameters, which occur higher in the tree, are affected greatest. This results in a much higher percentage error for these measurements. This increased error percentage is offset somewhat by the fact that this portion of the tree has much lower timber product volume and value, so errors are less significant from a volume and value perspective.

Any optical measurement system is going to be hampered by visibility in the forest setting. Along with contrast, light intensity and obscuring objects (e.g. foliage and other stems) contribute to measurement errors. Various image processing operations can adjust for lighting intensity, however, improving object clarity in the image. While not all possible diameter measurements may be available on an image due to obscured stem boundaries, careful examination of an image often leads to discovery of nearby diameters that can be measured instead.

There are a number of important benefits to this type of data collection system. First, accuracy is as good or better than any optical dendrometers available. Second, terrestrial imaging requires much less time to collect hundreds of times more data, i.e., each image contains a large number of diameter and height measurements. Third, tree images are acquired at one point in time, but measurements can be made many times for multiple purposes. Fourth, quality assurance can be simpler because fewer field operations are required. Fifth, re-measurement from a single image provides for very reliable quality control procedures. Finally, while this report does not address other stem characteristics, such as sweep and crook, it is obvious that camera images can easily capture these grading parameters.

The use of digital imagery and image processing software as a multi-measurement dendrometer offers many advantages over existing optical instruments, while providing accuracy that is equivalent to, or better than, traditional methods.

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