DEVELOPMENT OF A PHOTOGRAMMETRIC METHOD OF MEASURING TREE TAPER OUTSIDE BARK

David R. Larsen[1]

Abstract—A photogrammetric method is presented for measuring tree diameters outside bark using calibrated control ground-based digital photographs. The method was designed to rapidly collect tree taper information from subject trees for the development of tree taper equations. Software that is commercially available, but designed for a different purpose, can be readily adapted for use in this task. This paper presents the methods and procedures developed by the author.

INTRODUCTION

Tree taper refers to a set of diameters or radii measured at multiple heights on a tree. This describes the shape or profile of the stem being measured. With these measurements, the volume of a single tree can be determined accurately. The measurements can also be used to develop taper equations to predict stem diameter at any point on a tree. Taper measurements have long been of interest to foresters for estimating the volume of trees.

Taper measurements traditionally are acquired by one of several methods: direct measurement, felled tree stem analysis, measurement with dendrometers, and other optical methods (Clark and others 2000, Dean 2003). All of these methods have some disadvantages. Direct measurement requires physically measuring the stem at several heights. Stem analysis requires destructive sampling of a tree. Stem measurement with dendrometers, while not destructive, is very time-consuming. For all methods, there are no simple ways to archive the samples for re-measuring if an error is found. For example, for stem analysis, wood cross-section disks must be stored and protected from drying and cracking. The other methods require returning to the research site and remeasuring sample trees.

In this paper I describe the development of a new method for measuring tree taper using digital photographs of the trees (fig. 1). Two important benefits of this method are (1) most of the measurement time is spent in the office, allowing measurements to be made more carefully, and (2) the photographs provide a permanent record of the subject tree on the day sampled. This new method also provides a mechanism for the data to be processed by more than one person so that the results can be independently compared. If the measurements contain errors, the photographs can be reprocessed usually without returning to the field. The total time to process a single tree currently seems comparable to the traditional methods for measuring taper. However, the photogrammetric method requires less time in the field.

PRINCIPLE OF THE PHOTOGRAMMETRIC METHOD

The photogrammetric method produces a 3-dimensional model of the tree stem with a set of photographs. Unlike traditional stereo photography, the camera locations are not next to each other, and in fact, two images next to each other would produce very poor results. The analogy is to think of a clear box with things of interest inside. You want to photograph the box from as many sides as possible to fully describe the objects in the box. You are using the spatial relationships stored in the photographs to describe the 3-dimensional space of this imaginary box.

Photographs are samples of reflected light energy that also record the spatial relationships among objects from a particular viewing point. I can construct a spatial model of the objects when at least three photographic samples from different viewing points are combined. The quality of the 3-dimensional model depends on how well the photographs are aligned and how well the known distortions are accounted for in the model. Ultimately the limitations on the resolution of the procedure are dependent on the pixel resolution in the digital images

Figure 1—Example of a winter photograph and with the cylinders marked on a subject tree. This tree is a northern red oak (*Quercus rubra* L.) from the Baskett Wildlife Research Area, Ashland, MO. This is the tree used in the summer-winter evaluation (figure 7).

[1] Associate Professor of Quantitative Silviculture, Forestry at the University of Missouri-Columbia, 203 Anheuser Busch Natural Resources Building, Columbia, MO 65211.

Citation for proceedings: Connor, Kristina F., ed. 2006. Proceedings of the 13th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–92. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 640 p.

used in the model building process. In general, at the ranges used in this study, pixel sizes range from 0.04 to 0.8 inches, so positional accuracies within that range are possible.

If acceptable resolutions are possible, systematic error in the 3-dimensional model must be removed. Systematic errors come from three sources: the camera lens distortions, the orientation of the camera viewpoints, and in marking the object of interest. Camera lens distortion correction is a well-known problem that has been documented in the photogrammetry literature for many years (Thompson 1965). The procedure consists of imaging a fixed grid of targets from many angles. Through a series of steps, a matrix is created that describes the distortion space of a particular lens. This must be done on individual lenses as even two lenses of the same make and model will be slightly different. If using a zoom lens, a separate calibration for each magnification is required; because of this, most people use a single fixed zoom setting.

Orientation of the camera viewpoints is the most important part of the 3-dimensional model method, as errors from Incorrectly aligned photographs are propagated to all other dimensional measurements. This step defines the spatial relationships in the 3-dimensional model. The procedure is to identify common visible points on all photographs, and these points are identified as being the same physical locations. Once at least six common points have been identified, the 3-dimensional model can be processed. For greater accuracy, the points should be distributed throughout the sampled area but near enough the center of the sample space to be visible. A good compromise between these two competing needs will produce the best outcome. Identifying more than six visible points will improve photo alignment, producing a better model. Additionally, some of the points must be a known distance apart. This provides scale to the 3-dimensional model. A set of poles with two visible endpoints for this as well as a standard 25-foot height measurement pole works well for these measurements.

Once the above steps are completed, the next step is to measure the objects of interest in the 3-dimensional model. To measure tree taper, a series of stacked cylinders are marked. In each photograph, the edges of the stem are marked at a specific height. After marking these edges in two or more images, the cylinder edges are linked. This allows multiple estimates of the diameter of the stem at specified height (fig. 2). Again, the accuracy of the measurements at this point depends on not only the accuracy of the marking of the stem in multiple images but also the alignment of the images from the previous step.

APPLICATIONS

Sites

Example data for this study come from three sources. The first dataset is a cherrybark oak (*Quercus pagoda* Raf.) and sycamore (*Platanus occidentallis* L.) plantation near Helena, AR. These data have been previously described in Clatterbuck and others (1987) and Oliver and others (1990). A second dataset is comprised of scarlet oak (*Q. coccinea* Muenchh.) and white oak (*Q. alba* L.) trees collected at University Forest near Wappapello, MO. A third dataset is made up of white oak and northern red oak (*Q. rubra* L.) trees from the Baskett Wildlife Research Area near Ashland, MO.

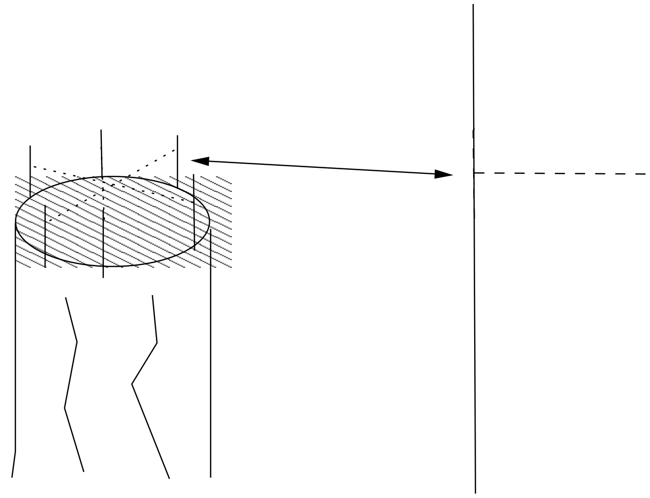

Figure 2—Illustration of how single marked silhouettes, which are marked on separate images, are used to estimate the diameter of a tree cylinder.

PROCEDURES

To evaluate the methodology I applied the procedures to a number of hardwood trees with images taken both during the leaf-on and leaf-off seasons. D.b.h. was measured with a diameter tape to compare to the diameters obtained by the optical procedures. In general, only the first 25 feet of each the tree's stem was measured for taper in roughly 1-foot increments.

The software I used to process the images was Photomodeler® (Photomodeler Pro 5 2003). This software was not designed for constructing taper equations. It was designed to produce "as built" drawings of buildings for architects. Archeologists use the software to document historical ruins of building, and insurance agents and law enforcement personnel use it to document vehicle collisions. Using this software to construct taper models, as reported here, is a novel application and not easily accomplished in the current configuration of the software; however, the company has been very helpful making changes and additions to the software to allow it to be used to estimate tree taper data.

I calibrated the camera by photographing a target from multiple angles. An automated procedure of the software processed the images and produced a correction matrix for the camera and lens that I used for subsequent tree measurements. Once calibrated, all photographs taken with this particular camera and lens combination were tagged for this calibration file.

I used three, 6-foot-long poles with yellow foam practice golf balls at each end to provide both matching points at fixed distances in the scene. I also used a 25-foot telescoping height pole next to the subject tree. These items were carried by one individual, and set-up time took < 10 minutes per tree. Once the matching points were established in the area, they were not moved during the process of photographing the scene.

I took 12 to 16 images in a circle around each subject (fig. 3). Not all images were useable, some because the camera was aimed at the sun, creating too much contrast, and others because some of the targets were behind leaves or stems. Typically, out of 16 images, I used 4 to 6 good ones. To further

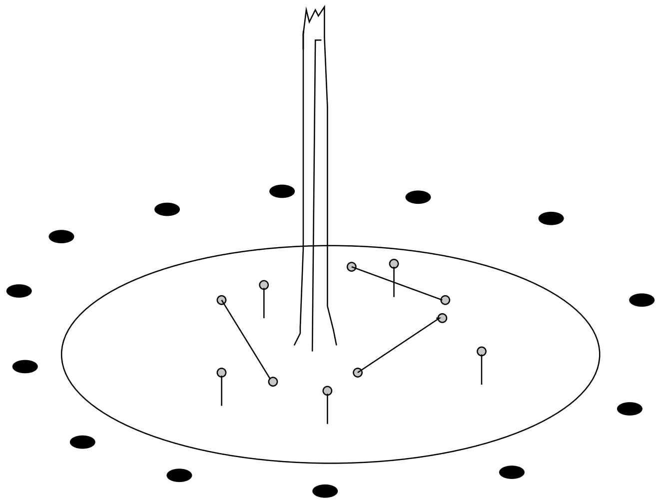

Figure 3—Illustration to describe the arrangement of control points around the subject tree. The black dots represent the potential photograph locations.

evaluate the method, images on one tree were taken in September and again in February. The procedures were the same each time.

Figure 4 shows the three images used to capture the sample space. In each photograph, the same point is marked. Each photograph must have 6 common points of known distance apart.

Figure 2 illustrates a single-stem silhouette tied together to produce a cylinder. It produced a cylinder having a diameter that was the average of three diameter measurements. If more images are used, the number of diameters averaged increases at one per additional image. The fact that the images are from very different angles improves the accuracy of the measurements.

RESULTS AND DISCUSSION

Nine trees are presented as representative examples of the type of data that can be acquired from these photographs. Most of the taper trend lines extend just beyond the 25-foot pole height, but one example in the cherrybark oak dataset extends to almost 60 feet (fig. 5). The height that could be measured was limited by the view of the tree from multiple

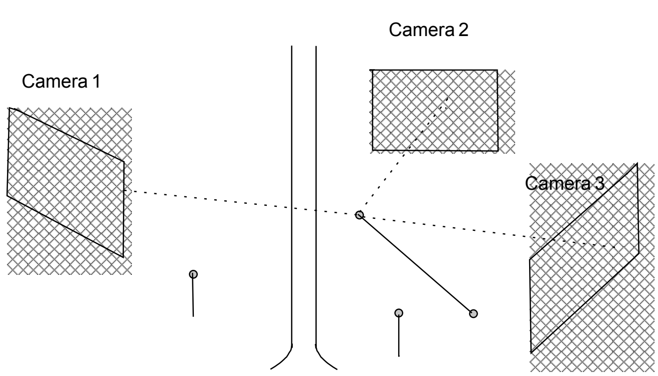

Figure 4—Illustration of how a single point is tied from three photographs to help create a 3-dimensional model.

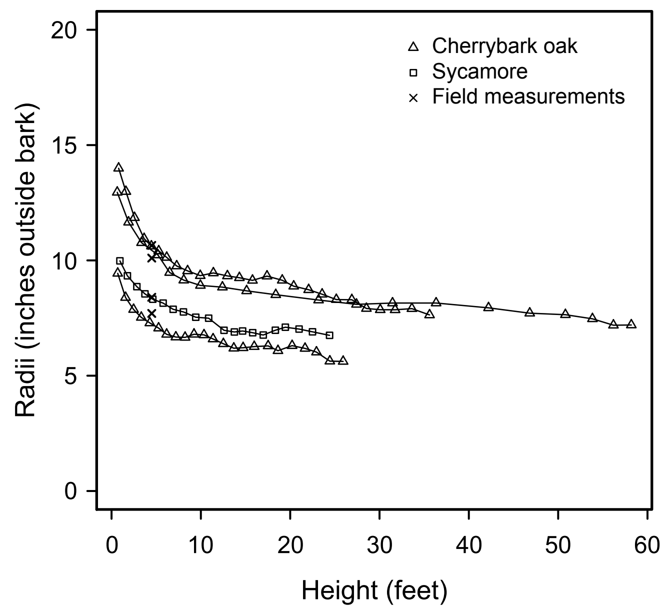

Figure 5—Graph of the taper data from the first dataset of cherrybark oak *Quercus pagoda* Raf.) and American sycamore (*Platanus occidentalis* L.) trees from plots near Helena, AR.

angles. Figure 6 illustrates the Missouri sample trees. The points labeled "field" are the diameter tape measurements for the sample trees. In most cases, they are the same value but sometime differ by as much as 0.2 inches. Several interesting points are evident. There is very good agreement between the diameters measured in the field and on the photograph, in most cases. Also, there was remarkable shape similarity among individuals of the same species. This has been noted elsewhere (Clark and others 2000), illustrating why taper equations are species specific.

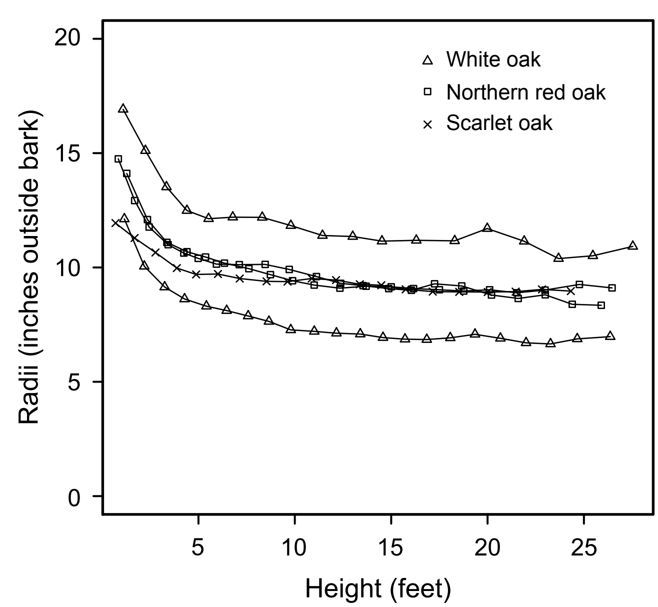

Figure 6—Graph of taper data from the second and third datasets of white oak (*Quercus alba* L.), scarlet oak (*Q. coccinea*, Muenchh.), and northern red oak (Q. rubra L.) collection at University Forest, Wappepello, MO and Baskett Wildlife Research Area, Ashland, MO.

The measurement of the same tree during two different seasons (leaf-on versus leaf-off) showed the high degree of reproducibility (fig. 7). However, I found some differences in stem radii, particularly near the top of the stem. These differences appeared to be due to foliage or branches blocking the stem when the photos were taken (fig. 1). The procedure seemed to work best when images were taken during the winter when there was no foliage to obstruct the view and there was more light shining on the bole of the subject tree. Also, measurements made higher along the stem were subject to some distortion because there were fewer control points at heights near the top of the measured portion of the stem.

One of the most difficult problems when working with tree images is to have control points that can be uniquely identified in all images. In images of buildings, it is easy to identify many unique control points such as window corners, building corners, and building trim pieces. In the forest, it is difficult to distinguish one twig or leaf from another when viewing images taken from different angles. To address this, I added man-made objects to the sampling area. I found incidental items like notebooks, water bottles, and clothing all increased the number of control points to align images. Additionally, I found that marking-pins made of yellow foam practice golf balls glued to the ends of fiberglass rods were helpful for aligning the images. Using marking pins each with balls having a unique color would make it easier to distinguish among control points. I also found that using flagging to mark the breast height diameter and stump diameter was very helpful for locating these points on the images and provided a means for checking estimated diameters with those made on the actual tree.

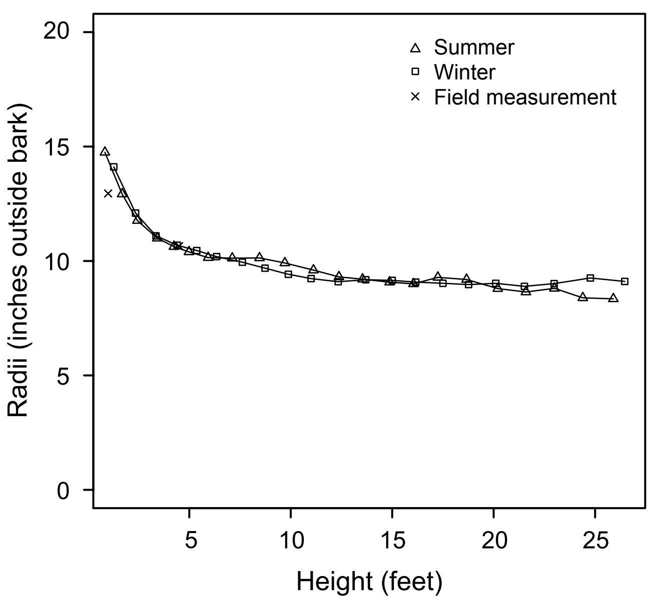

Figure 7—Graph of a single northern red oak (*Quercus rubra* L.) tree sampled in September and February to compare summer and winter measurements. The tree is from the Baskett Wildlife Research Area, Ashland, MO.

The procedure requires a fairly short set-up time to image a tree. I found that I could establish the control points, flag and measure the stump diameter and tree diameter, and take all the pictures in 20 minutes per tree. More time is required in the office as I generally spent about 2 hours per tree processing the images and generating the taper data. Thus, the amount of time required to generate taper data with this method is $\leq$ the time required by traditional methods. Moreover, the method has the added advantage of retaining a permanent record of the data, thus providing the means for remeasuring the tree without having to return to the field.

CONCLUSIONS

I believe that this photogrammetric method of measuring tree taper has accuracies comparable to traditional methods and has several advantages including: (1) creating a permanent record of the tree; (2) showing multiple sides of each tree to be measured; (3) allowing measurements to be done in the comfort of an office, not out in the cold, heat, or rain; and (4) providing a nondestructive method of obtaining tree taper measurements. Overall, the method appears to be a suitable and efficient one for obtaining tree taper measurements.

ACKNOWLEDGMENTS

Research support was provided through the study “Development of the Sylvan Stand Structure Model for Southern Bottomland Hardwoods” dated September 1, 2003 through August 31, 2006 of Cooperative Agreement SRS 03-CA-11330127-212. This research is funded by the U.S. Department of Agriculture, Forest Service, Southern Research Station Center for Bottomland Hardwood Research, Stoneville Mississippi. I thank Drs. Dan Dey and John Kabrick (U.S. Department of Agriculture, Forest Service, North Central Research Station, Columbia, MO) for reviewing this manuscript.

LITERATURE CITED

Clark, N.A.; Wynne, R.H.; Schmoldt, D.L. 2000. A review of past research on dendrometers. Forest Science. 46: 570-576.

Clatterbuck, W.K.; Oliver, C.D.; Burkhart, E.C. 1987. The silvicultural potential of mixed stands of cherrybark oak and (American) sycamore: (spacing) is the key. Southern Journal of Applied Forestry. 11: 158-161.

Dean, C. 2003. Calculation of wood volume and stem taper using terrestrial single-image close-range photogrammetry and contemporary software tools. Silva Fennica. 37: 359-380.

Oliver, C.D.; Clatterbuck, W.K.; Burkhart, E.C. 1990. Spacing and stratification patterns of cherrybark oak and American sycamore in mixed, even-aged stand in the Southeastern United States. Forest Ecology and Management. 31: 67-79.

Photomodeler Pro 5. 2003. User manual. V6J 1Y6. Vancouver, BC, Canada: EOS System, Inc. 488 p.

Thompson, M.M., ed. 1965. Manual of photogrammetry. Third edition. Falls Church, VA: American Society of Photogrammetry. 1199 p.