Journal of Horticulture and Forestry

Full Length Research Paper

A photographic method for measurement of tree height: More accurate and simpler than other methods?

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In the photographic method, a photo is taken of the tree with an object of known reference height beside it. An inexpensive cell phone camera can be used. The tree height is calculated by using a ruler to measure the tree height and reference height on the photo. Previously, this method was thought to be accurate only if the distance to the camera was many times the tree height. However, if the cell phone is held vertically, at a right angle to level, this eliminates the optical foreshortening in viewing a tall tree. The photo method produces a very accurate estimate of tree height. By using this method in a test experiment, the photo method had an inaccuracy of less than 1%. The most common measurement methods used by professionals are the tangent and sine methods, which use clinometers and laser rangefinders. These methods require measuring the distance to the tree, the elevation of the instrument above the base of the tree, and the angle to the top of the tree. The photo method is easier and potentially more accurate than the tangent and sine methods. It can be used by forestry professionals and the general public.

Key words: Tree, height, measurement, eastern white pine.

INTRODUCTION

Measuring the height of a tall tree is not a trivial problem. There are many ways of measuring tree height (Jones, 2020; Tim, 2020).

In the ruler method (Minnesota, 2020), the viewer stands back from the tree and holds a ruler at arm's length (Appendix A). This procedure requires simultaneously lining up portions of the ruler with the top of the tree, the bottom of the tree, and a mark on the tree, without moving your arm or head, while holding the ruler

exactly vertical. This limits the accuracy of the ruler method. A common method for professionals is the tangent method (Bragg, 2008; Larjavarra and Muller-Landau, 2013). A clinometer is used to measure the angle between the line of sight to the top of the tree and the horizontal (Appendix B).

Another common method for professionals is the sine method (Bragg, 2008; Hayek, 2020; Larjavarra and Muller-Landau, 2013; Tim, 2020). The sine method uses

Figure 1. The instrument used in the Photo Method: a cell phone taped to a small level.

a clinometer and a laser rangefinder (Appendix B).

This paper describes the photo method, which uses a cell phone camera or other camera to take a picture of the tree and an object of known height beside it. By holding the camera perpendicular to level, the photo method provides a very accurate estimate of tree height. The photo method is easier to use than the tangent and sine methods, and is potentially more accurate.

MATERIALS AND METHODS

Photo method

In the photo method, a photo is taken of the tree with an object of known height beside it. The reference height could be a separate stick. A cell phone camera can be used. The relative height of the tree and the reference height of the object can be compared by using a ruler to measure their respective heights on the photo. The photo can be sent to a computer and enlarged and printed out on plain paper for accurate measurements. The photo can be used as a permanent documentation of the measurement. The tree height H is calculated to be

$$H = (H_P/H_{RP}) H_R, \tag{1}$$

where H_R is the actual height of the reference, H_P is the height of the tree as measured on the photo, and H_{RP} is the measured height of the reference as measured on the photo. For reasons to be

discussed later, the cell phone is held vertically, at a right angle to level. This can be done by using a level that is at a right angle to the camera. One way to do this is shown in Figure 1.

The small level is temporarily taped to the cell phone at a right angle. The level and camera image can be clearly seen simultaneously as the photo is being taken.

The photo can be taken by holding the cell phone as vertically as possible without the level, but using the level gives higher accuracy.

The photo method is convenient because a cell phone or other simple camera can be used. Most people carry a cell phone, so a measurement can be made without pre-planning. For a quick estimate of tree height, the photo measurements can be made directly on the cell phone screen. You can even use the calculator on the cell phone to calculate the tree height from Equation 1.

Using a camera to take a photo of a tree with a reference height is a known method for estimating tree height. It is generally thought that this method is only accurate if the photo is "taken from a distance as large as possible to have the smallest perspective distortion possible" (Tim, 2020). However, in the field it is often impossible to get a good view of the tree from a long distance because the terrain, other trees, brush, and other objects obscure much of the tree. If no thought is given to the angle at which the cell phone is held, using a photo taken at shorter distances is indeed an inaccurate method because the photo distorts the image by foreshortening the tree height. The natural way of taking a tree photo is to center the tree in the photo, as was done in Figure 2 (Jones, 2020). This guarantees considerable height distortion, as will be shown. This problem is avoided if the cell phone is held vertically, at a right angle to horizontal.

The accuracy of the photo method, as outlined earlier, can be experimentally verified. The experimental set-up is as shown in Figure 3. The tree is emulated by a vertical board that is exactly 5 feet tall. The reference height is a one-foot ruler. The camera-level combination of Figure 1 was used to keep the cell phone at a right angle to horizontal. The photo was taken at a distance of 10 feet. The camera was level with the bottom of the board. This photo was not cropped.

The heights on the enlarged photo were measured with a steel ruler with marked increments of 1/100 of an inch. Using Equation 1, the calculated height of the board is 4.97 feet (0.6% error). This very small error is not surprising, because the height of the board and ruler on the photo can be measured with high accuracy.

The cell phone camera is held at a right angle to horizontal for Figure 3. Surprisingly, the board does not appear narrower at the top, even though the camera is viewing most of the board at an angle. Also, the width of the siding on the house does not narrow as you look higher on the house. This is fortuitous for the photo method because the board (tree) height and ruler (reference height) can be measured on the photo without image foreshortening.

If the camera is tilted so that the board height is centered within the photo, which is the usual way of taking such a photo as shown in Figure 2, the result is shown in Figure. 4. The camera is tilted back 14 degrees to achieve this.

Note that the board looks narrower at the top, and the siding also gets narrower higher up. The height of the board and the ruler are distorted in Figure 4, and therefore this photo cannot be used for accurate measurements. When the measurements were taken on this photo, the calculated height was 4.58 feet, which is an error of 8%. When the cell phone is held properly as in Figure 3, this foreshortening error is eliminated.

All of the photos in this paper (except Figures 1 and 2) were taken by an inexpensive Samsung Galaxy J7 cell phone camera. When a Samsung Galaxy S9+ cell phone was used, the foreshortening was also eliminated as in Figure 3, and there was no discernible difference in the image. The S9+ has two lenses for improved depth perception. When a Sony Cyber-shot pocket camera was used, the results were also about the same. It seems that the photo method can be used with almost any camera.
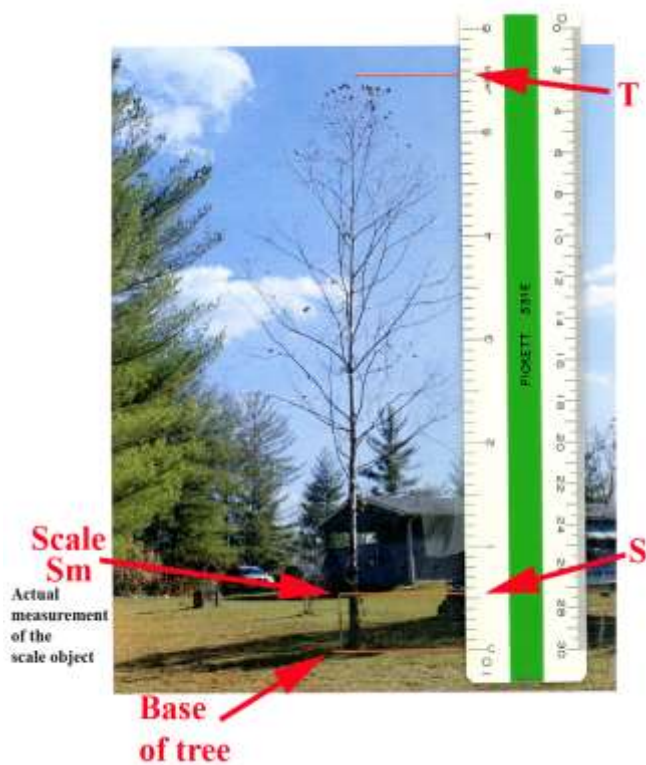
Figure 2. Centering the tree height in the photo when estimating tree height.

Figure 3. Experimental set-up to verify the Photo Method.

Figure 4. Distorted image when the board height is centered within the photo.

RESULTS AND DISCUSSION

Measuring the heights of Eastern White Pines

The Photo Method was applied to an Eastern White Pine shown in Figure 5. The reference height is a 12-foot birch stick with an orange cap on each end. The cell phone was held exactly vertically by using the camera-level combination of Figure 1. This photo was not cropped. The inset shows an expanded view of the reference stick. The camera is about 210 feet from the tree (but that number is not used in the height calculation). The pine is at the edge of the woods, so an unobstructed view can be easily obtained. The calculated tree height from Equation 1 is 88 feet.

Figure 6 shows the same tree with the photo taken from a distance of about 90 feet instead of 210 feet in Figure 5. The photo was taken previously with a reference stick that is a 15-foot birch stick with an orange cap on top. The photo is not cropped. The tree height is centered in the photo and the camera is not held vertically. For reasons stated before, this photo will not give an accurate estimate of tree height. From Equation 1, the estimated tree height is 71 feet. This is an error of 19%.

This white pine is a beautiful specimen. It receives lots of sunlight because it is at the edge of the woods. By counting rings on a dead tree of similar dimensions in these same woods, this tree is about 130 years old. The circumference at a height of 4 1/2 feet is 11 feet 4 inches. The crown width as measured from the photo of Figure 5 is 49 feet.

Figure 7 shows a photo of another Eastern White Pine

Figure 5. An Eastern White Pine with a 12-foot reference stick. Tree height is 88 feet.

Figure 6. The same tree as in Figure 5, but with the tree height centered in the photo. Reference stick is 15 feet tall.

and a 12-foot birch reference stick with orange caps on each end. The camera-level combination of Figure 1 was used for this and subsequent tree photos. This photo and subsequent tree photos were cropped. The camera is about 200 feet from the tree. The tree top, tree base, and reference stick can be discerned through the intervening trees and brush. The calculated tree height from Equation 1 is 119 feet.

There is a famous Eastern White Pine in Itasca State Park in Minnesota. It is thought to be the tallest white pine in Minnesota. It is 111 feet tall (Gilbert, 2020). The White Pine of Figure 7 is 8 feet taller than that.
In Figure 7, there is another tall white pine that is behind and to the right of the first pine. The two trees are about 140 feet apart. This other white pine and the 12-foot reference stick are as shown in Figure 8. The camera is about 240 feet from the tree. Figure 8 is expanded enough that the tree height can be accurately calculated by measurements on this photo. Using Equation 1, the tree height is 117 feet. This tree is 6 feet taller than the

Minnesota record Itasca white pine. It is remarkable that two Minnesota record white pines are so close together.

The circumference of each tree at a height of 41/2 feet is about 11 feet (or 31/2 feet in diameter).

Comparison of the photo method to the tangent and sine methods

Appendix B shows that the Tangent method requires measuring the distance to the tree (D), the elevation of the camera with respect to the base of the tree (H_1), and the angle A when looking at the top of the tree, none of which are required in the photo method.

Appendix B shows that the sine method requires measuring the distance to the top the tree (L), the elevation of the camera with respect to the base of the tree (H_1), and the angle A, none of which are required in the photo method.

The Photo Method simply requires taking a picture of

Figure 7. An Eastern White Pine with a 12-foot reference stick. Tree height is 119 feet.

Figure 8. Another Eastern White Pine with a 12-foot reference stick. Tree height is 117 feet.

the tree with an object of known reference height. This photo also serves as permanent documentation of the measurement.

The Tangent and Sine Methods require the use of a clinometer and laser rangefinder, whereas the Photo Method only requires a standard cell phone and a small level.

The tangent and sine methods are much more sensitive to how level the instrument (clinometer) is. Consider the case where D = 2H as in the test set-up of Figure 3. For the Tangent Method, Equation B1 shows that the angle A is then 26.6° degrees. If A is off by 1 degree, Equation B1 shows that the height changes by 4.5%. Similarly, for the sine method, Equation B4 shows that if A is off by 1°, the height changes by 3.3%. On the other hand, when the camera was tilted back by 5° in the test set-up of Figure 3, the height calculated by the photo method was only decreased by 3%. Therefore, for this example the photo method is about five times less sensitive to leveling error than the other two methods.

When the tree is leaning away from vertical, the tangent and sine methods measure the vertical height above the ground, not the length of the tree. The photo method can measure the true tree length, as illustrated in Figure 9. The tree of interest is the one on the left in Figure 9. The reference height is a 6-foot stick with an orange cap on top. The tree is measured along its length. The photo is taken from a distance of about 160 feet. The tree length as calculated by the photo method is 91 feet.

Conclusions

In the photo method, a photo is taken of the tree with the

Figure 9. A leaning Eastern White Pine with a 6-foot reference stick. Tree length is 91 feet.

sensitive to how level the instrument is. The base and top of the tree are easy to discern in the photo method. The photo method also requires fewer measurements than the other two methods. It is quite possible that the photo method is more accurate than these other two methods. This requires more research.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

REFERENCES

Bragg D (2008). An improved tree height measurement technique tested on mature southern pines. Southern Journal of Applied Forestry 32(1):38-43.

Gilbert J (2020). So little of Minnesota's once-vast pine forests remain. Minneapolis Star Tribune. Feb. 28, 2020 Outdoors Page. www.startribune.com>so-little-of-minnesota-   s-once-vast-pine-forests-remain

Hayek J (2020). The Sine Method: a better tree height mea- surement technique. Univ. of Illinois Extension Tech. Forestry Bull. NRES-1104

Jones L (2020). Measuring tree height from a photo. http://www.winter-tree-identification.com

Larjavarra M, Muller-Landau H (2013). Measuring tree height: a quantitative comparison of two common field methods in a moist tropical forest. Methods in Ecology and Evolution 4(9):793-801. https://doi.org/10.1111/2041-210X.12071

Minnesota Department of Natural Resources (2020). Measuring a tree. https://files.dnr.state.mn.us/natural   resources/plants/   trees shrubs/bigtree/measuringtree.pdf

Tim (2020). How to estimate the height of a tree. http://www.monumentaltrees.com>content>estimatingheight.

object of known reference height beside it. The camera must be held vertically, at a right angle to horizontal. An inexpensive cell phone camera can be used. The tree height is calculated by measuring the relative height of the tree and the reference height on the photo. The photo method is very easy to use and provides a very accurate measure of tree height. Compared to the tangent and sine methods, the photo method appears to be easier to use and only requires a cell phone rather than special instruments. Furthermore, the photo method is much less

APPENDIX

APPENDIX A: RULER METHOD

In the ruler method (Minnesota, 2020), a ruler is marked with tape at 1 inch and at 10 inches. The viewer holds the ruler at arm's length and steps back until the top of the tree lines up with the 10-inch mark and the bottom of the tree lines up with the bottom of the ruler. The viewer then lines up the 1-inch mark with a place on the tree and marks that spot on the tree. The distance H_1 is then measured from that mark to the ground. This is illustrated in Figure A1. The height (H) of the tree is then calculated to be
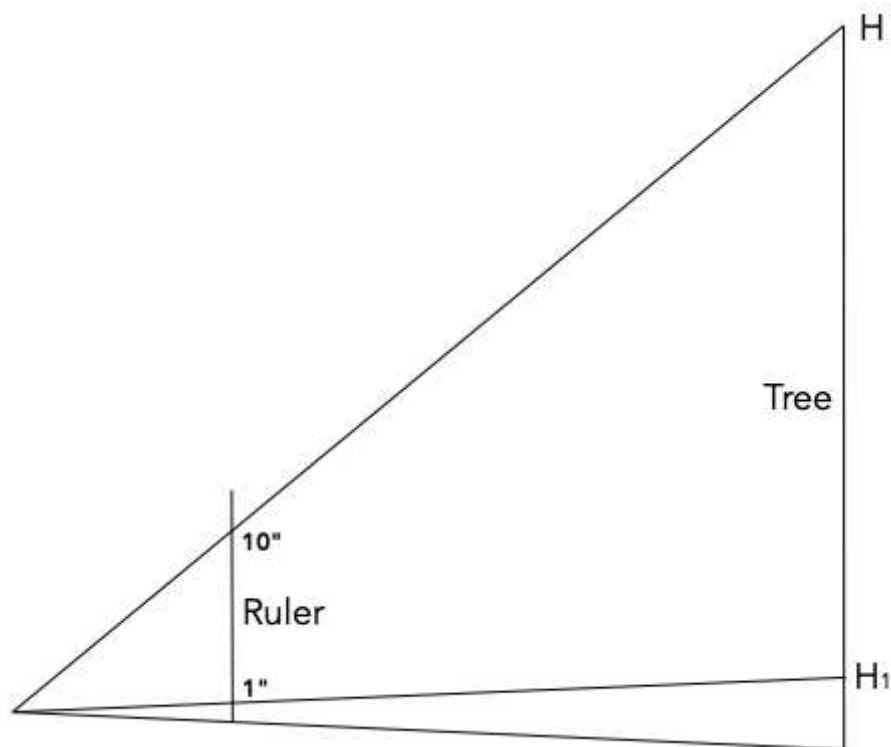
$$H = H_1 \times 10 \qquad\qquad (A1)$$

Figure A1. Measuring a tree by the Ruler Method.

This procedure requires simultaneously lining up portions of the ruler with the top of the tree, the bottom of the tree, and the mark on the tree, without moving your arm or your head, while holding the ruler exactly vertical. This limits the accuracy of the ruler method. The ruler method is a convenient way to get a rough estimate of tree height.

APPENDIX B: TANGENT AND SINE METHODS

The two most common methods used by professionals are the Tangent Method and Sine Method. Fig. B1 illustrates the Tangent Method (Bragg, 2008; Larjavarra and Muller-Landau, 2013). By using a clinometer, the viewer locates the top of the tree by line of sight.
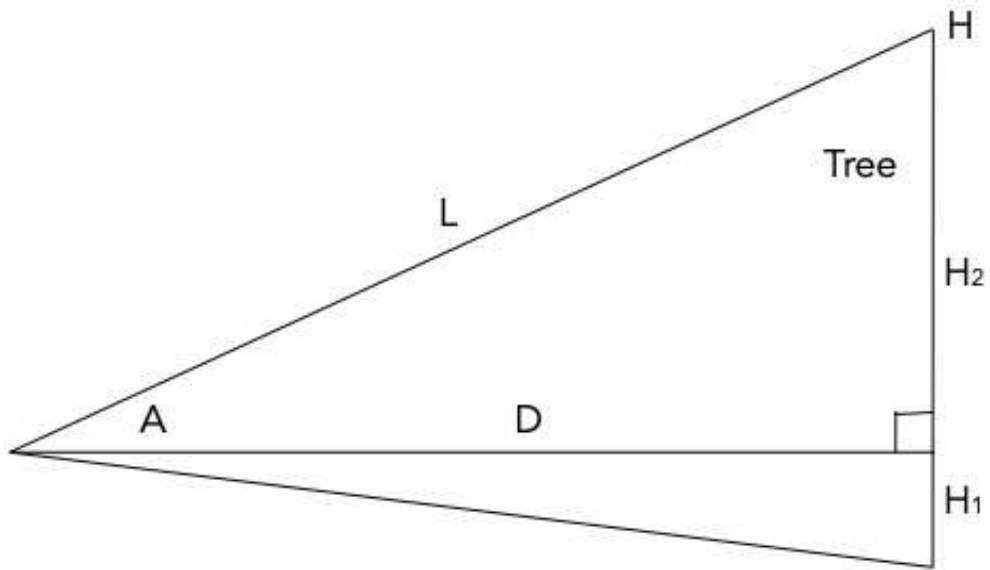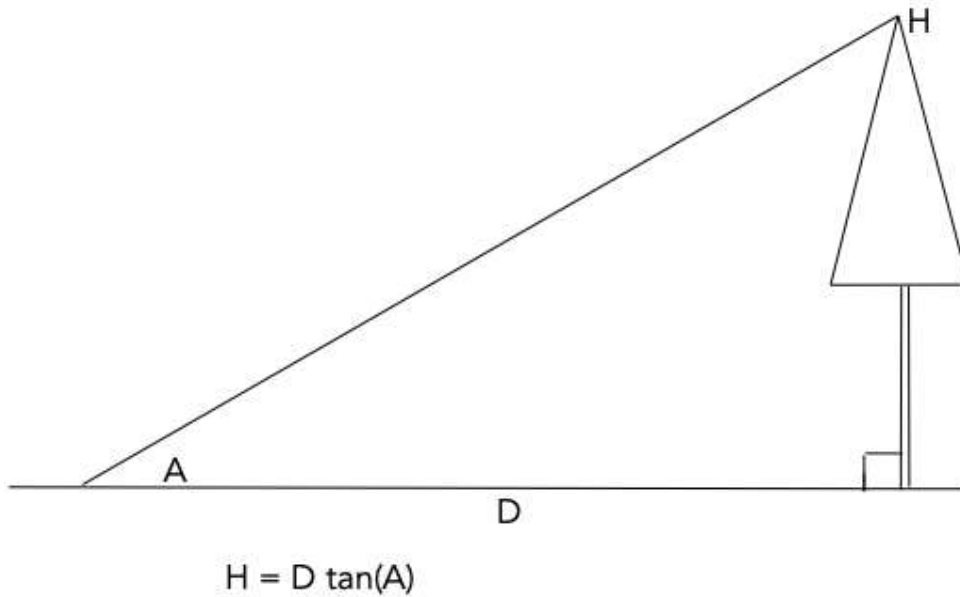
Figure B1. Measuring tree height by the tangent method.

The clinometer measures the angle A between this line and the horizontal line. The measured tree height H is

$H = D \tan(A)$ (B1)

where D is the distance from the tree to the clinometer.

$H = D \tan(A)$

Figure B2. Measuring tree height when the viewing instrument is at a higher elevation than the base of the tree.

When the clinometer is not at the same elevation as the base of the tree (because of the height of the person and/or the slope of the ground), the height calculation can be done as shown in Figure B2 (Bragg, 2008; Larjavarra and Muller-Landau, 2013).

H_1 is the elevation of the instrument from the base of the tree. H_1 can be determined by using a level. H_1 can be marked on the tree, where it can be measured directly from the ground. A clinometer is then used to determine the angle A. H_2 is then determined by

$$H_2 = D \tan(A) \hspace{4cm} (B2)$$

The total tree height is then

$$H = H_1 + H_2 \hspace{4cm} (B3)$$

The sine method (Bragg, 2008; Hayek, 2020; Larjavarra and Muller-Landau, 2013) uses a laser rangefinder to measure the distance from the instrument to the top of the tree. This distance is labeled L in Figure B2. Since L is the hypotenuse of the right triangle, the height H_2 is determined by

$$H_2 = L \sin(A) \hspace{4cm} (B4)$$

The total height H is then given by Equation B3.