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Research Article

A New Method for Forest Volume Measurement with an Electronic Angle Gauge

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Abstract: To realise precise, real-time measurement of forest volume, this study discusses the principles and method of forest volume measurement when utilizing an electronic gauge. Use of the electronic gauge, to count trees within five concentric circles, resulted in a decrease in the variation of estimated forest volume, as the number of circles increased. This estimate became reliable upon reaching the fourth concentric circle. In contrast, the use of a conventional angle gauge revealed no obvious regularity and no significant trend using multiple observation points. As well, for forest inventory plots with uneven spatial distribution, there was relatively low precision when using multiple observation points with a conventional angle gauge: the relative errors of forest volume measurement reached almost 40% in the first plot using multiple observation points. The electronic angle gauge is comprised of a telescope and Charge Coupled Device (CCD) system, which reduced the probability of a misreading and achieved accurate real-time measurement of forest volume. Observers can choose an arbitrary location to position the electronic angle gauge. The survey time with the new method was half that of using a conventional angle gauge at five different observation locations. The forest volume measurement was automated using a Personal Digital Assistant (PDA) with newly-designed software capable of identifying, registering and then counting the trees in a plot. This method improves accuracy of forest volume measurement and reduces the time and effort required previously.

Keywords: Conventional angle gauge, concentric circles technology, electronic angle gauge, forest volume measurement, Personal Digital Assistant (PDA)

INTRODUCTION

Forest volume measurement is an important aspect of a forestry survey. Bitterlich originated forest measurement using an angle gauge in Austria (Bitterlich, 1952; 1959). At that time, Grosenbaugh (1952) stated that angle gauge sampling was an unequal probability sampling. Later, Hirata (1955) estimated tree height by Bitterlich's method using vertical angle counting. From 1990 to 2008, many researchers invented and refined the shaped point's method of determining forest volume (Xu *et al*., 1990, 1997; Feng *et al*., 2003a, b; Feng and Xu, 2005; Feng and Wang, 2007; Dias *et al*., 2006; Lu, 2005; Dong, 2005; Dong *et al*., 2008). Large-angle gauge and remote sensing methods have commonly been used for tree measurement (Mani and Parthasarathy, 2007; Muinonen*et al*., 2001; Anttila, 2002; Muukkonen and Heiskanen, 2007; David *et al*., 2004; Makela and Pekkarinen, 2004). In addition, many forest researchers are interested in forest analysis using digital photography, CCD systems and other electronic equipment (Tanaka *et al*., 1998; Frazer *et al*., 2001; Kuusk *et al*., 2002; Nelson *et al*., 2003; Sevillano-Marco, 2009; Symposium, 2009). The traditional method used to determine forest stand basal area is with a conventional angle gauge, the forest volume then being calculated manually using the average experimental form factor of the tree.

However, there are three problems associated with the conventional angle gauge. First, the end of the angle gauge close to the eye must be held vertically and should not shift with body rotation. Second, the location of the angle gauge point should not be moved. Third, the critical tree must be determined carefully, otherwise substantial error may result. There can be a large error in determining forest volume using a conventional angle gauge approach if the forest spatial distribution is not uniform. In order to reduce forest volume measurement error, as well as time and effort, an

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electronic angle gauge for forest inventory was patented in China (Feng and Wang, 2007). However, it applied the method of the conventional angle gauge with a single observation and was not widely used in the forest resources inventory. This study proposes adopting a five concentric circles method to measure forest volume with an electronic angle gauge. The concentric circle approach uses the same observation station, with five different diameters, with measurements being automated using an electronic angle gauge and a PDA.

MATERIALS AND METHODS

Study area: The Jiufeng forest farm is located in the northwest Haidian District of Beijing, China (latitude 39° 54 ' N and longitude 116° 28' E). The forest covers 775.1 ha across the Haidian and Mentougou Districts. The Jiufeng forest farm is in the Taihang Mountains, the highest altitude being 1291m. The terrain is complex, with more than 600 species of woody plants. The main tree species are *Pinus tabulaeformis*, *Platycladus orientalis* and *Robinia pseudoacacia*. The annual average temperature is 11.6℃, the average annual precipitation is 630 mm and the annual evaporation capacity is about 1800 mm.

Forest volume measurement using a conventional angle gauge: Suppose that the diameters of trees at breast heightin a plot are D_i, of these trees, one is a critical tree, from which an angle gauge is used to form an imaginary circle with the observation point O at the centre (Meng, 2006). The radius of the circle R_i(m) is calculated as:

$$R_i = L \times D_i / l \tag{1}$$

where, L the length of the angle gauge (m), i the number of the trees, D_i the tree diameter at breast height (cm) and l the angle gauge gap width (m).
The sample circle area S_i(ha) is calculated as:

$$S_i = \pi \times R_i^2 = \pi * (L \times D_i / l)^2 \tag{2}$$

If there are Z_i trees in the sample circle, which have been identified, registered and then counted using the angle gauge, then the basal area of trees that fall into the sample circle is calculated as:

$$g_i = \frac{1}{4}\pi \times D_i^2 \times Z_i \tag{3}$$

$$S_i : g_i = 10000 : G_i \tag{4}$$

$$G_i = 2500 \times (l / L)^2 \times Z_i = Fg \times Z_i \tag{5}$$

where,

G_i = The stand basal area (m^2/ha)
Fg = The basal area factor of the angle gauge (m^2) and Fg values are designed to be chosen as 0.5, 1, 2 or 4. In this study, Fg is chosen as 1

Tree diameters at breastheight are never identical. If it is supposed that there are a finite number of groups of diameters D_i (i = 1, 2 .... n), then according to the principle stated above, for each diameter group we consider n concentric circles around the centre “O” with radius of $D*L/l$. The tree is counted when it is located within the sampling circle. Then, the stand basal area G(m^2/ha) and forest volume M (m^3/ha) are:

$$G = \frac{1}{m}\sum_{i=1}^{n} G_i = \frac{F_g}{m}\sum_{i=1}^{n} Z_i \tag{6}$$

$$M = G * (H + 3) * f \tag{7}$$

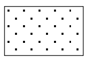
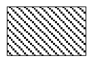
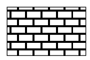
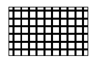
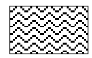
where,

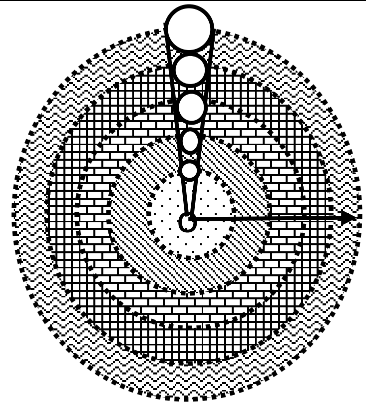
m = The number of observation points with a conventional angle gauge
H = The average height of the forest (m)
f = The average experimental form factor of the tree (in this study, f = 0.42)

Forest volume measurement using the electronic angle gauge: The electronic angle gauge is an optical, photoelectric and automated electronic system. The instrument is composed of a CCD system and digital camera. The images from the digital camera can be viewed through an eyepiece. The CCD system converts the optical signal of the entire visual field of the imageinto electronic signals; the PDA is used to collect, store the information and calculate the forest volume. The electronic angle gauge not only accurately aims at the target and accurately judges whether the trees are tangent with the double lines in CCD system, but it also measures the diameters at breast height of trees and tree height at any position. The tree measurement principle of the electronic angle gauge is described below and a schematic diagram of forest volume measurement with the electronic angle gauge is given in Table1.

Suppose that the forest stand for each basal area per hectare (ha) is $G = Fg \times Z$; that the supporting height (close to breast height and crown of the central height) basal area is $G_b = Fg \times Z_b$; And that the approximate point-shaped area of height-cut is $G_a = Fg \times Z_a$, where, Fg is the area index for the angle gauge; Z, Z_b and Z_a are the numbers of the angle gauge (Feng and Xu, 2005). The average height H of the forest and the forest stock M are given step by step, as follows:

Table 1: Parameters of five concentric circles

Concentric circles	1	2	3	4	5
Circles area (m^2)	100	300	500	1000	1500
Radius (m)	5.64	9.77	12.62	17.85	21.86
Logo					



The observation point O is only in the five concentric circles, and the radius of the circle is different

$$H_a = \frac{100}{\sqrt{\pi}} \tan \alpha_a \sqrt{\frac{G_a}{N}} \quad (8)$$

$$H_b = \frac{100}{\sqrt{\pi}} \tan \alpha_b \sqrt{\frac{G_b}{N}} \quad (9)$$

$$A = \log\left(2\left(\frac{\sqrt{G_b} - \sqrt{G_a}}{\sqrt{G} - \sqrt{G_a}}\right)^2\right) / \log 0.5 \quad (10)$$

$$R_a = \log 0.5 / \log \frac{(H_a^A (H_a - H_b))^{\frac{1}{A+1}}}{H_a} \quad (11)$$

$$R = \frac{\frac{R_a}{R_a + 1} 0.068375 + 0.39270}{\frac{1}{R_a + 1} 0.068375 + 0.39270} \quad (12)$$

In this step, we can take H_a, H_b, R_a and R into the following formula, then:

$$H = \frac{0.29289(H_a - H_b)\frac{\sqrt{G_b} - \sqrt{0.5G}}{\sqrt{G_a} - \sqrt{0.5G}} / (1 - 0.5^{\frac{1}{R_a}}) + H_b}{1 - 0.5^{\frac{1}{R}}} + 1.3 \quad (13)$$

$$M = \frac{1}{R+1}\left(\frac{H}{H - 1.3}\right)^R H \times G \quad (14)$$

where,

- H = The average height of the forest (m)
- H_a = The height of a referenced shape point which is 60 cm below the first branch of the tree (m)
- H_b = The assisted height, which is at the middle of the breast height and the height under the first branch of the tree (m)
- α_a, α_b = The vertical angles of the H_a and H_b
- A = The transition index
- R_a = The tree stem form index of the referenced height-shape point
- R = The index of the stand stem form
- M = Forest volume per hectare (m^3)

The electronic angle gauge has a self-adjusting function, which not only determines the characteristics of arbitrary cross-section values, but also measures distance with the help of a measuring scale to obtain the height and diameter at any cross section of trees. In addition, the electronic angle gauge can measure the heights of trees, compute and then show the forest volume automatically. When the synchronisation is completed, the device can greatly increase work efficiency, reduce the observation and count errors and decrease labour intensity. The measurement values can be entered into the system automatically (the average height H, the index of the stand stem R, the stand basal area G and forest volume M) and where they will be automatically displayed and stored.

In this research, we have selected three forest inventory plots with different tree species, different elevations and slopes in the Jiufeng forest farm. The area of each plot is 1500 m^2. Two methods are used to measure forest volume in each plot; one using a conventional angle gauge, the other using an electronic angle gauge. The area of each plot is decided by only the electronic angle gauge. Observers enter the forest and position the electronic angle gauge arbitrarily. The process of measurement is to determine the border of each plot with the area of 100, 300, 500, 1000 and 1500 m^2 according to the radius of each concentric circle; and then to distinguish the trees on the edge with different colours and symbols; the tree height and

Fig.1: Schematic graph of forest volume measurement with an electronic angle gauge

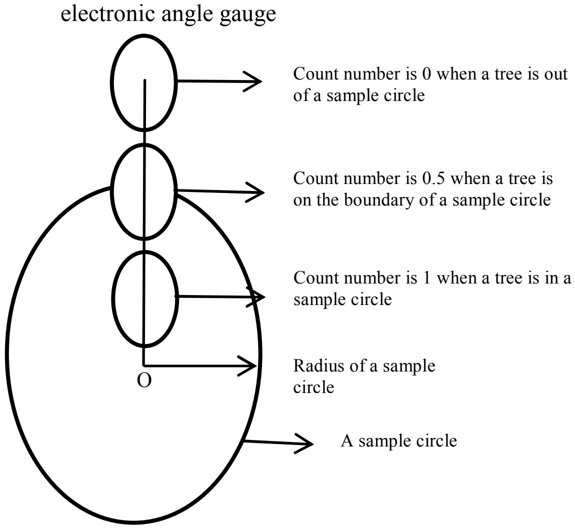


Fig. 2: Sample circles of tree measurements with a conventional angle gauge

diameter at breast height are measured; the data are entered into the PDA. The latitude, longitude and elevation of each plot are surveyed by a Global Positioning System (GPS). The stand average height and volume are calculated using the designed software of forest volume measurement. The parameters of the method with the electronic angle gauge are shown in Table 1 and Fig. 1. By contrast, we have selected five different observation points to measure forest volume in each plot with a conventional angle gauge. To do the observation, a conventional angle gauge is located by hand on the observation point O; the end of the angle gauge should be set close to the eye. Upon commencing the observation, the eye, the angle gauge gap and the tree should be in the same line. When the circle ring is completed, the counted numbers of the trees are Z_i. Trees measured and counted with a conventional angle gauge in a sample circle are shown in Fig. 2.

The first plot in the Jiufeng Forest Farm is located on the lower slope. The stand type is plantation and the dominant specie is *Platycladus orientalis.* The soil is barren and the spatial distribution of the forest is uneven. The second plot is located at mid-slope where the dominant specie is *Pinus tabulaeformis.* The spatial distribution of the forest is uniform. The third plot is located at the foot of the mountain and the dominant specie is *Pinus tabulaeformis*, the slope is less than 5% and the spatial distribution of the forest is uniform. The data of the three concentric circles plots are shown in Table 2 to 5.

RESULTS AND DISCUSSION

The survey time with a single point using the electronic angle gauge for five concentric circles was half of that when the conventional angle gauge was

Table 2: Five concentric circles of NO.1 forest inventory plot

	Electronic angle gauge method with multiple concentric circles					Conventional angle gauge with multiple stations		
Concentric circles	Tree counts on same observation point	Basal area (m^2)	Average diameter at breast height (cm)	Average tree height (m)	Forest volume (m^3/ha)	Tree counts on different observation point	Average tree height (m)	Forest volume (m^3/ha)
1	25	0.300	12.23	7.67	131.02	25	7.62	111.58
2	56	0.651	12.05	7.38	92.41	23.5	7.61	104.78
3	89	0.936	11.46	7.19	78.22	21.5	7.37	93.70
4	149	1.509	11.24	7.24	63.36	14.5	7.15	61.85
5	205	2.188	11.54	7.26	61.39	13	7.41	56.87

NO.1 forest inventory plot t in Jiufeng Forest Farm is located in a low slope position, and the spatial distribution of the forest is uneven

Table 3: Five concentric circles of NO.2 forest inventory plot

	Electronic angle gauge method with multiple concentric circles					Conventional angle gauge with multiple stations		
Concentric circles	Tree counts on same observation point	Basal area (m^2)	Average diameter at breast height (cm)	Average tree height (m)	Forest volume (m^3/ha)	Tree counts on different observation point	Average tree height(m)	Forest volume (m^3/ ha)
1	26	0.300	11.80	6.96	122.79	28	6.96	120.97
2	61	0.769	12.32	7.26	107.86	25	7.27	111.35
3	97	1.260	12.50	7.20	105.37	28.5	8.32	125.22
4	196	2.683	12.84	7.16	111.76	24.5	6.64	102.50
5	276	3.901	13.04	7.24	109.13	26	6.20	103.77

NO.2 forest inventory plot is located in the mid slope position, and the spatial distribution of the forest is uniform

Table 4: Five concentric circles of NO.3 forest inventory plot

	Electronic angle gauge method with multiple concentric circles					Conventional angle gauge with multiple stations		
Concentric circles	Tree counts on same observation point	Basal area (m^2)	Average diameter at breast height (cm)	Average tree height (m)	Forest volume (m^3/ha)	Tree counts on different observation point	Average tree height (m)	Forest volume (m^3/ha)
1	9	0.229	17.87	8.23	105.58	23	8.22	107.36
2	24	0.632	18.18	8.99	103.69	23.5	8.39	94.84
3	36	0.990	18.57	8.67	94.70	21	8.24	88.88
4	77	2.108	18.53	8.34	98.07	22	7.76	89.58
5	110	3.082	18.75	7.95	92.26	26	8.78	127.50

NO.3 forest inventory plot is located in the foot of the mountain, and the spatial distribution of the forest is uniform

Table 5: Comparison of the two methods of forest volume measurement

	Average tree height (m)		Using time (h)		Forest volume (m^3/ha)		Method with conventional angle gauge	
Plot	Method with electronic angle gauge	Method with conventional angle gauge	Method with electronic angle gauge	Method with conventional angle gauge	Method with electronic angle gauge	Method with conventional angle gauge	Forest volume Standard deviation (m^3/ha)	Forest volume Relative error (%)
1	7.26	7.43	2.6	5.7	61.39	85.73	11.55	39.7
2	7.24	7.08	3.8	8.1	109.13	112.76	3.63	3.33
3	7.95	8.28	1.9	4.3	92.26	101.63	2.58	10.2

The values of the electronic angle gauge method are cumulative of all rings; the fifth values of the concentric circle of forest volume are used as the reference value in each plot. This is done so the relative errors with the conventional angle gauge can be calculated

used for five different locations. Table 2 to 5 show how forest volume values vary by different plot property when measured by five concentric circles using the electronic angle gauge. The total number of trees increases rapidly with the broadening area in the three groups of five concentric plots. The value of forest volume per hectare became smaller with the increasing area. The forest volume approached a stable value at the fourth concentric circle. By contrast, there was no obvious regularity or significant trend detected using multiple observation points based on the conventional angle gauge. As for the forest inventory plots with discontinuous and uneven spatial distribution, there was relatively low precision with a relative error of 40% for volume measurement using the conventional angle gauge. Thus, we should select the angle gauges with different factors of basal area based on the differences in the diameter at breast height, tree height and canopy density. The appropriate range of the number of the observed trees is 10-30, out of this range, there will be a large observation error of the forest volume. For non-natural forest stands, the value of the forest volume measurement using the electronic angle gauge is stable with small variation and the result is within reliable estimates. If the forest spatial distribution is irregular, when the conventional angle gauge is used, the accuracy is still very low, despite the use of a large number of sample plots. The telescope and CCD system of the electronic angle gauge reduce the probability of a misread. Furthermore, automatisation and precision of the forest volume measurement are achieved through the automated identification, registering and counting functions of the software of the PDA.

CONCLUSION

Comparing the results of the two methods for forest volume measurement: The electronic angle gauge, using a telescope and CCD system, ensures that the correct tangent tree is chosen more often. The tree height, the Diameter at Breast Height (DBH), the average height and forest volumes can be automatically calculated. Thus, automatically collected, real-time digital data can be utilized by the software within the PDA.

The variation in estimated forest volume using an electronic angle gauge decreased with increasing number of concentric circles and the estimate became reliable when reaching the fourth concentric circle. So, the forest volume can be achieved at the fourth concentric circle per ha. By contrast, it is not easy to identify, register and then count manually the trees in a plot using a conventional angle gauge; the observation error of the forest volume is relatively large if the forest spatial distribution is not uniform. There was no obvious regularity and no significant trend using multiple observation points with a conventional angle gauge.

Observers can choose an arbitrary location to position the electronic angle gauge in the forest, which increases accessibility and ease of data collection. The survey time with the new method was half that of using a conventional angle gauge. The new method can greatly reduce labour time, while making forest volume measurement more accurate. In the forest volume measurement, for three chosen plots, the method needs two people and 8.3 hours with the electronic angle gauge; by contrast, four people and 18.1 hours are used with the conventional angle gauge. Assuming that the expense per person is 10 pounds per hour and then 558 pounds could be saved using the electronic angle gauge. If this new method could be widely used, large savings of forest resource investigation funds will be realised.

In short, forest volume measurement with an electronic angle gauge has important theoretical significance, as well as being more practical than other gauges currently on the market.

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NOMENCLATURE

CCD = Charge Coupled Device
PDA = Personal Digital Assistant
GPS = Global Positioning System

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