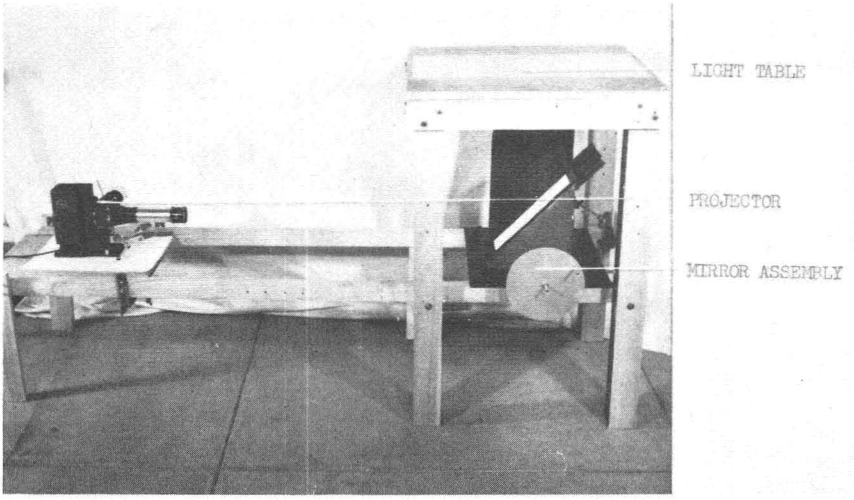

FIG. 1. Projector-light table combination.

Forest Inventory can be accomplished expeditiously through the application of terrestrial photographs taken with a 35 mm popular camera, and the *variable plot method.*

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A New Variable Plot Instrument

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INTRODUCTION

THE PROCESS of conducting an inventory in the field of forestry, as in other industries, constitutes a major fixed cost item. Today modern enterprises have developed electronic computers and other automatic machines to perform inventories on each phase of manufacturing, from the input of raw materials to the output of finished products. The forest industry, though far advanced in many phases of manufacturing, has had to rely on antiquated inventory methods in the production of its raw materials—trees. Nature, who provides the forester with trees, is constantly changing them in shape, size, quality and, to make the problem more difficult, distributes them throughout the forest tract in a random manner.

The generally accepted method of performing an inventory on a forest tract consists of two separate phases. The first phase, gathering of the field data, requires the measurement of all of the trees on certain small specified areas (plots or strips) which are methodically distributed throughout the tract. The second phase, analysis of the field data, requires the statistical application of the sampled data to the entire tract.

THE VARIABLE PLOT METHOD

In 1948 an improved method of collecting the field data was developed by Dr. Walter Bitterlich [4].[1] This new method, termed the "variable plot method," produces a basal

[1] Numbers in parentheses indicate references as listed in the bibliography.

area value per unit of land area of the tract by relatively simple calculations and field work. The basal area value is computed by counting about a point the number of trees whose diameters are greater than the intercept of a predetermined "critical angle." This count is then multiplied by a factor, termed "basal area factor" (developed from the numerical values of the critical angle and the unit of land area), producing a basal area value per unit land area. To obtain a stand table and a volume estimate from the variable plot data, the heights and diameters of only the counted trees need to be measured.

The accuracy of the variable plot method has been demonstrated by many foresters [1, 2, 3, 10, 11] and the increased speed by which this method can be performed, relative to conventional inventory methods, was reported in an unpublished thesis by Frank Shirley [16].

In order to perform a tree count, the cruiser must have an instrument with which he can construct the critical angle. Since the introduction of the variable plot method, Dr. Bitterlich has developed two instruments, the Relascope and the more compact and versatile Spiegelscope [5, 8]. Both of these instruments physically construct the critical angle by establishing an angular intercept.

In 1955 an elegant unique method of constructing the critical angle was introduced by D. L. Bruce [6]. By employing a small glass wedge or prism the critical angle is constructed between a refracted ray and an unobstructed ray.

The uniqueness of the variable plot method for obtaining basal area, combined with the ease with which the prism performs the operation, provided motivation to investigate the possibility of developing better instrumentation. After considerable research, instrumentation was developed to combine photogrammetric instruments and techniques to produce results identical to those obtained by careful use of the glass prism [13].

ABSTRACT: *This study introduces a new concept of timber inventorying by combining the geometric principles of terrestrial photogrammetry with the geometric mechanics of the variable plot method. This combination reduces the field operation of the variable plot method to an exposure of a series of photographs. In the office the projection of a field photograph is altered to permit counting of trees in an identical manner as employed in the field operation of the glass prism. In bringing this field process into the office by photography, four major advantages are obtained: a photograph is a permanent indisputable field record, a statistical improvement of the variable plot method, a reduction in the field time and cost, and the possible use of an unlimited number of critical angles and photographic measurements. This study suggests openings of several avenues for future investigation and development in the field of forest inventory.*

INSTRUMENTATION

The instrumentation consists of three main components: camera, projector, and a specially constructed light table.

The field component was a 35 mm., single-lens reflex camera about 3×4×7 inches in size and weighing about 1½ pounds. As the physical description indicates, this camera is of an ideal size and weight to be used as a field instrument. The construction and design of most 35 mm. cameras are such that they can accept the normal field abuse received in forest inventory operations.

In the field the same precautions that are taken when using the glass prism—not to mask out countable trees—are applied to the camera operation. The camera is adjusted for an exposure (setting the aperture and exposure time for existing lighting conditions, and focusing at infinity) and held so that the focal plane is vertical (a small bull's-eye level is attached to the camera to assure proper orientation). As soon as the camera is in proper adjustment, position, and orientation, an exposure is made. The exposure *instantaneously records all* of the *field data* that is necessary to measure basal area. This photographic feature alone makes the camera a valuable field instrument.

The basal area photographs are developed as positive transparencies and placed in the projector-light table combination as shown in Figure 1 (see first page of article). Figure 2 is the system of adjustable, front surface mirrors that is placed in the line of projection

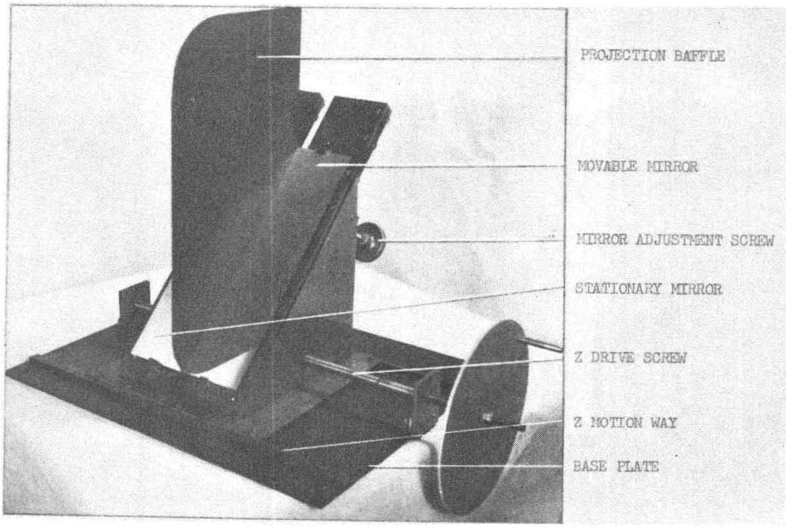

FIG. 2. Mirror Assembly.

to construct the desired critical angle by *reflection* rather than by *refraction*, as performed by the glass prism. The resultant projection of the basal area photograph, as seen in Figure 3, appears on the viewing surface of the light table exactly as would have been viewed by an observer in the field with a glass prism.[2]

So that the marginal countable tree may be compared at DBH (Diameter Breast High), the mirror system is mounted so as to provide movement of the offset line in the Z-direction of the terrestrial photograph. The operator may now make a count of those trees displaced less than their diameter in exactly the same manner as with the glass prism in the field.

FIG. 3. A field photograph as seen on the light table.

[2] A more complete description of the mechanics and optics involved may be obtained from Reference 16.

GEOMETRY OF THE SYSTEM

Neither mathematical nor mechanical correction for slope is necessary because of the geometry of the horizontal terrestrial photograph. As can be seen from Figure 4, any distance in the object plane (tree diameter) will be recorded in the ratio of f/D regardless of its position in the photograph. Therefore, any tree diameter in the field of the photograph is recorded exactly the same as an equal diameter that is level with the camera.

Tree diameters and height may also be measured from photographs if the scale of the photograph is known [15]. The scale of a terrestrial photograph (Figure 4) is defined as:

$$\text{Scale} = f/D = ab/AB$$

where f is the focal length of the camera, D is the distance from the camera to the object

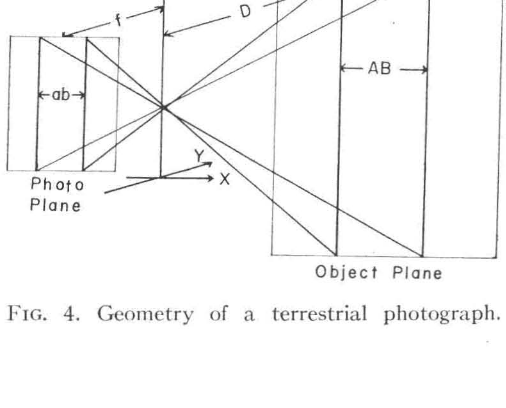

FIG. 4. Geometry of a terrestrial photograph.

plane (tree), *ab* is the photographic measurement of the image *AB*, and *AB* is the actual distance in the object plane. Therefore, the scale of the photograph may be established if either *D* or *AB* are known, because the value of *f* is known and value of *ab* may be measured from the photograph.

The value of *D* may be established by selecting any of the methods that are commonly used to measure distances, such as: pacing, chaining, rangefinders, etc. To eliminate excessive computation and to eliminate field recording, the value of *D* or *AB* should be constant for any set of scaled photographs.

When the scale of a tree in the photograph is established, any number of useful stem measurements may be made quickly and accurately. As an example, the diameter may be measured at any height by simply measuring the photographic distances between the two edges of the tree image and applying the scale formula. Merchantable heights can also be measured in the same manner, with the same degree of speed and accuracy, as the diameter measurements [7].

This mensurational photogrammetric feature is not limited to tree measurements, but may be applied to recording and measuring stacked pulpwood, stacked lumber, tree growth studies and many other field uses.

Using the previous scale formula, the distance *D* (distance from camera to object) may be found if the value of *AB* is known. The value of *AB* may be obtained from actual measurement or by placing a target on the object. This method will establish any distance with an accuracy that is directly dependent upon the size of *AB*, as it is recorded on the photograph.[3]

Angular measurements may be obtained from the formula $\phi = \tan^{-1}(r/f)$ where *f* is the focal length of the camera and *r* is the radial distance from the center of the photograph to an image [15].

As just explained, one of the camera's measuring capabilities is that of determining an angular field of coverage. This feature enables the camera to record a definite segment of a circular plot.

L. R. Grosenbaugh demonstrated how to use half and quarter plots in cruising small irregular areas to eliminate "slop-over" of countable trees[4] [12]. In using a defined plot segment, the tree count is weighted according to the size of the plot segment. That is, the tree count on a half plot is multiplied by a factor of 2, while the tree count on a quarter plot is multiplied by a factor of 4, or in general this factor termed "plot size factor" is defined as $Psf = 360°$ divided by the plot segment in degrees. To test this concept of using the camera's angular field coverage to define a plot segment an investigation was performed [14]. The results of this investigation indicated that a single photograph may be considered as a plot segment. Therefore, at each point a plot-segment sample can be taken in lieu of a full-circle sample. With a *decrease* in the *size* of the sample at each point, a proportional *increase* in the *number* of points must be made, *to maintain an equal intensity of sampling*. Statistically, a better sample can now be obtained, because the samples are smaller by $1/Psf$ and are more frequent by *Psf*, and an *increase* in the *accuracy* of the variable plot method is obtained. Also, using the photograph as an individual sample suggests *no increase* in *office time* and *calculations*, and a *decrease* in *field time*.

Use of the Light Table

Efficient and accurate use of the basal area light table requires precise adjustment of the movable mirror so that a projected photograph will exhibit a displacement equivalent to the angular intercept of the critical angle. The amount of displacement may be measured by two different methods, a graduated scale attached to the motions of the movable mirror and a method of measuring the projected photograph.

The first method appears to be less efficient because the prototype instrument was designed to accommodate a variety of projection distances, projectors and camera lenses. Therefore, for this instrument it would require a set of scales for each camera lens, another for each projection distance and still a third set for each projector. A commercial version of this instrument may be designed so that the scale method of adjustment would be efficient.

The second method, that of measuring the projected photograph, offers, a more versatile solution. The critical angle can be determined from the relationship $\theta/2 = \tan^{-1}(a/b)$ where *a* is one half of the angular intercept and *b* is the perpendicular distance from the point *c* to *a*. From Figure 5 it can be seen that the critical angle θ can be constructed, if a distance *2a* is constructed perpendicular to the line *cc'*. Therefore, a critical angle can be

[3] By plane geometry *D* is a function of the formula $\tan \phi = AB/2d$. Therefore, as *D* becomes large while *AB* remains constant, $\tan \phi$ approaches zero.

[4] Slop-over, as defined by L. R. Grosenbaugh, is when the generated circle of a tree is extended beyond the periphery of the tract.

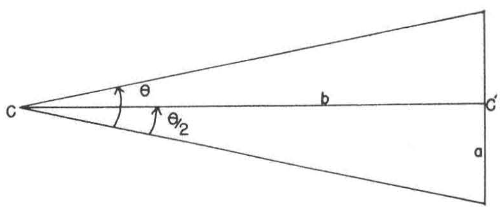

FIG. 5. Geometry of the critical angle.

constructed on the projection surface if the image offset is adjusted to equal *2a*.

THE CALIBRATION CHART

In Figure 6, the top half of the first scale is the tangent scale and was constructed to facilitate the measurement of the value *2a*. It was constructed by plotting half tangent values, but graduating the scale in full tangent values. As an example, the tangent of 20° $(\phi/2)$ is 0.36 (a) and the tangent of 40° (θ) is 0.83. To set off an angle of 40°, the bottom pointer on the scale is moved (by adjusting the mirror) to the 0.83 division, but the actual tangent value set off is 0.72 $(2a)$. This allows the operator to set off a critical angle by simply setting off its respective tangent value.

The bottom half of the first scale is the basal area factor scale. This scale allows the operator to set off the desired critical angle by setting the upper pointer on the desired basal area factor.

The second scale (bar scale) is used to establish the scale of the projection (b/d), where d is the distance at which the chart was photographed and b is the value of one unit on the bar scale. As an example, if the photographic distance d was 50 inches and each unit on the bar scale was 1 inch, then the scale factor will be 1/50. If the field distance is 100 feet, then the measured value of one unit on the projected bar scale will represent $1/50 \times 100$, or 2 feet in the object plane.

The third scale is the angular measurement scale, graduated in units of one degree. The scale was constructed by using the relationship $\phi = tan^{-1}(r/d)$ where r is the radial distance from the center of the chart and d is the distance at which the chart was photographed. This scale may be used to make angular measurements or may be used to define the angular coverage of the photograph.

SUMMARY

To summarize, the advantages obtained by applying photogrammetry to the variable plot method of forest industry are numerous.

1. The camera is an ideal field instrument, in that it is small, rugged and accurate. Also, the camera instantaneously records all of the field data required.
2. The angle measuring ability of the camera provides a better statistical sampling method (more frequent and smaller samples).
3. Semi-technical labor may perform the field work. The only instruction required is in the operation of the camera and the prevention of masking countable trees.
4. A photograph provides a permanent, indisputable record that offers the opportunity of remeasuring the area with a variety of critical angles, as may seem desirable.
5. The speed with which the field data is acquired permits more efficient use of favorable weather conditions. The more tedious task (counting and measuring trees) is to be accomplished in the office during inclement weather.
6. A photograph offers a wealth of information that may be obtained through proper photographic interpretation. Research and investigation may provide methods to utilize more completely the permanently recorded field conditions.
7. The instrumental design gives the cruiser an unlimited choice of critical angles. Any critical angle can be constructed by the proper adjustment of the movable mirror system. A basal

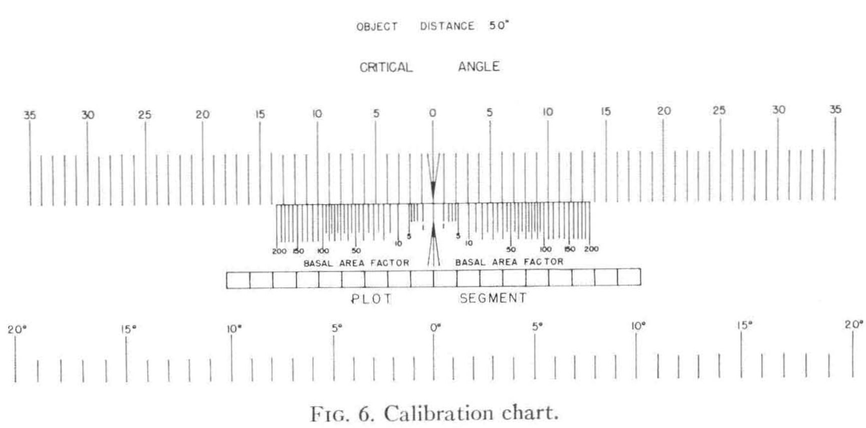

FIG. 6. Calibration chart.

area factor can be computed from the adjustment because the basal area factor is a function of the critical angle.

8. The basal area light table is a versatile instrument, in that it can be used to measure basal area in the office, to magnify photographic measurements, and to serve as a common light table.

9. The common home 35mm projector can now be used as a tool in forest inventory and thereby perform a paying task.

Conclusions

In conclusion, it is evident that a combination of terrestrial photogrammetric techniques and instrumentation can efficiently and accurately transform the variable-plot tree count from a field to an office operation. Also in this transformation the advantages listed in the Summary are appreciated.

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