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Application of a Total Station in savanna vegetation surveys

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Abstract

The article describes the methods used to obtain data with the use of a total station. The advantage of the proposed method is the ease with which data for investigation of spatial relationships between plants and topographical features may be obtained. In addition to location, the total station can be used to assess some plant parameters such as plant height, crown spread, trunk size and others.

Keywords: Spatial data, theodolite, total station, vegetation survey

Introduction

Savanna trees have been subject to a number of studies in southern Africa for a variety of purposes. For example, Coetzee and Gertenbach (1977) assessed woody vegetation as part of animal habitat evaluation. Smit (1989) determined forage quantity provided by woody plants, and Friedel and Chewings (1988) established crown cover of savannah trees. Woody plant density and distribution has been studied in the savannah woodlands of Southern Africa (Smith & Grant 1986, Smith & Walker 1983).

More recently Jeltsch *et al.* (1996) investigated tree spacing in semiarid savannas to explore ecological processes, and Wiegand *et al.* (2000) used topography and tree location to develop a spatial model of *Acacia radiana* in the Negev.

The various authors used different assessment methods as required for the purpose of their studies and the scale at which they were working. Methods ranged from to physical measurements taken in the field (Smith & Grant 1986) to remote sensing (Wiegand *et al.* 2000).

The spatial location of trees provides further insight into ecological processes. Tree density or size may for example be related to terrain feature, aspect or soil parameters, or the production of fruit may be related to distance to the nearest colony of bee’s.

The arrangement of trees in relation to members of their own species or trees of different species provides additional information about a vegetation. A mix of species, i.e. a high local diversity, provides greater ecological stability than a stand that tends towards mono-specificity. The same is true for other tree parameters such as size or age. Greater diversity of age classes will tend to greater long-term stability than a stand of single age.

While these insights are important, it is difficult to obtain the spatial data necessary. Conventional field measurements are difficult to obtain when plants are widely spaced. The use of long tape measures is tedious in the field, as they snag easily, or need to be unrolled and rolled up repeatedly. This is particularly so if a bush undergrowth exists.

Wiegand *et al.* (2000) used satellite remote sensing to determine the presence of trees within a wadi. Although large areas may be covered in a single image, these authors also found that the ground resolution of the sensors used was too low to provide the required information. While the resolution of satellite images is increasing, high-resolution images are still expensive.

Whiteman and Brown (1998) addressed this problem by using digitalised aerial photos to map the position of individual tree canopies. The usefulness of this approach depends significantly on the age and scale of the aerial photos, as these two factors determine what features are visible. Outdated images may not show more recent developments while small scales make the identification of features difficult. In Namibia many areas are only flown at long intervals, with most of the country last flown in 1996. It is therefore difficult to obtain up-to-date photos for most of the country.

The aerial photos currently available for Namibia were captured at a scale of approximately 1:78000. Even if the photos are enlarged, individual trees are almost impossible to identify.

In addition, this technique will not detect younger trees under the canopy of a larger one, and groups of trees might be identified as single plants if the resolution of the scanned image is below the minimum distance between trees.

Dominy & Duncan (2001) attempted to obtain tree positions in a tropical forest using differential GPS. However, these authors found that reception was poor under the canopy resulting in significant errors in position, or no reading. While the general canopy of trees in the Namibian woodland savannas is much less dense GPS reception is still poor. Additionally, individual species, such as *Guibourtia coleosperma*, develop very dense foliage. The use of GPS is then of questionable value (Lewis pers com).

The Total Station and its predecessor, the theodolite have been used in land surveying for many years. These instruments are used to measure angles in the horizontal and vertical planes. Together with the distance between the sampling point and the target of interest these angle measurements can be converted to coordinates, elevations and heights using simple trigonometric formulae.

The enumerator is therefore able to assess a number of parameters from a single point, including location, relative elevation, plant height, crown dimensions and bole-length, depending on visibility.

This article describes the method with which data may be collected and evaluated.

The Total Station

Detailed descriptions of the Total Station and theodolite, may be obtained from surveyors' handbooks, such as Anon (1980). However, in order to facilitate a basic understanding of the system, a general description of the equipment is provided below.

The Total Station consists primarily of a telescope and an infrared range finder mounted on a vertically orientated scale (the vertical circle) to measure angles of elevation, and a horizontally orientated scale (the horizontal circle) for measuring angles in the horizontal plane. These components are fixed to a base plate that is levelled on a tripod before any readings are taken.

The telescope contains a set of cross-hairs, the centre of which is used to sight a special prism target and later the plant, much like the telescope of a rifle is used.
The vertical circle is orientated in such a way that a 90^o angle is measured when the telescope is pointing parallel to the base plate. The 0^o and 180^o angles are directly above and below the device respectively.

In addition to the instrument, a prism target is required as part of the range finder. The prism is mounted on an adjustable pole usually at the same height as the centre of the telescope, when the later is pointing at 90^o. Although this is not strictly speaking necessary, it reduces the amount of calculation required to obtain ground elevation and subsequent heights. The practicality of this must be considered in relation to the visibility within the study area at the height of the telescope.

The prism target is sighted through the telescope, and the vertical angle, slope distance and horizontal angle are displayed on an LCD screen that is mounted on the reverse side of the instrument. The different types of basic and predetermined readings that can be obtained from the equipment may be obtained from the manual of the individual models.

Once the Total Station has been erected the user chooses the origin of the horizontal circle, and all horizontal angles are measured in relation to the chosen zero point. While surveyors generally try to choose a visible trig beacon, this may not be possible when vegetation is assessed, since such beacons may not be visible. Instead, another feature may be chosen that can be found again if measurements are to be taken repeatedly from the sample point. Features may include the tip of a wind-pump, the top of a water- or fire tower, the corner of a building, or any similar structure. When the position of the sample point and that of the chosen zero bearing are known, the entire data set may later be geographically referenced. For the purpose of local evaluation of data this is not, strictly speaking, necessary. However, if data sets are to be analysed in conjunction with those obtained from other sources, the sample points and zero points must be georeferenced.

In order to obtain reliable results, the equipment must be set up with care. Slight errors in the levelling of the base plate may result in large errors in the estimates of plant parameters, particularly when they are assessed over greater distances. In addition, the instrument may need to be re-orientated if the tripod is accidentally brought out of alignment. It is therefore important that the sampling point is marked prior to the setting up of the instrument.

In order to maintain a clear line of sight to different parts of the sample area, the equipment may need to be shifted to alternative, predetermined positions. Such alternative positions are recorded from the base point prior to the shift.

To incorporate the readings from the new position into the dataset, it is important to orientate the line of sight of the horizontal angle of the new position parallel to the one of the initial sample point. This is easily achieved by placing the prism target on the initial point and orientating the horizontal circle in such a way that:

$$b_{new} = 180 - b_{old} \qquad (1)$$

Where:
b_{new} is the bearing from the new sample point to the first sample point
b_{old} is the bearing from the first sample point to the new sample point

In addition, the X and Y coordinates of the new sample point must be added to the respective coordinates of the readings recorded from the new point since the point of origin is now shifted in relation to the original.

Data collection

When the total station is erected, levelled above the sampling point and a zero point for the horizontal circle is determined, the prism target is mounted on a measuring pole and the respective heights of the telescope and of the target are recorded.

To obtain the location and elevation of a particular point, the pole with the prism target is placed on the point of interest and sighted with the telescope. The LCD screen on the total station will then display the horizontal angle between the chosen zero point and the target, as well as the vertical angle and slope distance. These may be recorded on a field form or stored in the memory of the total station for later downloading. Alternatively, depending on the model of the instrument some pre-processing of measurements can be displayed.

While surveying software may be used to process the basic data, such software is expensive. Care need to be taken when using alternative software however. For instance, degrees need to be converted to radians if the data is to be processed in Microsoft Excel™ or StarOffice. The appendix provides the formulae that may be used to convert angles and distances to coordinates and tree parameters.

To determine the crown spread of the plant, it is assumed that the crown is circular when viewed from above. The horizontal angle to the left extreme of the crown is recorded, as well as the angle to the right extreme.

The average of the two estimates will then provide a measure of the radius of the crown.

Calibration of the Total Station

To test the application of the Total Station with regard to its potential in vegetation assessment, a normal sun umbrella was mounted in a surveyor's tripod as a test target, and assessed at increasing distance from the sample point along a road. The umbrella was chosen as a test target due to its shape, i.e. its "trunk" and spreading "crown", typical of many savannah trees.

A Geodimeter System 600 total station was mounted on a tripod and levelled on its base plate. The height of the centre of the telescope was measured and the prism target was set to the same height.

An arbitrary zero point was chosen for the horizontal circle. Once the readings for the vertical and horizontal angles, and the slope distance to the prism target were obtained, each of the following parameters were recorded:

- Height of the umbrella
- Radius 1 on the left hand side of the "stem"
- Radius 2 on the right hand side of the "stem"

The measurements were entered into a spreadsheet and converted to locations, lengths, elevations and heights. The results showed that 'tree' height and 'crown' spread could be detected accurately within 1cm over a distance of just over 140m. This level of accuracy is seldom required in vegetation surveys.

Field application

To determine the practicality of the method in the field 132 Trees were measured in a small section of the dry woodland savanna of northern Namibia, and species tree height, bole height and crown radius were noted. Together with the erection of the instrument the data was collected in 3hrs, averaging at just over 1½ minutes per tree, using only one 'rover' with a target.

The rover was not only placing the target, but also measuring the dbh of trees and identifying the individual species.

A total of six species were identified. An additional surrogate species of 'Dead' was assigned to those trees that had been burnt to death, and were unidentifiable.

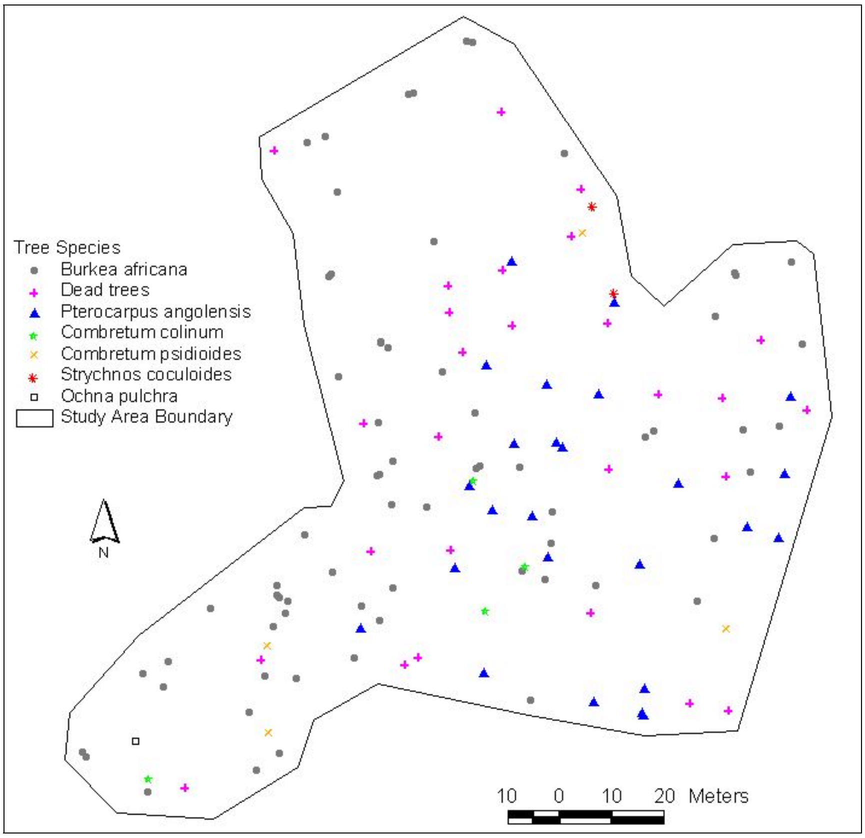

Figure 1: The dispersion of trees in a section of the dry savanna woodlands of northern Namibia.

The data was entered into a spreadsheet for processing and then imported into ArcView 3.2. Figure 5 shows of the dispersion of the trees that were assessed.

To determine the relationship between tree parameters and growing space Thiessen polygons were calculated using ArcView 3.2a. A poor correlation was found to exist between crown spread and growing space for *B. africana* and *P. angolensis* even when very small trees were removed from the analysis (r^2 =0.0958). This may be as a result of the different regeneration requirements of the different species, as well as thinning due to intraspecific and interspecific competition. While *Pterocarpus angolensis*, for example, is deep rooted, *Burkea africana* has a fairly shallow root system. The two species may therefore regenerate relatively independently, but influence growth and development of seedlings.

To obtain an indication of spatial diversity the tree based mingling index described by Gadow (1999) was calculated. The index is determined as follows:

$$M_i = \frac{1}{n}\sum_{j=1}^{n} m_{ij} \qquad (2)$$

Where

$$m_{ij} = \begin{cases} 1, & \text{if the tree is of another species} \\ 0, & \text{if the tree is of the same species} \end{cases}$$

n= The number of neighbours considered

i= Sample trees evaluated

When four neighbours are evaluated M_i may acquire one of five possible values:

0/4 none of the neighbours are of a different species,
1/4 one of the neighbours is of a different species,
2/4 two of the neighbours are of a different species,
3/4 three of the neighbours are of a different species; and
4/4 all of the neighbours are of a different species.

The distribution of M_i values was determined for each of the species and the mean mingling per species, M_{sp}, described by calculated. In addition, an overall mingling index was calculated to represent the study area as a whole.

The mean mingling values for each species as well as the number of trees of each species, n, are provided in Table 1. The table also provides the probability, P, that the values of M_i are randomly distributed, by comparing the observed distribution with the theoretical hypergeometric distribution of M_i values, using the Chi-square test.

Table 1: Species mingling for the woodland area, and the probability that the plants are interspersed randomly.

Species	M_{sp}	n	P
Burkea africana	0.500	68	0.000
Dead	0.148	27	0.294
Pterocarpus angolensis	0.277	26	0.000
Combretum psidioides	0.000	4	0.970*
Combretum collinum	0.050	4	0.944*
Strychnos coculoides	0.000	2	0.998*
Ochna pulchra	0.000	1	**
Overall	0.344	132	

* While the values are provided here for the sake of completeness, the Chi-square test should not be used when expected frequencies are very low.
** No hypergeometric distribution can be calculated.

The mean mingling of woodland species, M_{sp}, the number of trees of each species, n, and the probability, P, that the distribution of M_i values follows a random distribution.

The table shows that although a comparison to the hypergeometric distribution is theoretically sound there is a practical consideration. When a species contributes only a very small proportion of the overall, as do the two *Combretum* species, *S. coculoides* and particularly *O. pulchra*, it is questionable if the theoretical distribution is very meaningful.

Figure 2 shows the observed distribution of M_i values for four of the species, as well as the expected hypergeometric distribution based on the observed number of trees of each species.

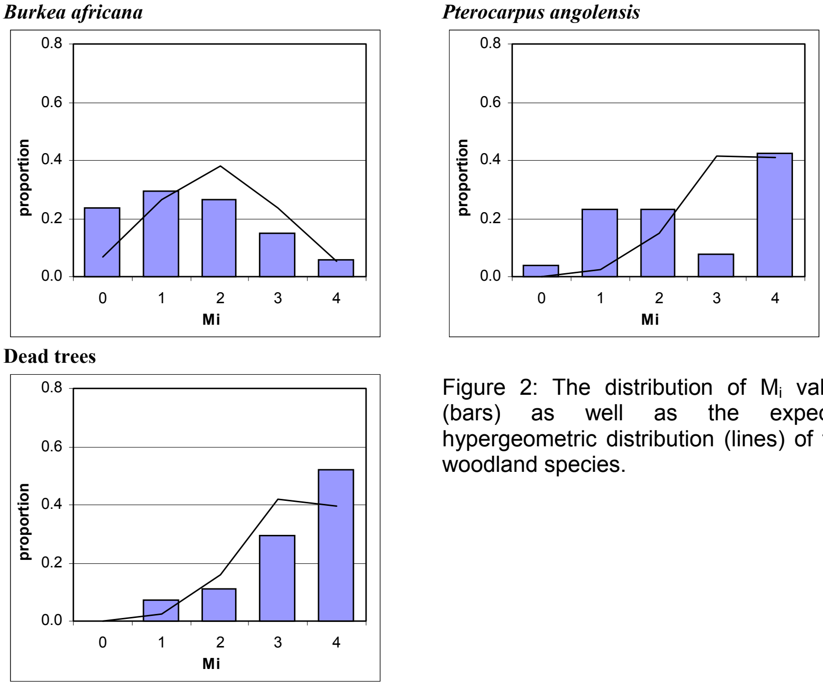

Figure 2: The distribution of M_i values (bars) as well as the expected hypergeometric distribution (lines) of four woodland species.

From Table 1 and Figure 2 it is evident that *B. africana* and *P. angolensis* are not dispersed randomly. While *B. africana* has a tendency towards clumping, *P. angolensis* shows a dichotomous behaviour. On the one hand the trees show a tendency towards interspersion with more than 40% of trees solitary, while on the other hand the species tends towards aggregation. This indicates that a stand of *P. angolensis* has been 'invaded' by other species. This is probable in view of its regeneration requirements of the species.

Discussion and Conclusion

While the equipment is expensive it is still cheaper than aerial photography and fairly large areas can easily be assessed, depending on the level of detail required and the number of assistants who rove with prism targets. In addition, if sampling points are marked clearly, the area may be assessed over a period of more than one day without fear that the data sets from the different days may not match.

The efficiency and effectiveness of data collection may be improved through some preparatory work. By demarcating a number of adjacent plots, the number of duplicate readings as well as omissions may be reduced. Alternatively, it may be useful to mark those trees that have already been recorded.

The data lends itself to analysis using GIS technology. Apart from determining dispersion patterns of plants, spatial relationships between the vegetation and natural features such as termite mounds, streams or even other plants, as well as man-made feature such as boreholes, roads or fences, may be investigated.

In addition to the location of plants within a plot the ecologist may obtain the necessary data for a digital terrain model (DTM) by recording elevations at random or regular intervals between plants. The DTM may in turn be used to analyse terrain specific relationships.

While the method may seem time consuming, multiple rovers with targets may increase efficiency significantly. This is particularly so if a DTM is to be established as part of the data set.

The method described above is not only appropriate for savannah type systems, but may easily be implemented in other areas such as the southern African Karroo or Kalahari, or any other area with sufficient visibility.

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Appendix 1

Determining horizontal distance and ground elevation

Once vertical angle and the slope distance are acquired, they may be converted into location and the change in elevation (e_{ground}) in centimetre or meter and horizontal distance (d_h) in meter to the target as follows:

$$e_{ground} = d_s \cdot \sin(\alpha_v) - (h_p - h_t), \quad (A.1)$$

and

$$d_h = (e_{ground} + (h_p - h_t)) \cdot \cot(\alpha_v) \quad (A.2)$$

Where
α_v is the vertical angle
d_s is the slope distance in meters
h_p is the height in meters of the prism target, and
h_t is the height in meters of the centre of the telescope above ground.

Determine Coordinates relative to Sample Point

The horizontal distance is used to determine the change in location relative to the total station, using an imaginary line in the 0^o as one axis, and the 90^o horizontal angle for the second. The total station represents the origin at x,y equal to 0,0. The change in location are calculated as:

$$\Delta y = dh \cdot \cos(\alpha h) \quad (A.3)$$
$$\Delta x = dh \cdot \sin(\alpha h) \quad (A.4)$$

Where

Δy is the change in location along the axis at 0^o, and
Δx is the change in location along the 90^o axis.
αh is the horizontal angle between to the bole

Determine Plant Height

Using the previously calculated parameters the height of the plant is:

$e_{apex} = d_h \cdot \tan(\alpha_{apex})$ (A.5)
$hpl = e_{apex} - e_{ground} + ht$ (A.6)

Where
α_{apex} is the vertical angle to the apex of the plant
hpl is the height of the plant
e_{apex} is the elevation of the plant apex, and
e_{ground} is the elevation of the ground level

Determine Crown Radius

The crown radius (r_{crown}) may be determined with the formula:

$r_{crown} = (r1 + r2) / 2$(A.7)

Where:

$r1 = dh \sin(\alpha h - \beta r1)$
$r2 = dh \sin(\beta r2 - \alpha h)$
αh is the horizontal angle to the bole of the tree
$\beta r1$ is the horizontal angle to the left extreme of the crown
$\beta r2$ is the horizontal angle to the right extreme of the crown