Accurate stem measurements key to new image-based system

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Abstract

PhotoMARVL is a new system of dendrometry that enables accurate measurements to be made of the stem of individual trees. These data allow improved log grade estimates to be calculated using the MARVL[3] pre-harvesting inventory procedure. Heights of features which are visible on the stem can be measured to an accuracy of better than + /- 10 cm, while stem and branch diameters can be measured to + / -1 cm. PhotoMARVL can also provide a reliable 3D measure of stem sweep. The method involves taking high resolution, oblique, stereoscopic photographs of the sample tree with a motorised 35 mm film camera. Six key parameters are recorded at the time of photography and these are used to define a measurement plane passing through a reference position on the tree stem.

Features of interest on the stem are identified stereoscopically and their X, Y and Z coordinates recorded. The coordinates can be processed to determine the dimension and location of features that ultimately govern the value of the log products that could be derived from the tree. Although the time required to PhotoMARVL a tree may be several minutes longer than that required to carry out a MARVL assessment, the data it provides will be more accurate and extensive.

PhotoMARVL is valuable as a broad-based mensurational tool and its output is inherently suited to tasks such as the construction of taper equations, the determination of internode lengths and the quantification of tree form. The technique could also be used in a double sampling role to improve the accuracy of MARVL assessments. Significant advantages of the technique are that PhotoMARVL data can be obtained non-destructively and without the need to climb trees. In addition, the images can be archived to provide a detailed record of tree and stand quality. This paper describes the field and analysis procedures involved in carrying out a PhotoMARVL assessment as well as the principles of the photogrammetry employed.

Key words

Dendrometry; Forest Inventory; MARVL; PhotoMARVL; Pre-harvest Inventory; Terrestrial Photogrammetry.

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[3] MARVL, or Method for the Assessment of Recoverable Volume by Log-types, is a software package produced by Forest Research. It uses dynamic programming to analyse measurements and estimates made on the stem of a tree at points where dimensional changes are likely to affect the value of the logs that could theoretically be cut from that stem.

Introduction

In recent years, a major aim of the New Zealand forest industry has been the optimisation of the various components of the forest value chain, from the standing tree to the finished timber product. This has led to an increasing desire for forest inventory information to have greater quantity and quality. As a partial fulfilment of this requirement, a three year Forest Research/ Industry programme was initiated in 1995 to develop a new system of dendrometry which would provide an accurate measure of stem dimensions, sweep, taper and defect size as input to the pre-harvest inventory software 'MARVL' (Deadman & Goulding, 1979).

MARVL is used extensively throughout New Zealand. However, because stem quality is assessed visually in the procedure, characteristics such as branch size and upper stem diameters have only been estimated. As these parameters can have a significant influence on potential log product yield, there is a need to be able to assess them more objectively.

Various techniques have been developed to enable upper stem measurements to be obtained remotely. These methods require the use of a dendrometer[4], an instrument that is commonly either inaccurate, or uneconomic to use routinely in a forest situation. In addition, measurements such as branch diameters are often difficult to make. As a result, the use of dendrometers tends to be confined to research tasks, such as constructing taper equations, rather than for routine field measurements.

Because of the large number and extensive range of measurements needed to satisfy modern inventory requirements, an alternative to the optical/mechanical design of traditional dendrometers was sought. The concept of taking images of the tree in the forest and using them for taking precise stem measurements was adopted at an early stage in this research project. These images also become a permanent record that can be re-assessed should a re-run of MARVL be required at a later date. An image-based system also has the advantage that the measurements can be collected without climbing or felling the tree.

The value of an image-based approach to tree stem assessment was recognised as early as 1965 (Shelbourne and Namkoong 1965). These authors sought to develop an accurate technique for assessing stem straightness in order to be able to rank different clones for tree breeding purposes. The method involved taking a 35

[4] The Society of American Foresters (1958) defined a dendrometer as "an instrument designed to estimate the diameters of standing trees at any given height by sighting from the ground." In the light of recent advances in the science of dendrometry, there is probably a need to expand this definition to include measurements other than just diameters.

mm diapositive of a tree stem and projecting the image onto a special grid with which the stem's straightness could be measured. However, the process was still essentially manual in nature and therefore potentially tedious when large amounts of data had to be collected and analysed. A further disadvantage was that errors occurred when tree lean or sweep characteristics were not in the plane of the photograph.

Recently there has been renewed interest in obtaining measurements from images of a sample tree. In the early 1990s, Régent Instruments Inc. developed a software package called MacARBOR which was designed for measuring stem shape on standing trees. Nourozi (1995) also developed an image-based dendrometry system. His method involved taking a sequence of large-scale images up the stem of the tree using a video camera attached to a step motor. It is understood that MacARBOR and Nourozi's system are still under development.

A novel approach to the problem was developed by Weehuizen et al. (1997). Their system employed a line-scan camera attached to a microcontroller-driven stepping motor to produce a composite digital image of the tree stem. The composite could then be analysed by a computer using parameter extraction software to estimate tree dimensions and shape.

An image-based system was also developed by Clark et al. (1998) to enable multiple measurements to be made on the stems of four hardwood trees. The images were taken with a digital camera. Clark found that, although some of the results were accurate, errors occurred when the trees were leaning.

For some time, mensurationists in the NZ forest industry have desired a practical system of dendrometry that could adequately handle the lean and sweep often exhibited by radiata pine, the dominant NZ plantation species. The need was for a method that could provide tree measurements to a high level of detail and accuracy.

The programme to fulfil this need began with a series of exploratory trials and conceptual analyses. These studies identified the following key technical specifications for the proposed system.

Technical specifications

- The equipment should be lightweight, robust and able to withstand the demanding physical conditions encountered in a forest environment.
- The resolution of the image-recording medium should be as high as possible in order to maximise the definition of the edges of features. This currently necessitates the use of film although digital cameras may be considered in the future when issues regarding coverage, resolution and cost-effectiveness have been adequately addressed.
- Stereoscopic images should be used. In many situations, for instance where the trees are unpruned and the stocking levels are high, it may be difficult to separate the features of interest from the surrounding vegetation. Use of stereo viewing significantly increases the likelihood of correctly identifying these features. Even with the advantage of stereo-imagery, it may not be possible to assess the top few meters of the sample trees. For most applications, however, this should not be a problem because the uppermost part of the stem represents a small proportion of the stem volume and usually has little or no commercial value.
- The camera and lens must be calibrated. These data are required in order to accurately determine the location of the perspective centre of the image, and to correct for the distortion inherent in the lens.
- Colour imagery is preferred over monochrome. Although colour imagery normally has a slightly lower resolution than its monochrome equivalent, colour increases the interpreter's ability to distinguish tree features, especially in the upper crown.
- The stem should be imaged with one pair of stereo-photographs rather than a mosaic of two or more. This avoids the difficult photogrammetric problem of accurately tying several images together.
- A measuring instrument is required that has a pointing accuracy of 20 microns or better. The instrument should also have stereo-viewing capability. These specifications are required to realise the potential of the high resolution imagery. An analytical stereoplotter fulfils these requirements.

The new system of dendrometry, which was developed from the research programme, is known as PhotoMARVL. Since the concept was presented to the research collaborative members in mid-1998, significant improvements have been made to the algorithms employed. In addition, the measurement procedures used in the forest have been streamlined. The revised PhotoMARVL technique is outlined below.

Methodology of PhotoMARVL

The PhotoMARVL methodology consists of two phases: image acquisition followed by image analysis. The first phase involves taking high resolution photographs of a tree stem and making six measurements in the forest which are used to describe the camera-to-object (i.e. tree) geometry. The second phase utilises a stereoplotter to take the measurements on the resulting images and to enable the dimensions of the features of interest to be determined.

The equipment needed in the forest to obtain stereo photographs of a tree stem and to take the required measurements, is outlined below:

- A Vertex[5] hypsometer.
- A surveyor's height pole[6] of known length.
- An inclinometer for measuring tree lean[7]
- A motorised 35 mm camera fitted with a 28 mm lens and a 'data back'. The focal length of the lens, its radial distortion characteristics and the dimensions of the camera frame at the plane of the film must be accurately known[8].

In order to make the necessary measurements on the photographs, the analytical stereoplotter used was an AP190[9]. This instrument has a pointing accuracy of about 12 microns at photo-scale.

When stereoplotters are used in their traditional role of map-making, at least 3 control points with X, Y and Z coordinates need to be established in order to determine the relationship between subsequent photo-measurements and the corresponding object coordinates. Because no practical way was found to establish these points in a forest situation, a reference-plane method (see Fig. 1) was developed[10].

Figure 1 shows a swept tree stem and three measurement planes (A, A' & B) passing through a common reference point (CP1). Two further reference points (CP2 and CP3), primary and secondary camera locations, and the position of a vertically suspended surveyor's height pole are also shown.

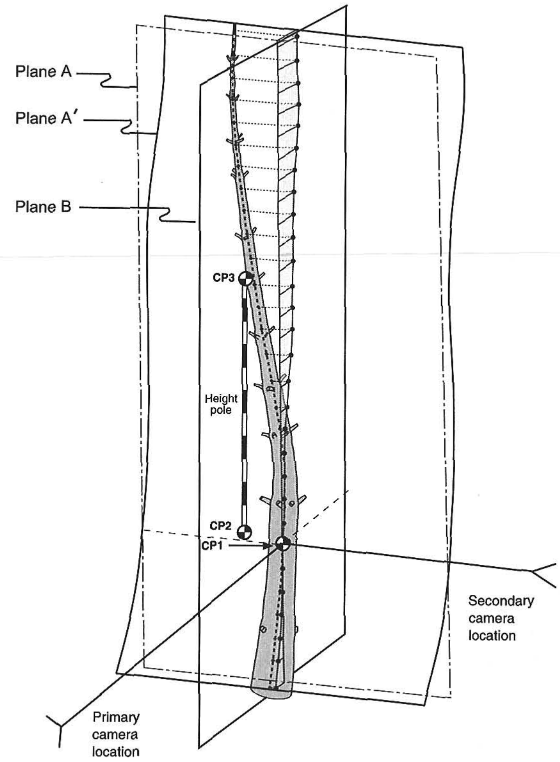
Point CP1 is located at the Vertex transponder, which is positioned on the front of the stem at approximately 1.4 m above the ground. Points CP2 and CP3 are located at the bottom and top, respectively, of the height pole.

Plane A, which is perpendicular to the axis of the camera at the primary location, is defined according to the interior and exterior orientation parameters of the camera. The interior parameters consist of the lens focal length, the lens radial distortion, the frame size and location of the principal point. The exterior parameters consist of the horizontal distance from the camera location to the transponder, and the angle, with respect to horizontal, which the transponder subtends from the same position. Coordinates of features on the tree stem are derived from plane A.

If the tree has lean or sweep present in one plane only, a primary camera location must be established at approximately 90 degrees to that plane. If these characteristics are present in more than one plane, the primary camera location can be established at any position but a secondary camera location must also be created at a position 90 degrees (maximum variation +/- 20 degrees) to it.

Should the tree show lean towards or away from the primary camera position, then the angle is measured in the field with the inclinometer and used to create a leaning plane A'. If the tree shows sweep towards or away from the primary camera position, the sweep profile is obtained by digitising the centre of the stem on the image taken from a secondary camera location. The resulting profile on plane B is then used to create a swept plane A' (as per Fig. 1).

Figure 1:
The geometrical concept of PhotoMARVL.
(In this example, plane A' incorporates a



The tree to be measured is assessed for the presence of lean, sweep and the visibility of features on the stem. The slope of the ground at the site and the available light are also considered. Based on these assessments, the optimum location of the primary and secondary (if required) photo-locations are chosen. These locations will usually be at a distance from the tree of just over half its height.

In some cases, branches and foliage may obscure stem features. Experience has shown, however, that selective pruning of one or two branches with a pole saw will usually overcome this problem.

The surveyor's pole is suspended from a suitable branch such that it hangs freely to provide a vertical reference. The lean of the tree towards (+), or away from (-) the camera position is measured using the inclinometer and the Vertex hypsometer is used to measure the horizontal distance and angle to the transponder.

The light meter in the camera may not compute the optimum exposure for the subject tree due to the difficult lighting conditions of a forest situation. This may be overcome by programming the camera's data-back to take a triplet of bracketed exposures at each camera firing. In order to ensure that at least one of the triplet has adequate exposure, a suitable interval for this sequence has been found to be two f-stops on each side of 'normal'.

The camera operator fires the camera then takes the stereo-photographs by moving approximately 1 metre

[5] An ultrasound-based instrument manufactured by Haglof, Langsele, Sweden. It consists of two components; a sound emitter / clinometer / display, and a transponder.

[6] The type used was a 4.4m 'True-Lock' prism pole, with hook attachment.

[7] The specific instrument used was purpose-designed and manufactured at Forest Research.

[8] This data is supplied with 'metric' cameras.

[9] A PC-based instrument manufactured by Carto Instruments Inc. PO Box 2379, Corvallis, Oregon 97339, USA.

[10] The algorithms are not described in this paper as they are proprietary.

to the right and firing the camera again. It is preferable, but not critical, for these second photographs to be parallel to the first. Vertex measurements of distance and camera angle are not required for these second photographs.

Figure 2: Field equipment being used for a PhotoMARVEL assessment

The following parameters need to be measured and recorded in the field.

1. The horizontal distance from the camera to the transponder.
2. The angle, relative to the horizontal, between the camera axis and the transponder.
3. The tree lean towards or away from the camera.
4. The height of the transponder above ground.
5. The stem diameter at the transponder.
6. The horizontal distance (in the tree-to-camera direction) between the transponder and the vertical surveyor's pole.

If a secondary camera location is established, its position to the left or right of the primary location should also be recorded.

The best exposed of the bracketed images are selected and 6x enlargements produced.

If photographs have been taken from the secondary camera location, these are set up in the stereoplotter first and the centre line of the stem digitised. These data are used to create a file describing the sweep profile of the tree in plane B. The primary location photographs are then set up in the stereoplotter and the sweep information derived from the secondary photograph analysis is used to create the swept measurement plane A'. Otherwise, the primary photographs only are set up and used to create plane A (in the case of a tree without lean or sweep) or plane A' (where a tree has lean only).

For each stereopair, the left photograph is registered to the instrument's measurement system and the position of the three control points, CP1, CP2 and CP3 is digitised. In order to transform the photo-coordinates into object coordinates (i.e. real world coordinates at the tree), the six parameters measured at each photo-location are entered into the PC and an absolute orientation carried out.

The features of interest are then digitised and their X, Y & Z coordinates stored in a point collection file with an associated feature identification code. These raw coordinates are subsequently processed into a spreadsheet file of feature dimensions.

Two opportunities are provided for checking the accuracy of the results obtained from a PhotoMARVL assessment. The first involves analysing the least-squares-fit residuals displayed by the stereoplotter. The second occurs after the photographs have been orientated in the stereoplotter and involves comparing the length of the surveyor's pole as measured on the photographs with its known length (4.4 m). Experience indicates that the difference between the measured and actual pole length will normally be less than + / - 2 cm.

System Accuracy

A sensitivity analysis was carried out to determine the accuracy with which the field parameters should be measured to obtain heights better than +/- 10 cm and diameters to better than +/- 1 cm. The results of these calculations are shown in Table 1.

Table 1: Accuracy requirements for camera orientation parameters.

Parameters	**Accuracy required**
Camera angle	< 1 degree
Horizontal distance, camera to tree.	< 10 cm
Tree lean	< 1 degree
Height of transponder	< 10 cm
Horizontal distance between transponder and bottom of surveyor's pole	< 5 cm

During the development of PhotoMARVL, trials were carried out at several locations to test the accuracy, functionality and practicability of the technique. Images of building frontages, as well as over 100 trees growing on a range of sites and under a number of silvicultural regimes, were used for this purpose.

The definitive validation of PhotoMARVL was carried out by photographing a 30 m high instrument mast which had a 1.0 m by 1.0 m cross-section. This mast offered clearly visible, uniformly sized elements of known dimension for precise interpretation and measurement over a height representative of forest trees.

In order to obtain the necessary coverage, the photographs were taken at a distance of ~22 m from the tower.

The results of measuring the elements at 23 heights on the mast are given in Table 2.

The heights of the cross braces were representative of heights up a tree stem, tower widths were representative of stem diameters, and widths of the cross braces were representative of branch diameters.

Table 2 shows that, apart from the cross–brace widths, measurement errors tend to become larger as the feature's height above the ground increases. The small values of the errors testify to the validity of the geometrical approach taken.

Table 2: Difference between actual dimension and PhotoMARVL measurement of the

Tower section height (m)	Mean difference from actual dimension			
	Height of cross braces. m (standard error)	Spacing of cross braces. m (standard error)	Tower width. m (standard error)	Cross-brace width. mm (standard error)
0 - < 10	- 0.03 (0.00)	0.00 (0.00)	0.00 (0.00)	-12 (2)
10 - < 20	- 0.06 (0.01)	0.00 (0.01)	-0.01 (0.00)	-6 (2)
20 - 30	- 0.16 (0.02)	+0.01 (0.01)	-0.01 (0.01)	-5 (2)

Forest trials have indicated that, when a PhotoMARVL assessment is carried out on a standing tree, stem measurement errors tend to be larger than the figures expressed in Table 2. This is because it is sometimes more difficult to accurately define the correct measurement points (eg. the edges of the stem) on a tree compared to the metal components of the mast. These trials suggested that heights on a tree stem can be reliably measured to ~ +/- 0.1 m while stem and branch diameters can be measured to ~ +/-0.01 m.

Discussion

Tests indicate that PhotoMARVL can be used successfully in forest stands covering a range of stockings, pruning intensities and undergrowth density. However, there were occasions where extremely steep terrain limited the number of photo-location options.

Experience indicates that it takes two to three people approximately five to six minutes (depending on the amount of site clearing required) to identify suitable photo locations, take the necessary images and measure the six field parameters. A further 20 minutes is required by one person to set up the primary location photographs in the stereoplotter, to take about 60 measurements per tree and to produce a full set of data outputs. If secondary location photographs need to be analysed as well, a further 15 minutes should be added to this time.

The PhotoMARVL technique should prove a valuable tool for tasks such as providing accurate descriptions of forest crop types, validating MARVL assessments, the construction of taper equations, and quantifying tree form.

The quantity and quality of the data that the PhotoMARVL system can provide now encourages an evaluation of potential cost-benefits through utilising the system in forest inventory.

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