Development of an In-field Tree Imaging System

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By

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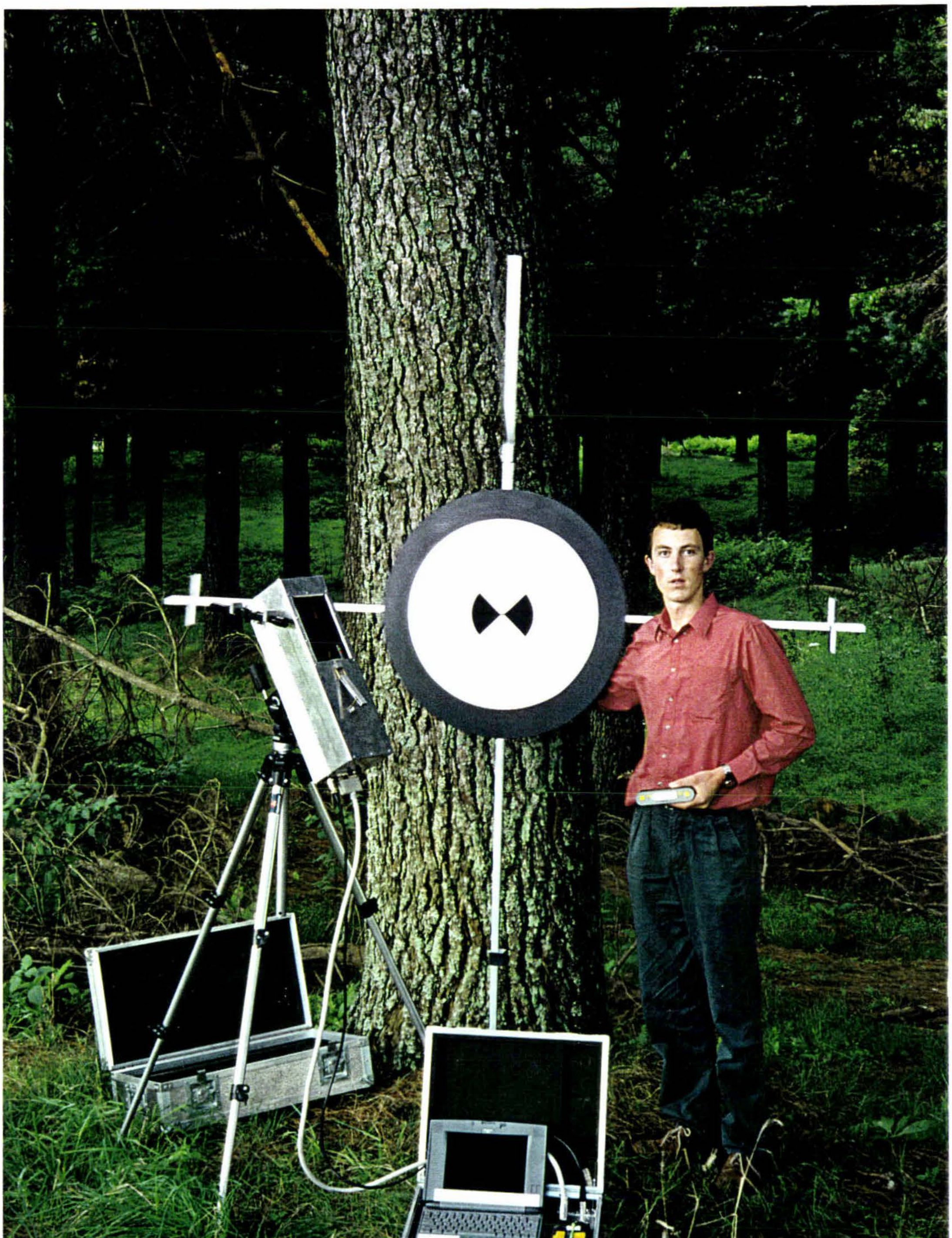

Abstract

Quality inventory information is essential for optimal resource utilisation in the forestry industry. In-field tree imaging is a method which has been proposed to improve the preharvest inventory assessment of standing trees. It involves the application of digital imaging technology to this task. The method described generates a three dimensional model of each tree through the capture of two orthogonal images from ground level.

The images are captured and analysed using the "TreeScan" in-field tree imaging system. This thesis describes the design, development, and evaluation of the TreeScan system. The thesis can also be used as a technical reference for the system and as such contains appropriate technical and design detail.

The TreeScan system consists of a portable computer, a custom designed high resolution scanner with integral microcontroller, a calibration rod, and custom designed processing software. Images of trees are captured using the scanner which contains a CCD line scan camera and a precision scanning mechanism. Captured images are analysed on the portable computer using customised image processing software to estimate real world tree dimensions and shape.

The TreeScan system provides quantitative estimates of five tree parameters; height, sweep, stem diameter, branch diameter, and feature separation such as internodal distance. In addition to these estimates a three dimensional model is generated which can be further processed to determine the optimal stem breakdown into logs.

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Publications

The following publications were prepared during the research for this thesis:

- Weehuizen, M., Pugmire, R.H. (1994): The use of in-field tree imaging in the pre-harvest inventory assessment in the logging industry, Proceedings of New Zealand Postgraduate Conference for Engineering and Technology Students, Department of Production Technology, Massey University, 1994.
- Weehuizen, M., Pugmire, R.H. (1994): The use of in-field tree imaging in the pre-harvest inventory assessment in the logging industry, Proceedings of the Second New Zealand conference on Image Vision and Computing, Department of Production Technology, Massey University, 1994.

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The contribution of Thomas Look was invaluable in the design and engineering of the mechanical components of the system.

Thanks also to the Gary Allen for the time spent constructing and testing the electronic aspects of the TreeScan system, and to Farshad Nourozi for his input into the design of the system.

I would also like to thank Tasman Forestry Ltd. for their backing of the development of the TreeScan system and continued support for further research. In particular I would like to thank Mike Colley (unfortunately moved on early in the project) for initiating the commitment of Tasman Forestry to in-field tree imaging.

Lastly, but certainly not least, I would like to thank Diana Foster for her editing skills on many chapter drafts and her unfaltering commitment whenever the project demanded more than its fair share of my time.

I must go down to the seas again, to the lonely sea and the sky,
And all I ask is a tall ship and a star to steer her by,
And the wheel's kick and the wind's song and the white sail's shaking,
And a grey mist on the sea's face and a grey dawn breaking.

I must go down to the seas again, for the call of the running tide
Is a wild call and a clear call that may not be denied;
And all I ask is a windy day with the white clouds flying,
And the flung spray and the blown spume, and the sea-gulls crying.

I must go down to the seas again, to the vagrant gypsy life,
To the gull's way and the whale's way where the wind's like a whetted knife;
And all I ask is a merry yarn from a laughing fellow-rover,
And quiet sleep and a sweet dream when the long trick's over.

" Sea-Fever " by John Masefield

Glossary

A/D	Analog to Digital, used as A/D convertor.
CCD	Charge Coupled Device
CMOS	Complementary Metal Oxide Semiconductor
EPROM	Erasable/Programmable Read Only Memory
Kink	A short deflection of a log affecting less than 2 m of the log (see appendix C).
Log	A single section from a tree stem which has been cut into sections. A tree stem is cut into a number of logs for transport to the mill (typically 6-12 m in length).
Log grade	A measure of log quality and value. Each log grade has specifications which a log must meet (see appendix C).
LSC	Line Scan Camera
MARVL	Method of Assessment based on Recoverable Volume by Log type. The preharvest inventory system used by many forestry companies.
Plug-in	Macintosh code resource which complies with the Adobe interface specification and may be used to extend applications.
RAM	Random Access Memory
ROM	Read Only Memory
SCC	Scanner Control Command
SCSI	Small Computer Systems Interface, a high speed flexible computer interface commonly used to connect peripheral devices to computers.
SED	Small End Diameter, minimum diameter of a log.
Stem	A tree which has been felled but not yet cut into logs.
Sweep	Deviation from straightness along a length of log (see appendix C).
Wobble	Deviation from straightness of a log where the axis of a log deviates in two or more directions (see appendix C).
SBC	SCSI Bus Controller

Chapter 1

INTRODUCTION AND BACKGROUND

1.1 Scope of Research

The strategic objective of this research is to improve forest stand assessment by using imaging techniques to make the preharvest inventory assessment more quantitative. If successful this will have a far reaching impact on mensuration in the forestry industry.

In order to make the preharvest inventory assessment more quantitative two aspects are important; the dimensions of the standing radiata pine trees must be measured, and the method used to calculate recoverable volume from tree dimensions must be modified. The research for this masters project focuses on the development of a suitable image capture and processing system which can be used to accurately estimate tree dimensions.

More specifically, the objective of this masters project was to develop a line scan based image capture system that would allow the dimensions of standing pine trees to be estimated. As a result of this clearly defined objective this masterate has been a technology development project rather than a theoretical research project.

1.2 Thesis Overview

The research and development for this study takes the project from the design concept stage through the design and development stage up to the final testing stage. The structure of the thesis reflects this design path.

Chapter 1 provides an introduction and context for the research. The scope of the research is defined and a background to the forestry industry is provided with an emphasis on the preharvest inventory assessment. This chapter presents a statement of problem, independent of the proposed solution.

In chapter 2 alternative methods for improving inventory assessment are reviewed. The approaches identified in a Massey University feasibility study are outlined and analysed for design constraints. Based on this analysis a design proposal is put forward which provides the basis of the subsequent development work.

In chapter 3 the design considerations and theoretical foundations upon which the development is based are explored. This chapter describes how the system works in principle and proves that the solution is technologically feasible. Key areas of technical difficulty are identified and individually analysed.

Chapter 4 describes the hardware of the TreeScan system, with an emphasis on the custom designed scanner. Functional blocks of the scanner are described in detail and the reasons for this particular implementation are presented. In addition to this the obstacles encountered during hardware development are briefly discussed.

In chapter 5 the algorithms implemented in the TreeScan software are described. This includes both the image capture software used to capture images with the scanner and the parameter extraction software which is used to estimate actual tree dimensions.

Chapter 6 is an evaluation of the system accuracy and discusses the modifications made to convert the scanner, as originally designed and built, to an accurate scientific instrument.

In chapter 7 possible implications of this technology on the forestry industry are presented. Strengths and limitations of the TreeScan system are discussed and recommendations are made regarding the future directions for this research and development work.

To conclude the thesis, the main points of this research are summarised in chapter 8.

Relevant detailed technical documentation and software listings are included in the appendices.

Unless noted to the contrary in the text, all work is the authors own work. This includes; analysis of design considerations, system sensitivity analysis, design and testing of all digital hardware, design and testing of the majority of analog hardware, all microcontroller software development, and the majority of the system evaluation tasks.

The development of the image acquisition plug-in, the distortion correction methods, and the image processing macros were a joint effort between the author and his supervisor (Dr. Ralph Pugmire).

Notable tasks completed by other development team members were all mechanical engineering, design and testing of stepper motor controller, design and testing of power supply, and the final accuracy tests in two dimensions.

1.3 Forest Industry Background

The aim of this section is to provide a forestry background to set the context for this research. It is aimed at the reader with very little forestry experience, providing a brief overview of key aspects of the industry. It is intended to be an introduction and does not comprehensively cover all aspects of the forestry industry.

1.3.1 Introduction

Plantation forestry is the sector of forestry that deals with production forests. Production forests are forests specifically planted with the aim of being harvested. Plantation forestry does not include the felling of natural forests and is therefore a sustainable and renewable industry.

Plantation forestry is a major export industry of New Zealand. In 1993 the export of forestry products constituted New Zealand's third largest export earner, generating 2.5 billion dollars. This is almost on par with meat and dairy exports, 3.0 and 2.8 billion dollars respectively (Forestry Facts & Figures, 1994).

New Zealand production forests are predominantly radiata pine (90%), with smaller quantities of douglas fir, softwoods, and native hardwoods. The New Zealand radiata pine estate constitutes 34% of the global radiata pine estate (Forestry Facts & Figures, 1994). New Zealand radiata pine plays an important role in the New Zealand economy and constitutes a large proportion of the global radiata pine market.

The main plantation forestry area in New Zealand is the Rotorua district in the Central North Island with smaller scale forestry blocks scattered throughout the country. The ownership of these forests is divided between three large forestry companies and a significant number of smaller owners. The three largest owners are Fletcher Challenge Ltd., Carter Holt Harvey Ltd., and the Forestry Corporation of New Zealand. They own 16%, 25% and 13% of plantation forestry resources respectively (Forestry Facts & Figures, 1994).

The forestry industry has seen a phenomenal growth over the last three years. This is largely a result of increased international demand driving world timber prices up. As the value of sawn timber rises, the value of the raw product also rises and it becomes important to maximise the use of business resources. Good tree breakdown is no longer good enough, the tree breakdown must be optimal.

1.3.2 Forestry and Sawmilling

The timber industry traditionally contains a clear distinction of roles. The role of forestry operations is very different from the role of sawmilling operations.

- The role of **forestry operations** is to produce logs. In practise, forestry operations includes the planting, growing, and maintenance of the trees during the time they are growing. Once the trees are ready to harvest they are felled and cut into logs of one of a number of specified grades (see appendix C).
- The role of the **sawmilling operations** is to process logs. The sawmilling operations commence with the raw product of logs of a certain grade and process these into sawn timber and other wood products.

The result of this division in the industry is that a sub optimal resource optimisation may be achieved. If this division is reduced and the tree optimisation can be based on final timber usage rather than log breakdown, resource optimisation could be improved. Many companies are currently restructuring to reduce this division.

1.3.3 Forest Operations

The basic unit of measurement in the forestry industry is the stand. A stand is a block of trees of similar age, size and other characteristics. Each forest is subdivided into even aged stands of typically 20 to 40 hectares. Stands are harvested as a whole at a tree age of 25 to 30 years.

The life cycle or rotation of a stand of radiata pine begins when the trees are planted. It is split into three phases, with an inventory assessment made during each phase:

- **Early growth** during which pruning and thinning operations may be completed
- **Mid rotation** during which the trees are left to grow largely unattended
- **Harvest** during which the trees are felled

The **early growth** phase, 0 - 10 years, determines the quality of the trees in a stand. Trees are pruned in successive lifts up to a maximum of 6 or 8 m. The result of pruning is trees which grow straight and have large sections of clearwood. Clearwood is wood which does not contain any knots or defects outside a defect core.

Stands will undergo two thinnings to select the best trees and reduce the stocking to a level that will produce a maximum tree growth rate. The first thinning is at a tree age of 4 to 6 years, the second at 7 to 9 years.

During the **mid rotation** phase, 10 - 25 years, very little tree maintenance is required. Generally the only task completed is the mid rotation inventory assessment.

During the **harvest** phase, 25 - 30 years, the trees are felled to produce stems. These stems are then cut into logs based on the current cutting strategy.

Once the trees in a stand are felled, the stems are taken to a skid site. A skid site is a small area of the stand which has been cleared and where the stems are cut into logs. Typically there will be several skid sites per stand. There are two primary methods of stem removal; the skidder and the hauler. A skidder is a large wheeled vehicle which drags the stems to the skid site. The hauler is a cable based pulling system which must be used when the terrain is too steep for a skidder.

On the skid site the stems are cut into logs. This breakdown is intended to optimise the use of a tree, but is a compromise between maximising value and meeting orders. The log maker decides on the best breakdown for a particular stem based on the log maker's assessment of stem shape and features, and the current log requirements. The total value of the recovered logs depends on the performance of the log makers. Generally the performance of a log maker is very good, typically 95% of optimal. If the performance of a log maker drops below this level, this results in a very large loss in stem value.

Once the stem is cut into logs they are stacked until they can be trucked out of the forest.

1.3.4 Inventory Assessment

Assessing the value and potential yield of a stand of trees is one of the basic concerns of commercial forest growers. During each of the three phases in the stand life cycle an inventory assessment is made. This involves gathering information on a representative sample of trees from a particular stand.

The first inventory assessment is made during early growth phase, at a tree age of 4-10 years. This is the **quality control inventory** which allows the forest owner to check that the pruning and thinning have been completed properly. Basic information is collected regarding the condition of the stand as a whole such as total tree stocking, tree diameter, tree height and the pruned height.

At a tree age of 15-16 years the **mid rotation inventory** assessment is made. This enables the owner of the forest to gain information on the growth progress of the trees.

The **preharvest inventory** assessment is made 1-2 years prior to harvest, at a tree age of 23-28 years. The main aim of this final inventory assessment is to aid in market planning and harvest scheduling. Information is collected regarding the stocking of the stand as well as detailed information regarding the characteristics of individual trees. Section 1.4 will discuss the preharvest inventory assessment in greater detail.

1.4 Preharvest Inventory Assessment

As stands mature growers require detailed inventory information to plan harvesting, marketing and utilisation of the timber. Logs are cut on a 'to order' basis, with no buffering of stock on hand. This implies that good inventory information is necessary to determine what log grades can be expected from a particular stand. On a short term basis if there are not enough logs to meet a particular order, higher quality logs may be downgraded to fill the outstanding order. The result of this is a serious loss in profitability.

The aim of the preharvest inventory is to provide information regarding the value and quality of individual stands. This information is used in :

- **Harvest planning** - The log grades which can be most profitably cut from a stand are estimated. Harvesting operations are planned based on which stand can provide the optimal log grades to meet particular orders.
- **Market planning** - The volume of harvest, by log grade, is estimated up to three years ahead of harvest. Export contracts are based on the estimated volume of harvest.
- **Valuation** - The absolute value of a particular forest block can be estimated from the inventory information. The value of a forest may need to be established if the forest is sold or if company assets are valued.

The assessment of total volume and quality should be based on the actual measured condition of the trees. The effect of disease and damage, and management operations such as pruning and thinning must be directly taken into account. However the data collected should be flexible enough to allow harvest to be estimated even if log specifications change after the inventory team has visited the stand.

There are two important aspects of any tree which must be measured in order to be able to estimate the optimal log breakdown; the shape of the stem, and the quality of the stem. The shape of the stem, or sinuosity, is defined by the amount of sweep and wobble the tree has (see glossary or appendix C). The quality of the stem is defined by the branch sizes, pruned height and defects such as rot, broken tops, forks and nodal swelling.

Currently the 'MARVL' (Method of Assessment based on Recoverable Volume by Log type) system is being used by most major forestry companies in New Zealand. MARVL is an inventory assessment method designed specifically for the preharvest inventory.

1.4.1 MARVL Inventory Assessment

MARVL was developed by the Forestry Research Institute of New Zealand in the 1970's in response to the need for a general purpose inventory tool and is now widely used in Australia and the Pacific as well as New Zealand. It is based on the visual assessment of a sample of trees. In addition to the visual assessment, a number of tree parameters are measured. From this information log production estimates are calculated.

The MARVL system is a general purpose method which has been designed to allow flexibility in its use (Deadman & Goulding, 1979). As result, each user of the MARVL system has a slightly different implementation. The MARVL system involves three steps: sampling, cruising, and estimating log production.

Sampling

A series of bounded plots are defined as a representative sample of the stand. Each plot covers an area of 0.04 to 0.06 hectare, with a total of approximately 4% of the stand area sampled. The number of plots per stand is based on stand area. A typical number of plots per stand is 15, but can vary from 10 to 100.

Cruising

Once the plots have been established, a team of two people is sent out to assess each plot. During the assessment the heights of two trees are measured using a clinometer, stem diameter at breast height is measured for each tree and an visual assessment is made for each tree.

The visual assessment estimates sinuosity (in three classes of sweep), and quality features from the base of the tree. The sinuosity of the tree is recorded by describing the stem as consisting of sections of estimated length with a given sweep class and branch size class. For example:

- Sweep may be classified into three classes: <SED/4, SED/4-SED/2, >SED/2.
- Branch size may be classified into three classes: <7 cm, 7-14 cm, >14 cm.

There are a large number of quality features. Quality features include pruned height and other defects such as rot, broken tops and forks (see appendix C). The height of each feature of interest is estimated and recorded.

The measured and estimated parameters are entered into a portable computer used as a data logger during the work out in the field.

Estimating log production

The recorded data is down-loaded from the data logger onto a computer running the MARVL software to estimate log production. If necessary the trees are "grown on" to harvest age, using growth models. The data from each tree is individually processed to calculate the best log breakdown. Essential cuts such as those at the position of forks and stumps are made first with simulated felling breakage if required. The resulting yield for the plots is statistically extrapolated to provide an estimate of recoverable volume by log type of the entire stand.

1.4.2 Weaknesses of the MARVL System

The MARVL system provides essential information, however it has limitations. Several aspects of the assessment are subjective, and the system has been developed to the point where it is limited by this subjectivity. This has been the result of an increasing need for more detailed and accurate inventory information and a greater variety of markets since the system was developed.

The log volumes actually cut from a particular stand often do not match the log volumes as predicted by MARVL. The total volume estimate is very good, typically within ± 5%, but the breakdown of this the volume by individual log types may vary between ± 10% to ±80%. This is not solely due to the limitations of MARVL as logs actually cut depend on a large number of interrelated factors. For example, a sub optimal cutting strategy may have been used intentionally to fill a particular order.

The results of MARVL depend on:

- The ability of crews to accurately estimate tree parameters.
- Information loss inherent in the method of calling particular trees.
- The ability of the MARVL software to extract the desired information from the recorded descriptions.
- Size of the sample and how representative this is of the stand.

MARVL depends largely on the accuracy of **human estimates**. Branch class, tree height and the height of quality features can be surprisingly accurately identified. The greatest limitation of MARVL is that the estimation of sweep is subjective. Estimation of sweep is difficult as it involves making an estimate of sinuosity in two dimensions for sections of the tree. Two different people calling the same tree can give two different classifications.

A second limitation of the MARVL system is that there is **information loss** when describing a tree. Ambiguity can develop if all the relevant information is not retained.

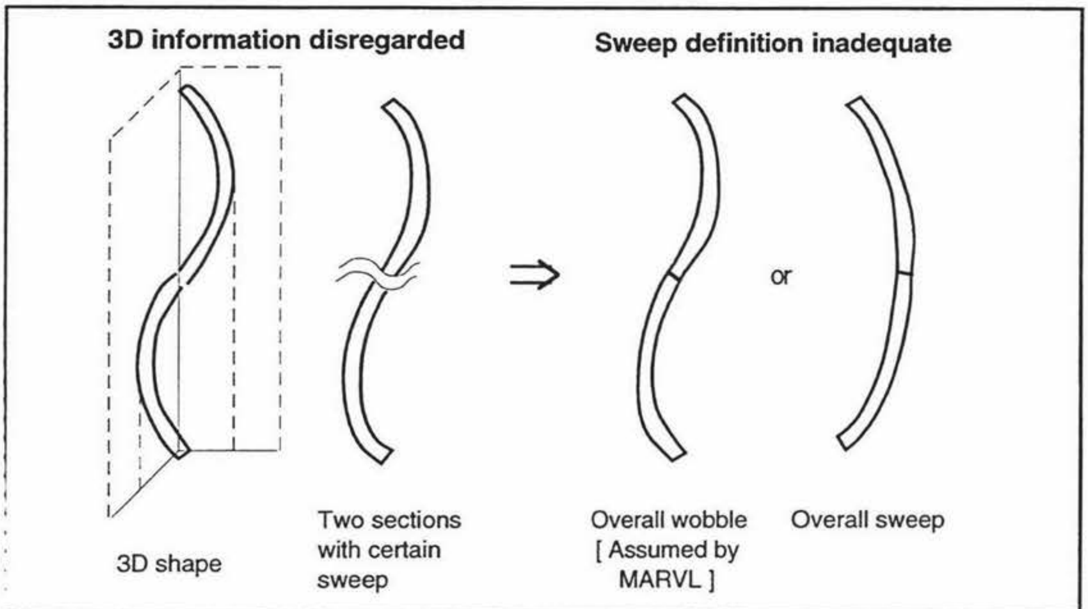

Figure 1.1 - Information loss inherent in the MARVL tree description

wo examples of this ambiguity are:

1. MARVL is a two dimensional system. Three dimensional information is disregarded. If a tree is called as consisting of two sections of certain sweep, this could indicate the sweep is in the same plane or at right angles. This information which has an important impact on the optimisation of stem breakdown is disregarded (see figure 1.1).

2. Secondly the definition of sweep for different log lengths is inadequate. If a tree is called as consisting of two sections of certain sweep, this could indicate one of two situations. The tree could have a large sweep over the combined length or the tree could have wobble over the combined length (see figure 1.1).

ı the above situation MARVL is not able to extract necessary information from the log :scription, so a simplifying assumption is made. MARVL assumes that a long log of e same sweep class as the greatest sweep of its subsections can be cut. i.e. that the log ›ntains wobble in a single plane.

ıstly the sample must be statistically representative of the stand. Often there is a large ıriation of tree growth even within a stand. As a result the sampling procedure or ınd area sampled may need to be modified.

1.4.3 Possible Improvements

In order to improve the forecasting system, one or more of the above weaknesses must be targeted for improvement. If a more quantitative system can be provided which does not suffer from loss of information, this would mean a great improvement for the preharvest inventory assessment.

A key consideration to maintaining high quality while retaining MARVL, is feedback to the staff involved regarding the results of subjective estimates. The more frequent and precise this feedback is the more successful it will be in maintaining the accuracy of the subjective assessment. However this is difficult in the assessment of sweep. The only reference to compare an assessment of a single tree, is how a more experienced person would call the tree. Even if the tree is felled, the extent to which the sweep was called correctly is difficult to determine.

In chapter two, several methods are proposed that can be used to improve the inventory accuracy using a partially automated system. This will produce more accurate and repeatable results.