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New Developments in Stem Feature Recognition using Machine Vision

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Abstract

TreeGrabber is an ongoing software/hardware development project at ***Forest Research*** *the purpose of which is to generate digital descriptions of individual felled tree stems. These descriptions will be obtained automatically using computer vision technology with minimum human interaction and will be used by the software to generate an optimal bucking patterns for each stem in real-time in order to maximise value recovery. TreeGrabber uses digital images to capture a two dimensional representation of the stem which is then converted by means of image processing and photogrammetric algorithms into a geometrically accurate three dimensional stem model. It will also incorporate algorithms for detecting stem defects such as knots which allow it to assess stem quality objectively. The stem descriptions will also be of use in conjunction with sawing models and predictive stand based inventory models.*

Keywords: softcopy photogrammetry, bundle adjustment, graphical interface, machine vision, image analysis, image correlation, feature matching, log-making, value recovery

1. Introduction

In the early 1990's log-making normally involved tools like tape measures and hand held callipers to determine gross stem dimensions as well as sizes of some of the visible quality features on the stem such as knots. Once log-makers had these dimensions, they then used their own judgement to combine it with the forest owner's requirements to prescribe a bucking pattern for that stem. According to Murphy, *et. al.* [1], while some log makers were very good at making this subjective decision, many were not and this variation resulted in lost stem value, estimated at NZ$200 million per annum to NZ forest industry.

Today use of in-forest computerised tools, such as the TimberTech Logger, should allow log-makers to narrow this gap substantially. To help close the gap even further ***Forest Research*** has undertaken to develop a machine vision system, TreeGrabber, whose purpose is to help individual log-makers measure and objectively assess the quality of individual tree stems on skid sites in the forest [2]. Machine vision has the two major advantages of automatic data entry and objective stem quality assessment. In addition to measuring the stem accurately in three dimensions, it will remove the laborious and error prone process of punching stem data into a computer keypad. By detecting and measuring quality features it will also be capable of performing the quality assessments that, at present, can only be done by subjective human judgement.

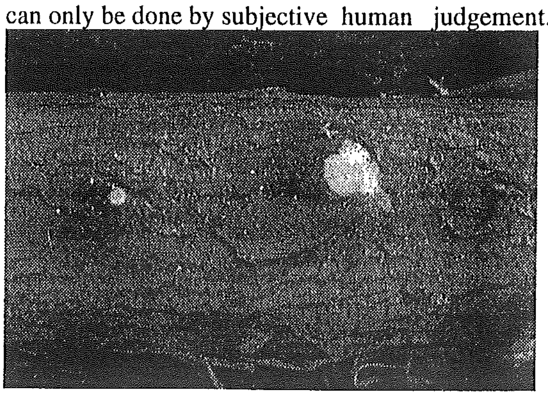

Figure 1: Machine vision has two major advantages; automatic data entry and objective stem quality assessment.

When it is completed, the TreeGrabber system will be capable of performing its task in a number of environments. To date, development has concentrated on the most complex application - stem assessments with a hand-held battery operated system on the skid site. Other places this technology might be applied include central processing facilities and on feller-buncher cutting heads.

Our intention is to develop tools that will be able to work with the other software and hardware components being developed by ***Forest Research*** as part of a comprehensive harvesting coordination and optimisation system [3,4,5,6]. We envisage that the system will also be capable of additional tasks such as printing barcodes so that stems cut into logs prescribed by its optimal bucking pattern will be labelled appropriately for subsequent tracking from the landing to the mill or wharf.

This paper contains an overview of TreeGrabber's present and planned capabilities. An overview of its operation is in Section 2, a more detailed description of its measurement capabilities in Section 3, a description of current work on knot recognition in Section 4, and finding the stem edges in the images in Section 5.

2. Operational Overview

Development of the TreeGrabber system thus far has focused on software rather than hardware development. We have chosen to develop algorithms which are, in many cases, too computationally intensive to run with reasonable speed on current computer hardware. Given the trajectory for computer hardware development and power, we are very confident that computing technology will surpass our requirements by the time a production system is ready for market. TreeGrabber's input data requirements are straightforward: to perform its task of measuring a stem and providing an optimal bucking solution it needs only three basic forms of data:

1. A sequence of colour digital images
2. Ground truth and camera information
3. Log product specifications and prices

The sequence of colour digital stem images must be of sufficient quality and resolution (one pixel ≤ 2mm on the stem). They must overlap one another by 60-80% in terms of stem content to allow for stereoscopic effect. For a typical 40 metre stem, this might be 40 images with a pixel resolution of approximately 1200x800. The ground truth information should consist of either fixed known camera locations, camera locations determined by GPS, or some form of calibration targets visible in all the images. The focal length of the camera must also be known with high accuracy. Finally, optimisation parameters for ***Forest Research's*** AVIS (Assessed Value of Individual Stems) optimal bucking software package such as quality grades, inventory information, market factors, and prices, must also be available.

To service these data requirements, we expect that the TreeGrabber system hardware for the skid site will consist of a powerful battery powered computer processor, a digital camera with quality optics, a GPS for determining camera location, and a wireless modem for downloading optimisation parameters and uploading stem descriptions. Of course, these requirements will be simplified in a central processing yard or on a feller-buncher cutting head where cameras can be mounted and calibrated permanently, and there is more power available for faster processors and communications equipment.

To cope with the many possible hardware configurations under which it will operate, the TreeGrabber software has been designed in a modular fashion to allow developers to ``plug in" appropriate data interfaces to the main TreeGrabber software engine. The modular approach is ideal for development purposes as well, as a graphical point-and-click interface permits human interaction with the various modules allowing them to be tested independently [2,5]. The TreeGrabber software's main operational modules are the following:

- Operation manager - controls the behaviour of the various modules, collection of data, and insures the proper procedural flow of the software.
- Image preprocessor - modifies the raw colour image data to determine initial information about the image, i.e. the location of the stem in the image, locations of knots and other quality features, whether the stem forks, etc. It will also perform other standard image processing operations such as brightness and contrast balancing to deal with possible interference from shadows and light variations as well as general image smoothing to remove extraneous image noise.
- Image matching module - the overlap

between adjacent images insures that each section of stem will appear in two images. Many points on the two images of each stem section must be matched to allow construction of a dense map of points on the stem surface. Special features such as knots must also be matched to ensure that their size and orientation are also computed accurately.

- Surface reconstruction module - performs the initial analytical photogrammetric computation, essentially an analytical aerotriangulation implementation based on [7,8] and described in more detail in [9,10], that combines selected matched image features and ground truth to generate a geometrically accurate relationship between the images in the stem image sequence. Another photogrammetric algorithm, an analytical space intersection [9], uses the inter-image relationships to reconstruct a dense set of points corresponding to the geometry of the visible stem surface. Testing of these modules indicates that accuracies of ±2mm are achievable as described in Section 3.

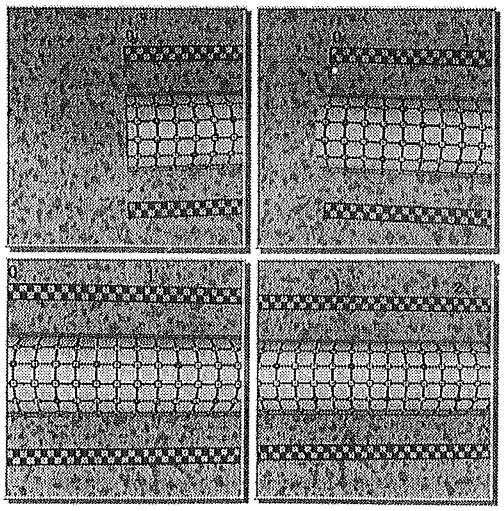

Figure 2: The first four of ten rendered pseudo-stem image sequence demonstrating the overlap between images, control strips, and random variation in camera location and orientation.

- Stem modeler - the surface map must be converted into a three dimensional stem model consisting of a series of oval cross sections at known intervals, giving diameter, length, and sweep information. The model will also include knot and other defect locations and sizes. A statistical tool is being developed to determine the effect of the non-visible stem surface on the stem quality assessment.

- Model postprocessor - the model data must then be converted into quality graded information suitable for the AVIS optimal bucking algorithm. The operation manager passes the results of this module as well as the optimisation parameters to the AVIS library which generates the final bucking pattern for the stem.

3 Measurement Capabilities

TreeGrabber's stem reconstruction module assumes a sequence of overlapping images covering the entire stem for which each camera position is known, and in which common stem surface points on adjacent images are matched to pixel level accuracy. The matched pixel data is sorted to find 4 - 10 of the matched features which happen to lie at the edges of the overlap regions which are used to perform the aerotriangulation calculation. This calculation uses the measured locations of the camera for each image, the camera focal length and focal plane dimensions, as well as the matched feature locations and constructs a single massive least squares adjustment problem. The adjustment converges iteratively to a simultaneous solution for all the unknowns in a way that distributes error evenly between them, minimising it over the entire computation.

To test the aerotriangulation calculation a reference image sequence was synthesised on the computer. A computer rendered, perfectly cylindrical ``pseudo-stem" was created which has the major advantage that its surface is completely described in space. Using a mathematically precise object removed the nontrivial effort of building or otherwise creating a suitable fully defined physical test subject. It also eliminated the uncertainty normally associated with a conventional three dimensional reconstruction process, namely error introduced by imprecision of camera optics, film development and scanning as well as possible human errors in measuring a physical model. We added random translations to the locations of the camera stations and camera orientation angles to simulate the variation expected from having a log-maker taking the images while walking beside the felled stem on the skid site. We decided that a sequence of 10 images would be a sufficient number to demonstrate the accuracy of the algorithm. The first four images are shown in Figure 2.

Ground truth for the image sequence was provided by two strips of control points appearing on either side of the pseudo-stem in the image. These were for testing purposes only as they allow for the resection of the camera locations as part of the bundle adjustment itself, giving us an indication of the accuracy of camera station position and orientation needed to achieve acceptable stem measurement accuracy.

For the purposes of the test, corresponding object points on the stem surface were selected manually using TreeGrabber's graphical interface, as shown in Figure 3. The resulting stem surface point locations agreed with the known locations of those points within the root means squared distance of approximately ±2mm, with a maximum error of 3mm. The corresponding locations of the camera stations computed by the bundle adjustment had an error of ±20mm. This indicated that we could do away with ground based control information and still get acceptable stem measurement accuracy if we were able to determine the camera station locations to approximately ±20mm accuracy by some external means such as GPS (Global Positioning System). A more detailed description of the test is available in [2].

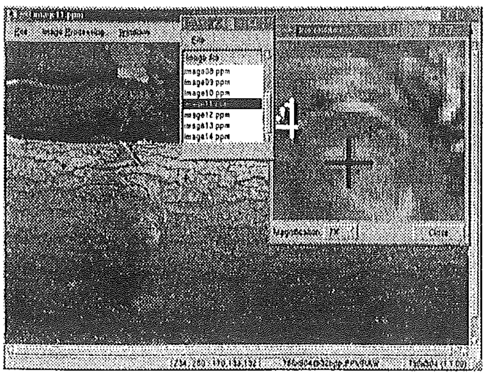

Figure 3: An example of the TreeGrabber user interface, with main file window, open stem image window and stem zoom window.

The test also demonstrated that further gains in accuracy could be made without requiring any algorithmic improvements simply by using a higher resolution camera. This favourable scaleability is possible by virtue of the fact that accuracy of the aerotriangulation results is directly related to the accuracy with which image feature matches can be made, which in turn is proportional to the resolution of the stem images. Higher resolution does, however, increase the computation power required to perform image analysis tasks, though given the rate with which computer technology is improving, this may not be an issue.

4 Knot Recognition

One of the major strengths of the TreeGrabber system is the fact that it can recognise and measure stem defects which affect stem quality decisions. Chief among these is knots. TreeGrabber incorporates a promising new algorithm, developed at ***Forest Research***, for recognising knots in digital images described in more detail in [11,12]. Figure 4 shows the sorts of intermediate images produced by the process. The algorithm uses the numerical colour values of pixels in the digital stem images to generate a texture orientation field of the stem surface. This orientation field is a quantitative representation of the characteristic visual ``flow direction" of stem surface features such as bark fissures, shading, relief, and colour variation. The algorithm also produces a gradient magnitude image which represents a measure of the strength of the bark texture. The brighter the image feature, the larger the resulting gradient magnitude. The flow direction is estimated by mathematical formulae. Detection of knots is done by analysing the estimated flow directions shown in 4(e) resulting in the detected knots, with their bounding boxes in 4(f).

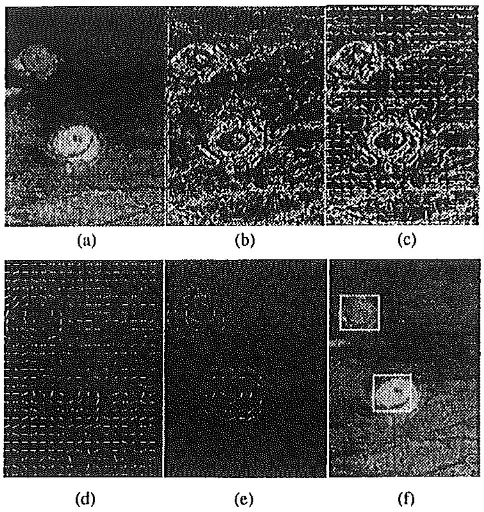

Figure 4: (a) An original image of log bark with knots; (b) The gradient magnitude image; (c) The estimated flow directions overlayed on the gradient magnitude image; (d) The estimated flow directions overlayed on a black background; (e) The results of flow pattern recognition; (f) The detected positions of knots overlayed on the original image.

The algorithm has been tested on close to three hundred images of freshly harvested Radiata pine tree stems. Samples have included logs with a range of knot sizes, different knot types (trimmed branch stub, trimmed flush with stem and occluded) and some without knots (to test for false detection). The algorithm even in its early stages shows excellent results, correctly detecting the knots on better than 90% of the test images [5].

5 Finding Stem Edges

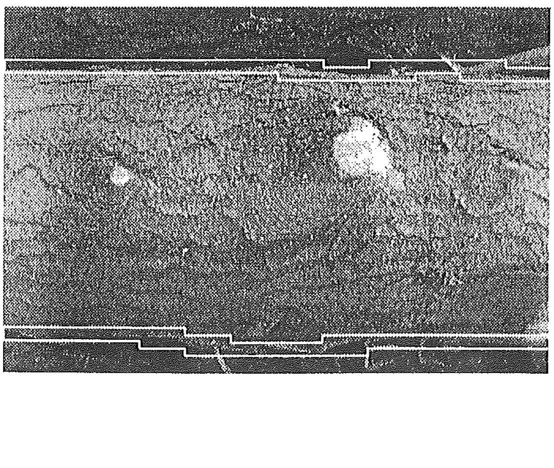

Figure 5: A sample stem image with stem edges ``isolated" using TreeGrabber's window based intensity gradient algorithm. The next step is to find the exact stem edge pixels within these bands of edge boxes.

The critical functionality required to make TreeGrabber a usable system is a method for reliably and accurately matching image features in overlapping stem images. This is a very complicated task given the possibility of scale, rotational, and brightness variation between these images due to the fact that each image is taken from a different point in space. One of the few real references in these images are the top and bottom edges of the stem (see Figure 5). If the stem edges can be determined accurately in every image, it greatly reduces the burden on the feature matching algorithm which would otherwise expend computational energy on the unnecessary and generally futile task of matching image features from the image background around the stem.

We are currently exploring two main methods for stem edge extraction: one essentially statistical, which tries to isolate the stem into smaller and smaller rectangular pixel windows using image intensity gradients similar to those used in knot detection. The other is a more complicated and computationally intensive tool called an active contour or ``snake."

A snake is simply a curve connecting a series of image pixel points. The image context, i.e. locations of these points and the values of the pixels adjacent to them, determines an ``external energy" for the snake. The shape of the snake itself, how curvy it is, and how long it is determines an ``internal energy" for the snake. The snake can move iteratively in the image to balance these internal and external energies while minimising its overall energy. Depending on how the expressions for internal and external energy are formulated, the snake can often find edges in images which are very vague due to its ability to overlook small breaks in the edges. An assortment of literature detailing snakes is available at [13].

Due to the complexity of implementing a snake algorithm, the statistical approach has been the initial focus. Figure 4 show early results from this approach. The rectangular windows sitting over the edge of the stem isolates the stem edge into a smaller space, making it possible for the more computationally intensive fine tuning needed to isolate the actual edge pixels to take place in a limited space.

6 Future Work

TreeGrabber is a tool with a huge potential value to forest industry. It involves a number of complex and emerging technologies, but ones which, if properly utilised, could conceivably revolutionise forestry harvesting and processing practices. Several critical technological elements are still required for TreeGrabber to perform its intended task of automated stem measurement, grading, and optimal bucking, but significant groundwork has already been laid. Once we have developed a working image feature matching algorithm, in conjunction with a robust stem edge finding algorithm, we will be able to explore various TreeGrabber hardware configurations and provide working prototypes of this tool for industry to evaluate. In the meantime we will also explore application of this technology to other harvesting scenarios such as central processing yards and feller-buncher cutting heads.

5. References

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