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Wood Property Mapping Techniques: Development and Applicability to the Programme of Mechanobiology of Wood Formation

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EXECUTIVE SUMMARY

This report summarises the main wood property mapping methods used in IFS Objective 2. It describes improvements made to the original methods, difficulties encountered during mapping, and future needs.

Four methods used for mapping wood properties in whole discs are described.

- Digital Red Green Blue (*RGB)* imagery

Digital *RGB* imagery was one of the key techniques used for spatial mapping of the distribution of wood properties within stems of radiata pine. This is a fast and cheap technique for mapping wood properties and digitally reconstructing the stem shape using G2ring software, particularly in this instance where it involved slicing an entire stem into 25-mm thick discs and photographing the top surface of all these discs, i.e., around 350 per stem. Imagery was also used to capture both the whole tree shape of standing trees, and the stem shape of logs, before cutting discs. The process was automated by constructing a camera booth for capturing high quality digital images of stem disc surfaces routinely. The quality of the images has been improved vastly by adapting a Peterson Radial Saw Bench for skimming off the chainsaw-cut disc surfaces before imaging. These improvements have allowed high quality images to be captured efficiently.

- Chemical composition by chemometric methods based on 2D Near Infra Red (NIR).

The NIR scanning rig, a device built at Scion, was adopted as a rapid and a relatively easy means of mapping chemical composition over entire discs at a spatial resolution of 1.72 mm/pixel. Scanning the radial transverse surface of an entire disc takes only 1-2 minutes. Hence this is a relatively fast technique. However, NIR does not directly determine chemical composition, and consequently the spectral information needs to be used in conjunction with chemometrics. Development of a partial least squares model (PLS), correlating NIR spectral information with wet chemistry (lignin, cellulose and hemicellulose) is well under way. (Milestone 2.05.4 2009/2010). Once the PLS model is completed, this will provide a much cheaper alternative to wet chemistry analysis for mapping wood chemistry in whole discs.

- Microfibril angle patterns in 2D by using ultra sound velocity (USV) mapping.

Ultrasonic time-of-flight measurements were used to map changes of microfibril angle (MFA) in entire discs. The method was optimised for the ideal thickness of the discs, and different ultrasonic transducers, with and without tip attachments. Using the method optimised, the actual measurements of discs were carried out at the University of Canterbury using that organisation's USV facility, a very similar system to the one at Scion. (Scion's facility is not fully automated yet.)

- Grain orientation by T2 imaging

The Laboratory T2 grain angle instrument developed at Scion was used to map the surface and dive angles (into or out of the wood surface) along four radii for each disc. The radial measurement resolution used was 5 mm. A considerable amount of development work has been carried out to improve the original method.

INTRODUCTION

In 2008/2009, considerable time and effort has been devoted to mapping wood properties in the IFS Objective 2 programme. Large amounts of wood property data collected in this programme will be used to benchmark the simulation of physical processes involved in tree growth and wood formation, as well as their interactions (Task 2.3). The mapping exercise involved modifying and adapting tools and methods developed previously within the FRST Tools Programme and WQI to obtain best possible results. Modifications were necessary, as the discs collected in the first destructive sampling were of age 7 and hence of considerably smaller diameter than the commonly encountered much older trees. Also, in some cases automation was necessary as the large number of discs, in the order of thousands, were involved. Methodologies developed here will also be taken up by IFS Objective 1, and within other FFR programmes - for example, within University of Canterbury projects.

The main methods used for mapping wood properties were:

- digital *RGB* imagery;
- chemical composition by chemometric methods based on 2D Near Infra Red;
- microfibril angle patterns in 2D by using ultra sound velocity mapping; and
- grain orientation by T2 imaging.

In the first destructive sampling round (2008/2009), a total of twenty-four 7-year-old clonal trees from Esk forest have been mapped using these techniques. The second destructive sampling round will be in 2011, when all these techniques will be re-used. The detail of the methodologies involved can be found in an earlier (2007/2008 F10202 Q3) milestone report. This report summarises improvements made to the original methods, difficulties encountered during mapping, and future needs of characterisation methods used.

METHODS

Digital red green blue (*RGB)* imagery

Digital *RGB* imagery used for spatial mapping of the distribution of wood properties within stems of radiata pine was one of the key techniques used in the first destructive sampling. Imagery was used to capture both whole-tree shape of standing trees and shape of logs, as well the digital images of all the discs made from each individual stem. This involved photographing ~300 chainsawed disc surfaces per stem, which would enable the digital reconstruction of the stem shape using G2ring software (Pont *et al.*).

Considering the large number of discs (in the order of thousands) that had to be photographed, and the labour intensive nature of the method, a dedicated camera/light booth (Figure 1) was constructed to facilitate the imaging of stem discs. The objective was to establish procedures for capturing high quality digital images of stem disc surfaces routinely. The images will be used in conjunction with image analysis (IA) software, customised for automatically locating and mapping the wood property features on the disc surfaces. A series of test images was captured to investigate scenarios, optimal procedures and settings, (with regard to using a Canon EOS 5D Mk11, full frame 22MP digital camera), to capture the images using camera remote control operating software. On-going testing of the camera booth led to replacement of the original four halogen lights with two fluorescent light units. These provide a more even distribution of light and problematic hotspots have been removed.

The second issue that had to be dealt with was the poor quality of images produced from chainsaw-cut surfaces. The original concept of using image analysis techniques for mapping wood properties visible on the cut face of stem discs has been elevated to a new level of capability with the advent of an improved method of preparation of the cross-cut surfaces of the stem discs. This has been achieved by adapting a Peterson Radial Saw Bench for skimming off the chainsaw-cut disc surfaces, which was developed at Scion by John Lee *et al*. Even though this is an additional step in the disc cutting exercise, the vast improvement of the quality of images obtained is much more beneficial. The time involved in skimming each disc is less than one minute.

Chemical composition by chemometric methods based on 2D NIR

Moisture content and chemical composition maps of entire discs have been created via an NIR scanning rig. The NIR scanning rig was developed by ENSIS Wood Quality in collaboration with CSIRO. The rig consists of an NIR camera fixed above a rotating aluminium turntable where the discs are placed for acquiring spectra. For creating maps, discs were first scanned green (for moisture maps) and then again after drying to about 10 % moisture content (for chemical composition). Only seven discs per stem were cut from the point where each year's annual height increment terminates. A total number of 168 discs (7*24) were mapped by NIR. The protocol for mapping has been documented (Appendix 1). The original rig was further improved by installing screens to block any incident light that might interfere with mapping (Figure 2).

The field of view of the camera was optimised for the smaller diameter size discs encountered in this project (ranging from 5 to 20 cm diameter). Spatial resolution has been increased to 1.06 mm/pixel from 1.72 mm/pixel. The spectral resolution remains the same at 3.125 nm/pixel.

A dark image, which is acquired with the lens cap on the camera, gives the image at zero intensity. This image is used for noise correction. A second image is a 100% image and is acquired using a white Teflon reference material mounted at the focal length.

Discs were scanned with their bark taken off. This reduces the number of variations that need to be considered in the consequent multivariate analysis step, and helps focus on the chemical properties of interest.

Surface preparation was a major problem as the chainsaw-cut surfaces were uneven and rough from raised fibres. Due to the random nature of light scattering from these surfaces, the NIR images were of poor quality. This problem has been solved as mentioned in the previous section, by adapting a Peterson Radial Saw Bench for skimming off the chainsaw-cut disc surfaces. The fully automated nature of the rig allows the acquisition of NIR spectra for a whole disc in approximately two minutes. However, thickness variations within and between discs meant that each disc had to be adjusted and levelled individually, which slowed down the scanning process substantially.

For scanning an entire disc, discs mounted on the turntable were rotated for only 180º. That is, half of the disc was measured by positions to one side of the line camera centre position, and the other half of the disc was measured by line positions on the opposite side of the centre position. When a principal components analysis was carried out on the disc images, it was noted that there was a sharp difference between the principal component scores at the two places on the disc image where the spectra were measured by different (opposite) line camera positions. These differences could arise from variations in light intensity and direction in combination with spiral grain angle or surface preparation methods of the wood surface.

A few NIR images were also created with a full 360º rotation of the disc for selected discs. Hence we produced two images for each disc, one image from line camera positions to the left of centre and one image from line camera positions to the right of the centre. Principal component scores for each image were very different. It was also noted that sometimes saw teeth marks were more apparent in one of the images. More investigation is required into the differences between the images. The two images in combination could potentially provide information for modelling of spiral grain angle variation.

Programs were developed in SAS for processing the NIR images. These programs included batch run routines for scaling the readings with the current light and dark calibration, optional removal of non-wood features, removing spikes or pixels with non-linear behaviour, standard normal variate scaling of spectra, Savitsky-Golay smoothing polynomials, transforming rotational coordinate system results into rectangular coordinates, principal components analysis and data visualisation, and database output of results.

Future work:
NIR does not provide direct access to chemical composition, and consequently the spectral information needs to be correlated to wet chemistry data (lignin, cellulose, hemicellulose). This has been written as a milestone in 2009/2010 F10205 tasks. A teleconference was held on 15.06.09 between A. Thumm, Roger Meder (CSIRO), J Harrington and B Nanayakkara to discuss the work plan for the creation of a NIR-wet chemistry Partial Least Squares (PLS) model. A draft work plan has been circulated for comments.

The NIR camera used in this project is on loan from CSIRO. If this method continues to be used in 2011 sampling round, a new camera will/may have to be purchased. A CAPEX proposal has been submitted to purchase one.

Microfibril angle patterns in 2D by using ultra sound velocity (USV) mapping

Ultrasonic time-of-flight measurements were used to map changes of MFA in entire discs. Twenty-five-mm-thick discs have been mapped along eight radii at 2-mm radial steps using 500 kHz transducers with 9-mm-wide circular, flat-faced, soft coupling tips. Only discs (from seven annular heights per stem) were mapped by USV, which is a total of 170 discs.

Experiments were undertaken to evaluate the best transducers to use and the ideal thickness of the discs. Two different transducers, 500 kHz (with plastic tips and without tips), and 1.25 MHz transducers, were tested on 100-, 50-, 25- and 12.5-mm-thick discs at 2 mm radial steps (Figure 3). 500 kHz transducers with plastic tips, utilising 25-mm or 50-mm-thick discs, gave best results at 2 mm resolution.

For this technique, the disc drying procedure was absolutely critical as the discs needed to be dried without forming cracks. Excessively large cracks may cause errors by increasing the effective path length of the acoustic pulse, which is transmitted from one side to the other side of the disc. After a few initial drying experiments, a kiln with 60ºC dry bulb/56ºC wet bulb and 14% equivalent moisture content (EMC) was used to dry discs without forming cracks. The discs were dried to 18-25% of moisture in the kiln and further conditioned to 10 % moisture in a constant conditions (25º C/65 RH) room for 2-3 weeks. The discs have to be dried and conditioned to 10% (± 1%) moisture content before USV measurement to avoid the effect of moisture content on USV measurements. Ten per cent moisture content matches the moisture content of *Pinus radiata* material used to calibrate USV against MFA for these types of ultrasonic transducer in a previous project.

The actual measurements of discs were carried out at the University of Canterbury (UoC) USV facility (Figure 4), a very similar system to the one at Scion. The fully automated nature of UoC equipment allowed labour costs to be reduced.

Grain orientation by T2 imaging

The Laboratory T2 grain angle instrument developed at Scion was used to map the surface and dive angles (into or out of the wood surface) along four radii for each disc, i.e., in the North, East, South, and West directions. The radial measurement resolution used was 5 mm. A considerable amount of method development work has been carried out to improve the original method.

Discs were dried as described in the earlier section prior to T2 measurements. A study was done comparing spiral grain angles measured on cores with the spiralometer instrument, with measurements made on radial x longitudinal faces cut to measure radial transects parallel to the 10-mm core hole. The longitudinal and radial surfaces were prepared for T2 measurement by sawing followed by electric rotary hand tool planing. The spiralometer and the T2 instrument showed similar trends, but the magnitude of dive angle variation from bark-to-bark was approximately 40% less than the magnitude of spiralometer bark-to-bark variation. The fact that the T2 instrument is calibrated with a wound wire calibration standard made us look more closely at the T2 surface preparation method.

A second experiment was done using discs similar to the samples being measured for this study. The experiment compared T2 measurement on longitudinal x radial faces prepared, with an electric rotary hand tool planer, to manual measurements of dive angle using the angle of resin canals on longitudinal x tangential faces made by splitting the radial strip tangentially. These measurements also showed that T2 dive angles were 30 to 40% lower than the manual resin canal measurement method when the surface is prepared with an electric rotary hand planer.

A third experiment was done using 25-mm radial x 25-mm tangential small clears. This experiment compared the average of the scribe angles on both tangential faces of each specimen to T2 results on the radial faces where handplaning with a very sharp plane blade was used to prepare the radial faces. The T2 dive angle measurements on the handplaned radial faces were in good agreement with the average of the scribe angle measurements on the two adjacent tangential faces.

A fourth experiment was done using blocks of wood. This experiment showed that surfaces prepared by sawing had measured dive angles up to 30% lower than those measured on surfaces prepared with a very sharp handplane. Also, the T2 measured surface angle on surfaces prepared by sawing is up to 4 degrees out. The direction of change in surface angle is consistent with a brushing effect on surface fibres in the direction the saw teeth are moving across the sample. Also, the influence of sawing on both surface and dive angles is greater when the in-feed direction of sawing is in the fibre rising direction, and less when the in-feed direction is in the fibre diving direction. Handplaning with a very sharp blade was adopted as the preferred method for T2 surface preparation.

A workstation was set up for honing handplane blades (Figure 5). The workstation is composed of a honing jig and four flat glass plates used to hold sheet abrasives. Plane blades were honed with three microbevels on both flat and bevel sides, using grit sizes down to 0.3 micrometers. The purpose of honing a plane blade is to prepare a blade that keeps its edge by providing a cutting edge that is free of deep scratches and less prone to rounding and fracturing.

Another observation was the large differences of the dive angles (spiral grain angles) of the longitudinal x radial faces between the four radii. The frame of reference for the measured angles is the bottom plane of the disc. This plane is assumed to be perpendicular to the stem longitudinal direction because of the way the stems are supported and cut at right angles with the chainsaw cutting jig. In fact, the bottom plane of the disc is more dependent on the longitudinal direction of the whole part of the stem that remains uncut at the time of disc cutting. However, it was noted that if surface angles of adjacent radii from the same disc are used to adjust the measured dive angles, there is a massive 90% reduction in the circumferential variation in radial mean spiral grain angle (Figure 6). For example, the T2 measured surface angles on the North and South radii are used to adjust the measured dive angles on the East and West radii to produce a tilt adjusted dive angle for the East and West radii as if the disc was cut perpendicular to the local growth direction. Similarly, the East and West surface angles are used to adjust the North and South dive angles. After tilt adjusting, four measurements are available every 5 mm along each radius – the raw surface and dive angles, and the tilt adjusted surface and dive angles. The tilt adjustment is made so that the tilt-adjusted surface angles in opposite directions (North and South, or East and West) are equal and opposite.

Figure 1. Camera/light booth.

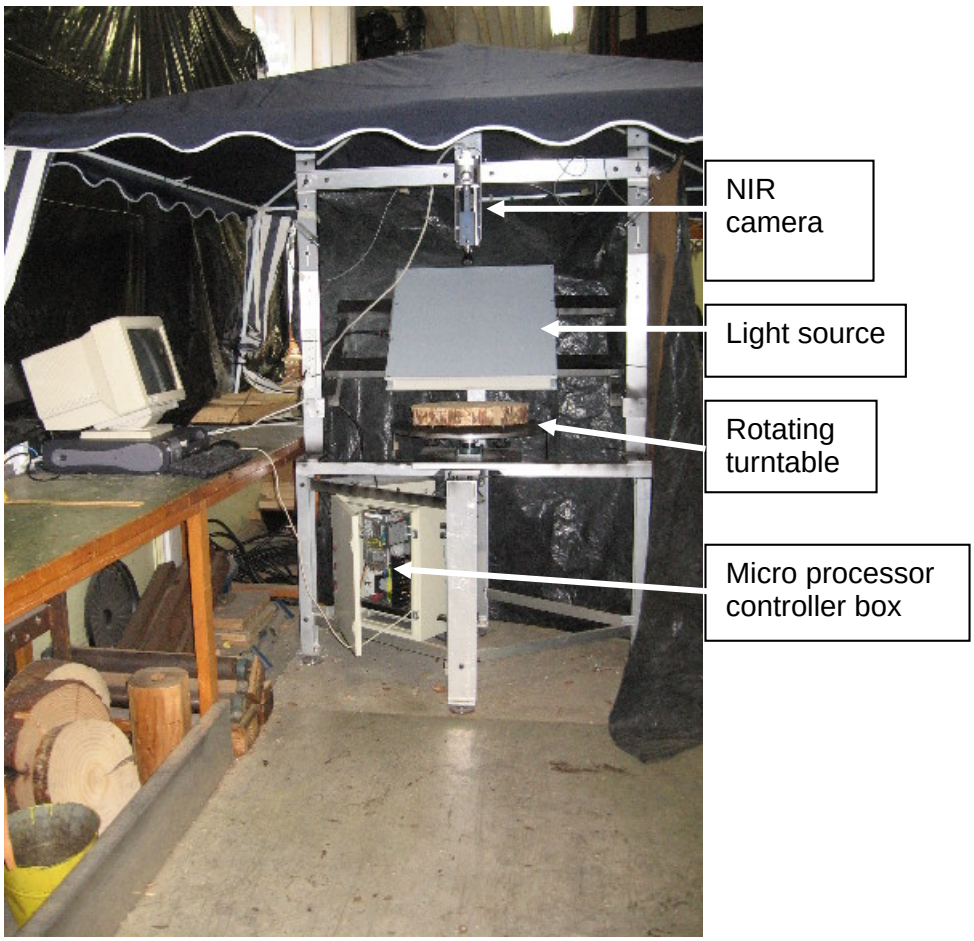
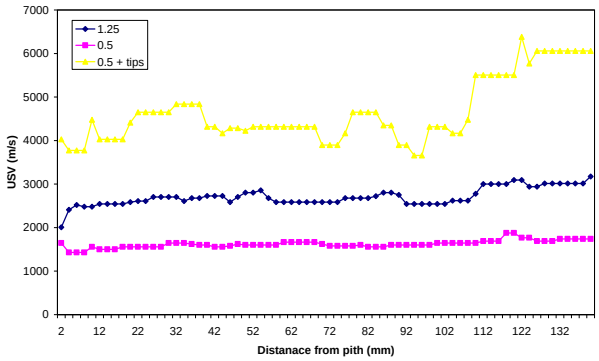
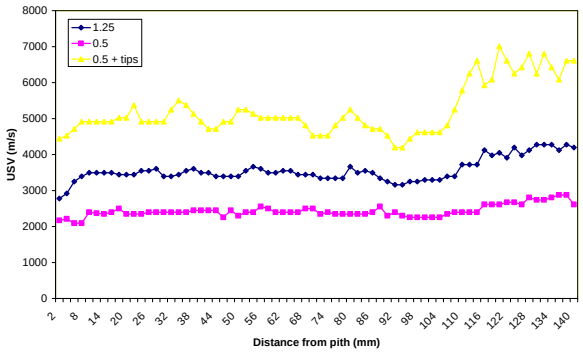


Figure 2. Full view of NIR rig.

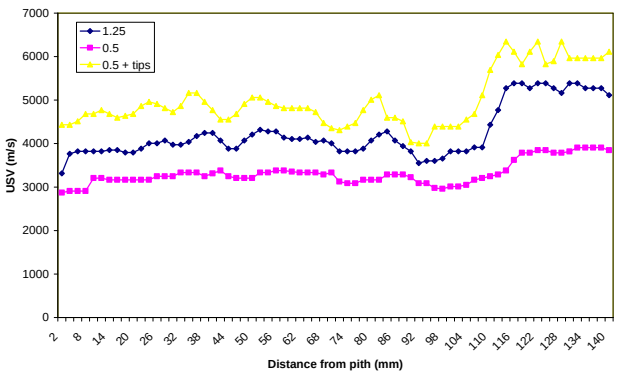
A.


1.25
0.5
0.5 + tips
USV (m/s)
Distanace from pith (mm)

B


1.25
0.5
0.5 + tips
USV (m/s)
Distance from pith (mm)

C


1.25
0.5
0.5 + tips
USV (m/s)
Distance from pith (mm)

D

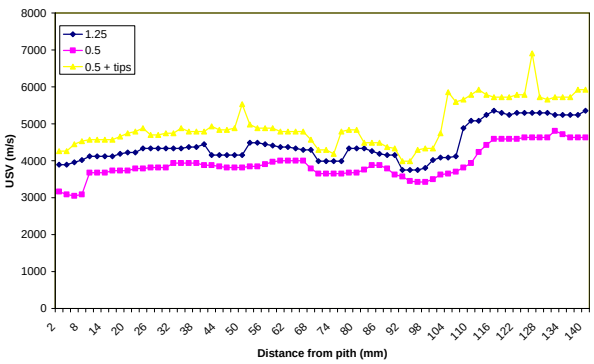

1.25
0.5
0.5 + tips
USV (m/s)
Distance from pith (mm)

Figure 3. USV measurements of 12.5 (A), 25 (B), 50 (C) and 100-mm-thick (D) radial strips using 1.25 MHz, 0.5 KHz and 0.5 KHz transducers with pointed tips.

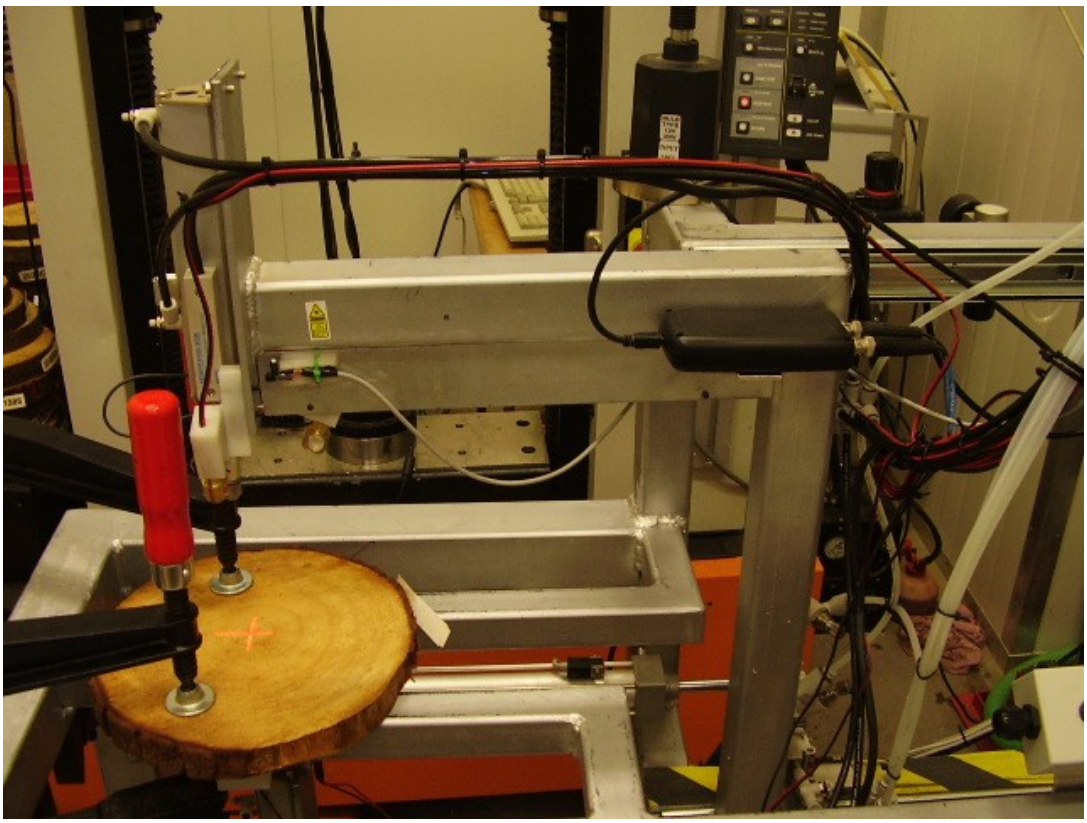


Figure 4. University of Canterbury fully automated USV measurement apparatus.

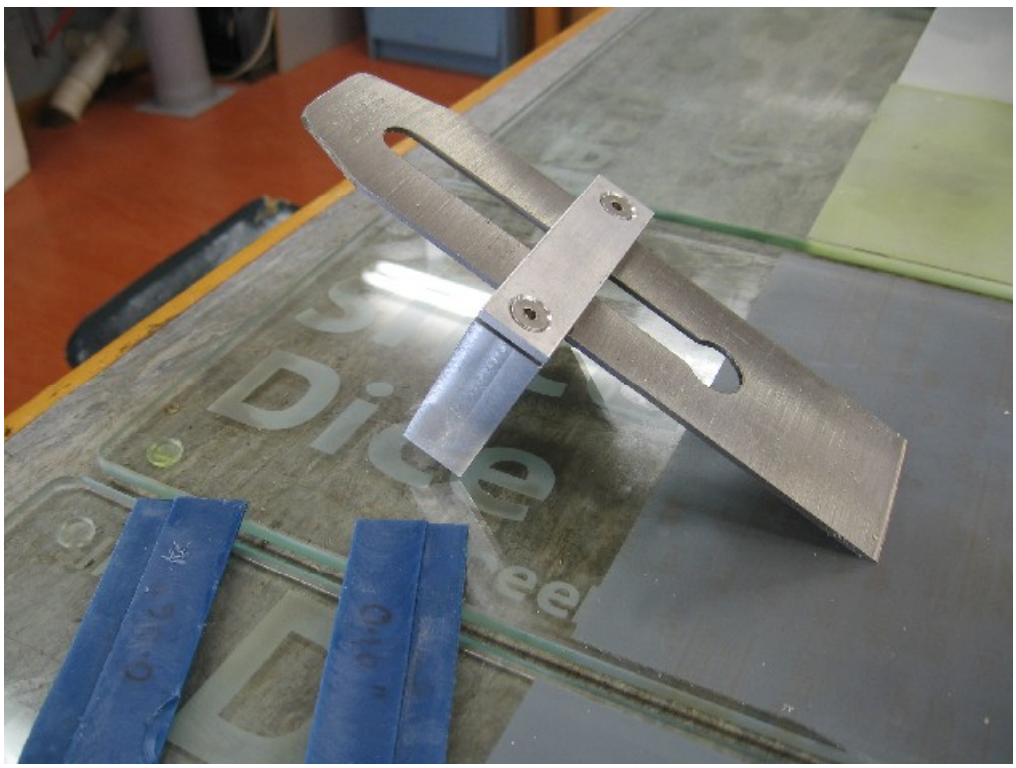
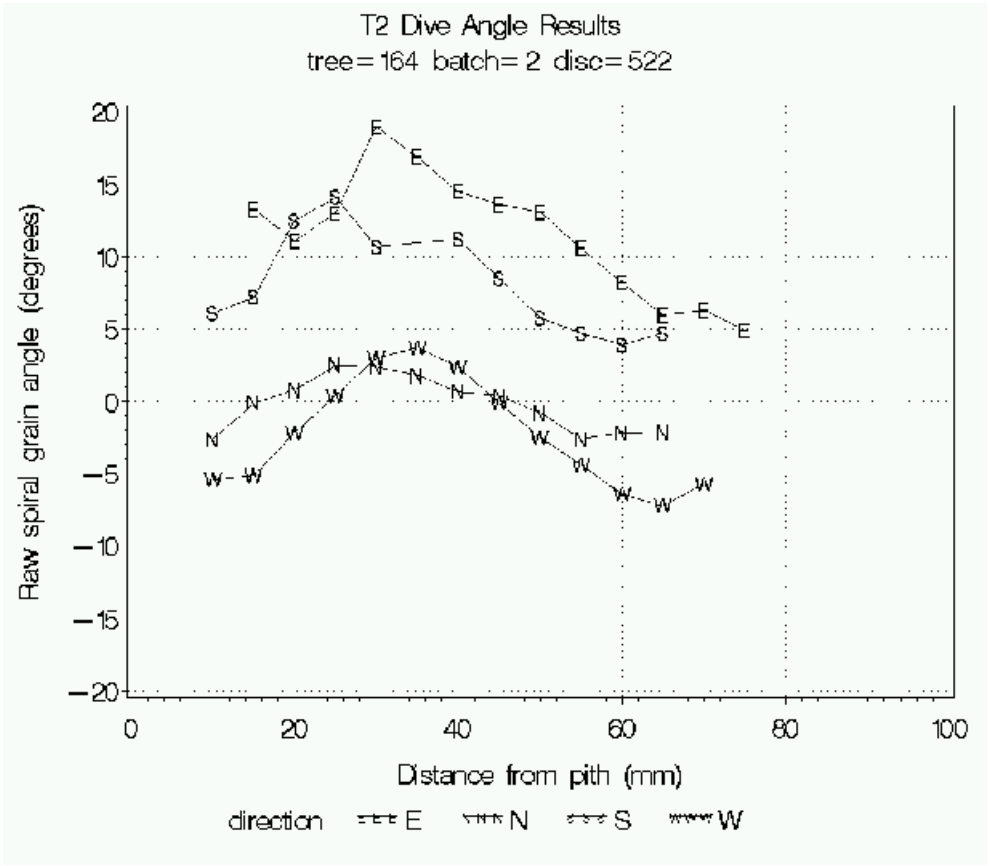


Figure 5. Workstation for honing handplane blades.



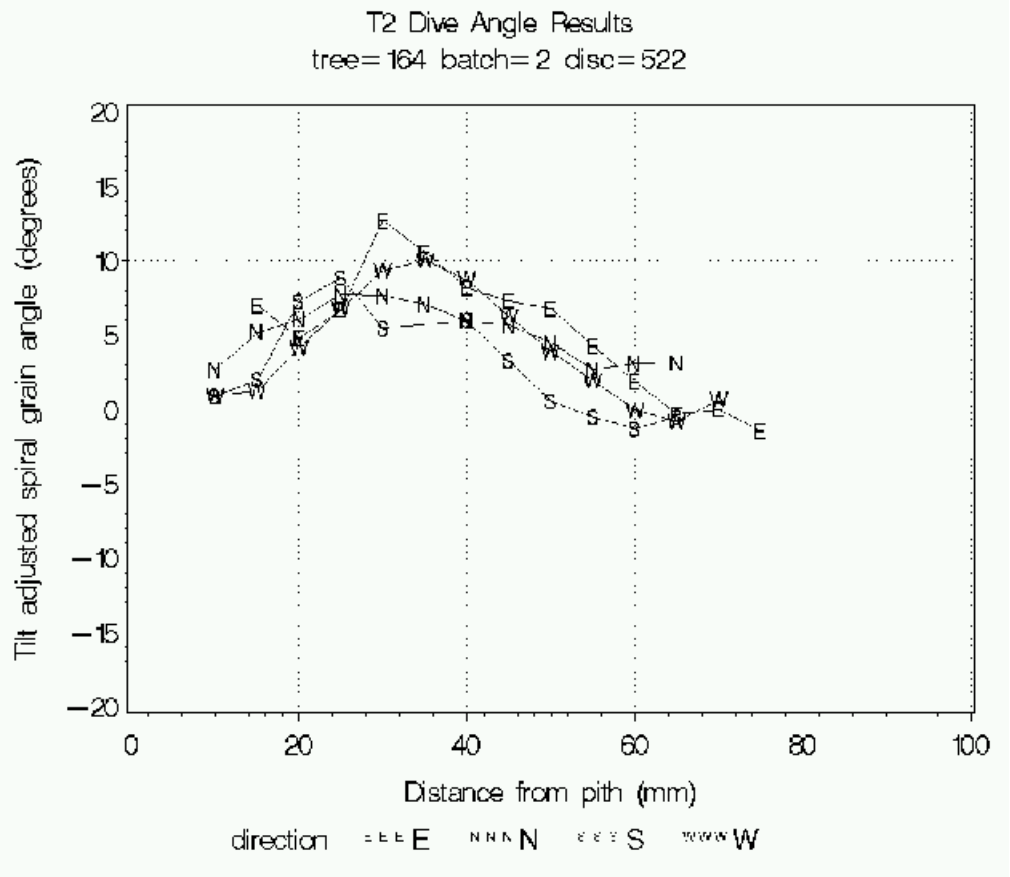


Figure 6. Spiral grain angel measurements for four radii before (top) and after (bottom) tilt adjustment.

APPENDICES

Procedure for scanning discs on NIR Rig - July 2008

Setting up the camera

1. Switch off the neon lights in the workshop. If others working at least ones directly on top of the instrument should be switched off. Light switches are on the back wall next to USV scanning room.
2. Switch on microcontroller main switch and lights. Camera is connected to main and will be on. Lights need to be on at least 30 mins before scanning.
3. Remove lens cap.
4. Turn on the computer login to network and open **Spectral Cube**. Ignore the error message. A popup widow then comes up saying full spectra view. Click apply. If it doesn't come up click on two dots and go and select the file NITE_1106_82_full.bnd (this is for full range 900-1700nm). For scanning 1000-1700nm another file is available.
5. Spectral Cube opens up three windows. One with image, another with spectral view with red and blue ref lines. These lines should be fairly straight; might have to fiddle with light sources until a fairly straight line is obtained. Third window at the bottom.
6. A red image is a sign of an overlading. Untick **Ext** check box and select suitable **Frame rate** and **Exposure time**. 20 Hz/sec and 25ms usually work. Image should look b/w with out red areas. Tick **Auto**. **NUC** comes up automatically. **Shutter** open do not worry.
7. Prior to measurements camera needs focussing using b/w pattern strip until a sharp border between b/w areas is achieved.

Reference Measurements

8. For measurements external trigger is used. External trigger sends signals to board in microcontroller to trigger turntable movements and camera functioning.
9. Open Basic X down loader by clicking the icon on desktop*. File< open editor*
10. Opens BasicX Editor. *Open project< open* **triggersonly-fast.bxp** file. Down load the program to microprocesser. <*compile & run.*
11. Go to Spectral Cube software page. Cube maker window. Enter same frame rates and exposure time as before and press SET
12. < Cube maker window<*recording mode*<click *free* option for external trigger. *Scripted* is used for internal trigger. Tick **Ext** check box on the side panel**.** (Frame rate is greyed on now). Tick AUTO it sets up NUNC value automatically.
13. To record reference spectra <Cube maker window< give a file name<press **SET**. Otherwise it records on the previous file name. Manually drive the disc into position and then Press GO and red start button on the microcontroller box.
14. Scan takes about 40 sec. Check if some frames are dropped out of 32 frames (for references). Press STOP.
15. Do dark and white references first thing before start. Dark reference is done with lens cap closed. White ref is a strip of white Teflon. Repeat once again during the day. Give chronological file names so Mark knows which ref files to use with which samples. Each day clean up any unwanted ref files in D:/NIR to avoid confusion later.

Disc measurements

16. Prepare a smooth the disc surface by using the skill mill. Mark a North (ref line). Align the disc using the two laser pointers on the pith and north mark on the rotator. Switch for laser is behind the computer. Before proceeding **REMEMBER** to switch off laser.
17. For actual samples also follow step 9-12. HOWEVER this time use **Thisworks_highres.bxp** file and follow same procedure as per refs.
18. Check if some frames are dropped out of 2304 frames (for actual discs). Press STOP.

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