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HIGH FREQUENCY RADAR FOR DETECTION OF STEM ATTRIBUTES

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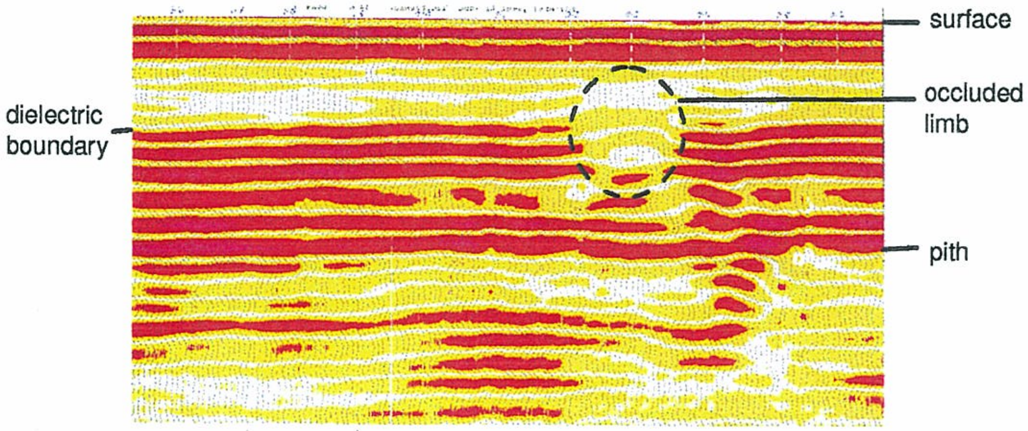
Executive Summary

All whorls of occluded branches were successfully identified by linear (lengthwise) radar scanning of a fresh *Pinus radiata* log. To our knowledge, this is a completely new and innovative use of radar technology.



Radar scan of a 1 m section of Pinus radiata log

The length of the clear wood zone between whorls was identified. However, the depth of the clear wood over branch stubs was not able to be determined visually from the scanned image.

The preliminary results obtained in this study indicate the potential for radar scanning technology to be used for detection of internal defects (particularly size of the defect core) in commercial applications. However, considerable development work remains to be done before a commercial system can be produced. The first system could be a stand-alone radar scanner for standing or felled stem assessments. The second could see the utilisation radar scanning in conjunction with other scanning technologies to produce an integrated technology package for log-sorting in to various processing or end-use categories.

Introduction

The purpose of this research is to:

- Review literature since the July 1998 report (Parker, Gibbons & Riddle, 1998)
- Trial radar technology using improved techniques learned in the 1998 work
- Provide recommendations as a result of these findings.

Background

Non- destructive testing of wood

Internal characteristics of tree stems can result in value loss when stems are cut into logs and logs subsequently manufactured into products. Many of these features cannot be seen from the outside of the stem. However, if the internal structure of the stem can be imaged and interpreted, cutting decisions can be made before the stem is opened and value recovery maximised.

Radar

The radar scanning unit consists of a transmitting antenna and a receiving antenna mounted in a scanning head. The radar is detecting the differences in dielectric constant between different regions of the stem. The dielectric constant of a material is a measure of the ability of the material to hold an electric charge on its surface. Air has a dielectric constant of 1, and water, 81. Fresh *Pinus radiata* has a dielectric constant of approximately 65. Features of the stem have differing dielectric properties due to their moisture content and the material they are made of. For example late wood is less saturated and more dense than early wood and so has a different dielectric constant.

Current work

The results of research in the 1997/1998 year showed that radar can image features inside logs. However the results were equivocal. The logs used were short (1.5 m) and had occluded whorls at each end. Radar images of these whorls were degraded by "end effects" where the radar beam was disrupted by reflections off the log end.

In the current research, we limited our goals to identifying the linear location (distance from large end) of pruned whorls, and the depth of clear wood. This work was done with short logs with the whorl located half way along the log to minimise end effects. A long log - more representative of "real-life"- was also scanned.

Literature review

Eleven databases were searched for combinations of the following key words:

radar, microwave, CT, computed tomography, non destructive testing, wood, log, timber, lumber, tree

The databases searched were:

Main

• CAB abstracts	1972 - 1998
• CRIS/USDA	1972 - 1998
• NTIS	1972 - 1998
• Ei Compendex	1970 - 1998
• INSPEC	1969 - 1998
• JICST - Eplus	1985 - 1998

Secondary

• AGRIS	1974 - 1998
• PAPERCHEM	1967 - 1998
• Derwent Biotechnology Abstracts	1982 - 1998
• Wilson Applied Science & Technical Abstracts	1962 - 1998
• Aerospace Database	1962 - 1998

A comprehensive search of the World Wide Web was done with the search engines:

- Ask Jeeves
- Alta Vista
- Profusion.

Radar was <u>not</u> identified in any search. Results of the searches are held at Liro.

Radar scanning trial

Purpose

To determine the degree and accuracy of internal stem attribute recognition.

We chose occluded branch whorls and stubs as a stem feature which we had experience in identifying. The features measured were linear whorl location in the stem (distance from butt), and depth of stubs from surface (and corresponding clearwood depth).

Sample logs and method

Electrical interference

Significant delays during the trial were caused by external electrical interference of the radar scanner. It was suspected that aviation radar operating at the airport nearby was the cause. This could not be tested without closing Rotorua Airport, so we worked with the interference. Rotorua airport has Distance Measuring Equipment for guiding aircraft which transmits a continuous signal at 1.019 GHz, near the centre frequency of the antenna (1.5 GHz). An intermittent signal (one rotation every eight seconds) is emitted from aviation radar located on the Kaimai Ranges at 1.03 and 1.06 GHz.

After delays and interference and viewing the scan images in real time it was decided to limit the trial to:

- Two short logs - scanned longitudinally (from large end to small end and back)
- One short log - scanned radially at a whorl on a turntable
- One fresh 4 m x 0.25 m SED log - scanned longitudinally.

To rigorously test the performance of the radar images with reality, the location and shape of the whorls (number of branches and depth of clear wood) in the log were determined by cross-sectional analysis (Somerville, 1985).

Scanning

Longitudinal scans - short and long logs

Marks, ten centimetres apart, were painted on the external surface of the logs. The radar antenna was moved, by hand, as close to the surface as possible, along these marks at a fixed speed determined by times called out by a timekeeper. While scanning, a "datum" line was placed on the radar scan file corresponding to each 10 cm line past for later reference. Each log was scanned along the top, bottom and each side (Figure 1).

Radial scan - short log

One log was placed on a turntable and scanned at the nodal swelling and 10 cm above and below the swelling (Figure 2). Again reference lines were added to the radar scan file at every quarter turn.

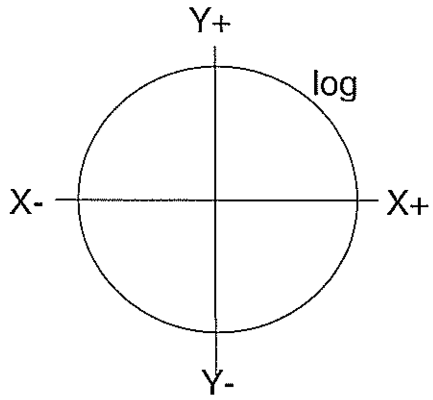


Figure 1 - Scanning axes from large end of log

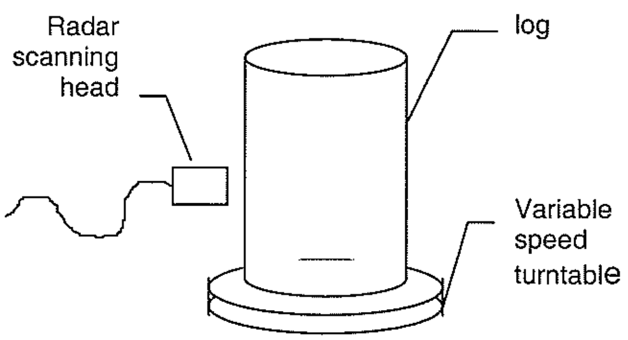


Figure 2 - Radial scanning of log

Results

The radar scan data is presented in the form of a "line" (coloured) plot and superimposed "wiggle" (black and white) plot. The changes in colour (and corresponding change in amplitude of the "wiggle") indicate material of different dielectric constant. Water content has the greatest influence on dielectric constant.

Short logs

Longitudinal scans

The scans were difficult to interpret even though the whorls were located half way along the log to reduce end effects (Figure 3).

Figure 3 - Longitudinal radar scan of 1.5 m log. Changes in colour and "wiggle" indicate dielectric boundaries

Radial scans

Again the scans were poor and difficult to interpret (Figure 4). The turntable wobbled as it turned adding "noise" to the radar signal and making it less clear.

The low moisture content of the short logs (71 % and 73 %) may have contributed to the poor scanning results.

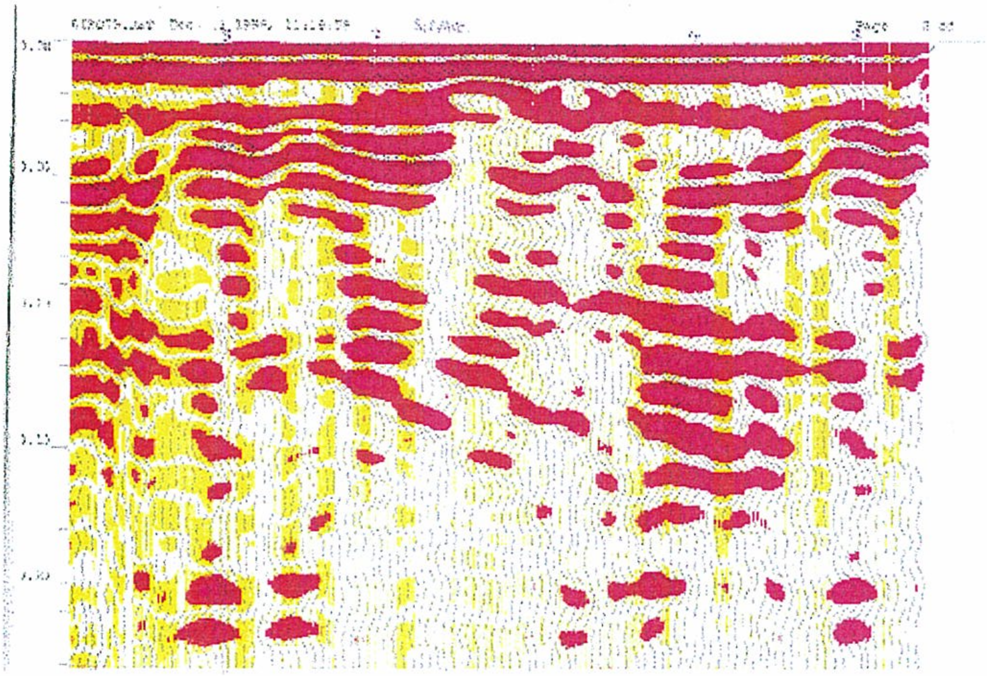


Figure 4 - Radial radar scan over whorl

Long log

The long log had a moisture content of 130 %. The scan images were much easier to interpret (Figure 5). The location of the whorls was obvious from the scans.

Results for location of whorls are presented in Table 1 and Figure 6.

Actual	Radar estimate location from butt (m)			
distance from butt (m)	Y+ axis	Y- axis	X+ axis	X- axis
0.21	*	*	*	*
0.70	-	~ 0.65	-	~0.55
0.92	~0.95	0.95	0.8	0.98
1.40	-	~ 1.2	~1.4	1.45
1.79	1.9	1.8	~1.8	~1.8
2.27	-	~ 2.1	2.2	2.25 - 2.4
unseen when log analysed	2.4	2.4	2.55	~2.7
3.09	3.2	3.1	3.2	-
3.61	*	*	*	*

* Whorls at the ends of the log were difficult to detect because of the close proximity of the wood/air boundary

Table 1 - Comparison of actual whorl location and estimated (radar) whorl location from the large end

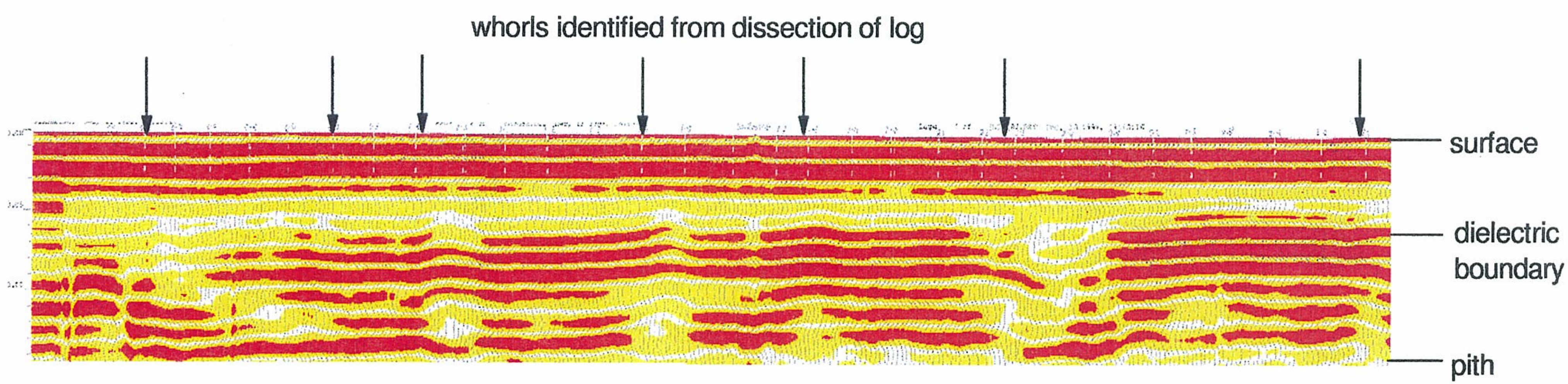


Figure 5 - Radar scan image of 3.1 m by 0.14 m section of log showing the estimated location of whorls of occluded branches.

LED is shown on the left.

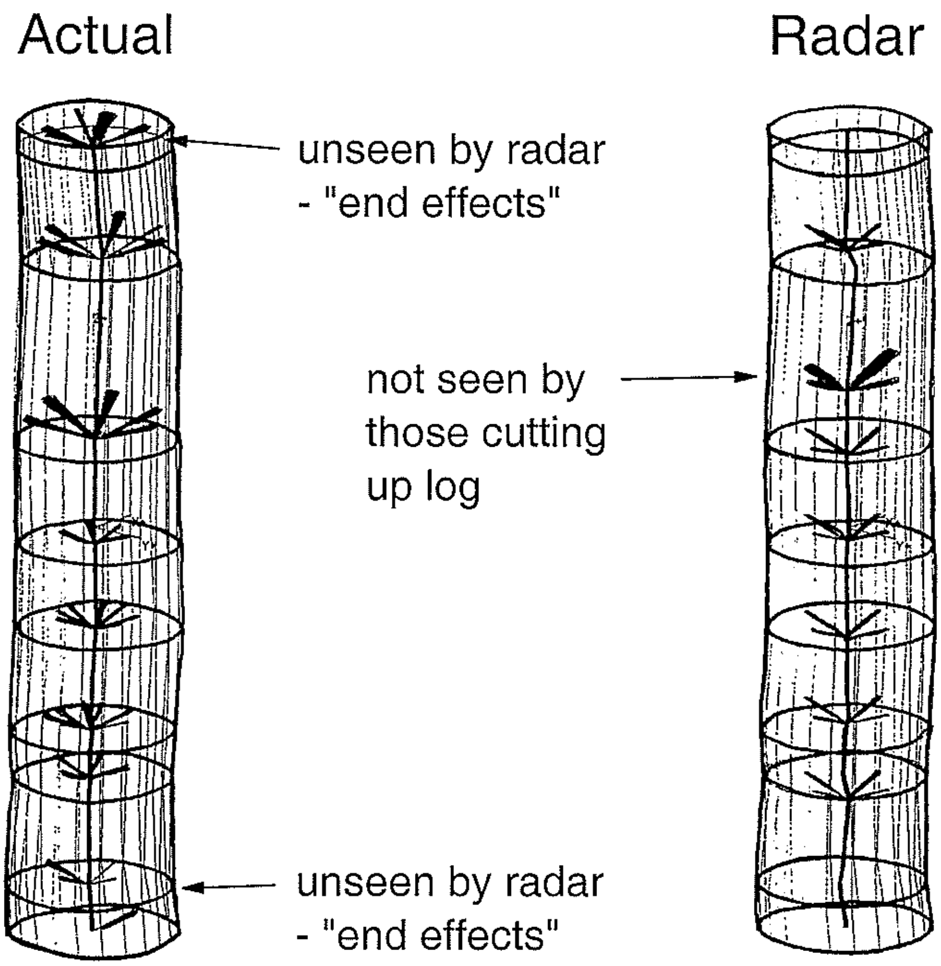


Figure 6 - Images generated by TreeMaps comparing actual and estimated (from radar) linear location of whorls from the large end (disregard branch size and shape)

Depth of clear wood

We attempted to measure the depth of clear wood from the radar scan images but results were mixed. This may be due to the difficulty of identifying a small target among background clutter (Figure 7). The presence or absence of bark had no effect on the radar images. Some branch stubs appeared on the radar scan to be the correct depth below the surface of the log (Figure 8). Other branch stubs could not be seen at all on the scan images.

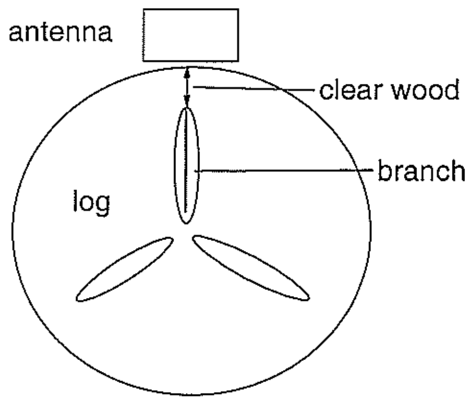


Figure 7 - Cross section of log indicating the internal features and location of antenna

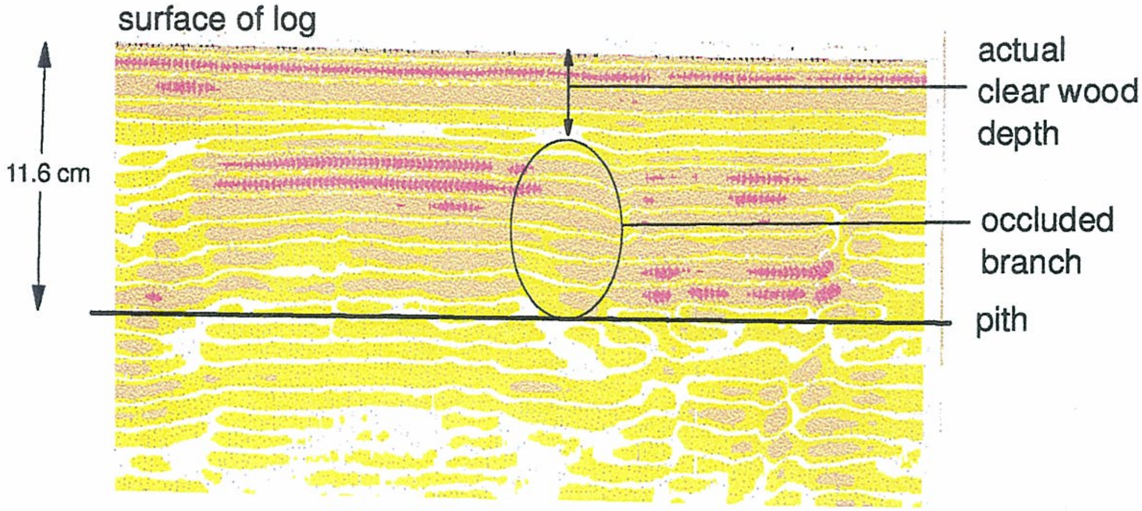


Figure 8 - Example of difficulty estimating depth of clear wood from radar scan. Large end at left, small end at right.

Discussion

The best scans were obtained from the fresh long log and whorls of occluded branches could be located. This is a significant finding.

The drier wood of the short logs could have made interpretation more difficult because the radar signal could travel further and was reflected off occluded branches on the far side of the log (Figure 8). In wet wood the radar cannot travel so deeply, and multiple reflections are less likely.

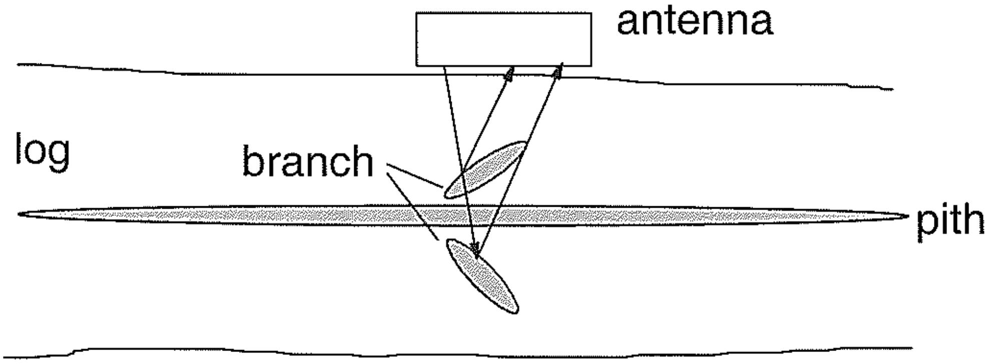


Figure 8 - Multiple reflections from deeper structures in the log

Future Directions

The preliminary results obtained in this study indicate the potential for radar scanning technology to be used for detection of internal defects (particularly size of the defect core) in commercial applications. However, considerable development work remains to be done before a commercial system can be produced. The first system could be a stand-alone radar scanner for standing or felled stem assessments. The second could see the utilisation radar scanning in conjunction with other scanning technologies to produce an integrated technology package for log-sorting in to various processing or end-use categories.

Building on the strong relationship between ***Forest Research*** and Detection Solutions (the New Zealand agents for radar technology), a Memorandum of Understanding has been entered to further investigate the potential use of radar in forestry operations. If successful, the result will be the production of a radar scanning tool for stem assessments which will be made available to industry through Detection Solutions.

Forest Research will be responsible for development of the fully integrated log-sort solution, but at this stage it is too early to state whether radar will be part of that solution since several different technologies are currently under evaluation.

A provisional, broad, patent application has been filed covering use of radar in several modes of operation to protect the invention whilst essential on-going assessment and development is undertaken.

References

Parker, R.J.; Gibbons, W.; Riddle, A. (1998) *Potential log scanning technology*. Confidential LIRA Report.

Somerville, A. (1985) *A field procedure for the cross-sectional analysis of a pruned radiata pine log*. FRI Bulletin No. 101. New Zealand Forest Research Institute.