Non-destructive detection of the heartwood-sapwood barrier

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Confidential Report for the Specialty Wood Products, Forest Growers Research, NZ

Date: September 2019

Publication No: SWP-T088

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Summary

This study examined the feasibility of using synthetic aperture radar (SAR) imaging to identify the heartwood-sapwood barrier in trees (Eucalypt *globoidea*, Eucalypt *bosistoana* and Cupressus *ovensii*). The dielectric properties measured of the heartwood and sapwood for each species demonstrated sufficient variation to alter the behaviour of the radar frequencies used. A SAR system was used combined with custom build code and software.

The SAR system was successful in detecting the amount of heartwood present in a tree cross section to within 2.2% accuracy, when compared to using a ruler and physically measuring the cross section. The SAR system was also able to determine the distance from the edge of the tree to the heartwood. These results are promising and would need to be verified across a larger sample size.

Materials

Cut trees were provided by Paul Millen as follows:

1. Eucalypt *globoidea*, 12 years old
   - a section from near bottom of tree (to maximize heartwood content)
   - a section from the top of the tree (with little or no heartwood).
2. Eucalypt *bosistoana*, 12 years old
   - a section from near bottom of tree (to maximize heartwood content)
   - a section from the top of the tree (with little or no heartwood).
3. Cupressus *ovensii*, 10 years old
   - a section from near bottom of tree (to maximize heartwood content)
   - a section from the top of the tree (with little or no heartwood).

Samples were approximately 30cm in length and varied from 12cm to 16cm in diameter for the larger cuts and 4cm to 6cm for the smaller cuts.

Figure 1. From left to right, Eucalypt *globoidea*, Eucalypt *bosistoana* and Cupressus *ovensii.*

A Keysight FieldFox Portable Vector Network Anlayser (N9918A 25.6 GHz), S11 mode utilizing three separate wave guides were used; low frequency waveguide (2.5-4GHz), medium frequency waveguide (5-8.5GHz) and high frequency (10-18.5GHz), -15dBm power output and 401 frequencies with a sweep time of 250ms. A Keysight dielectic probe was used to measure the relative dielectric permittivity (e' and e'') of each sample.

Methods

Synthetic aperture radar (SAR) imaging was used at three separate broadband frequencies (low, medium and high). Each tree sample was scanned at each of the frequency ranges at multiple points around the around a cross section; the cross section scanned set at mid-height of the sample. Data was collected and transferred from the FieldFox, and custom build software was used for the image reconstruction. A depth camera was attached to the waveguide to accurately determine (+/- 1mm) the distance of the waveguide to the object.

Each sample was then cut at the scanned cross section and an RBG photo was taken. A ruler was used to measure the diameters of the tree as well as the heartwood and sapwood diameters for each species.

Post cross section cut, the dielectric parameters (using a dielectric microwave probe) were measured to aid in understanding the physical properties of the wood.

Adobe photoshop was used to count the number of pixels in the heartwood section via a threshold analysis; and to determine the distance of the heartwood boundary line from the outside of the tree via a glowing edge filter.

K-mean clustering was used to automatically classify the pixel clusters, however, due to the limited sample size it was discarded.

Results & Discussion

Note that for the results and discussion, only the larger, lower sections of the trees are presented. The small diameter of the upper sections are too narrow in diameter to give a reliable result (system improvements discussed later in the document).

The Dielectric Constant (relative permittivity)

The dielectric constants of all tree species, for both the heartwood and sapwood were dependent on the frequency scanned. All tree species demonstrated significant differences between the heartwood and sapwood, regardless of the frequency used (figure 2 to 4).

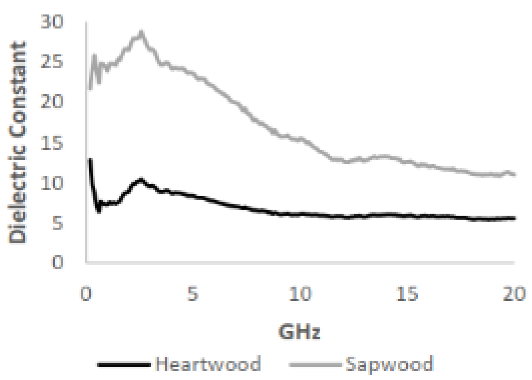

Figure 2. Dielectric constants for E. globoidea

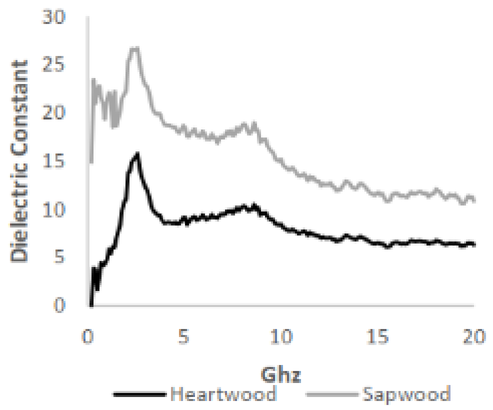

Figure 3. Dielectric constants for E. bosistoana

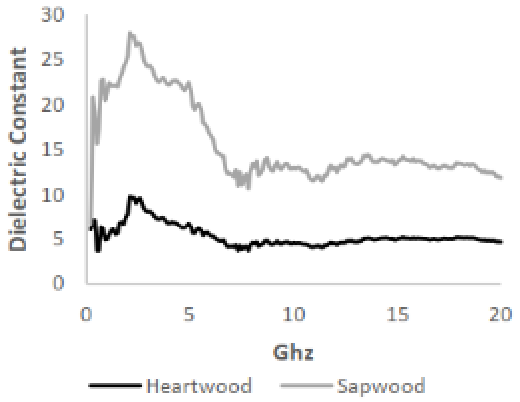

Figure 4. Dielectric constants for C. ovensii

Image Reconstruction for Heartwood Detection

The reconstructed SAR images (adjusted for the dielectric properties of the wood) are listed in figure 5 to 7. For each SAR image, the reflection of the heartwood-sapwood barrier is represented by the bright white rings.

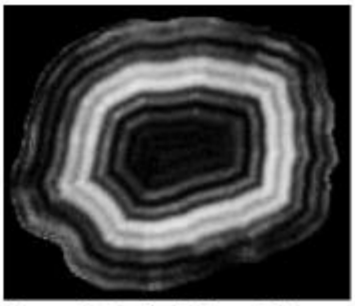

Figure 5. E. *globoidea* SAR image.

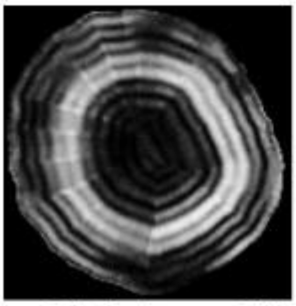

Figure 6. E. *bosistoana* SAR image.

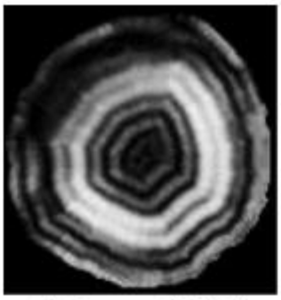

Figure 7. C. *ovensii* SAR image.

Quantification of Heartwood Content in Trees

Cupressus *ovensii* is used as the example of how the quantification of the heartwood content occurred.

Figure 8 is the SAR image (adjusted for the dielectric properties of the wood). Figure 9 is a threshold analysis of the SAR to isolate the heartwood section in Photoshop; the black pixels represent the heartwood area. Figure 10 a glowing edge filter of the SAR; the distance to the inner most glowing circle represents the distance from the edge of the tree to the heartwood-sapwood barrier.

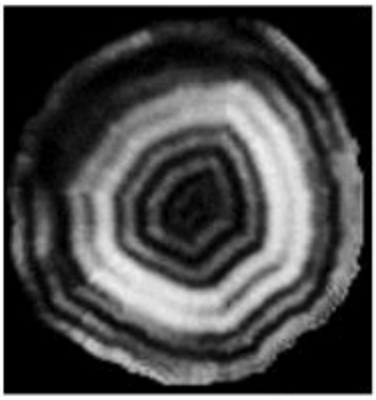

Figure 8. SAR of C. ovensii

Figure 9. Threshold analysis for heartwood area of C. ovensii

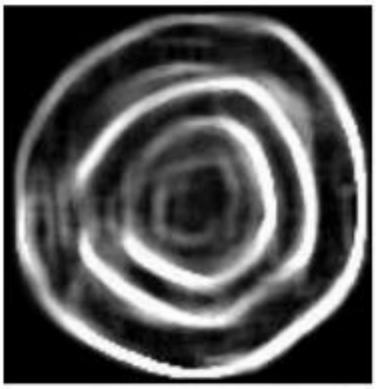

Figure 10. Glowing edge filter for distance from edge to heartwood of C. ovensii

Table 1. Heartwood (HW) analysis for all trees.

Sample	% HW (with a ruler)	% HW via SAR Image Threshold Analysis	Error between ruler and SAR analysis	Distance (mm) to HW Barrier via SAR Image Glowing Edge Analysis
E. *globoidea*	30.2%	28.5%	-1.7%	33
E. *bosistoana*	25.3%	27.5%	-2.2%	35
C. *ovensii*	19.9%	19.1%	0.8%	34

Figure 11 is a plot of the distance (mm) from the edge of the tree to the heartwood section (for C. *ovensii*), at 45-degree increments around the tree. The results indicate the depth a saw could be placed, from the edge of the tree, to maximize heartwood recovery.

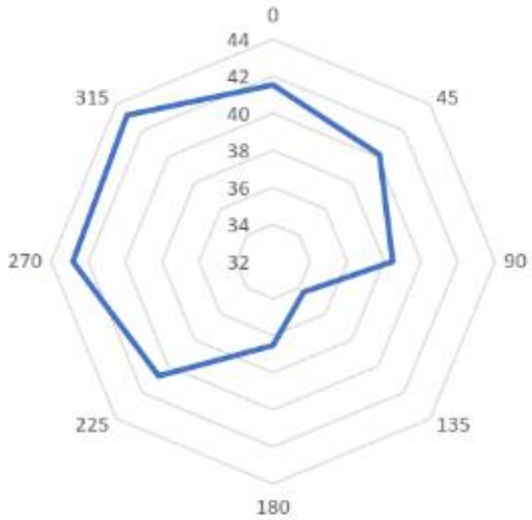

Figure 11. Plot of the distance (mm) from the edge of the tree to the heartwood barrier for C. *ovensii* at angles around the tree (o to 360)

Conclusion and Future Work

The SAR system was successful at determining the amount of heartwood in cross sections of the trees, as well as the distance from the edge of the tree to the heartwood barrier. While the results are promising, a larger sample pool would be required to verify the results and increase accuracy.

Future work will involve: building a prototype to use in the field, largely comprising of off the shelf components; building a larger dataset; automating the image analysis; speed improvements in the code and trialling the use of simple time domain data (instead of SAR) to compare for speed / accuracy