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Unitec Research Committee

Final Report Template

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Project Title:	Development of a wood density independent function for electromagnetic measurement of timber properties
Project Code:	RI12002
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Executive Summary

The work undertaken in this project was aimed at developing a technique which could measure the moisture content of lumber at moisture contents typically found post drying. It involved the measurement of the dielectric properties of timber samples at a broad range of moisture contents (10% to 100% by dry basis) and relating this electrical property to physical properties.

Using the measured and published data for pinus Radiata timber a refinement was made to the universal density independent model for moisture measurement and tested. This showed that the existing model failed for moisture contents below 33%, where all free water has been removed from the timber. By incorporating the ratio of earlywood and latewood (the seasonal growth rings) as a simple linear correction to the model errors of less than 0.6% can be achieved in the measurement of moisture content. This work has shown that wood below 33% cannot be considered as a homogeneous but rather as a layered material.

The quality assured outputs of this work are currently under development with a journal paper and conference paper for submission this year.

Background

This project is in-line with the Electrotechnology Departments strategy of developing a centre of excellence in New Zealand in the area of Civionics. This is the blending of electrical and electronics with civil engineering for the purposes of structural monitoring, building health, Intelligent buildings and the development of sustainable and novel building technologies. This builds on Unitecs strengths in Building, Architecture, Civil and Electrical Engineering.

The final performance of any product or structure is heavily influenced by the properties of the raw materials used. Wood is one such raw material extensively used in both structures and products (such as paper, plywood and LVL). The fundamental quality influencing property of wood is its moisture content (mc). The assessment mc is critical in the processing and application of wood based products and has ramification on energy use during processing and structural performance.

Traditional methods of real-time measurement of wood moisture are inherently inaccurate (>10% error) as none of the current in-line techniques cater for the large variation in basic density of wood and hence these errors flow into the moisture content measurement. The technique proposed will produce a model for electromagnetic measurement of timber mc which will cater for and negate the effects of basic density, in essence a true measurement of moisture content, which can be applied in real-time measurement situations.

Such a sensor can be used for increasing energy efficiency in wood drying kilns (by segregating timber into batches based on mc), and also as a key indicator in the measurement of wood strength and stiffness for structural use. In addition to the commercial applications of this work publication of such a model would be of great interest in both Forestry and Electrical Engineering journals

Aims and Objectives

This project encompassed three main objectives:

- Develop a data base of permittivity data for timber samples covering a range of species and basic density from both measurement and literature sources.
- Explain the deficiencies of existing density independent permittivity functions (DIF) in terms of physical timber properties
- Develop corrections to the DIF which will allow for the effects of basic density to be negated in electromagnetic moisture measurement in wood.

Methodology

This project contained five major steps.

1. A universal software definable radio system (USRP), operating in the 900MHz to 6GHz range, was configured to perform transmission coefficient measurement (magnitude and phase of the transmitted energy) through a waveguide measurement cell.
2. With the assistance of Scion four wood sample sets of 25 wood samples each were gathered. Each sample set was equilibrated to a specific moisture content (10% ,33%, 50%,and 100% by dry basis).
3. Using a six-port reflectometer, on loan from Scion, both transmission and reflection measurements were performed in the range of 2 to 6GHz. From these measurements the permittivity of each wood sample was determined for each of the three possible wood grain orientations using the Nicholson,Weir,Ross Algorithm.
4. After the microwave measurement each sample had the following physical properties measured to allow for model development
   a. Actual moisture content
   b. Basic density
   c. Number of Early wood\ Late wood bands
   d. Volume % of Early wood\Late wood banding
   e. Grain angle
5. Using the experimental data gathered a new dielectric mixture model was developed that related the measured wood permittivity to the moisture content of wood independent of the basic density.

Outcomes/findings

Wood has an anisotropic structure that arises from the cell pattern laid down in a defined direction by seasonal changes while the tree is growing. This Earlywood Latewood layering has the effect of ducting the microwave energy in a preferred direction (polarisation of the fields) as shown in Figure 1 below.

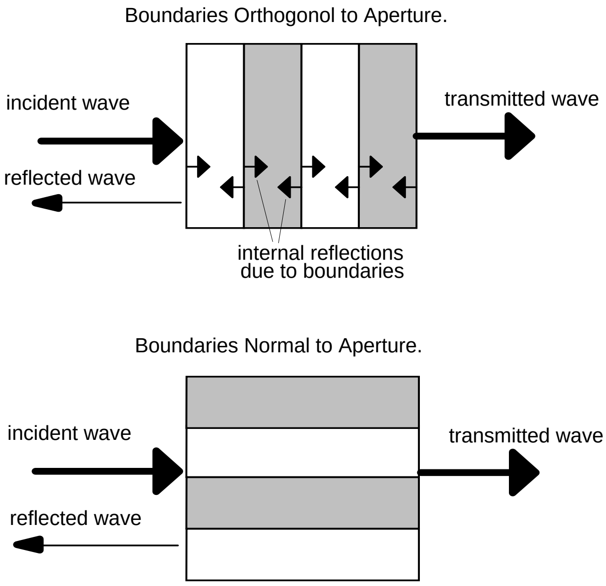

Figure 1 EW/LW layering

The change in polarisation of the microwave fields due to EW/LW layering has given rise to many systems proposed for the measurement of grain angle. One such system was developed by [1] which involved a rotating antenna that used the angle of the antenna and a maximum in the received signal to determine the grain angle of lumber.

In 1993 [2] coaxial probe permittivity measurements where made on a number of sawn lumber samples. The measurements where made every 5mm and the permittivity for two samples was plotted versus distance across the sample to produce Figure 2 from [2] shown below.

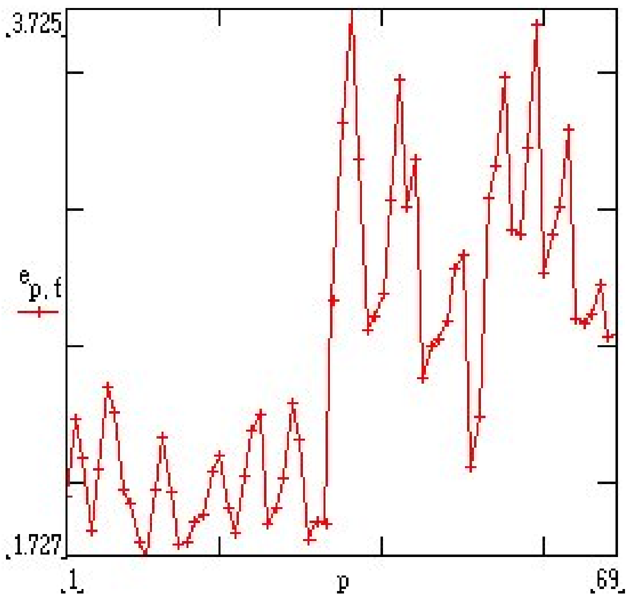

Figure 2 EWLW variation across wood sample

This EWLW experiment showed the cyclic variation in permittivity due to the EW/LW regions. The step change is due to the second sample having a significantly higher basic density due to a mix of heartwood and sapwood within the sample. This published graph does clearly demonstrate however the localised differences in permittivity between EW and LW.

The density independent function developed at the USDA by Trabelsi [4] is a commonly used method for microwave sensors to remove the effect of density from their measurements on cereal crops.

The universal permittivity based method for determining moisture content independent of density was reported and has the form

$$\Psi = \sqrt{\frac{\varepsilon''}{\varepsilon' \cdot (a_f \varepsilon' - \varepsilon'')}}$$

Where a_f is a constant that is a function of frequency only, and is determined by a least squares minimisation so that the resulting function Ψ varies linearly with moisture content.

Figure 3 shows the density independent function versus moisture content for a range of wood densities spanning 300 to 700 KG/m3 using data from Torgovnikov [3]. It can be easily seen that as the moisture content drops below the Fibre Saturation Point (FSP, approximately 33% by dry basis and the point where free water has been removed) the function no longer accounts for the density variation.

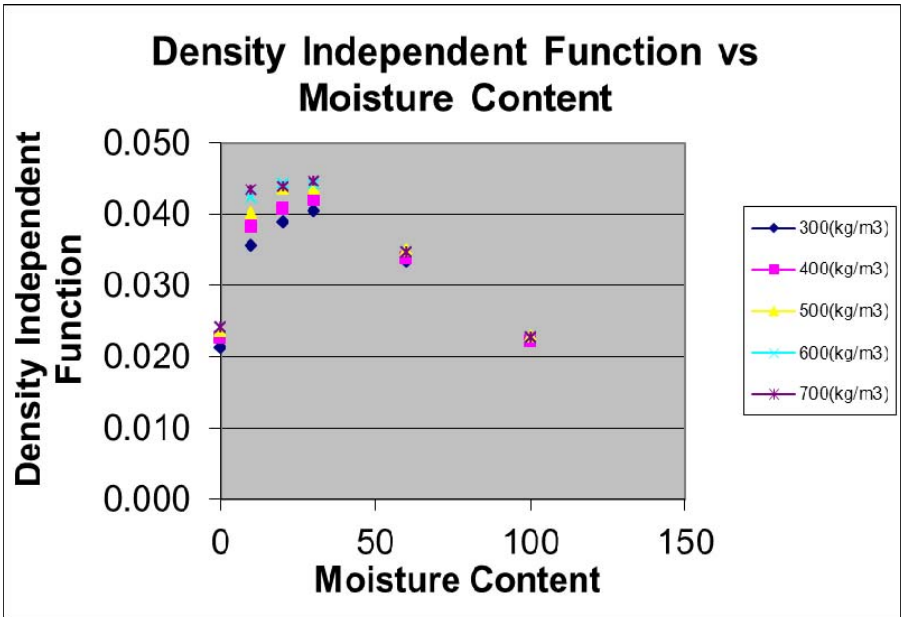

Figure 3 Independent function versus moisture content for published data

The explanation for the failing of the density independent function is in the nature of the water binding below the fibre saturation point. The water in this region is heavily bound in the structure of the wood and the dielectric properties of the water approach that of ice. This means that the remaining water no longer contributes significantly to the dielectric losses, and the loss factor (ε”) becomes small. However what this figure does show us is that above the FSP we can easily negate the effects of density and accurately extract the moisture content. This in turn would also let us accurately determine the density so that it can be used later as a correction in measurements below the FSP.

Our alternative approach for samples who are below the FSP is to apply a linear correction to the Trabelsi model. This correction is essentially the ratio of earlywood to latewood and caters for internal reflections within the now layered dielectric. To examine the effect of this, the data covering flat and intermediate sawn where used in the error analysis. Figure 4 below using only this data shows that the RMS error in moisture content using density correction is now reduced from 3.59% to 0.63%. Hence we can see that much of the residual error can be demonstrated to be due to the effect of EW/LW layer orientation.

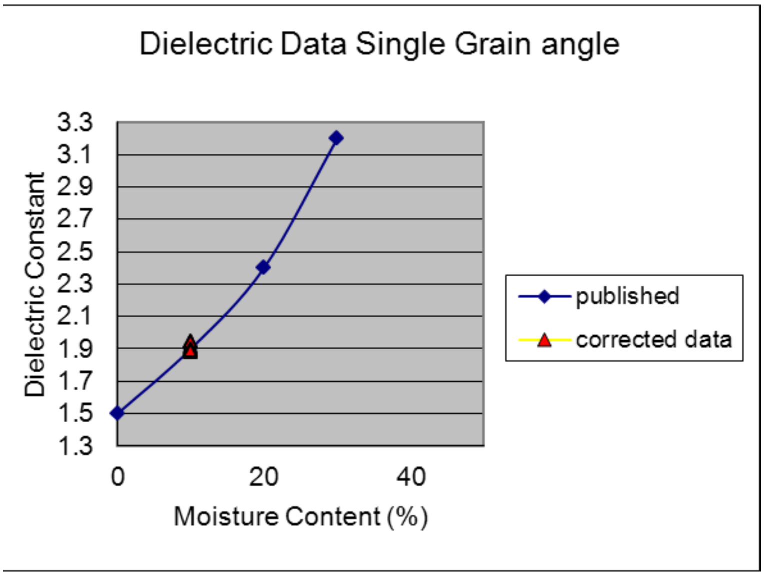

Figure 4 Density corrected measurements for flat and quarter sawn samples

Conclusions

This work was aimed at determining the potential accuracy in moisture content measurement that microwave sensing techniques could achieve for lumber dried below the FSP. Previous published work had shown an RMS residual error of 3%. In order for further development of the microwave approach to continue, a reduction in this error was required and also density independence of the measurement was critical.

This study has shown the weakness in the previous approach of using the universal permittivity based density independent function for wood below the FSP. This work also showed that if we determine the ratio of seasonal growth rings prior to measurement, it can be easily used to correct the measurement and result in residual RMS errors of 0.6% for all lumber flat through to quarter sawn.

Implications

The key benefit of this research is to the timber processing industry. This work has seen the development of a method based on microwave sensing that can measure both moisture and density of processed lumber at commercially acceptable levels of accuracy. The application of this technology will allow timber processors to both allocate material to appropriate end users and also achieve ever more challenging quality requirements being set by end users. In addition to timber processors this work could also be applied to any layered material were either density or moisture content is a major quality factor.

Further work will be required to develop a sensing system to provide information on the growth ring proportions to a microwave system. This most likely would be a computer vision system.

Whilst, on our first attempt, not delivering the required measurement accuracy the USRP software definable radio approach to the measurement of material properties still shows significant promise. We will actively progress this work in 2013 as it would significantly impact on the area of microwave based sensing. This work could provide low-cost readily available hardware, which to date has proved a significant barrier to industry uptake of microwave sensing technologies.

Publications and dissemination

Delivered:

- Presentation at 2012 Unitec Research Symposium, October 2012

Journal Paper In progress:

- "Microwave density measurement of lumber", IEEE Trans. Instruments and Measurement, Dec 2013

Conference Paper In progress

- "Impact of seasonal growth rings on dielectric measurement of lumber", 7th International Conference on Sensing Technology, ICST 2013, Wellington, New Zealand Dec 3-5, 2013.

References (if applicable)

1. R. J. King, "A Microwave Method for Measuring Moisture Content, Density and Grain Angle of Wood," USDA Forest Service Research note FPL0250, 1985.

2. W. S. Holmes and J. R. Holdem, "Measurement of Moisture and Preservative Content of Timber using Microwave Sensing Techniques," Industrial Research Limited Report No107, Auckland, New Zealand, 1993.

3. G. Torgovnikov, Dielectric properties of wood and wood based materials, Berlin Hiedelberg New York: Springer, 1993.

4. S. Trabelsi and S. O. Nelson, "Dielectric sensor for multiparameter microwave sensor," Rotorua, 2003.