Non-destructive assessment of wood properties in tree stems using acoustic imaging

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Abstract

There is significant interest in non-destructive testing of trees and felled logs. One way of imaging the interior of tree stems is using acoustic techniques. This paper describes a study which investigates the potential of acoustics for au-tomatic detection of knots in felled logs for optimising the value that can be achieved during sawmilling. Pulses of sound, in the audio frequency range, were excited at one end of a log using an air coupled transducer. The sound emitted from the log was then detected at a range of positions along the log using a single microphone in contact with the log and then using a non-contact acoustic camera. Initial results are presented which indicate that this technique may have potential as a means of automatically detecting knots. Results from current research, including the development and use of high power ultrasound will be presented. Future research plans will then be outlined..

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1. Introduction

The ability to predict the properties of a tree stem or felled log can have a significant effect on the profitability that can be achieved [1]. One factor that can affect the structural properties of wood is knots. Identification of the location of knots in saw milling processing plants is often performed using manual inspection. It would be desirable to have an automatic method of detecting knots.

The acoustic wave propagation in wood is anisotropic, having different velocities and attenuation rates in the longitudinal, radial, or tangential directions. The highest velocity and lowest attenuation rate is in the longitudinal (along the grain) direction [2,3]. This has been used to measure the grain direction in living trees and lumber [4,5]. In lumber, it has been reported that an ultrasonic signal follows the grain and propagates around knots [6,7]. An ultrasonic signal transmitted at the base of a log follows the grain and tends to come to the surface of the log with a higher amplitude at the knots [8,9]. Few details are provided in these references but the suggestion is that this phenomena may be used as a method of detecting knots in logs.

This paper presents initial work performed, with funding from SWI , to investigate the use of acoustics for detecting the location of knots in logs. In a similar manner to that suggested by [8,9], speakers were attached to the base of logs. Audio frequency signals, which have lower attenuation than ultrasound, were used. RMS measurements of the signal propagating through the wood was obtained using microphones which were in contact with the surface of the log. A microphone phased array (acoustic camera) was then used to image the sound coming from knots.

2. Contact mirophone technique

2.1 Experimental Procedure

Experiments were performed to investigate if an acoustic signal excited at the base of a log resulted in increased acoustic emission at knots. Figure 1 shows the experimental setup used. Excitation signals were created using MatLab. These were Hann windowed, tone bursts in the audio frequency range. These were converted to an analogue signal using a DAC channel of a Data Translation DT9836 board with a sampling rate of 225 kHz. This was amplified using a commercial audio power amplifier and used to excite one or more tweeter speakers attached to the end of logs.

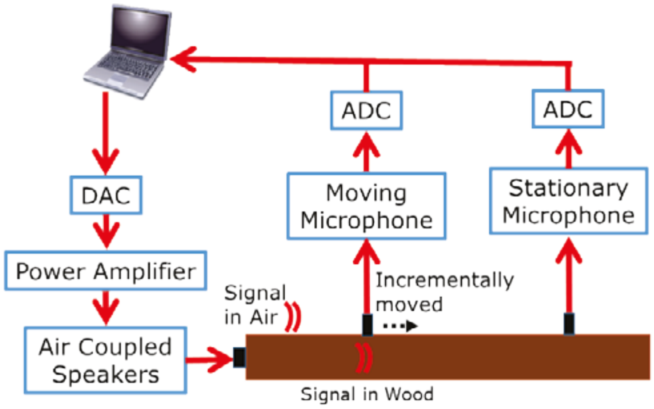


Figure 1: The experimental set-up used to measure RMS values as a function of position on a log for knot detection

The resulting signal was measured using two low noise GRAS microphones which were in contact with the surface of the log. This was amplified using the GRAS low noise preamplifier and sampled using analogue inputs of the DT9836 board using a sampling rate of 225 kHz and a resolution of 16 bits. One microphone was kept stationary, while the other was moved along the log in steps of 25 mm.

An AIC picker algorithm [10] was used to detect the first arrival of the signal, see Figure 2. A RMS value was then obtained from a set number of samples following this first arrival time. This was assumed to be the signal emitted from the wood before the first arrival of the signal through air. This was repeated for each measurement point along the log. The stationary microphone signal was optionally used to normalise the moving microphone RMS signal.

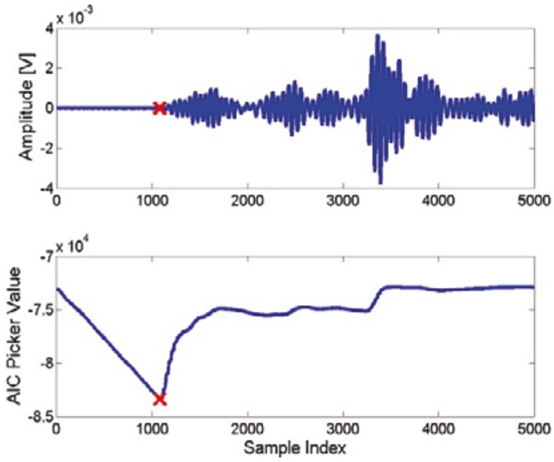


Figure 2: Example of the use of AIC picker algorithm output used to obtain time of arrival for pulse.

2.2 Lab Measurements

Initial measurements were made in the acoustics lab of the Physics Department of the University of Auckland. Figure 3 shows the wooden post used for these lab measurements. This post was a retaining wall post which was 2.4 m long and 130 mm in diameter.

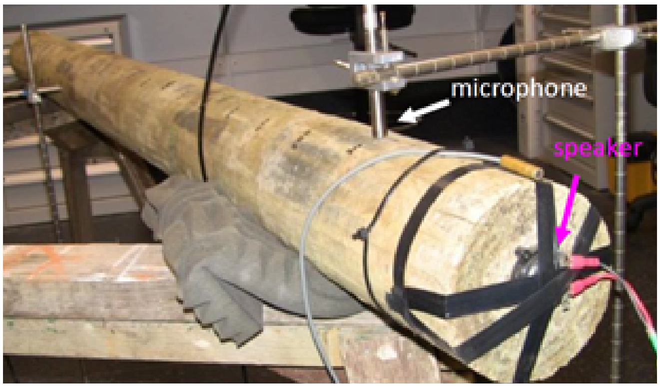
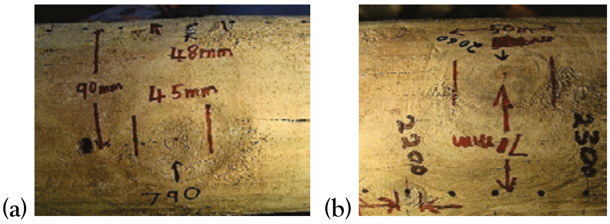


Figure 3: Photo of experimental set-up in the lab for contact microphone measurements

RMS measurements were calculated for a range of transmit frequencies (see Figure 5 for several example plots).

There appeared to be a correlation with RMS peaks and the size and location of some knots. This correlation appeared to occur even if the measurement location was offset circumferentially from the knot location. However, this varied with transmit frequency and individual knots.



(a) (b)

Figure 4: Photos of the two main knots which corresponded to peaks in the RMS measurements at (a) 790 mm and (b) 2200 mm. The dots show the contact microphone measurement locations

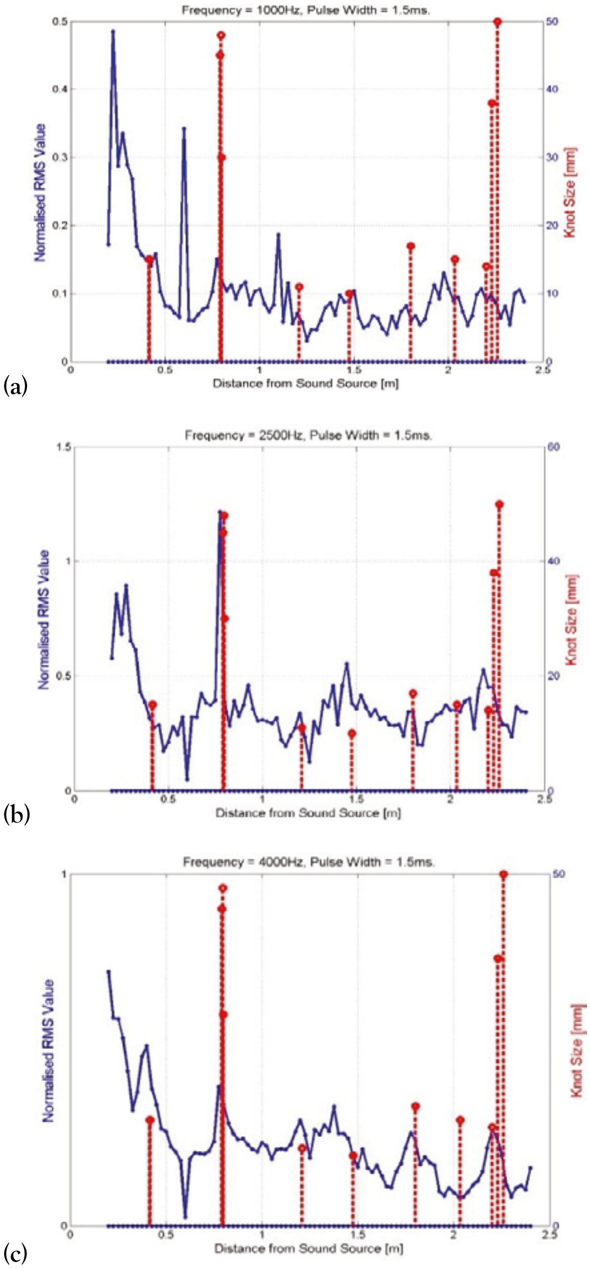


Figure 5: Lab measurement signal RMS values (blue) as a function of distance from source for 1, 2.5, and 4 kHz. Also shown on the plots (red) are the knot location and size (right hand axis). For some transmit frequencies, such as in (b) and (c), peaks in the RMS signal appeared to correlate to the location of knots.

2.3 Field trials

RMS contact microphone measurements were also performed on larger logs with higher moisture content in field trials at a site in Rotorua. The attenuation in these logs was much larger than had been observed in the post used for lab measurements. Therefore, an array of speakers was used for excitation, as is shown in Figure 6(a). However, the received signal from the wood was still relatively low. The excitation signal was a 3 kHz Hann windowed tone burst signal.

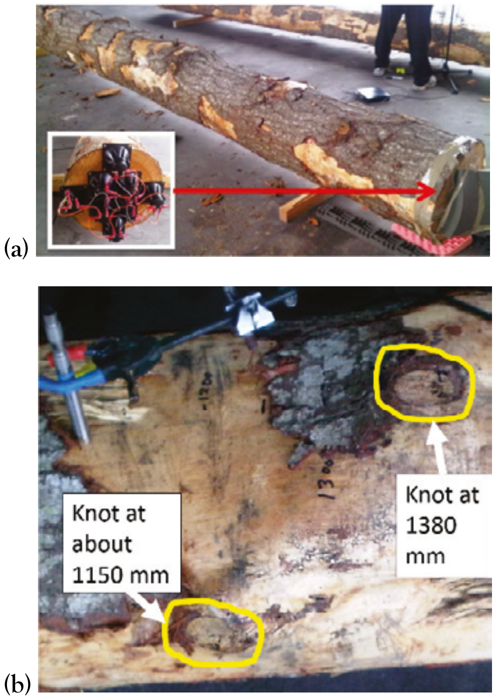


Figure 6: Photo (a) shows the logs used for field measurements with the speaker array used to excite the logs. Photo (b) shows the main knots.

The contact microphone measurement locations were orientated on the log so that they passed through a main knot located at 1380 mm from the sound source, see Figure 6(b). RMS values, were obtained using the AIC picker technique, see Figure 7. There is a strong peak in the plot which appears to correlate with the location of the main knot at 1380 mm.

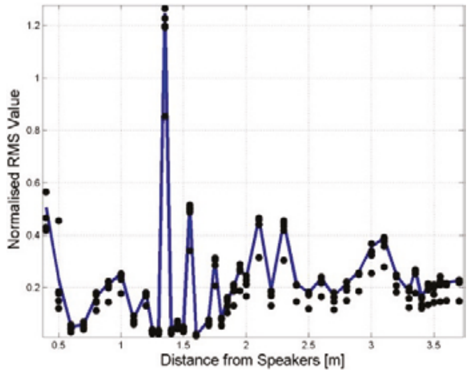


Figure 7: Plot of the RMS values for the field trial contact microphone measurements obtained using AIC picker algorithm

3. Phased array measurements for knot detection trials

The contact microphone measurements indicated that more sound was being emitted at the location of some knots. However, a non-contact method of detecting knots would be desirable. A microphone phased array, often called an acoustic camera, is a device that enables the sound emitted from an object to be imaged as an acoustic plot over a camera image. Experiments were performed to try to see if an acoustic camera had potential for detecting knots.

3.1 Experimental procedure

Figure 8 shows the experimental setup used to image the sound emitted by the log. The excitation signal used for lab measurements was a 3 kHz Hann windowed signal. A microphone phased array, built at the Physics Department of the University of Auckland [11,12], was used to measure the signal emitted from the log. The sampling rate used was 90 kHz with a resolution of 16 bits.

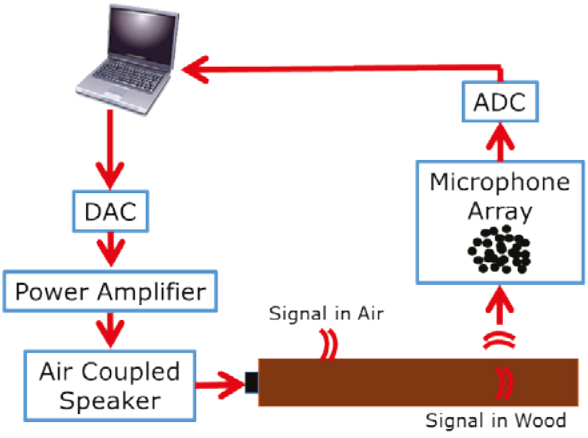


Figure 8: The experimental set-up used for microphone phased array measurements to try to image knots

Beamforming was used to generate acoustic maps. Beamforming maps contain blurring artefacts referred to as side lobes. To sharpen the image, the CLEANSC algorithm [13] was used to remove these artefacts and try to more accurately image the sound source distribution on the logs.

3.2 Lab measurements

Figure 9 shows the phased array setup in front of the log in the acoustics lab. Measurements were made at different positions along the log. Due to the separation of the phased array from the log, knots on the log near the source were not imaged, since the signal coming from the log could be merged with the direct signal through the air.

Figure 10 shows a beamforming and CLEANSC map for a knot that showed peaks that correlated with the location of a knot. These peaks were consistently seen for this knot for different positions of the microphone array relative to the knot. For other knots, such as that shown in Figure 11, no correlation was observed with the CLEANSC peaks and location of the knots.

Figure 9: Photo of the microphone phased array experimental setup used in the lab to image the location of knots

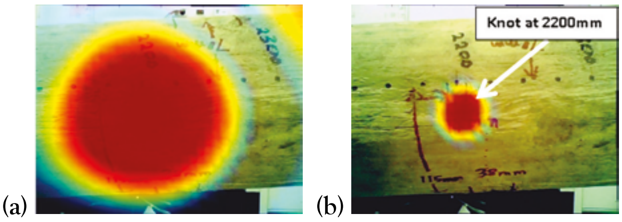


Figure 10: Microphone phased array (a) beamforming and (b) CLEANSC plots imaging the sound coming from the wooden pole in the lab. The plots show peaks in the vicinity of a knot, located 2200 mm from the source.

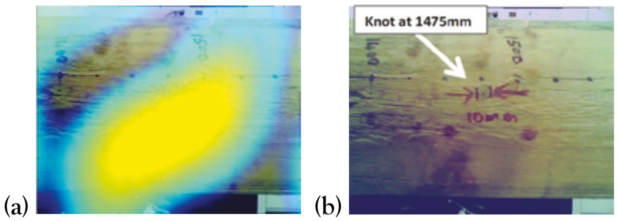


Figure 11: Plots showing an example where the microphone phased array (a) beamforming and (b) CLEANSC plots did not show any peaks in the vicinity of a knot, located at 1475 mm for the wooden pole in the lab

3.3 Field trials

Microphone phased array measurements were also performed for the larger logs. As in the case of the contact microphone measurements, the amplitude of the measured signal from these logs was low. Figure 12 shows the experimental setup used for the microphone phased array. Beamforming and CLEANSC acoustic maps were generated.

Figure 12: Photo of microphone phase array setup used for field measurements to investigate knot detec-tion imaging

Figure 13 shows an example where a peak in the beamforming map was obtained which correlated closely with a knot location.

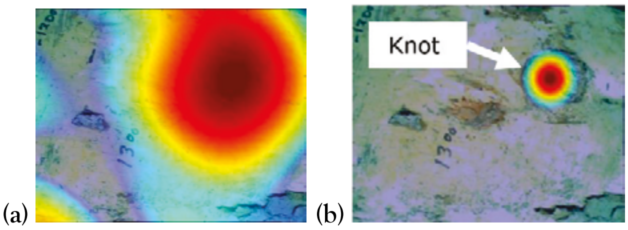
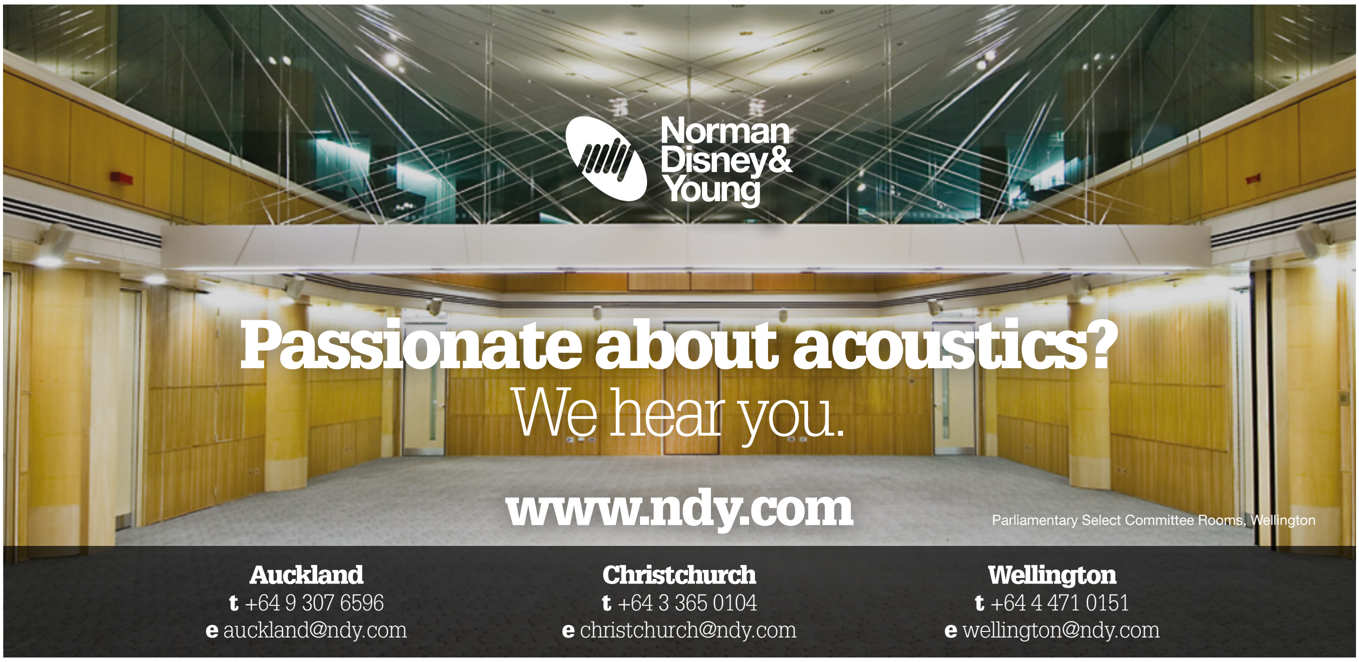


Figure 13: Microphone phased array (a) beamforming and (b) CLEANSC plots imaging the sound coming from a log in field measurements. The plots show peaks in the vicinity of a knot, located 1380 mm from the sound source. The excitation source was a 3 kHz Hann windowed tone burst.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However, Figure 14 shows an example, for the same knot but a different transmit frequency, which did not show this correlation of peak and knot location. Figure 15 shows an example, for a larger knot on a different log, which illustrated a tendency for the CLEANSC peaks to be located at the edges of the knots.

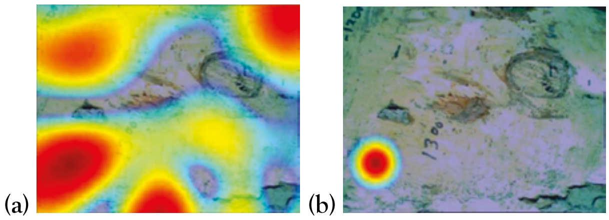

Figure 14: Plots showing an example where, for a different transmit frequency (6 kHz), the microphone phased array (a) beamforming and (b) CLEANSC plots did not show peaks in the immediate vicinity of the same knot that was imaged in Figure 13.

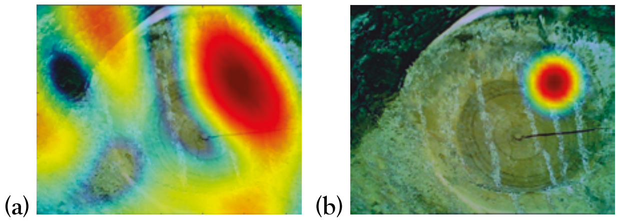

Figure 15: An example plot showing that often the peaks in the microphone phased array (a) beamforming and (b) CLEANSC plots appeared to occur at the edge of a knot on the same side as the sound source.

4. Conclusions and remarks

The individual microphone results show that there is an increased acoustic signal emitted from the vicinity of some knots when an acoustic signal was transmitted at the base of the log. For the individual microphone measurements, and for those with the acoustic camera, the challenge was to get a sufficiently strong signal. Improved coupling of the acoustic signal into the end of a log and improved hardware was required. Knots were able to be detected but not with the consistency required for commercial application. There were variation between individual knots and different transmit frequencies. More work was required to understand why this variability occurred.

This work is being continued in a subsequent project with Scion under the Growing Confidence in Forestry Future program . Improved excitation of the log is being investigated using contact ultrasonic transducers and high voltage power amplifiers. Potential benefits of using ultrasound are smaller wavelength, better coupling into wood, reduced effect from background noise, and reduced noise traveling through the air to the sensor. In addition, ultrasonic guided wave techniques can be used to provide better control of the signal being excited. The mechanism of acoustic emission at knots will also be investigated in more detail.

Acknowledgments

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