Ultrasonic Tomography for Nondestructive Studying in Tree with Presence of Defects

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Abstract

There are many trees with unnoticeable internal decay in the city especially in the public park. On a windy day, some of them are ready to fall down anytime because of the defects inside the tree such as air hold, knot, fungal attack, etc. So, checking the inner structure of the trees is important. The ultrasonic scanning is one of the tree tomography techniques available nowadays. It uses either reflection or transmission data collected by scanning the tree trunk from different directions to determine the tree condition. To obtain ultrasonic image, a number of characteristic parameters of the wave interacting to the tree such as amplitude, phase, time of flight (TOF), frequency spectra of the waveform, etc are required. In this project, ultrasonic transmitter and receivers are used to find TOF in the tree cross sections. followed by using simulation program to predict the structure of the tree cross sections that match with the TOF data in the experiment. Finally, the approximation of tree cross section structures could be obtained. Moreover position and diameter of a defect can also be predicted.

Tree Tomography

Ultrasonic tomography is the technique for nondestructive imaging of material cross-section. The technique is based on the measurement of the time of fight (TOF) and analyzing the TOF graph to determine the presence of defect.

Ultrasonic Velocity in Orthotropic Materials

Tree is an orthotropic material with unique properties along three mutually-orthogonal twofold axes of rotational symmetry such as strength, stiffness, and sound velocity. The ultrasonic velocity V in RT plane of the orthotropic material can be expressed as

$$V = \sqrt{\frac{\Gamma_{11} + \Gamma_{22} + \sqrt{(\Gamma_{22} - \Gamma_{11})^2 + 4\Gamma_{12}^2}}{2\rho}} \quad (1)$$

$$\begin{aligned} \Gamma_{11} &= C_{11}\cos^2\theta + C_{66}\sin^2\theta \\ \Gamma_{22} &= C_{66}\cos^2\theta + C_{22}\sin^2\theta \\ \Gamma_{12} &= (C_{12} + C_{66})\cos\theta\sin\theta \end{aligned} \quad (2)$$

$$[C]^{-1} = \begin{bmatrix} \frac{1}{E_R} & -\frac{\nu_{TR}}{E_T} & 0 \\ -\frac{\nu_{RT}}{E_R} & \frac{1}{E_R} & 0 \\ 0 & 0 & \frac{1}{G_{RT}} \end{bmatrix} \quad (3)$$

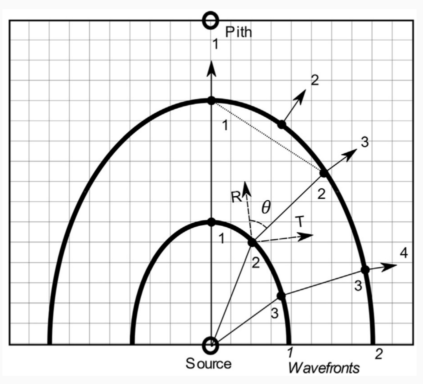

Fig. 1: Wavefront construction principle

Where

V Velocity
Γ Christoffel coefficient
ρ Density
C Elastic moduli
E Youngs modulus
ν Poisson ratio
G Shear modulus
θ Angle between wave normal and R-axis.

Simulation Method

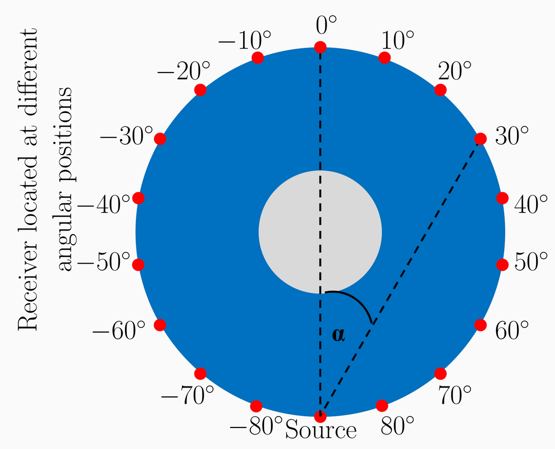

Fig. 2: Simulation Model

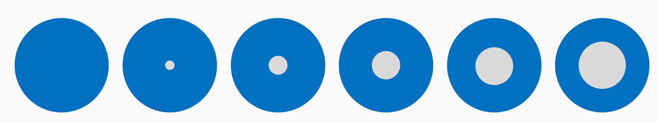

Fig. 3: Healthy and defects of 10, 20, 30, 40, and 50% tree diameters

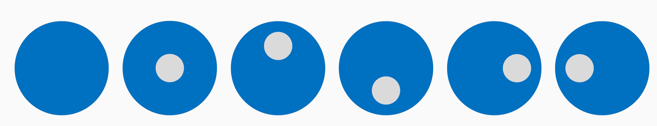

Fig. 4: Healthy and defects at center, top, bottom, right, and left of tree cross section

The round wood slab with a circular air hole (defect) is used as a design model (figure 2). The ultrasonic velocity in the wood is calculated by equation 1, and the ultrasonic velocity in the air hole is equivalent to the speed of sound in the air. Two parameter of particular interest include the diameter and position of the defect as shown in figure 3 and 4, respectively.

Simulation Results

The results for varying defect diameters are shown in figures 5 and 6.

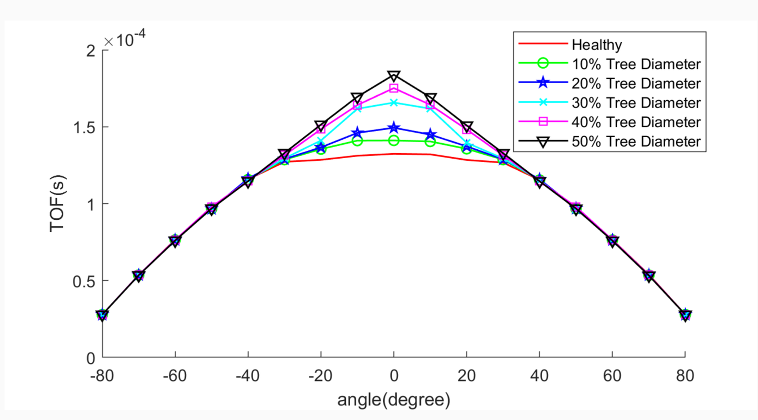

Fig. 5: TOF for healthy and defects of 10, 20, 30, 40, and 50% tree diameters

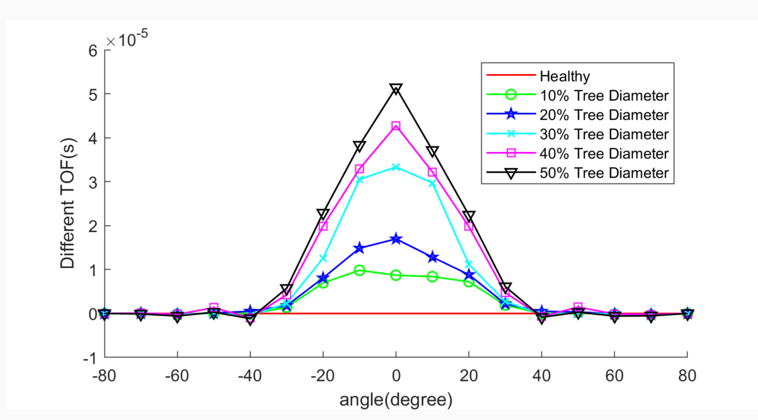

Fig. 6: Different TOF for healthy and defects of 10, 20, 30, 40, and 50% tree diameters

The results for varying defect positions are shown in figures 7 and 8.

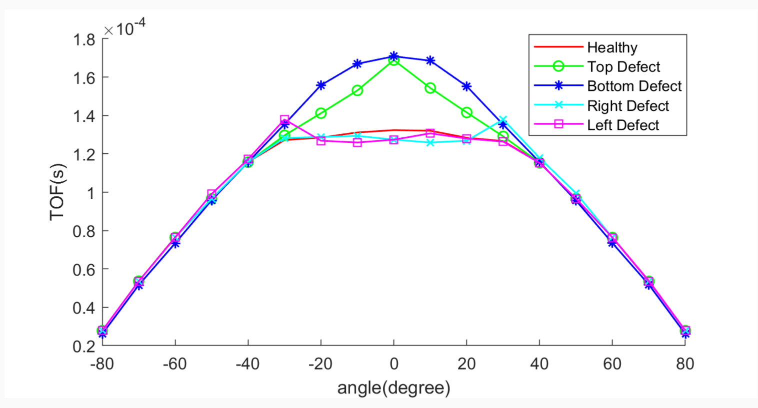

Fig. 7: TOF for healthy and defects at center, top, bottom, right, and left of tree cross section

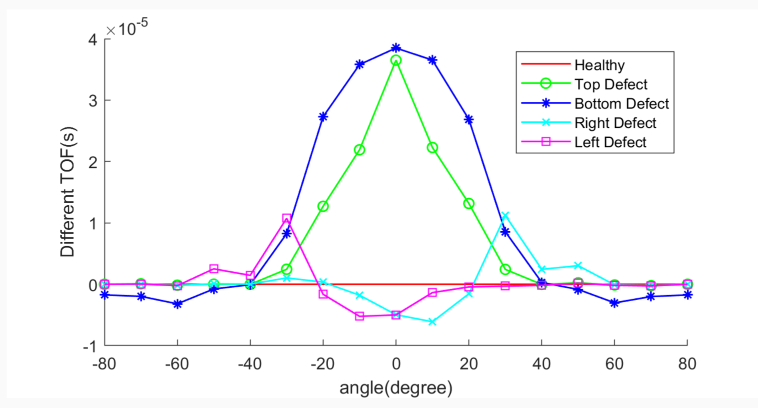

Fig. 8: Different TOF for healthy and defects at center, top, bottom, right, and left of tree cross section

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Experimental Setup

The arrangement for the TOF of box wood and round wood slab.

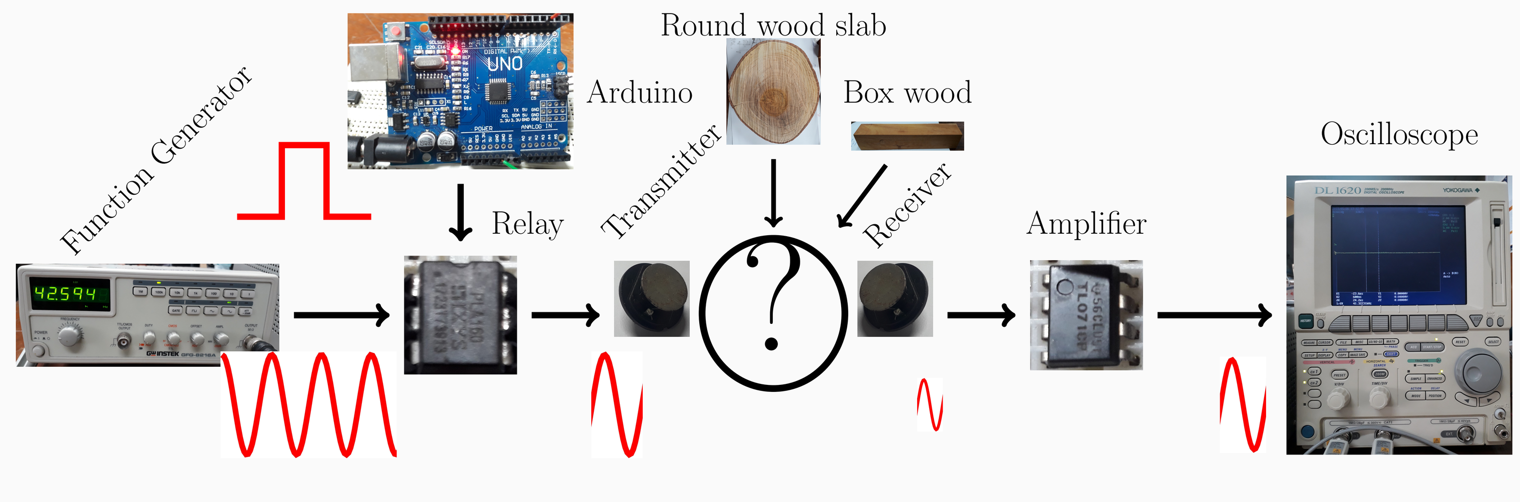

Fig. 9: Experimental Setup

A sinusoidal signal is generated by a function generator. An arduino and a relay are used to control the on and off of the transmitter to achieve pulse signals. To ensure a large amplitude signal, amplifier is used after the wood sample. The signals are clearly displayed on digital oscilloscope.

Experimental Results

The signals before and after passing through long and short of box woods are shown in figures 10 and 11, respectively.

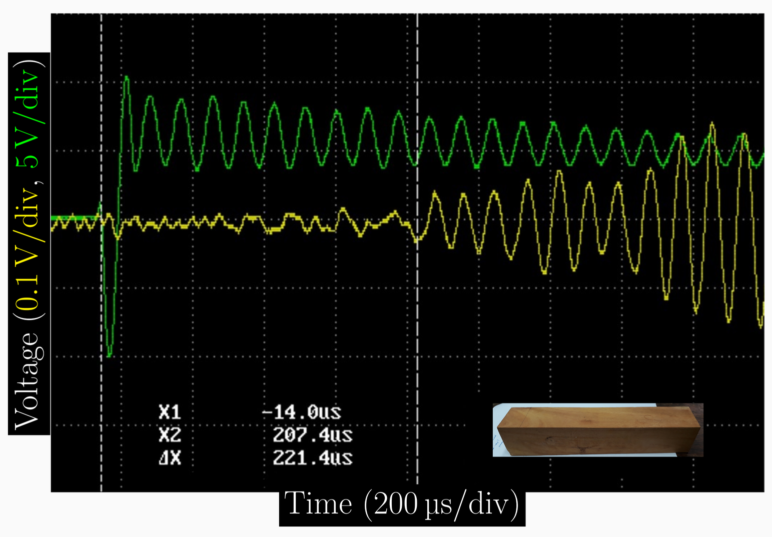

Fig. 10: TOF measurement in long length of box wood

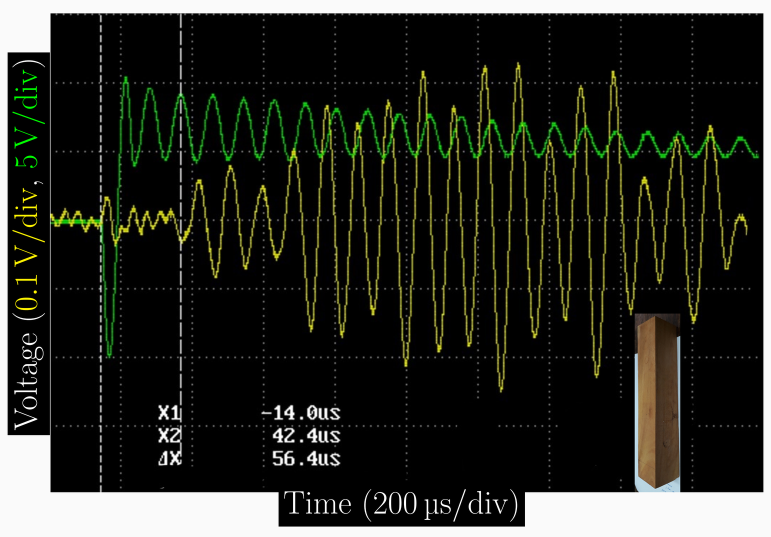

Fig. 11: TOF measurement in short length of box wood

However, the TOF measurement from the round wood slab was unsuccessful. This is because the signal to noise ratio is very poor.

Conclusions

Simulation part

- The characteristics of TOF can clearly be used to differentiate between healthy and decaying trees.
- Position, a number of receivers, and strength of the signal have significant influences on the accurate determination of the presence, position and diameter of the defects in the tree.

Experiment part

The TOF from the box wood could be measured experimentally whereas it failure to measure the TOF from the round wood slab. Using transmitter and receiver with better performance are expected to overcome the problem.

Acknowledgements

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