An Ultrasonic System for Detecting Defects in Wood

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Abstract

This paper aims to describe a low cost ultrasonic system which can distinguish between good and defective woods. In this preliminary investigation, two samples of wood from the *acacia* species are chosen. The defects in the wood can be detected by the system without damaging the wood. A low cost 40kHz ultrasonic system has been successfully developed for this purpose. Two 40kHz ultrasonic transmitter and receiver transducers configured based on the through transmission technique are used to evaluate the strength of the wood. The acquired data is later transferred to the MATLAB software for signal processing. The analyses based on SNR and cross-correlation of the received signal evaluated the Modulus of Elasticity of the sample in the longitudinal direction. The results show that the ultrasonic system has the capability of distinguishing between a good wood and a defective wood.

Keywords: Defect, Sensor, Ultrasonic, Wood.

1. Introduction

Wood has a versatile characteristic and it is a foundation of the global economy. The quality of wood has an effect on its use or application for a particular objective. As an example, the suitability of using wood in constructing a building is related to the strength of the wood (which depends on the type of wood), the texture of the grain, the dimension, distribution, and position of flaws. Due to its extensive application, it is vital that products made from wood be accurately categorized for utilization in a particular application. If the grade of the wood can be investigated at the initial stage in the processing process, then it can be transferred to the sawing stage to the most optimum application. Occasionally, for wood with extreme flaws, it is better to eliminate the wood from the process, and prevent extra costs [1]. It is important that wooden structures which suffer from decay be removed or else it can create risks to human beings [2]. Mechanical methods are categorized as destructive techniques. These techniques include bending test, compression / tensile test and torsional test. When these techniques are used, the specimen will be damaged during the test in order to obtain a precise and accurate information. These tests are applicable on wood. Universal tensile testing machines are used for the standard specimens of the wood. Bending and compression test are used for small specimens.

Non-destructive testing (NDT) utilized non-invasive methods to assess the integrity of a material without changing the physical or chemical properties of the object. Ultrasonic testing is a non-destructive technique and it can be used to determine the defects in a material and can be used to determine the thickness of the sheets of blocks used in the industry [3]. Ultrasonic methods do not pose any hazard and are safe to use. It also does not damage the object to be investigated and does not harm anyone who conducts the investigation. Ultrasound has been used to characterize and detect defects[4]. An ultrasonic sensing system can transmit the required energy into and out of the wood. As an example, Brenjaux et al [5] investigates the use of high power ultrasound for oak wood barrel. Skowroński and Stawiski [6] conduct an investigation regarding the impact of corrosion on roof trusses using ultrasound.

The ultrasonic through transmission method can be used in the detection of defects in the wood. In the through transmission technique two aligned transducers are utilized. The transducer are placed opposite to each other on either side of the wood. One transducer acts as a transmitter whereas the other play the role as a receiver. The through transmission method is mostly used in measuring thickness measurement and defects inside a material. It is suitable for the acoustic measurement of coarse grain and porous material such as wood [7]. When the ultrasonic wave is transmitted via wood, it must be acquired and processed to obtain the vital features of the wood. Among the vital parameters that can be extracted by an ultrasonic measuring system are acoustic impedance (Z), attenuation coefficient (α), frequency (f), time of flight (TOF), amplitude wave, stiffness of medium and density of medium [8].

The ultrasonic velocity is directly related to the properties of wood and as such it is often used to detect flaws in the wood. Various factors such as fungal decay, cracks and voids can reduce the strength and toughness of wood. Woods containing flaw reduces velocity and increases attenuation [9].

The formula used for measuring speed of sound in through transmission is:

$$c = \frac{d}{t} \tag{1}$$

where c = speed of sound(m/s), d = distance of the specimen (m), and t = time between transmission and reception of sound wave (s).

Sound waves travel through a medium under the effect of sound pressure, because atoms in solid are bound elastically to each other, the increase in pressure cause the wave to propagate in solids. The acoustic impedance of a material is defined as the product of its density and sound velocity.

$$Z = \rho v \tag{2}$$

where Z = acoustic impedance. ρ = density of material and v = acoustic velocity.

The time of flight (TOF) is an important parameter in ultrasonic measurement system. Time of flight is defined as the time required by the ultrasonic wave to arrive at the receiver end. It can be obtained from the following equation.

$$t = \frac{d}{v} \tag{3}$$

where t = time of flight, d = distance between transmitter and receiver, and v = velocity.

The cross correlation technique is performed to determine the time at which transmitted and the received signals are most similar. The determined time is termed as the required TOF.

The density of the medium is also one of the important factor in propagation of wave. If the medium is high in density, the sound wave velocities will be slower. The velocity, density and bulk modulus are related as shown in equation 4.

$$v = \sqrt{\frac{\beta}{\rho}} \tag{4}$$

where v = velocity, ρ = density and β = bulk modulus.

The modulus of elasticity E_L measures a wood stiffness indicating overall strength. It is determined by measuring the wave velocity of the wood specimen using through transmission technique. Equation 5 determines the E_L .

$$E_L = \rho v^2 \tag{5}$$

where ρ is the density (kg/m^3) and v is the speed of sound (m/s).

Equation 5 clearly shows that the modulus of elasticity is directly proportional to the density and square of sound velocity inside the medium.

2. The Measurement System and the wood samples

The block diagram of the measurement system is shown in Figure 1. The Multicomp MCUSD14A4OSO9RS is selected as the ultrasonic transducer for this project. It is low a cost ultrasonic sensor with a center frequency of 40 ± 1 kHz. It has a sensitivity ≥ -75 dB/V/microbar. A higher frequency will decrease the wavelength resulting in an increase in the attenuation of wood because of the coarse grain structure of the wood. As such it is better to use the lower frequency range.

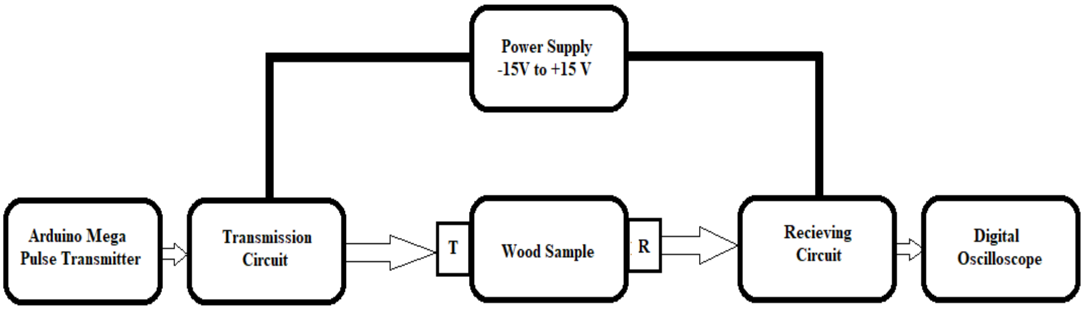

Figure 1 A block diagram of the measurement system

The electronic circuit consists of a transmitter circuit and a receiver circuit containing an amplification circuit. A pulse transmitter is used to excite the piezoelectric material in the transducer. A 40kHz of frequency is required to operate the ultrasonic transducer. To generate a 40kHz of square wave, a period of 25 microseconds is achieved using the clock frequency of Arduino Mega. A digital Tektronix oscilloscope is used to observe the received signals. The experiments are conducted at a room temperature of 25^oC. Aloe Vera gel is used as a coupling agent between the transducer and the wood sample. The coupling agent assist the transmission of the pulses of the ultrasonic transmitter into the wood.

The received data is subsequently processed and analysed to extract relevant parameters. The Matlab software is used to develop a code for the estimation of time of flight (TOF) of the acoustic wave signal. The cross-correlation technique is used to obtain the TOF. Cross-correlation is executed to determine the time at which the two signal are most similar. In the case of wood as a medium estimation of signal, the TOF between the transmitter and the receiver is obtained by finding the delay of earliest peak of the cross-correlation of the received signal with respect to the reference transmitted signal [10].

Table 1 shows the characteristics of the wood samples used in this investigation.

Table 1. Characteristics of the wood samples

Sample No	**Wood Type**	**Wood Scientific Name**	**Sample Condition**	**Dimensions (mm) (L) x (W) x (H)**	**Sample Density ($\frac{kg}{m^3}$)**
Sample 1	Hard Wood	Acacia	Good	128.50x70.70x38.70	834.32
Sample 2	Hard Wood	Acacia	Degraded Biologically	128.30x70.95x38.0	829.38

Sample 1 (Figure 2) is a hard wood of the Acacia species. Acacia is a high density hard wood. This species have a density range of 650 to 850 kg/m^3..As seen in Table 1 the difference in densities is because of the biological defects in sample 2. Sample 1 is a good wood i.e. it does not have any inernal defect whereas sample 2 (Figure 3) has an internal defect containing voids and cracks. The defect can also be seen from the exterior. Both samples are induced with 40kHz of ultrasonic wave signal. After transmitting and receiving the acoustic signal, the results are calculated from the code designed on the Matlab platform.

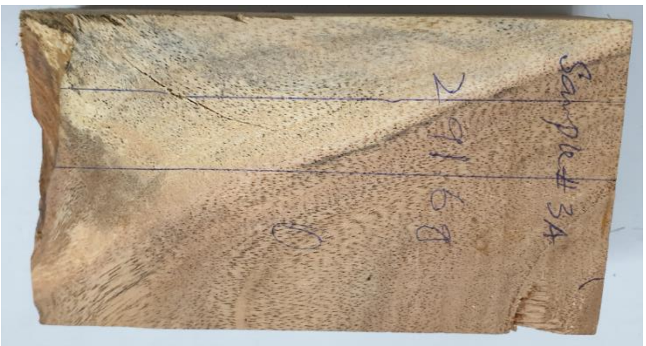

Figure 2 Sample 1

Figure 3 Sample 2

3. Results and discussion

The transmitted wave, the received wave and the cross-correlated wave forms for sample 1 are shown in figure 4.

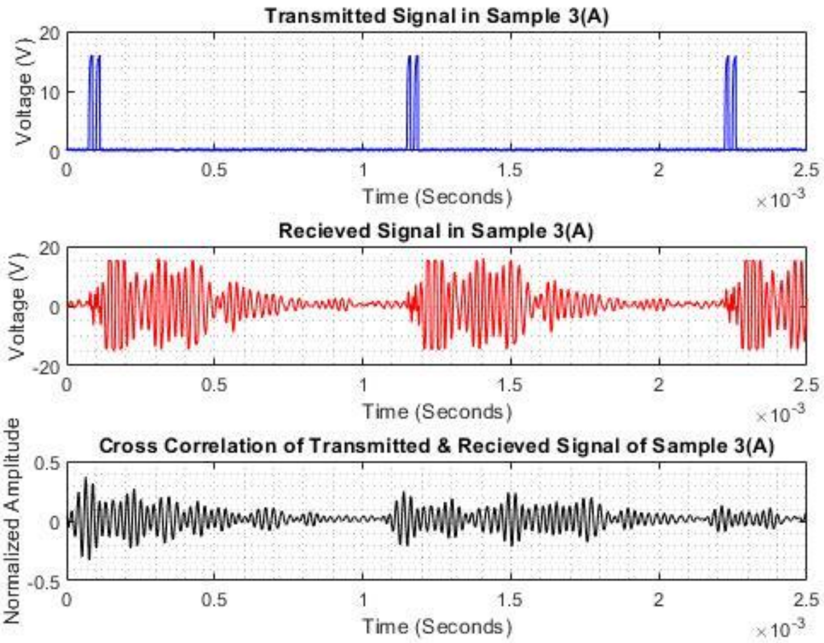

Figure 0 CrosscCorrelation of transmitted and received data of Sample 1

The transmitted, received and cross-correlated wave forms for sample 2 are shown in figure 5.

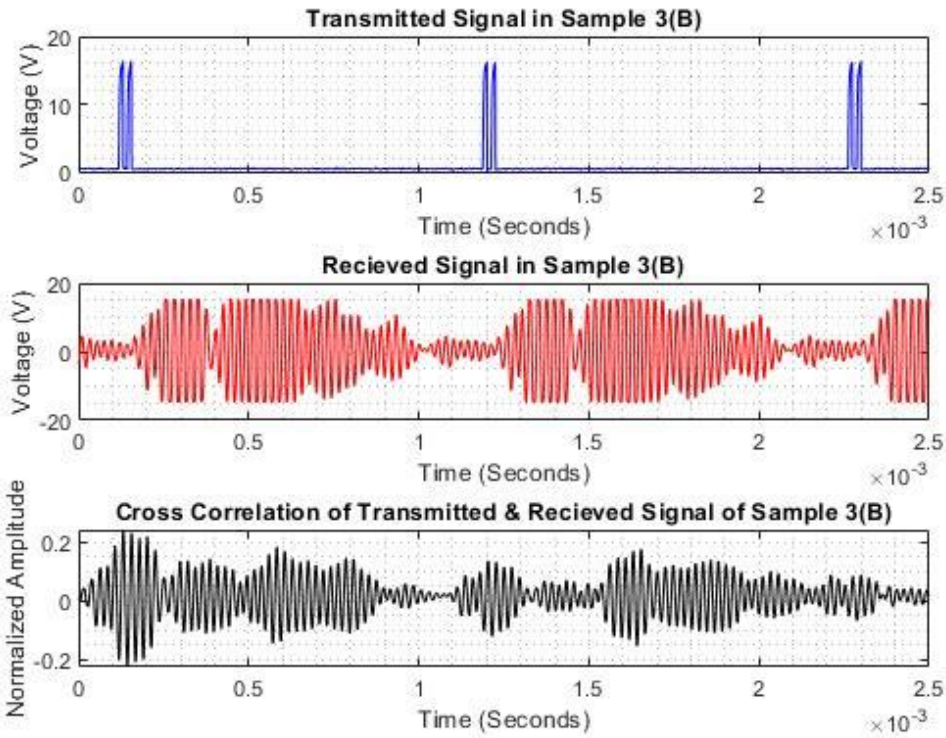

Figure 5 Cross-correlation of transmitted and received data of Sample 2

The difference in the time of flight (TOF) acquired from both samples can been seen in Table 2. The time taken by the acoustic wave in sample 1A is measured to be 37.86 µs. It is a good wood sample which have no cracks or biological degradation and that is why the wave reached the receiver in a minimum amount of time. Whereas sample 2 have nooks or biological degradation, which creates obstructions in propagation because the change of medium occurs at every moment the nooks occur. The flaw inside the wood caused the ultrasonic signal to be reflected to other directions and as such the signal takes a longer time to reach the receiver. The ultrasonic waves travelling from the ultrasonic transmitter to the receiver have to propagate around the flaw thus increasing their propagation distances. The velocity for the good wood is 6.737×10^{-3}m/s whereas for the decayed wood is 1.969×10^{-3}m/s. The velocity in the case of the decay wood decreased as the sample has internal defects. Both parameters affect the modulus of elasticity (E_L) and hence sample 1 has higher modulus of elasticity than sample 2. A higher modulus of elasticity indicates that the sample 1 has much less defects than sample 2.

Table 2. Experimental values of samples 1 and 2

Sample No	Sample Condition	Wood Name	Wood Type	Sample Length (m)	Density Kg/m^3	TOF (s)	Velocity (m/s)	E_L (GPa)
Sample 1	Good	Acacia	Hard	0.128	834.32	19	6.737×10^{-3}	37.86
Sample 2	Biologically Degraded	Acacia	Hard	0.128	829.38	65	1.969×10^{-3}	3.21

4. Conclusion

Ultrasound is suitable for detection of defects in wood by providing vital information on the quality of the wood. The 40kHz through-transmission ultrasonic method in the 40kHz range has been used to perform defect detection and analysis. The ultrasonic system as such can provide enormous benefit to the the wood industry in accessing the strength of the wood especially various old wooden structures. For example the system can be used in the palm tree plantation to determine the health of the tree stem. The gathered data from the ultrasonic system can provide vital contribution to pre determine the biological life of the palm trees.

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