In-Forest Wood Quality Assessments—Where Are We with NDT Technologies?

Xiping Wang *
USDA Forest Service Forest Products Laboratory, Madison, Wisconsin, USA, xiping.wang@usda.gov

Robert J Ross
USDA Forest Service Forest Products Laboratory, Madison, Wisconsin, USA, robert.j.ross.@usda.gov

* Corresponding author

Abstract

Recent research and development on nondestructive testing technologies has brought the in-forest assessments of wood and fiber properties of standing trees into forest management, resource evaluation, harvesting operation, and efficient wood utilization. Significant values are associated with the wood and fiber quality of our forests for the production of structural lumber, engineered wood products (such as glulam, LVL, and CLT), and pulping and paper. Rapid and nondestructive measurements on trees allow this value to be realized through better silvicultural practices, as well as the allocation of resources to highest value users and application of best processing methods. This paper provides an overview of recent research and development on in-forest wood quality assessments using emerging precision-based nondestructive technologies with a focus on forest resource evaluation and wood utilization. These include, but are not limited to, SilviScan™, near infrared, DiscBot, acoustic waves, and resistance drilling. A brief discussion is followed on how these technologies and the knowledge obtained from them can support the development of the next generation of forests, e.g. through tree breeding and silviculture.

Keywords: wood and fiber properties, wood quality, standing trees, forest resources, silviculture, genetic improvement

Introduction

Efficient wood production and utilization requires knowing the wood quality attributes of forest resources relevant to various end uses, prescribing appropriate silvicultural treatments that positively influence wood quality, and then, at the time of harvesting, sorting and allocating standing timbers to the most appropriate markets (Wang et al. 2007a; Amishev and Murphy 2018; Briggs et al. 2008). The field of forestry has many widely accepted field tools, sampling procedures, and models for gathering and summarizing data and making projections of growth, yield, and tree size; however, counterparts for wood quality assessment have lagged behind (Briggs et al. 2008). One of the reasons for this lag has been a lack of simple field tools permitting rapid collection of wood quality data from trees in a stand or sample plot.

The traditional method for evaluating wood quality in standing trees is to extract core samples from living trees using an increment borer, analyzing growth trends based on inspection of the ring patterns, and measuring basic wood properties (density and stiffness) in a laboratory (Cown 2006; Wiemann and Williamson 2013; Gao et al. 2017). This procedure has been used by foresters around the world for many years for defining wood quality of forest resources. The main disadvantages of this method are as follows: first, it is time consuming and labor intensive, which often prevents its use because of the high cost involved; and second, the tree is wounded in the coring process even though it has been practiced as a ″nondestructive″ sampling procedure. To achieve rapid, reliable, and economical wood quality assessment in trees, forest managers and landowners are interested in implementing more robust nondestructive testing technologies in field operations. Nondestructive is a relative term, because damage is done whenever the protective covering of bark is compromised; the term is used in comparison with sampling methods that require the felling of trees.

In this paper, we provide a brief overview of the research and development of nondestructive evaluation technologies for assessing wood quality of standing trees, highlighting several emerging precision-based nondestructive technologies (SilviScan™, near infrared, DiscBot, acoustic waves, and resistance drilling) and their applications in resource evaluation, harvesting operation, forest management, and tree genetic improvement.

Emerging nondestructive technologies

SilviScan™ system

Since the 1990s, there has been a steady increase in the development of tools for nondestructive assessment of wood quality in trees prior to harvesting. One significant development has been the SilviScan™ system specifically designed for characterizing many wood and fiber properties by taking core samples from trees and then conducting scanning and post analysis in the laboratory (Evans and Ilic 2001; Evans and Kibblewhite 2002). This instrument, as shown in Figure 1, was developed by Dr. Robert Evans and his team in CSIRO, Australia to meet the requirements of plantation assessment and breeding programs. It involves several measurement principles, including microscopic image analysis (tracheid and fiber diameters, vessel size and position, ring boundary position, ring orientation), x-ray densitometry (density profile, fiber tilt, ring boundary position), and x-ray diffractometry (microfibril angle (MFA), tracheid and fiber 3D orientation, cellulose crystallite width) (Figure 2). This laboratory instrument system can generate a series of high-resolution wood property data from the same wood sample, including wood density, stiffness, microfibril angle, and tracheid properties such as tracheid diameter, coarseness, and cell wall thickness. All SilviScan™ data can be related to individual annual rings so that detailed ″tree property maps″ can be developed, allowing quantification of the effects of site, silvicultural treatment, or genotype.

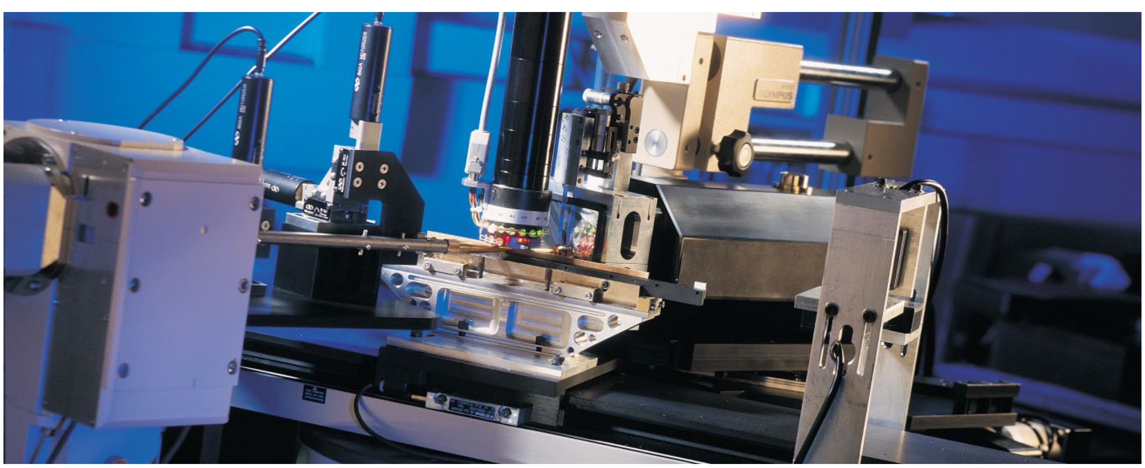

Figure 1. SilviScan system developed by Dr. Robert Evans and his team in CSIRO, Australia (Schimleck et al. 2019. Photo credit: Robert Evans)

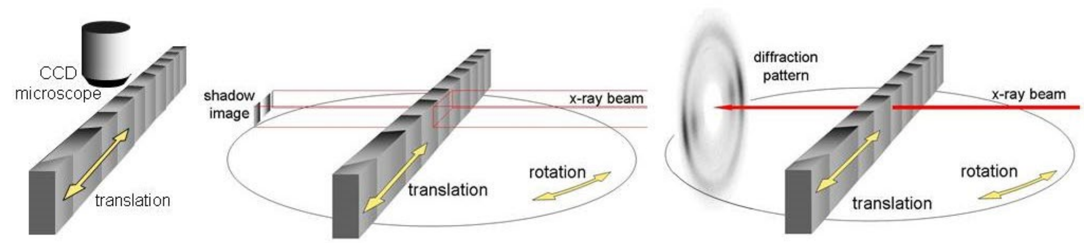

Figure 2. The three analysis components of SilviScan (Cell Scanner, Densitometer, Diffractometer) (Schimleck et al. 2019).

Currently there are three SilviScan™ systems in operation, one in the University of Melbourne, Australia; one in Innventia, Stockholm, Sweden; and one in FP Innovations, Vancouver, Canada. These three systems are now being used for a range of basic and applied research and commercial programs, providing test data to researchers around the world. These three systems together are capable of measuring 10,000 samples per year. The main advantage of SilviScan™ is that it can nondestructively assess a large number of trees and produce high resolution wood property profiles from pith to bark and along the tree height. Drawbacks are that it is a laboratory instrument with a relatively high cost requiring the user to have specialized knowledge and expertise to run the scanning process and interpret the results.

Near infrared (NIR) spectroscopy

Near infrared (NIR) spectroscopy is another laboratory technique that can be used to assess the wood quality of standing trees. Similar to SilviScan™, it requires taking core samples or wood chips from trees and then conducting scanning in the laboratory. Near-infrared is the region of the electromagnetic spectrum immediately after the visible region with the wavelength range of 780–2500 nm. NIR spectroscopy can measure the chemical composition of a material very rapidly, with minimum sample preparation. The technique was originally developed for use in biomedical applications. It has also been thoroughly investigated for use in the forest products industry, and it is particularly well-suited to quality control and process monitoring in pulp production (So et al. 2004). Many studies have been performed to explore the potential of using NIR spectroscopy to characterize wood and fiber properties, specifically linking the wood chemistry to a range of properties, such as tracheid length, density, microfibril angle, and physical and mechanical properties (So et al. 2004; Schimleck et al. 2019).

One of the most successful applications of NIR spectroscopy is in the estimation of genetic parameters, particularly those related to pulp production (Schimleck et al. 2019). In-forest wood quality assessment can potentially be achieved using spectra collected on standing trees (Figure 3) or in the lab based on spectra collected from a milled increment core. Utilizing milled increment cores to estimate whole-tree properties has been the most common approach and it has been demonstrated that spectra from milled breast height cores can provide good calibrations for estimating whole-tree properties (Schimleck et al. 2005, 2006). This approach has been adopted by several forest industry companies to assess progeny in their breeding programs (Meder et al. 2010).

However, there are some challenges in implementation of NIR spectroscopy. For example, data interpretation and post-processing can be complicated and require expertise; calibration must be maintained and updated. There are also issues related to calibration accuracy and applicability in harsh environmental conditions outside of the laboratory. Sandak et al. (2016) provide many practical recommendations for the successful application of this technique.

Figure 3. NIR acquisition on standing trees using a handheld device (Meder et al. 2010. Photo credit: Roger Meder).

DiscBot system

Although taking pith-to-bark core samples enables the radial patterns of wood property variation to be understood, such an approach does not capture the circumferential variation that exists in internal wood properties. In addition, the sample collection and preparation costs may also make it impractical to take core samples from multiple heights up the stem of a tree, thus making it difficult to capture the longitudinal variation. To address some of these challenges, Scion—the New Zealand Forest Research Institute Limited, has developed a new semi-automated platform, the DiscBot (Figure 4), for the rapid and cost-effective assessment of wood properties on cross-sectional discs (Schmleck et al. 2019; Moore 2018). With the DiscBot, a disc is systematically moved under each of five measurement stations to collect data on disc size and shape, spiral grain angle, density, wood chemistry and microfibril angle. Data are collected at high resolution to give two-dimensional wood property maps for the sample. By scanning multiple discs within a single stem, the DiscBot can produce intra-stem wood property maps that provide a more complete picture of the full extent of variation that exists (Figure 5). These data and subsequent simulations provide greater insights into the full impacts of silvicultural practices, environment, and genetics on wood quality of the forest resources.

Figure 4. Scion's (New Zealand Forest Research Institute Limited) DiscBot (Moore 2018; Schimleck et al. 2019. Photo credit: John Moore).

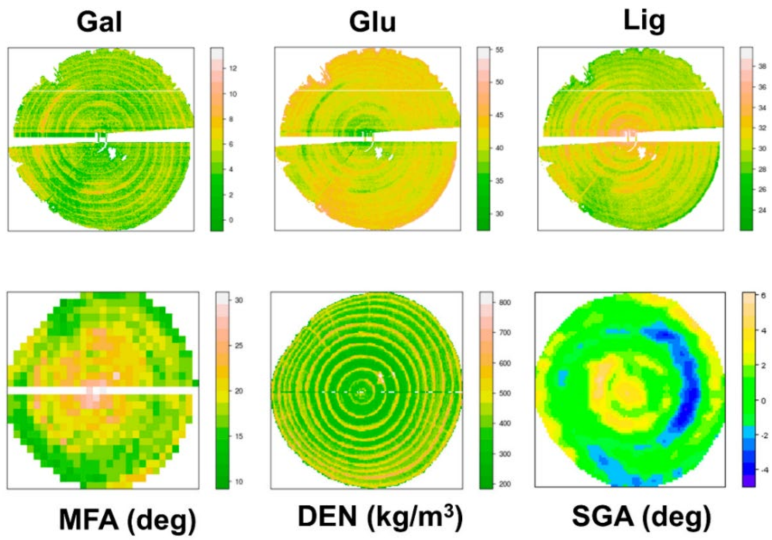

Figure 5. Examples of wood property maps produced by the DiscBot for galactan content (Gal), glucose content (Glu), lignin content (Lig), microfibril angle (MFA), density (DEN), and grain angle (SGA) (Schimleck et al. 2019).

Time-of-flight (TOF) acoustic technique

Another example is the development and commercialization of standing tree acoustic tools for assessing wood stiffness in trees (Wang et al. 2001, 2007a; Carter et al. 2005, 2013). The concept of using acoustic wave velocity as an effective measure of wood quality has been widely recognized in the forest products industry (Wang et al. 2007a, 2017b; Carter et al. 2005; Carter 2011; Harris and Andrews 1999). A resonance-based acoustic method, with a single sensor gauged with the material end, has been successfully used to grade structural timber, logs, poles, and wood-based composite materials (such as laminated veneer lumber and glued laminated timber) (Harris et al. 2002; Wang et al. 2006; Achim et al. 2011). However, the resonance-based acoustic tool cannot be used on standing trees because it requires two end-cut surfaces for compressional waves to reverberate between. To measure acoustic velocity on standing trees, a time-of-flight (TOF) acoustic wave technique was developed to gauge two sensor probes with a tree trunk by inserting the probes into the sapwood (Wang 1999; Huang 2005; Wang et al. 2008; Divos 2010; Huang 2000). In tree acoustic measurement, an impact impulse is introduced by a hammer impact on the start probe and TOF readings can be obtained by analyzing the receiving signals of the start and stop sensor probes (Wang 1999; Wang et al. 2008; Huang 2000; Addis et al. 2000).

The TOF acoustic method has been validated through various field and laboratory experiments. Hand-held standing tree acoustic tools have been commercialized (Figure 6) and are currently used by many research organizations and forest companies around the world, providing a means for silviculturists, forest managers, and planners to predict the stiffness potential of trees and stands prior to harvest, which enables management, planning, harvesting, and wood processing to be carried out in a way that maximizes extracted value from forests. The latest development on acoustic wave technology is the automated acoustic optimization system integrated into the processor head of a harvesting machine (Figure 7), allowing the processor head to acoustically test a stem and obtain its stiffness prior to making a log length cutting decision (Carter et al. 2013). The system allows wood producers to cut logs according to the measured stiffness, match logs to their requirements, and therefore extract more value from the trees. This automated acoustic optimization system has gone through experimental trials in UK, Australia, New Zealand, and the U.S. and it has shown improved precision over the head-held tool—ST300. While ready for operational application, the system still needs the harvest head manufacturers to adopt the technology and fully integrate it into their harvest head design.

(a) (b) (c)

Figure 6. Measuring acoustic velocity in standing trees. a) Prototype of TOF measurement system; b) Hitman ST300 (fibre-gen, Ltd.); c) Fakopp TreeSonic (Fakopp Enterprise Bt.).

(a) (b)

Figure 7. Harvesting machine with an automated acoustic optimization system. a) Harvesting operation; b) Hitman PH330 processor head (Photo credit: Peter Carter).

Resistance drilling

Resistance drilling is another method that has been extensively studied for its use in assessing wood quality of standing trees. The resistance drilling tool is an electronic micro-drill system that measures the relative resistance profile as a thin drill bit is driven into wood (Figure 8). The technique operates on the principle that drilling resistance is directly related to the density of the material being tested (Rinn et al. 1996). A resistance drilling tool consists of a power drill unit, a thin spade-type drill bit, and an electronic device that can be connected to a computer or a portable printer. As the needle drill bit cuts into the wood in a linear path, the drilling resistance is measured by recording the power consumption. The trace of change in drilling resistance is recorded as a digital representation display. This method was originally designed to characterize the radial density variation within a tree. However, resistance drilling tools have mostly been used for urban tree decay detection and wood structure inspection (Wang and Allison 2008; Allison and Wang 2015; Rinn 2012; Ceraldi et al. 2001; Ross et al. 2004).

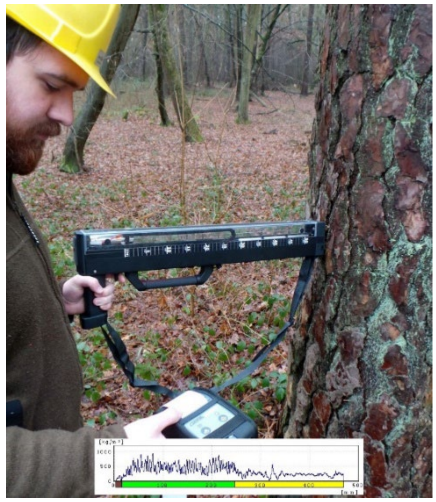

Figure 8. Electronically regulated resistance drilling in a standing tree using a Resistograph® tool (Photo credit: Frank Rinn).

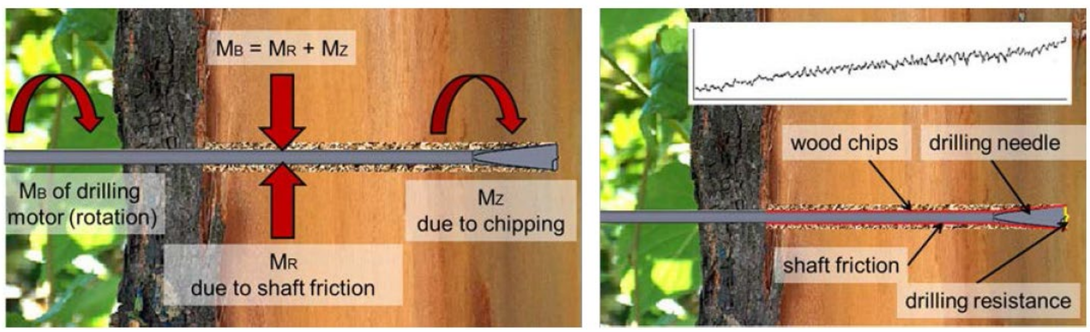

Figure 9. Illustration of resistance drilling process in a standing tree. The wood chips accumulate inside the cutting channel and cause friction on the needle shaft, leading to an increase in drilling resistance (Nutto and Biechele 2015).

Recent improvements in resistance drilling instruments have prompted research efforts to evaluate the potential of using resistance drilling to estimate the wood density of standing trees, particularly in tree genetic improvement programs. One of the challenges in assessing wood density of trees using a resistance drilling tool is the effect of friction. As illustrated in Figure 9, during the resistance drilling process, the wood chips can build up inside the cutting channel and cause friction on the needle shaft, which leads to an increase in drilling resistance (Nutto and Biechele 2015; Sharapov et al. 2017). New research has offered potential solutions to improve the accuracy of resistance measurement by developing friction models and using the models to remove the shaft friction from the original resistance profiles (Wang 2017; Downes et al. 2018). More research is needed to characterize the friction levels for different tree species.

NDT technologies for tree decay detection

Tree decay, or tree rot, is common to many tree species in forests. Internal tree decay, if goes undetected, can destroy lignin and cellulose in a tree trunk rapidly and cause significant loss to forest owners and timber buyers. It is estimated that for all the timber harvested annually in the United States, heartwood decay fungi destroy about 30% of the timber volume (Tainter and Baker 1996). The economic loss caused by heartwood decay is most significant for the hardwood trees that are used to produce appearance-grade veneer products. Early detection of internal decay in hardwoods could provide a significant benefit to the industry in terms of making accurate quality assessments and volume estimates and use of the resource. It can also help foresters in prescribing silvicultural treatments for improved management decision-making and thus help maintain a healthy forest. Researchers have developed various methods and tools for nondestructively testing trees for internal decay. These methods include simple visual inspection, single path stress wave timer, multi-sensor acoustic tomography, microdrills, ground penetrating radar, and x-ray scanning etc. A general review of these technologies can be found in Allison and Wang 2015 and Allison et al. 2020.

Conclusions

The research and development of nondestructive evaluation technologies for assessing wood quality of standing trees is still ongoing. Recent technology advances have brought the operational assessment of wood and fiber properties of standing trees into resource evaluation, harvesting operation, forest management, and tree genetic improvement. Significant values are associated with wood and fiber quality in wood supply chain for production of structural lumber, engineered wood products (such as glulam, LVL and CLT), and pulping and paper. Rapid and nondestructive measurements on trees allow this value to be captured through better decision-making, allocation of resources to highest value users, and application of best processing methods.

References

Achim, A.; Paradis, N.; Carter, P.; Hernandez, R.E. 2011. Using acoustic sensors to improve the efficiency of the forest value chain in Canada: A case study with laminated veneer lumber. Sensors 11: 5716–5728.

Addis, T.; Buchanan, A.H.; Walker, J.C.F. 2000. Selecting trees for structural timber. Holz Roh-Werkst 58: 162–167.

Allison, R.B.; Wang, X. 2015. Nondestructive testing in the urban forest. In: Ross, R.J., Ed. Nondestructive Evaluation of Wood, 2nd ed.; General Technical Report FPL-GTR-238; Department of Agriculture, Forest Service, Forest Products Laboratory: Madison, WI, USA, pp. 77–86.

Allison, R.B.; Wang, X.; Senalik, C.A. 2020. Methods for nondestructive testing of urban trees. Forests 11, 1342; doi:10.3390/f11121341.

Amishev, D.; Murphy, G.E. 2018. In-forest Assessment of veneer grade Douglas-fir logs based on acoustic measurement of wood stiffness. For. Prod. J. *58*:42–47.

Briggs, D.G.; Thienel, G.; Turnblom, E.C.; Lowell, E.; Dykstra, D.; Ross, R.J.; Wang, X.; Carter, P. 2008. Influence of thinning on acoustic velocity of Douglas-fir trees in western Washington and western Oregon. In: Proceedings of the 15th International Symposium on Nondestructive Testing of Wood, Duluth, MN, USA, 10–12 September 2007; Forest Products Society: Madison, WI, USA; pp. 113–123.

Carter, P. 2011. Real-time measures of wood quality—Transition from research to application. In: Proceedings of the 17th International Nondestructive Testing and Evaluation of Wood Symposium, Sopron, Hungary, September 14–16, 2011; pp. 34–39.

Carter, P.; Briggs, D.; Ross, R.J.; Wang, X. 2005. Acoustic testing to enhance western forest values and meet customer wood quality needs. In: Harrington, C.A., Schoenholtz, S.H., Eds. Productivity of Western

Forests: A Forest Products Focus; PNW-GTR-642; USDA Forest Service, Pacific Northwest Research Station: Portland, OR, USA, 2005; pp. 121–129.

Carter, P.; Wang, X.; Ross, R.J. 2013. Field application of processor head acoustic technology in forest harvest operations. In: Proceedings of the 18th International Nondestructive Testing and Evaluation of Wood Symposium, Madison, WI, USA, September 24–27, 2013; pp. 7–14.

Ceraldi, C.; Mormone, V.; Ermolli, E.R. 2001. Resistographic inspection of ancient timber structures for the evaluation of mechanical characteristics. Mater. Struct. 34: 59–64.

Cown, D.J. 2006. Wood quality in standing timber—Evolution of assessment methods in plantations. In: Kurjatko, S., Kudela, J., Lagana, R., Eds. Proceedings of the 5th IFRUO Symposium “Wood Structure and Properties 06”, Sliac-Sielnica, Slovakia, 3–6 September 2006; pp. 11–17.

Divos, F. 2010. Acoustic tools for seedling, tree and log selection. In: Proceedings of the Future and Quality Control for Wood & Wood Products, Edinburgh, UK, May 4–7, 2010; p. 5.

Downes, G.M.; Lausberg, M.; Potts, B.M.; Pilbeam, D.L.; Bird, M.; Bradshaw, B. 2018. Application of the IML Resistograph to the infield assessment of basic density in plantation Eucalypts. Aust. For. 81: 177–185, doi:10.1080/00049158.2018.1500676.

Evans, R.; Ilic, J. 2001. Rapid prediction of wood stiffness from microfibril angle and density. For. Prod J. *51*:53–57.

Evans, R.; Kibblewhite, R.P. 2002. Controlling wood stiffness in plantation softwoods. In: Beal, F.C., Ed. Proceedings of the 13th International Symposium on Nondestructive Testing of Wood, University of California, Berkeley Campus, California, USA, August 19-21, 2002; Forest Products Society: Madison, WI, USA, 2002; pp. 67–74.

Gao, S.; Wang, X.; Wiemann, M.C.; Brashaw, B.K.; Ross, R.J.; Wang, L. 2017. A critical analysis of methods for rapid and nondestructive determination of wood density in standing trees. Ann. For. Sci. *74*, 27, doi:10.1007/s13595-017-0623-4.

Harris, P.D.; Andrews, M.K. 1999. Tools and acoustic techniques for measuring wood stiffness. In: Proceedings of the 3rd Wood Quality Symposium: Emerging Technologies for Evaluating Wood Quality for Processing, Forest Industry Engineering Association: Rotorua, New Zealand, 1999.

Harris, P.; Petherick, R.; Andrews, M. Acoustic Resonance Tools. 2002. In: Proceedings of the 13th International Symposium on Nondestructive Testing of Wood, Berkeley, CA, USA, August 19–21, 2002; pp. 195–201.

Huang, C.L. 2000. Predicting lumber stiffness of standing trees. In: Proceedings of the 12th International Symposium on Nondestructive Testing of Wood, University of Western Hungary, Sopron, Hungary, September 13–15, pp. 173–179.

Huang, C.L. 2005. System and method for measuring stiffness in standing trees. U.S. Patent No. 6,871545, March 29, 2005.

Meder, R.; Trung, T.; Schimleck, L.; Schimleck, L. 2010. Seeing the wood in the trees: Unleashing the secrets of wood via near infrared spectroscopy. J. Near Infrared Spectrosc. 18, 3.

Moore, J. 2018. DiscBot—A new automated system for measuring wood properties on discs. In: Proceedings of the IUFRO Technical Workshop “New Advances in Nondestructive Evaluation of Wood”, Beijing, China, 7–9 May 2018.

Nutto, L.; Biechele, T. 2015. Drilling resistance measurement and the effect of shaft friction—Using feed force information for improving decay identification on hard tropical wood. In: Ross, R.J., Gonçalves, R., Wang, X., Eds. Proceedings of the 19th International Nondestructive Testing and Evaluation of Wood Symposium; General Technical Report FPL-GTR-239; Department of Agriculture, Forest Service, Forest Products Laboratory: Madison, WI, USA, pp. 154–161.

Rinn, F. 2012. Basics of micro-resistance drilling for timber inspection. Holztechnologie 53: 24–29.

Rinn, F.; Schweingruber, F.H.; Schar, E. 1996. Resistograph and x-ray density charts of wood comparative evaluation of drill resistance profiles and x-ray density charts of different wood species. Holzforschung 50: 303–311.

Ross, R.J.; Brashaw, B.K.; Wang, X.; Pellerin, R.F. 2004. Wood and timber condition assessment manual; Forest Products Society: Madison, WI, USA.

Sandak, J.; Sandak, A.; Meder, R. 2016. Assessing trees, wood and derived products with near infrared spectroscopy: hints and tips. J. Near Infrared Spectrosc. 24, 485–505.

Sharapov, E.; Wang, X.; Smirnova, E. 2017. Drill bit friction and its effect on resistance drilling measurements in logs. In: Proceedings of the 20th International Nondestructive Testing and Evaluation of Wood Symposium, Madison, WI, USA, September 12–15, 2017; Gen. Tech. Rep. FPL-GTR-249. Department of Agriculture, Forest Service, Forest Products Laboratory: Madison, WI, USA; pp. 413–423.

Schimleck, L.R.; Kube, P.D.; A Raymond, C.; Michell, A.J.; French, J. 2005. Estimation of whole-tree kraft pulp yield of Eucalyptus nitens using near-infrared spectra collected from increment cores. Can. J. For. Res. 35, 2797–2805.

Schimleck, L.R.; Rezende, G.D.S.P.; Demuner, B.J.; Downes, G.M. 2006. Estimation of whole-tree wood quality traits using near infrared spectra from increment cores. Appita J. 59, 231.

Schimleck, L.; Dahlen, J.; Apiolaza, L.A.; Downes, G.; Emms, G.; Evans, R.; Moore, J.; Pâques, L.; Van den Bulcke, J.; Wang, X. 2019. Non-destructive evaluation techniques and what they tell us about wood property variation. Forests *10*, 50.

So, C.; Via, B.K.; Groom, L.H.; Schimleck, L.R.; Shupe, T.F.; Kelley, S.S.; Rials, T.G. 2004. Near infrared spectroscopy in the Forest Products Industry. For. Prod. J. 54: 6–16.

Tainter FH, Baker FA. 1996. Principles of forest pathology. John Wiley & Sons, New York, NY. 803 pp

Wang, X. 1999. Stress wave-based non-destructive evaluation (nde) methods for wood quality of standing trees. Ph.D. Dissertation, Michigan Technological University, Houghton, MI, USA, 1999; p. 187.

Wang, X. 2017. Partial resistance drilling to assess wood density in trees. In: Proceedings of the 20th International Nondestructive Testing and Evaluation of Wood Symposium, Madison, WI, September 12–15, 2017; Gen. Tech. Rep. FPL-GTR-249; U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: Madison, WI, USA; pp. 22–35.

Wang, X.; Allison, R.B. 2008. Decay detection in red oak trees using a combination of visual inspection, acoustic testing, and resistance microdrilling. Arboric. Urban For. 34: 1–4.

Wang, X.; Carter, P.; Ross, R.J.; Brashaw, B.K. 2007a. Acoustic assessment of wood quality of raw forest materials—a path to increased profitability. For. Prod. J. *57*:6–14.

Wang, X.; Ross, R.J.; Carter, P. 2007b. Acoustic evaluation of wood quality in standing trees: Part 1. Acoustic wave behavior in standing trees. Wood Fiber Sci. 39: 28–38.

Wang, X.; Ross, R.J.; Mattson, J.A.; Erickson, J.; Forsman, J.W.; Geske, E.A.; Wehr, M.A. 2006. System for and method of performing evaluation techniques on a log or round timber. U.S. Patent No. 7,043,990, May 16, 2006.

Wang, X.; Ross, R.J.; McClellan, M.; Barbour, R.J.; Erickson, J.R.; Forsman, J.W.; McGinnis, G.D. 2001. Nondestructive evaluation of standing trees with a stress wave method. Wood Fiber Sci. 33: 522–533.

Wang, X.; Sharplin, N.; Carter, P.; Ross, R.J. 2008. Method and apparatus for evaluation of standing timber. U.S. Patent No. 7,418,866 B2, September 2, 2008.

Wiemann, M.C.; Williamson, G.B. 2013. Biomass determination using wood specific gravity from increment cores. General Technical Report FPL-GTR-225; Department of Agriculture, Forest Service, Forest Products Laboratory: Madison, WI, USA, p. 7.

United States Department of Agriculture

Proceedings

22nd International Nondestructive Testing and Evaluation of Wood Symposium

Quebec City, Canada
2022


Photo by Gadiel Lazcano on Unsplash


Photo by Julie Boulanger on Unsplash


Photo by Gadiel Lazcano on Unsplash

Forest Service, Forest Products Laboratory
Université Laval
Forest Products Society
International Union of Forest Research Organizations

General Technical Report
FPL–GTR–290

May
2022

Abstract

The 22nd International Nondestructive Testing and Evaluation of Wood Symposium was hosted by the Université Laval in Quebec City, Canada, May 24–27, 2022. This symposium was a forum for those involved in nondestructive testing and evaluation (NDT/NDE) of wood and brought together many international researchers, NDT/NDE users, suppliers, representatives from various government agencies, and other groups to share research results, products, and technology for evaluating a wide range of wood products, including standing trees, logs, structural lumber, engineered wood products, and wood structures. Networking among participants encouraged international collaborative efforts and fostered the implementation of NDT/NDE technologies around the world. A special on-line session was conducted to accommodate individuals who could not attend in-person due to the ongoing COVID-19 pandemic. The technical content of the 22nd symposium is captured in these proceedings. Full-length, in-depth technical papers for most of the oral presentations, along with abstracts for all the oral and poster presentations, are published herein. The papers were not peer reviewed and are reproduced here as they were submitted by the authors.

Keywords: Nondestructive evaluation, nondestructive testing, wood properties, wood products, logs, trees, wood structures

May 2022

Wang, Xiping; Ross, Robert J., eds. 2022. Proceedings: 22nd International Nondestructive Testing and Evaluation of Wood Symposium. General Technical Report FPL-GTR-290. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 324 p.

A limited number of free copies of this publication are available to the public from the Forest Products Laboratory, One Gifford Pinchot Drive, Madison, WI 53726-2398. This publication is also available online at www.fpl.fs.fed.us. Laboratory publications are sent to hundreds of libraries in the United States and elsewhere.

The Forest Products Laboratory is maintained in cooperation with the University of Wisconsin.

Contents
