Forestry White Paper**: Nondestructive testing (NDT) of live trees**

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Abstract- The Allegheny Institute of Natural History, a research unit of the University of Pittsburgh located at Bradford ,PA adjacent to the Allegheny National Forest, can provide apparatus and methods for determining the presence of decay in the interior wood of live trees. This paper discusses how this can be done through the development of photon and electromagnetic wave backscatter technologies.

Index Terms- non-destructive testing, wood, live trees, x-ray backscatter

Why test live trees?

When negotiating over the value of uncut wood, the problem often arises that the negotiated price is affected by the possibility of decay in the heartwood of valuable trees, for instance Black Cherry, *Prunus serotina*. This is a problem that affects both the buyer and the seller. The seller would be in a much better bargaining position and the buyer would suffer less risk if it were possible to assess the internal quality of trees without cutting them. Besides this obvious economic advantage of testing trees, nondestructive tree testing could allow foresters to make better decisions about thinning and about measures to control disease and pests. This paper focuses on the application of a new technology, photon backscatter, developed for aircraft corrosion assessment, to testing trees for hidden decay. Except as a means of finding hidden contraband, backscatter has not yet been explored in the US for testing wood and its use in Europe is just beginning. In fact, the entire subject of testing live trees is itself relatively new.

Introduction to photon backscatter NDT

- *Historically used for measuring overall density*

Gamma ray and x-ray backscatter have long been used to measure the gross or overall density of materials including wood and concrete. A gamma or x-ray beam is directed into the material to be tested. A portion of that beam is reflected back. The amount reflected back, termed backscatter, depends on the density of the material. When the geometry of the test is simple, consisting of just a source and a detector, the detail of the quantitative relationship between the density and the amount of backscatter is often complex. There can be two widely different densities that give the same amount of backscatter. Gamma backscatter has been used to test trees for decay in Poland.

- *Advanced geometries allow evaluation of local subsurface densities*

The need to detect corrosion in subsurface layers of aircraft skins and similar problems have led to the development of new testing geometries for gamma and x-ray backscatter. Corrosion and wood decay are similar in that both involve the loss of internal material and the formation of empty spaces, known as voids, or pockets of low-density. Photon backscatter (using either x-ray or gamma photons) has been found to be useful in measuring corrosion damage because the amount of backscatter from a single volume element is proportional to the density of that element. Geometries which permit the sampling of individual volume elements give photon backscatter a better signal to noise ratio for finding voids than most other methods. For example, the conventional x-ray (transmission) method images a void or low-density region as if it were a change in the *total* thickness of the material tested rather than a change in a specific region. Sponsored by the US Federal Aviation Administration, x-ray backscatter tools for high-resolution (micrometer accuracy) volume imaging of aircraft have been successfully built and tested by one of the authors. This equipment needed no auxiliary shielding and has been safely demonstrated in a hangar to a live audience. When knowing the total density along a line is sufficient, backscatter tools can be made very small. Also, the amount of radiation is further reduced when volume imaging is not required. One device used for qualitative imaging of aircraft skins is made by Northrop-Grumman and is hand held resembling a pencil. In fact, a device using this principle is routinely used in prisons to check prisoners for contraband hidden in body cavities.

- *Detection of multiple scattering allows more inference with less radiation*

Besides being proportional to local density, backscatter has a second property that is useful to detecting and measuring voids. This is the property that when a void is present, the probability of a photon being scattered twice before reaching the detector increases. This property has been termed “lateral migration” since the doubly scattered photon travels some distance between its first and second scattering collision. Utilizing both the density and the lateral migration properties simultaneously has proven valuable in detecting and measuring small subterranean voids. This type of combined method holds considerable promise for efficiently detecting and measuring density loss in trees. Using such a method reduces the intensity and thus the size of the source. This means less radiation and more portability. The relationship between observable multiple scattering and specimen-detector geometry is often extremely complex. The practical use of multiple scattering requires the generation of models that yield relatively simple mathematical approximations of the relationship between defect geometry and the observed scattering. Such models are generated using Monte Carlo computer simulations. These simulations have proven to be extremely accurate predictors.

- *Photon backscatter NDT specifics for testing trees*

In general, a tool to assess density loss in trees as from decay or shakes (fissures between growth layers) would consist of a collimated gamma or x-ray source, a photon detector having sensitivity to the position and angle of the detected photon and a means for scanning the source respect to the trunk of the tree. Additionally there would be some device, such as a laptop or palm-pilot computer to perform the needed calculations and display the result. Within this general description, many variations are possible. The object of research would be to find the configuration having the lowest cost and greatest portability while providing the user with adequate information.

Nondestructive testing of live trees: the current scenario

No specific method has been yet found to be entirely satisfactory for testing live treed.

Only the most primitive backscatter techniques appear to have been tried for testing trees. Sonic, ultrasonic and x-ray tomographic methods have also been tried for the purpose of locating decay in live trees. These can be compared. X-ray tomography requires access to both sides of the object tested and needs precision in the placement of source and detector. Large stationary systems capable of efficient detailed analysis of logs at the sawmill have been in use for years. Ultrasonic methods are frustrated by the presence of bark, surface effects and the somewhat limited penetration of ultrasound into dry wood. Nevertheless, because so many research facilities work with ultrasonics, the literature of the subject of ultrasonic wood testing is relatively large. Sonic methods seem promising for testing live trees. These are broadband phase correlated methods. Typically a multiplicity of detectors is attached to the tree and the tree is struck with a hammer or its electronic equivalent. The scattering of the sonic wave is analyzed. In a sound tree the wave will propagate in straight lines from the source to the detectors. In a faulted tree, the wave is scattered by the fault resulting in a different pattern of arrival times at the various detectors. Bark and cambium interfere with good reception. For best results the detectors need to be nailed to the tree. Accurate placement of the detectors is essential to obtaining accurate results

An Alternative Technology for Testing Trees

Backscatter testing need not be confined to that with high-energy photons. Radio frequency scattering is also a possibility for testing trees since high spatial resolution is not needed. In fact it has seen some application in the testing of lumber. The interaction of wood with low-frequency radio energy is well-documented through the use of radio to expedite gluing. The remarks already made about x-ray scattering would in general also apply to radio frequency backscatter except that large wavelength of radio waves complicates the mathematics. However, the use of radio for nondestructive testing has been limited overall. Microwaves have been used for testing concrete. In the testing of trees, moisture would be expected to scatter radio more strongly than voids. This would mean that radio backscatter could be used to image moisture content. Since there is no such thing as "dry rot" the presence of excessive moisture in heartwood might signal decay. A decided advantage of radio experimentation is the simplicity of the apparatus involved and the ready availability of components.

The Allegheny Institute of Natural History

The Allegheny Institute of Natural History (Directed by noted biologist, Dr. Tom Pauley of Marshall University) is a good platform for conducting research in the nondestructive testing of trees. Dr. Lawrence Lawson, co-author of this paper, is one of the world's foremost authorities on x-ray backscatter nondestructive testing and was chosen to author the portion of the American Society for Nondestructive Testing's *Radiographic Testing* handbook on backscatter NDT. He has designed and built a great deal of testing apparatus including one for backscatter testing of commercial aircraft. The Institute is located on the edge of the Allegheny National forest in a logging community. It is not far from US Forestry Service experiment stations. Being part of the University of Pittsburgh, the Institute has faculty, student and laboratory resources including access to the supercomputer a the University of Pittsburgh. These include workers in forest biology and an additional faculty expert in scattering physics. The University of Pittsburgh at Bradford has been one of the nations leaders in undergraduate research. It founded the Penn-York Undergraduate Research Conference series.

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