Level 3 Inspections:
A non-invasive approach to tree risk management

By Robert Booty

As you travel home one evening, you notice a consistent dull pain in your lower back. As the weeks pass, the pain intensifies and you are increasingly concerned. You visit your family physician, and after an examination, your physician explains your options for determining the source of your pain . . . Exploratory surgery may provide some answers. But there are other options, including non-invasive ones, such as an ultrasound, MRI (magnetic resonance imaging) scan, or an X-ray image. Knowing that complications may develop using exploratory surgery, your physician doesn't take any chances and orders an MRI scan of your lower back.

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There is value in using non-invasive technology for advanced tree inspections. Pictured here: radar technology being used to determine wood density during a Level 3 inspection.

Trees are somewhat like people; at some time during their life, they too will develop internal problems that are not always identifiable through an external examination alone.

Arborists have used all sorts of methods and calculations to determine the internal condition of a tree and its potential risk. Some of these methods were very invasive, such as removing core samples, drilling, or even cutting away decay within a cavity. Some of these methods are still in use today. There's reason to believe that the term "tree surgeon" was coined as a result of these invasive procedures.

What are the benefits of using non-invasive diagnostic procedures during Level 3 inspections?

Trees, like people, can be adversely affected by the methods used to evaluate their health, particularly procedures that penetrate the bark.

The establishment of decay (Nicolotti et al. 2009) in living trees is affected by urban environmental stresses that range from a general weakening of a tree's natural defense system to injuries that allow wood-rotting agents to gain entry through wounds. Trees have their own protection system that uses a series of four internal walls, all beautifully designed to block or resist the spread of disease-causing pathogens that invade them. This is what we refer to as CODIT (the compartmentalization of decay in trees).

When invasive testing methods are used, these protective walls can be pierced, allowing decay pathogens, which at one time may have been localized or contained, to continue their spread within the tree.

When performing Level 3 assessments, understanding the internal structural condition of a tree is a vital part of that process. However, if this internal data could be collected without drilling or using other invasive methods, if you could just collect your data and walk away as if you were never there, then it could be a win-win situation for the tree under evaluation.

Why use radar technology?

Today, technology has advanced to the point where non-invasive data collection via radar is possible. Ground-penetrating radar (GPR) is being used to evaluate internal, structural changes within a tree in a non-invasive way during Level 3 inspections.

For arborists, radar imaging on trees creates the same type of high-resolution image that a medical professional, using MRI imagery, would use to diagnose a patient. This is the latest method to safely evaluate the internal structure and condition of a tree without causing physical harm. Having the ability to create and review an internal image of a tree, and then identify hidden problems, fills a critical gap in risk assessment and tree preservation.

How does it work?

GPR is an established technique that has been used worldwide for over 30 years. Radar is an object-detection system that uses electromagnetic waves—specifically, radio waves—to identify the range, altitude, direction, or depth and speed of both moving and fixed objects. Its uses today seem endless. For example, when you look at the weather report, you are looking at a weather radar, which tells you where and when the heaviest amounts of precipitation will fall in your area. The radar, as it passes through the clouds, measures the density of the moisture in them and the speed they are traveling. Provided with this information, meteorologists will know approximately when it will start raining and how much rain will fall. Radar is used in aviation, automobiles, law enforcement, and locating objects underground.

But what exactly is it that makes radar work?

When an electromagnetic wave emitted from a small surface transmit-antenna encounters a boundary between objects with different electromagnetic properties, it will reflect, refract, and/or diffract from the boundary in a predictable manner (Daniels 1996). Radar waves or signals are reflected especially well by materials of considerable electrical conductivity. The radar signals that are reflected back towards the transmitter are the desirable ones that make radar work. An air-filled tree trunk (as in a decayed hollow area) or partially air-filled area in an incipient (early stage) decay zone inside a cell wall of a tree are excellent reflectors for detection by GPR systems. The use of GPR instrumentation for internal tree trunk decay detection is one of its latest uses in the field of tree risk assessment.

How does radar distinguish between decayed and healthy wood?

Wood decay fungi decompose lignified cell walls within living wood tissue by using enzymatic and non-enzymatic systems (Nicolotti et al. 2009). This creates, in the beginning, a microscopically detectable hollow or void within the cell walls of the wood, thereby reducing normal wood strength. If you were using a fish finder to locate fish, the sonar waves would bounce off the "air bladder" within the fish, giving you its location and depth. Ground-penetrating radar does the same thing, as it identifies changes in wood composition and strength (only radio waves are used). Radar imaging can identify these changes within the wood cell composition. It's the loss of the wood's mechanical strength that is inherently linked to hazardous situations, which can result in significant property damage or personal injury.

GPR is an important addition to non-invasive forensic technologies for wood decay analyses because its sensitivity to hollows, internal cracks, and voids enables the detection (and creation of a visible image) of these sometimes small, internal molecular changes in wood density and composition.

Take a look at the figure below. You can see the radar antenna is slowly moved around the circumference of the tree. As it travels, it sends out radar waves every two-tenths of an inch (0.51 cm). With no obstructions, these waves are calibrated to penetrate to the center of the tree while the antenna is moved around the trunk (or branch).

The radar waves, in turn, are reflected back to the antenna or receiver when changes to normal wood composition are encountered anywhere within the scanning area.

The presence of sometimes hundreds of these reflected radar waves create an internal image of any compromised area within the tree. By measuring the density of the wood, the level of severity of the newly discovered defect can be evaluated.

During this process, the remaining, solid healthy wood is identified and displayed to the technician in inches or centimeters.

The trained arborist, knowing the diameter of the tree section being scanned, can use the resulting data to determine if the internal deficiencies, if present, are sufficient to warrant further action.

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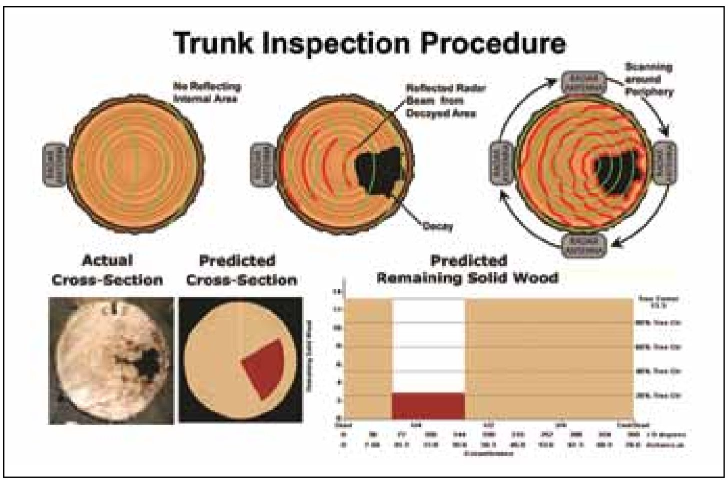

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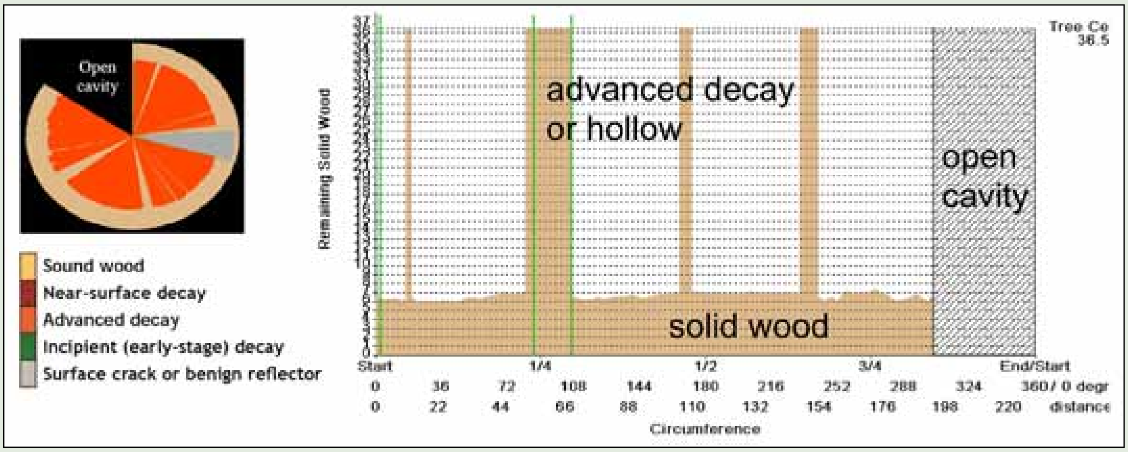
Although radar images or any other imaging devices will not create an *actual* picture of the inside of a tree, they will provide the arborist with a *likeness* or *image*, allowing for reasonable recommendations for future care.

Case Study #1: *Quercus lobata*

This valley oak (*Quercus lobata*), situated between two residential homes, is about 200 years old. The tree's structural stability was a primary concern. Open pockets of decay, the result of large, old pruning wounds were visible. Homeowners from both adjacent properties were concerned because there was so much branch weight overhanging their homes.

Four separate elevations of radar scans were completed on the oak, starting in the lower buttress area below the deck. All results predicted advanced decay or hollow, with average remaining solid wood of seven inches (17.78 cm).

The trunk diameter was 73 inches (1.85 m). Before removal, this imaging data was confirmed by invasive testing methods, using a RESISTOGRAPH®, and removing core samples.



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Finalized imaging data for scan #4. At left, note that the gaps in the plot indicate bumpy sections of the trunk where the antenna was not making good contact.

Analyst Notes: Appears to be advanced decay throughout the entire sector at this elevation, with an average remaining solid wood of approximately seven inches. The gray area is where the antenna was over a depression.

Case Study #2: *Quercus agrifolia*

This coast live oak tree (*Quercus agrifolia*) was located at the rear entrance of a hospital. Staff (coming from the parking lot) walked under this tree every day.

Radar can be used for full circumferential trunk imaging, as seen in Case Study #1, or in a data collection mode as we see here, where the trunk is very uneven. In this case, the radar sends a single wave form into the tree. If it encounters changes in wood density, the wave reflects back to the antenna, measuring the remaining amount of sound wood. It works just as if you had physically drilled into the tree, inspecting it for decay, only this method is non-invasive. The following is a detection key for the tree's upper trunk evaluation data:

Scan ID #	Wave form #	Decay detected?	Remaining sound wood
#502	0	yes	9.3 inches (23.62 cm)
#708	15	yes	9.4 inches (23.88 cm)
#505	13	yes	7.7 inches (19.56 cm)

The radar wave was calibrated to penetrate 30 inches (76.2 cm) into the tree; the numbers on the tree and in yellow are the actual sites that tested positive for decay. The upper elevation of testing involved the area of the main scaffold limb attachments, from about 11 to 16 feet (3.35 to 4.88 m) in height.

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How well has this been integrated into arboriculture? What are its limitations?

As with all Level 3 technologies used in decay detection, radar imagery has its strengths and weaknesses.

Some of the difficulty with the use of GPR involves the shape of the tree trunk verses the dimensions of the antenna used in data collection. Not all trees are the same shape: some have deeply furrowed bark, others are smooth; some trunks are round, others are not. When you are scanning an area on a tree, the antenna being used should make good contact with the surface of the tree. Although the antenna is very forgiving in this regard, it can be a challenge at times, especially for the new user.

As your experience in using this equipment grows, you will come to understand that in difficult situations, a slow and steady scan over a deeply furrowed or oddly shaped trunk will provide the needed information for your inspection. In Case Study #1, shown here, a nylon strap was used to mitigate the situation over this deeply furrowed oak bark.

At times, you may come across a tree whose shape indicates that the antenna you normally use just won't fit the intended area, or maybe the tree has an open cavity.

This is where your experience comes into play. When faced with a cavity, a sector or partial scan can be performed. In other words, you are retrieving data from what's left of the tree, minus the open cavity. When faced with situations involving tight areas where equipment just won't fit (and the area can't physically be scanned using the traditional scanning methods), data point collection can be just as successful, as depicted in Case Study #2.

Technicians can also make use of an accessory antenna—a smaller antenna that can easily scan odd tree shapes and will extract data from these difficult areas. The 2000 MHz antenna, for example, is a much smaller antenna with dimensions that measure a little more than three square inches (19.35 cm^2). It can be used for full or partial scans and data collection analysis on smaller diameter scaffold limbs, trunks, or buttress areas of the tree where the larger antenna can't always be used.

And when it comes to making sense of the data, training is required in the use of the TreeWin™ analysis software (TreeRadar Inc., Silver Spring, Maryland, U.S.). This particular software for trunk inspection offers semi-automated data analysis collected from your field data.

Data analysis can be performed on a laptop in the field or back in your office as you finalize your report. When used properly, your radar data is quite accurate. Normally, within a few hours, an individual can completely scan approximately six trunk elevations on a tree.

For trunk inspection, radar systems have mainly been used on hardwood species. And because GPR will only produce straight lines or circles, the actual visual shape of the trunk will always be depicted graphically as a circle (or partial circle), which may not be the case in the real world. The collected data, however, would still be correct; that is, the predicted distance between the bark to any internal changes in wood density would remain valid.

Other uses for GPR?

The use of ground-penetrating radar has opened up other doors in the field of arboriculture. These opportunities are valuable in other aspects of Level 3 inspections, such as belowground root mapping.

How many leaning trees are removed each year because one assumes there is a lack of sufficient roots on the opposite side of the lean to support the tree? And what about irrigation? Trees are damaged every year because irrigation trenches are cut across root systems. Is that tree root causing damage to your sidewalk or driveway? Use GPR to find out. And how many roots can be safely removed to install your root barrier? You won't know unless you excavate!


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A technician using the Palm 2000 antenna during a Level 3 inspection.

GPR is successfully being used to non-invasively locate and map tree roots below ground, without removing the concrete or digging up those roots just to see if they are the nasty ones really damaging the property.

Literature Cited

Daniels, D.J. 1996, Surface-Penetrating Radar. London, UK. The Institute of Electrical Engineers.

Nicolotti, G., P. Gonthier, F. Guglielmo, and M.M. Garbelotto. 2009. A Biomolecular Method for the detection of wood decay fungi: A focus on tree stability assessment. *Arboriculture & Urban Forestry* 35(1):14–19.

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For further information on how this technology is being used, enjoy this video, courtesy of the Smithsonian Institution of Washington, D.C. (http://vimeo.com/50095039).

Brown Rot

Wood decay is typically classified into three groups: brown rot, white rot, and soft rot.

Brown rot, pictured here, breaks down cellulose and hemicellulose, leaving a modified, lignin-rich brown substrate.

This results in a large reduction in the strength of the wood early on, often before there are visual indications of the decay.

In advanced stages, the residual wood will crack or crumble into cubical pieces. **A•N**

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