PiCUS Tree Tomography Methods at a Glance

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1. Overview

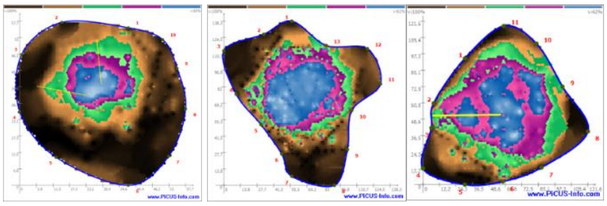
Currently there are two tomographic methods available for trees: Sonic Tomography (SoT) and Electric Resistance Tomography (ERT). Both methods use different physical ideas and thus, do show different information of the tree. SoT gives information about the integrity of the mechanical structure of the wood while ERT shows – so to say – "chemical" information.

Both methods do have advantages and limitations. SoT for instance suffers from cracks in the tree that do interfere with the acoustic waves sent through the trunk.

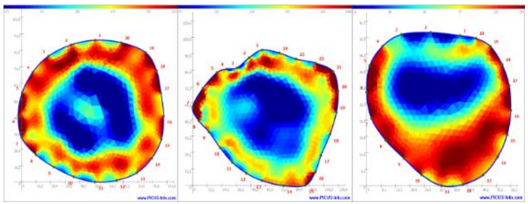
Combining both SoT and ERT method we can overcome those limits and derive more and better conclusions about the tree. In particular it is possible to:

- Finding out about the **type of a defect**: what are we looking at in the tomogram: is it a hollow, or decay or just a crack?
- What **stage of decay** is in the tree: incipient or advanced or old?
- Measuring the **size of the defect more precisely**.
- Detect **decay below ground level**
- Avoid wrong conclusions!

This document briefly describes how SoT and ERT work on trees and how the results can be understood.



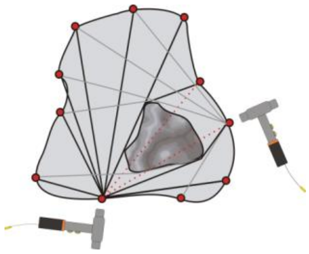
Sonic Tomograms

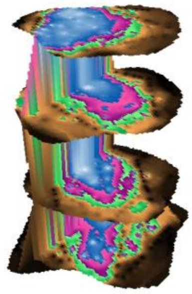


Electric Resistance Tomograms

2. Sonic Tomography (SoT)

Sonic Tomographs are instruments that detect decay and cavities in standing trees non-invasively. The instruments measure the velocity of sound waves in wood. The acoustic velocity depends on the modulus of elasticity and the density of the wood itself. Most damage and disease causes fractures, cavities, or rot and reduces the wood's elasticity and density.

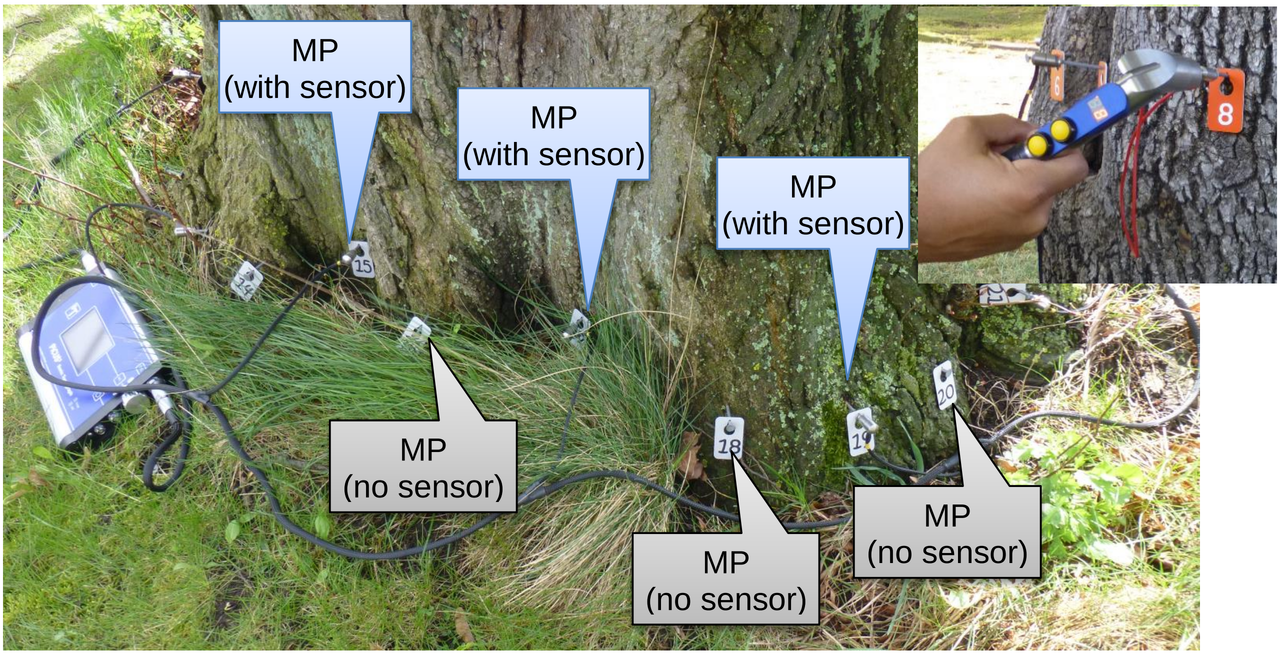




The sketch displays the basic working principle, in that sound waves cannot take a direct path through the wood (red dotted line) if there is a cavity between the transmitter and receiver.

The acoustic waves are created manually with a little hammer, sonic sensors (receivers) record the signals. Little pins are used for coupling the sensors to the wood. Number and positions of the test points are critical to the accuracy of the scan.

The PiCUS technology differentiates between sensors and measuring points (MP). A MP is a simple nail. For a PiCUS scan a virtually unlimited number of measuring points (nails) can be used because of that technology. The photo below shows a setup of 12 sensors on 24 MP. The electronic hammer can create sonic signals on all 24 MP!



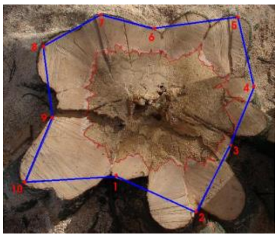
PiCUS 3 on a *tilia cordata* tree

2.1. How to record a sonic tomogram

Taking sonic measurements involves four basic steps:

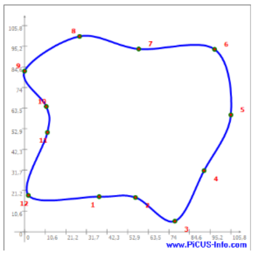
1. **Determine the level, number and positions of measuring points**
   Care must be taken when selecting the level of tomography and the locations of the measuring points (MP). Inappropriate MP locations may lead to inaccurate tomograms.

2. **Measure the geometry of the tree at the level you are working at**



Cross section of a tree

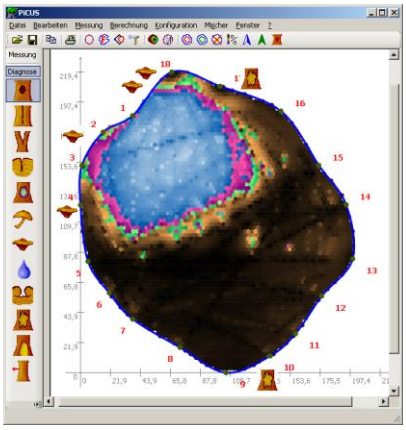
Using Triangulation method and electronic calipers to measure positions of all MP



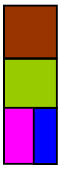
Graphic representation of that measurement in PC program

3. **Take the sonic measurements**

Each measuring point (nail) is tapped with the electronic hammer in order to create sonic waves.



4. **Calculate the tomogram, Interpretation**
   The tomograph main unit itself or the PC calculates the sonic tomogram when all readings have been taken. The tomogram shows the relative and apparent ability of the wood to transmit acoustic waves. Different colours display the various properties of the wood:



Areas of good wood, where the fastest velocities can be found, are represented in (dark) browns. The meaning of green varies according to the defect. It often describes the distance between healthy and damaged wood, but can also indicate early fungus infection. Violets and blues represent damaged areas.

2.2. Advantages of the PiCUS Tomograph

- Extremely **quick tapping**
- **Less cables**: sensors are assembled to a sensor-cable-harness
- **Unlimited number of measuring points**: 10, ... 15, … 20, … 50
- **Sensors are small** land light-weight: pins are not deep in the wood. Pin diameter < 3 mm!
- **No special pins needed**, regular nails from hardware store work well. No extra after-sales costs!!!
- New **compact system design**: just one main control unit, no extra sensor-supply boxes

- **Low weight** of the tomograph, approx. 4 kg only! All gear fits into a small shoulder bag if needed. Ruggedized transportation case is supplied.
- **NO PC** needed in the field. Can operate the entire tomography scan with or without PC
- Preview sonic tomogram shown on screen on-site
- **Three-point-measurements** (no PC needed) to quick-test the tree to help to decide whether a full tomogram is needed
- Main control unit saves scans on non-volatile memory.
- **Inbuilt GPS**
- Inbuilt semi-automatic **tree height measurement**
- **Precise and fast geometry** of any tree using triangulation functions and PiCUS calliper

Left: Tomography in rain – the operator needs to be protected. The sensors? Not so much.
Middle: Tomography in the tropics in Panama.
Right: Ruggedized transportation case.

3. Electric Resistance Tomography (ERT)

<u>E</u>lectrical <u>R</u>esistance <u>T</u>omographs using electric current/voltage to examine the tree. The resulting measurements are displayed in a two-dimensional map showing the apparent electrical resistance of the wood, called an *Electrical Resistance Tomogram* (ERT).

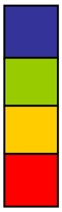
The electric resistance of the wood is influenced most of all by the

- water content
- chemical elements which change according to the status of wood and
- cell structure: reaction wood or roots do have different resistances compared to "normal wood"

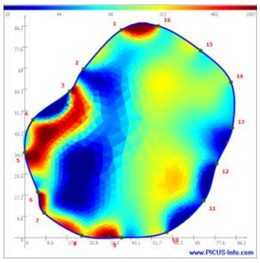
When used in **combination with a Sonic Tomograph**, an ERT offers you more information about the tree:

- distinguish between different types of damage (for instance crack/cavity vs. decay) in many cases
- detect early stages of decay
- get information about areas above or below the measuring level. This is interesting for analysing root decay problems.

In order to analyse an ERT, the operator will need knowledge about the specific type of tree species. **Each species has its own typical resistance** (water/moisture) **distribution**.
The ERT are coded with rainbow colours:

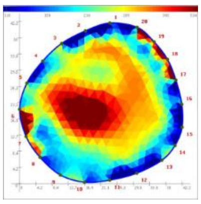


Blues indicate areas of low resistance (high water content, etc.)
Greens and yellows show increasing resistance
Red colours indicate areas of high resistance (lower water content, etc.)

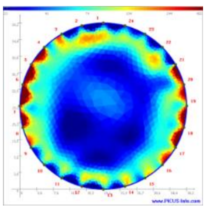


How to read resistance tomograms

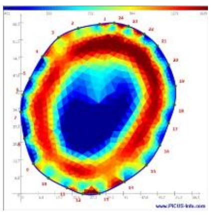
The main aspect of interpreting ERTs is the distribution of high and low conductive areas. You are looking to see where high resistance is and where low resistance is. This information needs to be compared with the normal resistance distribution in sound trees of this particular species. The interpretation of the ERT is most accurate when done in combination with the SoT. So far we have identified **three types of typical resistivity distributions** in trees.



ERT type 1



ERT Type 2

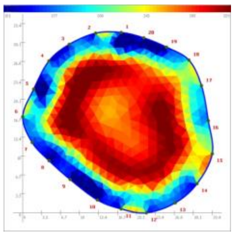


ERT Type 3

The table below shows general rules of interpretation for *ERT Type 1* trees. *ERT Type 1* trees usually have lower resistance (blue in ERT) in the sapwood on the edge and high resistance in the heartwood (red in ERT) in the centre:

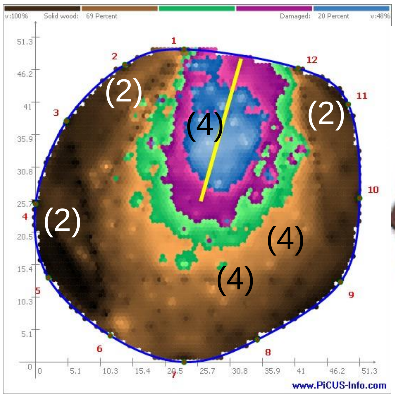
The table helps to evaluate the **centre** of the tree

SoT **Sonic velocity [m/s]**	**ERT** **Resistivity [Ω*m]**	**Conclusion**
High (brown)	High (red)	Healthy
High (brown)	Low (blue)	Still safe, but early decay
Low (blue/violet)	High (red)	Cavity / dead decay
Low (blue/violet)	Low (blue)	Active decay



3.1. Example 1: Different stages of decay

The example shows a Linden tree with decay and cavity. Linden trees belong to ERT type 1. Areas shown in brown colours show high sonic velocity (= sound wood), areas in blue/purple show decay or the cavity.



Sonic Tomogram (SoT)

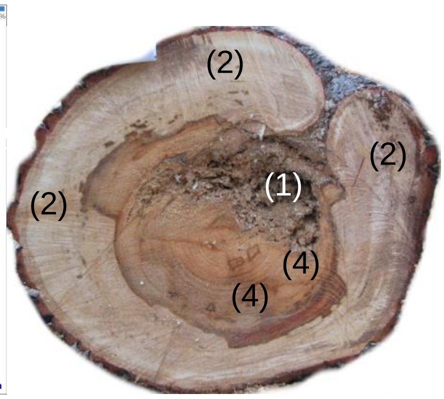
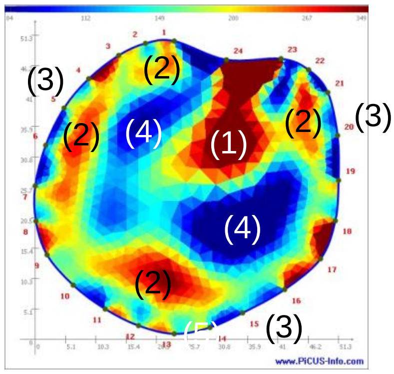


Photo of cross section



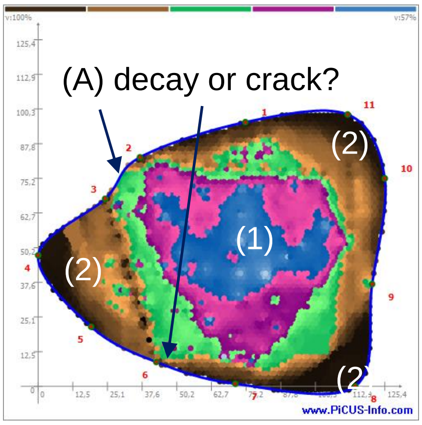
Electric resistance tomogram

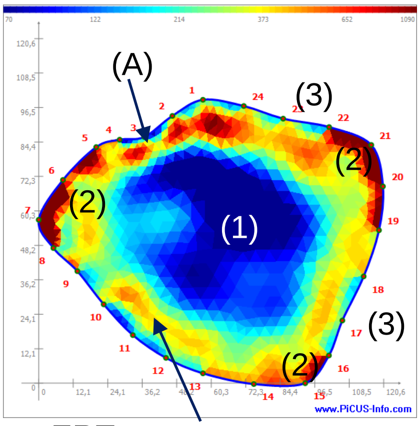
(1) Low V*) and high R*): Cavity, or dead dry wood
(2) High V and medium R: sound wood
(3) Low R at the very edge: normal sapwood.
(4) Medium V and Low R: active decay but wood is still relatively dense

*) V = velocity, R = Resistance

3.2. Example 2: decay or crack?

The example shows a *castanea sativa* in Rostock. The SoT seems to show that the left part of the tree is separated from the right part. What is the reason for the separation – decay breaking through or just a bark inclusion (crack) at positions (A)?





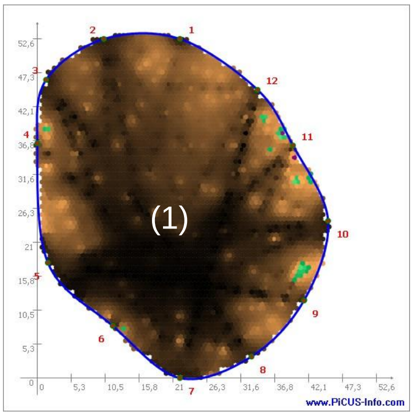
SoT ERT (A)

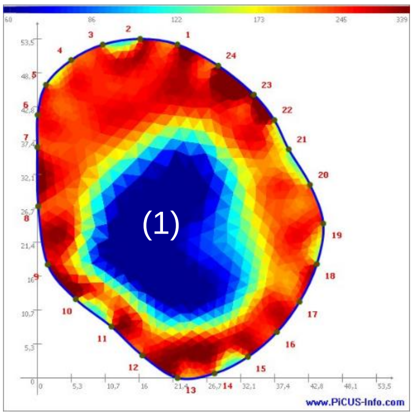
(1) Low V*) and low R*): advanced wet
(2) High V and high R: sound wood
(3) Low R at the very edge: normal sapwood.

The wood near (A) does not transmit acoustic waves well. But the material has a high R. Thus, there is no decay! It is a "regular" bark inclusion!
The ERT shows the size of the defect more precisely than the SoT due to the bark inclusions. All red/yellow area will be good material! The defect is a little smaller than the SoT shows.

3.3. Example 3: incipient decay

The SoT of the linden tree in this example does not show a problem. However, the electric resistance of the wood is already changed due to incipient decay like the ERT proves.





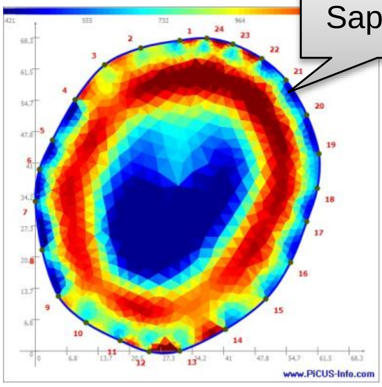
SoT ERT

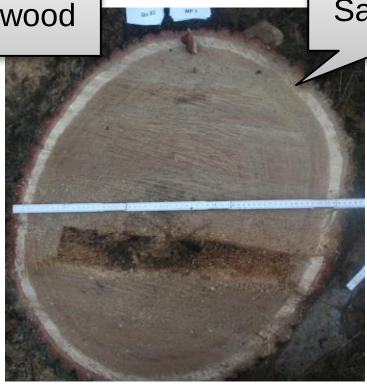
(1) High V*) and low R*): still good sonic propagation but wet! Incipient decay.

*) V = velocity, R = Resistance

3.4. Example 4: Detecting hardwood/sapwood using ERT

Some tree species develop a distinct sapwood area. If the resistance of the sapwood is different from the rest of the tree then the ERT can measure the thickness of that layer. The example shows an oak (*quercus robur*).

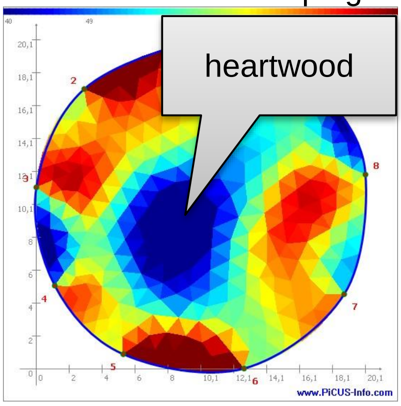




ERT (120 cm above ground)   Stump (20 cm)

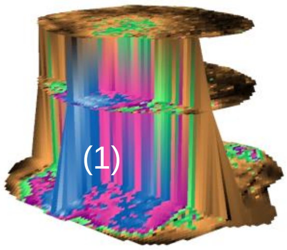
3.5. Example 5: Detecting hardwood/sapwood in teak (tektona grandis)

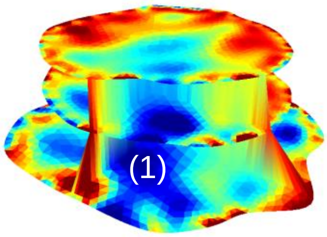
Teak wood develops a distinct heartwood, which is the most valuable part of the wood. The electric resistance of that heartwood is apparently low. The example shows a teak tree in Mexico that is developing a dangerous dry rot.



4. 3D Scans

The most accurate way of getting 3D information of trees is to record several levels and calculate the 3D image of the tree. The example below shows a beech tree with *ganoderma* infection. The SoT shows little damage in the 3ed level, but the blue colour in the ERT (low resistance) indicates wet material – an early stage of the fungus.

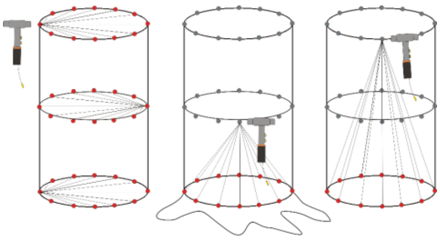




SoT ERT

(1) Slow V + low R = active fungus

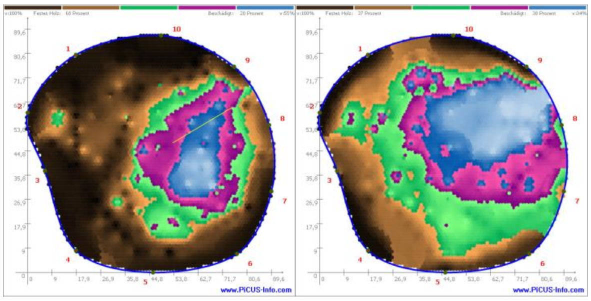
The sketches below show options to record 3D acoustic data. Red dots represent sonic sensors, grey dots are the measuring points - “just” nails. Because of the unlimited number of measuring points (the nails) – the data can be collected in many different configurations.



Data collection options for sonic scans.

5. Timelines

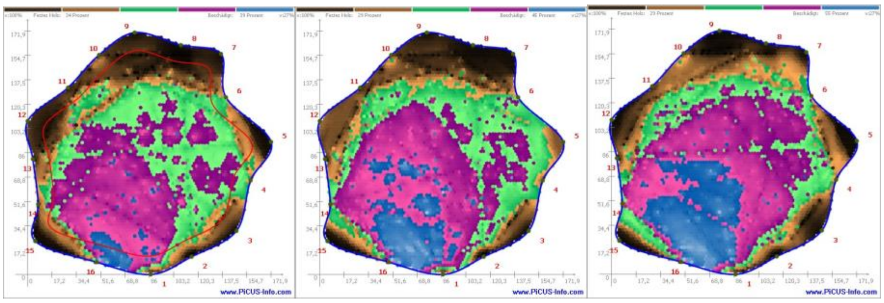
Trees can be tomographed every couple of years to find out about the progress of a decay. When doing so it is important to use the same MP-positions all the time.



SoT 2007 20110

The example shows the progress of a fungus infection in a beech tree. The tree was tested in 2007 and in 2011.

The fast progression of the decay does not inspire confidence about the future of that tree.



SoT 2006 2008 2010

Tomograms of an oak. The size of the damaged area seems to stay constant. Apparently the tree did find a way to stop the fungus growing into good wood.

6. Contact information

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