Combining Sonic and Electrical Impedance Tomography for the Non-destructive Testing of Trees

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Abstract

For the non-destructive testing of standing trees sonic tomography is currently the “state-of-the-art” in many parts of the world. The most significant step forward in this technology in the recent years is the reduction in hardware requirements – by using an electronic hammer the number of sensors can be halved. Especially in large trees this increases the accuracy of the measurements.

Although in the majority of cases the results are correct and easy to interpret, some limits remain. To overcome the limits of sonic tomography our research group has been adapting electrical impedance tomography (EIT) from geoelectrics to be used for trees since 1998 [4]. Among other properties, the system allows the detection of early stages of decay, wet wood and different types of heartwood [9].

Since 2004 new reconstruction algorithms for the electric impedance tomography have improved the results by using the exact shape of the measured cross-section of the tree. To achieve this, modern inversion algorithms and finite element based simulation techniques are applied [2]. Recently we began to combine the two tomographic methods. Because they are based on different physical properties of wood, the combination yields more detailed information on the stem cross section and results can be interpreted with greater ease and reliability. While sonic tomography is based on biomechanical properties of wood, electrical impedance tomography mainly visualizes chemical properties.

The recently introduced PiCUS: Treetronic system, which is based on this research, allows the fast and efficient use of both techniques in combination.

Key words:
Sonic tomography, electrical impedance tomography

Sonic Tomography

In 1999, sonic tomography for trees was introduced as a new method for non-destructive testing of standing trees (PiCUS Sonic Tomograph, argus electronic gmbh, [3]). This technology, also presented on the NDT of wood 2000 [6,7], overcame a number of disadvantages of one dimensional methods.

The idea in hardware design at the time was to assign a sonic sensor to each measuring point around the circumference of the tree and to record the transmission time of sonic signals simultaneously. The new idea in software design was to compare all the sonic velocities recorded at one level with each other, rather than trying to find an absolute velocity trigger level that would determine whether wood is sound or defective. The reason is that sonic velocity in wood varies not only among different species but also among the trees of the same species and even within the same tree.

The sonic-based reconstruction of the measuring level – in other words, calculating the tomogram – can be done in different ways based on different assumptions. The sonic velocity does not necessarily vary at a measuring level. Depending on the type of defect (decay, crack, etc.), the sonic waves might have been slowed while passing through an area of lower density (early decay,) or forced to bypass a cavity at (nearly) constant velocity. In both cases it is difficult to determine which wave reached the receiver first. For this reason, when analyzing tomograms the ability of the wood to transmit sonic waves should be considered instead of velocity or density maps.
The algorithm we have developed since 1997 is a sort of ‘back-projection’. The intersections of the ‘beelines’ between the measuring points determine an apparent sonic velocity on each point. The long wavelength of the sonic waves causes a significant diffraction. No exact ‘sonic shadow’ can be observed behind the anomaly. Even so, the calculation of size and location of the defect can be done rather accurately because the time of travel of the sonic wave is used instead of the amplitude of the waves. Resolutions of up to 1 cm can be achieved under favourable conditions regarding the location of defect, the number and position of measuring points, the size of tree, etc. Those circumstances cannot be matched on every tree. The main difficulty is to assign the apparent velocity of a point of the cross section to a colour that represents acoustic properties. There are many different theories about reconstruction algorithms for sonic data. An overview was given by Nicolotti et al. [5].

**Limitations of Sonic Tomography**

A limitation of sonic tomography (SoT) is that different defects in trees can cause the same tomogram. Under certain circumstances the tomograms of trees with cracks, ring-shakes or cavities may look similar. For this reason it is strongly recommended to apply the full range of knowledge about trees when interpreting a sonic tomogram. It is important to know typical defects of the tree species and the theory of operation of the sonic tomography instrument. In some cases the use of other tools is recommended. It is reasonable to use another physical method to get additional information.

**Electric Impedance Tomography – EIT**

While sonic tomography is based on biomechanical properties of wood, electrical impedance tomography mainly visualises chemical properties. The idea to use electricity for the investigation of wood in general and for the investigation of trees in particular is relatively old. This article is focussed on *Electrical Impedance Tomography (EIT)* for living trees. In 1998 Just and Jacobs [4] introduced the use of the EIT technology on standing trees. They used geophysical instruments and adapted the mathematical algorithms to trees. In the following years scientists at the University of Applied Sciences and Art (HAWK Göttingen) used EIT to find colourized wood in trees [9,10]. Since 2004 new reconstruction algorithms for the EIT improved the result by using the exact shape of the stem cross section. To achieve this, modern inversion algorithms and finite element based simulation techniques are applied [2].

The measurement uses point-like electrodes (nails) at the boundary of the object. By two of these a current is injected. The resulting electric field depends on the resistivity distribution and is measured by using the other electrodes pair-wise to obtain a potential difference (voltage). Data collection is followed by the reconstruction of the resistivity distribution. By the introduction of additional constraints, e.g. demanding a smooth model, we can restrict the ambiguity to yield a unique solution. This procedure is a non-linear reconstruction solved iteratively.

The reliability and resolution are crucially depending on the used electrode survey. The more accurately we measure, and the greater the number of electrodes used, the more able we are to calculate the likely resistivity distribution. Furthermore, tree shape is very important and should be measured accurately.

**Combined Interpretation of Sonic and Electric Impedance Tomography (Examples)**

While sonic tomography is based on biomechanical properties of wood, electrical impedance tomography mainly visualises chemical properties. The electrical properties of wood – in particular the electric resistance – depend on a number of factors. Water content and concentration of ions are most important. In addition, electrical properties are influenced by cell structure (heartwood-sapwood) and external conditions (temperature, etc.), which in turn can affect biological processes.
**Acer - Maple**

Maple is diffuse-porous species without regular heartwood formation. Sap flow and moisture content decrease from bark to pith. The EIT should show low specific resistances (blue colours) on the outermost rings of the tree. In contrast to these considerations the electric impedance tomograms of the damaged “two – trunk” maple (fig. 1) show low resistances in the centre of the trunk. The tree was measured in several levels. The software assembles the tomograms to 3D graphics.

![Figure 1: Tomograms of damaged maple: SoT (left), EIT (centre), and stem (right)](image)

**Fagus sylvatica - Beech**

This beech (fig. 2) suffers from an off-centre damage that is clearly shown in the SoT. The EIT shows very low impedances in the same area. Three cores samples where taken (increment borer): A, B and C. The positions refer to the location in the EIT. Core samples “B” and “C” show the damaged wood in the depth the SoT predicted. Core sample “A” shows seemingly sound wood up to a depth of 9 cm. The EIT shows an impedance of 40 to 60 Ohm*Meter, clearly indicating that sound (defect-free) material is present (a cavity would be shown with high impedances). Both EIT and SoT showed changed wood properties in this region. Obviously the tree is reacting to the decay attack. The EIT explains the apparent incorrectness of the SoT: the low sonic velocity is very likely caused by the higher moisture contents in this area.

**Cedrus - Cedar**

The cedar tree (fig. 3) was measured with SoT and EIT in Dorset (UK). Cedars do often have star shaped cracks that interfere the sonic investigation. Prior to testing, the tree owner mentioned that he thought the tree had originally developed from multiple stems. Evidence of this was apparent as there were co-dominant stems high in the crown, with visible signs of stem fusion around mid-height. These signs are not apparent around the base. The high resistance in the centre of the EIT suggests included bark. Typically cedars have very low specific resistances in the centre. Preserving of the tree was supported by the EIT which confirmed the theory.
Limitations of EIT

Due to the nature of the electric field there are some restrictions that we have to pay attention to when using EIT on trees. Most importantly, the reconstruction algorithm assumes a vertical extend of the tree of approximately the diameter of the tree above and below the measuring level. This is to be taken into consideration when working close to ground level. In contrast to sonic tomography where a distance between measuring points should not fall below the value of 12 to 15cm, the EIT requires as many measuring points as possible. In rare cases, a ring of very low resistance inside the tree can hide...
the material properties in its inside. Each tree species has a typical resistance distribution. This distribution may vary in different seasons.

**Conclusions**

The results of the research document that electric impedance tomography can visualize very early changes in the wood of trees, due to changes in specific resistance. Knowledge of the “typical” sonic and electric impedance tomogram is indispensable to evaluate the readings. Each tree species has a specific resistance distribution that may change against season or climate. The combination of sonic tomography and electric impedance tomography offers new opportunities in tree defect analysis and research.

On the strength of past experience we expect to get more answers about the following points when combining electrical and sonic tomography:

- detection of early stages of decay and possibly reaction zones
- information about the type of defect (in many cases)
- colourized wood (depending on species)
- areas of water movement (and effects of chemical elements)

**References**