GPR and Microwave Tomography for the Assessment of Hollowed Tree Trunks

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Abstract

The danger related to the structural stability of hollowed trees is a matter of wide discussion among the scientific community. Hollow cores in trees can extend to more than 50% of the total diameter and, while the presence of a hollow tree might appear dramatic in terms of public safety, it is not always a cause of concern. It is known that hollow trees can form in many years or even decades and, although the heartwood is effectively dead, the tree can continue to form sapwood on the exterior of the trunk to create a cylinder. However, robustness and structural support provided by this cylinder to the trunk and canopy above depend on the ratio of healthy to diseased tissue. In this context, Ground Penetrating Radar (GPR) has proven to be an effective non-invasive tool, capable of generating information about the inner structure of tree trunks in terms of existence, location, and geometry of defects. Nevertheless, it had been observed that the currently available and known GPR-related processing and data interpretation methods and tools are able to provide only limited information on the tree inner structure. In this study, we present a microwave tomographic approach for improved GPR data processing with the aim of detecting and characterising the geometry of hollowed trees. The results proved the viability of the proposed approach in identifying the position of cavities and decay in tree trunks.

Introduction

The protection of natural heritage is of crucial importance, since the incidence of emerging infectious diseases (EIDs) is continuously increasing. Specifically, some particular bacteria and fungi attack the trees by entering wounds or damage created by the action of external agents.

These infections, such as the heart rot disease, can escalate into the decomposition of heartwood, and subsequently forming cavities and hollows into the trunks. To this effect, it is important to note that a tree hollow does not necessarily compromise the survival of the plant, as heartwood is composed of dead tissues, and consequently it does not contribute to the bio-physiological processes of the tree.

However, the decomposition of the heartwood, whose primary function is to provide structural support, and potential formation of hollows can affect heavily the stability of the tree. Strength of the stem is reduced by the presence of cavities and hollows, resulting in trees being structurally weaker and more likely to break under the action of external forces, such as wind load. This can create dangerous scenarios, especially in case of trees located in public parks or alongside roads, where breakage can be harmful to people and properties.

Non-destructive Testing Methods – the Ground Penetrating Radar (GPR)

Ground penetrating radar (GPR) has proven to be a suitable and powerful method in forestry engineering applications. given the cylindrical-like shape of tree trunks and the random location and size of internal anomalies, traditional GPR signal processing techniques do not represent a viable solution to the problem of decay detection. On the other hand, tomographic approaches have proven to be effective for investigation of trees and other cylindrical-shaped objects

Aims and Objectives

The aim of this study is to implement a viable and robust GPR data processing methodology for the assessment of the main structural features of hollow trees (i.e., thickness of the structural solid layer and potential cracks).

To achieve this aim, the feasibility of a microwave tomography inversion approach is analysed in the present research.

Specifically, GPR data from a hollow tree were collected, and pre-processing was applied to create the input dataset for application of the microwave tomographic approach. The tree was eventually felled and a few sections were cut for validation purposes.

Methodology

Data Processing Framework: the Pre-Processing Stage

Raw data are given in the time domain whereas the input data to the inverse scattering approach are given in the frequency domain. In view of this, a pre-processing stage is necessary to achieve the input data to the inverse scattering approach. The pre-processing stage consists of the following steps:

- zero timing;
- background removal and/or time-gating to remove the effect of the air/trunk interface;
- Fourier transform of the filtered raw data in order to achieve the data in frequency domain;
- adjoint inversion.

Data Processing Framework: the Tomographic Inversion Approach

The microwave tomographic approach is based on a linearised model of the EM scattering exploiting the Born Approximation (BA). In this work an inverse scattering approach is adopted, exploiting a multi-monostatic/multi-frequency configuration. The host medium is assumed as homogeneous and characterised by an equivalent permittivity. The presence of targets in D is described by the contrast function χ, which accounts for the difference between the targets' permittivity and the permittivity of the background medium. For each measurement point $\boldsymbol{r_m}$ and angular frequency ω, the measured scattered field E_s is related to the unknown contrast function χ by the following linear integral equation:

$$E_s(\boldsymbol{r}_m, \omega) = k_b^2 \iint_D g_e(\boldsymbol{r}_m, \boldsymbol{r}, \omega) E_{inc}(\boldsymbol{r}, \omega)\chi(\boldsymbol{r}) d\boldsymbol{r}$$

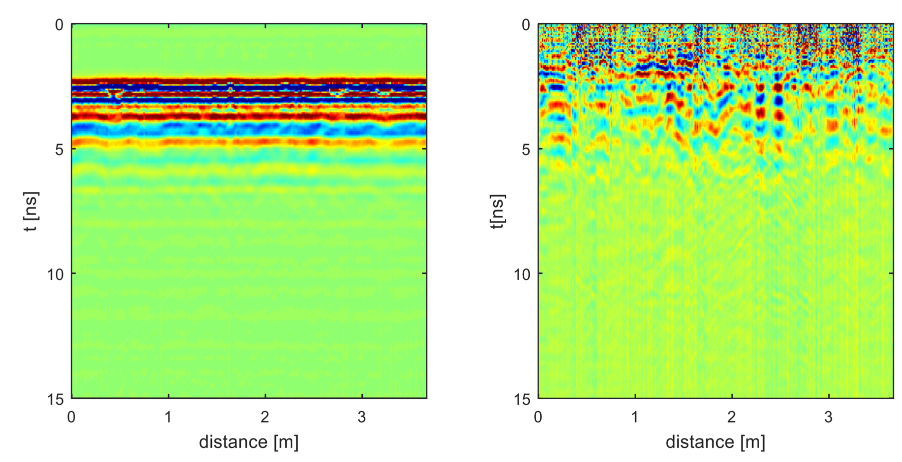
where k_b is the wave-number of the medium, E_{inc} is the incident field in D and g_e is the Green's function accounting for the radiation at $\boldsymbol{r_m}$ by the elementary source located at $\boldsymbol{r}$. The defined inverse problem is solved by resorting to the adjoint inversion scheme:

$$\chi(\boldsymbol{r}) = \iint \left(g_e(\boldsymbol{r}_m, \boldsymbol{r}, \omega) E_{inc}(\boldsymbol{r}, \omega)\right)^* E_s(\boldsymbol{r}_m, \omega)\, d\omega d\boldsymbol{r}_m$$

which is basically equivalent to a frequency-domain back projection.

Results

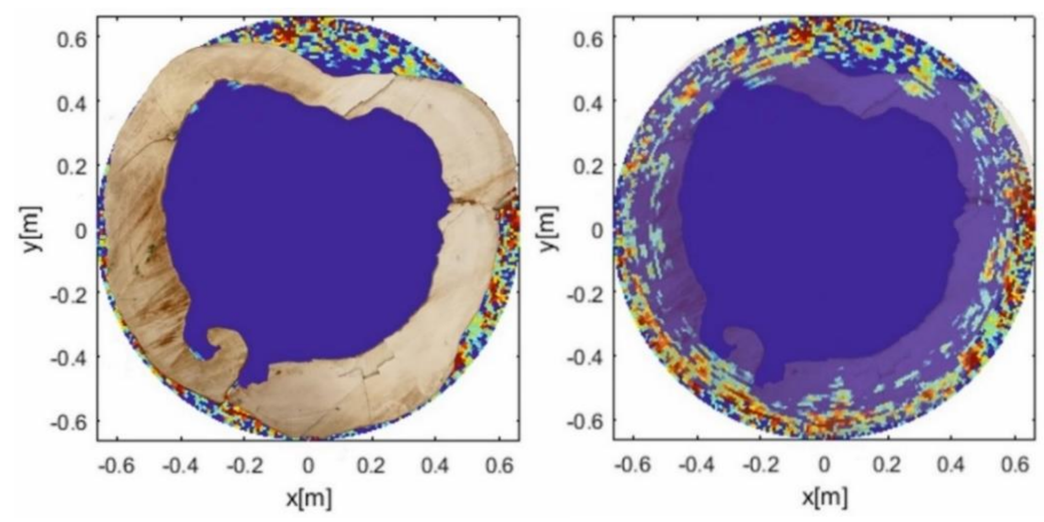
Data pre-processing was applied to the raw radargrams by setting the zero-time at 2.2 ns. Moreover, the SVD-based background removal procedure was implemented by filtering the first Nt =10 terms in the singular spectrum of each B-scan. The figure below shows a comparison between raw and pre-processed radargrams collected along the first profile (h=0). The presence of the tree hollow is identified in the processed data output by the signal reflections at a two-way travel time in a range until to about 5-6 ns.



Radargrams of the investigated tree at h = 0 m. Raw radargam (a) and processed radargram after the application of the pre-processing stage (b).

After the pre-processing stage, the adjoint inversion approach was then applied by considering the frequency band 500-2000 MHz sampled with 31 frequencies uniformly spaced by 50 MHz. The trunk section was discretised into image pixels with size 1 cm and the relative dielectric permittivity was set at ε = 40. Permittivity measurements were conducted using a 1 GHz horn antenna system from IDS GeoRadar (Part of Hexagon).

The tomographic image in the figure below refers to the tree section h = 0 m. Several anomalies can be observed in the wood area, whereas no targets are detected in the tree hollow. This result is consistent with the radargrams, which show a notable attenuation of the signal reflections after 6 ns. Regardless of these attenuation effects, it is important to note how the tomographic approach allows to focus those reflections at the location points where they originate.



Tomographic image of the tree section at h = 0 m. (a) Planar view of the cut tree section, and (b) superimposition with the spatial map, representing the contrast function of the trunk section.

Conclusions

This study presents a demonstration of the ground-penetrating radar (GPR) capability in detecting hollows and cavities in tree trunks.

The application of a tomographic inversion approach was proven effective in detecting the main structural features of a hollow tree. In particular, it is clear how the proposed approach can assess this particular tree types as well as other information such as the thickness of the solid structural layer.

Future research could task itself on the application of the tomographic approach to multi-frequency GPR data collected on hollow tree trunks, in order to explore whether a more comprehensive amount of information, in terms of decay types and their location, can be provided.

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