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Non destructive detection of woody root systems in urban contexts

N. Yard^{a,b}, G. Saracco^a et C. Zanetti^b

^aCEREGE CNRS-UMR7330, AMU, CdF, IRD, INRAE, F-13543 Aix en Provence, France

^bARBEAUSOLutions, SARL, 13720 Belcodène, France

yard@cerege.fr , saracco@cerege.fr, c.zanetti@arbeausolutions.fr



For environmental, landscaped and ecological reasons, the planting of trees in cities is becoming increasingly important, in parallel with the growing development of urban areas. Controlling the development of roots, parts not visible, becomes essential for their preservation in the face of urban development work such as burial of pipes and networks, transport routes, parking or place, sometimes near foundations.

As part of the redevelopment of a bitumed square in the cultural site of the "Substances" of Lyon, where eight lime trees had been planted at the same period with a regular spacing, some showed a particular development. Non-destructive detection of the main roots was necessary in order to understand this difference in evolution and to minimize the impact of future work.

Two prospecting methods (electrical and acoustic) were implemented on the asphalt square. If the electrical resistivity tomography (geophysical exploration method) makes it possible to obtain information on the structure of the subsoil, we have developed an acoustic method based on the Rinn method, making it possible to detect the propagation of a wave between a woody root subjected to acoustic excitation and the part of the trunk to which it is attached. The signal propagating through the sapwood can thus be detected by means of accelerometers attached to the trunk, differentiating in amplitude and speed from the acoustic signal passing through the ground only. An estimate of the extent of the root system and, the direction of major roots buried under an asphalt area can thus be obtained. The particular development such as heaving of the bitumen, regular or puny growth of the trunk or root extent can thus be controlled, and a better preservation of trees or buildings can be envisaged.

Keywords : Bioacoustic, woody root systems, non destructive electrical & acoustic methods, tree in urban contexts

1 Introduction

In the context of urban development work, transport routes, burying pipes and networks, the preservation of trees and in particular of their invisible root part, is essential. On the other hand, opportunistic root systems are often the cause of degradation of bituminous coatings or underground networks (pipes, fibres, etc.), sometimes even of structures (e.g. wall, building). The study sites are :

i) the place of the Cultural Center "Les Substances" backed by the Balms of the city of Lyon, and on the edge of the Quai de la Saône. Eight lime trees deployed with a regular spacing at the same period, present today a particular development; ii) the Parc de la Torse site within the city of Aix-en-Provence ; iii) a nearby forest, where dying and healthy trees coexist (reference sites)

The objective of these experiments is to characterize the rooting of these lime trees in an urban context in comparison with the development of trees in a natural environment.

2 Background

Electrical and acoustic root detection methods have been implemented in order to locate the main roots of linden trees. On the Lyon site, three subjects were selected, a large tree, a subject with poor development and the last whose root system had lifted the bituminous coating. On the Aix en Provence sites, a healthy lime tree planted in the ground was selected and, by comparison, a healthy and dying tree in a forest environment was added. The goal is to estimate the root volume by the position of the main roots and their expansion in order to identify the underground constraints influencing their development and conversely the biological constraints necessary for the development of this type of tree on the surrounding environment.

3 Properties of root systems

3.1 Root structure

Two types of roots can be distinguished; the carpenter roots which seek to ensure the stability of the tree, the prospecting roots which seek to explore the ground in search of resources. These ligneous roots are distinguished from non-ligneous roots (called rootlets or mycorrhizae) which collect and store the water and nutrients necessary for the life of the tree. Danjon et al. 2005 [1] propose in their work a modeling of the root architecture of a 50-year-old maritime pine, showing a good part of the types of roots that can exist within a root architecture.

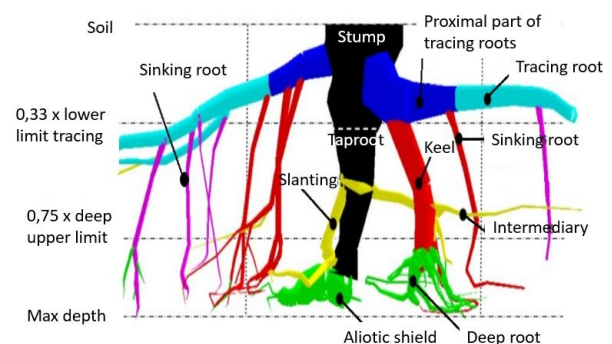


Figure 1 : Scheme of the root compartments of a 50-year-old maritime pine. 3D reconstruction of the root system (from Danjon et al., 2005 [1])

3.2 Properties of wood

Root wood also has specific properties that are linked to the mechanical and biological roles that roots provide. While the heartwood is an insulator, which is an advantage

for the acoustic method (waveguide), the part below the bark, called "sapwood" is an excellent conductor via sap flows circulating through the characteristic pores of tree species (Figure 2 and 3). Polarization and relaxation phenomena can therefore be measured in organic materials when an alternating electric field passes through.

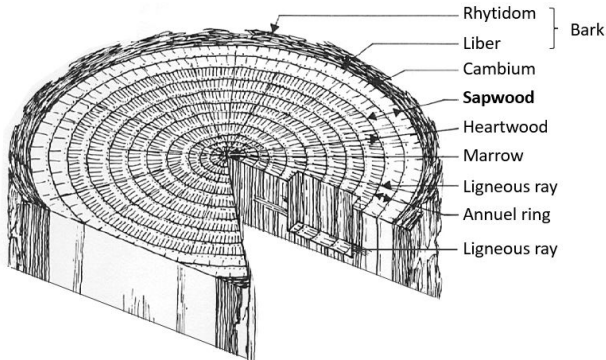


Figure 2: Macroscopic characteristics of wood, (from Schweingruber, 1990 [1])

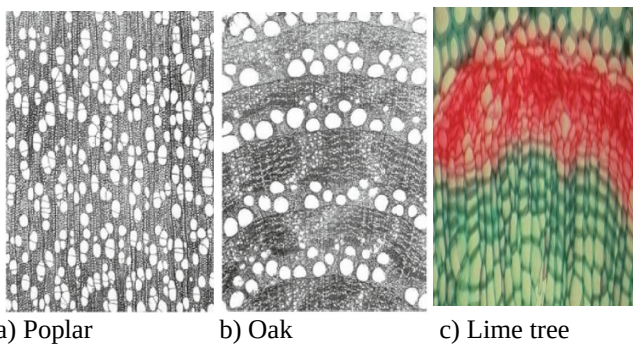


Figure 3: a) Poplar (*Populus nigra*); b) Oak (*Quercus pubescens*); c) zoom of the cross section of a lime tree (*Tilia*) (from Schweingruber & Bosshard, 1982 [12])
The pores (or vessels) influence by their distribution and size, on the properties of the wood.

4 Methodology

Prospecting by electrical method consists, here, of measuring some potential differences by pairs of electrodes distributed on the ground surface or trees. This potential field can be present naturally (spontaneous potential), or induced using a pair of electrodes injecting direct or alternating current into the ground (induced potential or polarization (Mary et al, 2016, 2017 [3, 4]).

Polarization is a mechanism that accounts for the local displacement or reorientation of bound charges when an external electric field is applied. Membrane polarization is the one that plays a major role in organic media (Kiberu 2005 [13], Reynolds 2011 [14]).

4.1 Characterization of the subsoil by electrical resistivity

The electrical resistivity tomography method (ERT) is the underground investigation technique based on the measurement of electrical resistivity using a pair of injection and measurement electrodes. The injection of a direct current of known intensity according to a chosen protocol (Wenner, Wenner-Schlumberger,..) adapted to our investigation environment (Mary et al 2016, [3]). The measurement of the induced electric potential distribution, give us an estimate of the apparent resistivity (ρ_a) of the subsoil. By inverting these pseudo-sections ρ_a , we obtain a structural and geological estimate of the subsoil (Saracco et al., 2007, [5]).

The electrical properties of a soil are not limited to the resistivity effect measured by ERT. Soils behave both as pure electrical conductors but also as dielectrics (insulators). To quantify the insulating nature of the ground, we use the quantity of resistivity (ρ) and its inverse the conductance (σ) as well as another quantity, depending on the type of polarization: the phase shift (in PPS - Spectral Induced Polarization) or chargeability (in TPP - Temporal Induced Polarization).

The equipment used is the Terrameter SAS4000 (ABEM system) equipped with 64 electrodes, distributed over 2 cables. Three equidistant profiles were made with a spacing between electrodes of 20cm (Figure 4). The implementation of the device was quite long (about 2 hours of preparation per profile due to the presence of the 15 cm thick layer of bitumen to cross).

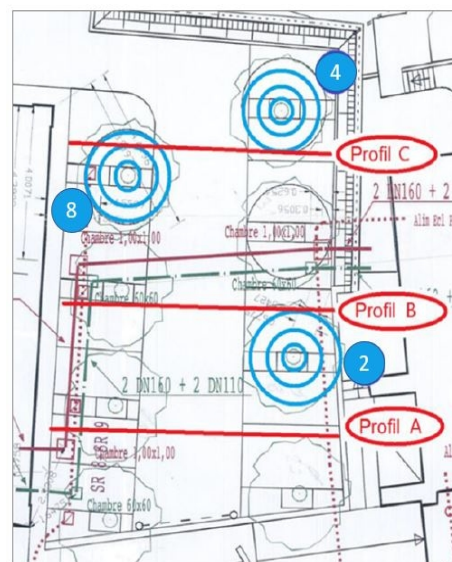


Figure 4: Experimental setup. Red lines **A, B, C**: ERT profiles equidistant from 7m; Concentric blue circles: Acoustic profiles with diameters of 0.15m, 1m and 1.6m for each lime tree selected, -A large lime tree (**2**); Tree with a root system lifted the bituminous coating (**4**), and Tree with a weak development (**8**).

4.2 Electric root detection by the so-called "grounding" method.

Widely used in mining prospecting, this technique makes it possible to delimit metallic clusters, their directions or even to find connections between the veins. It is used in the case of organic media on a conductive zone (in our case, the possible directions of the roots are visually marked from the base of the trunk). It is an active method: a current is injected using one electrode directly supplied in the conductive zone (B) and the other current electrode is placed at infinity (A) (see Figure 5). By moving the measurement electrode M, (the other N being at infinity, pole-pole protocol), an equipotential map can be obtained.

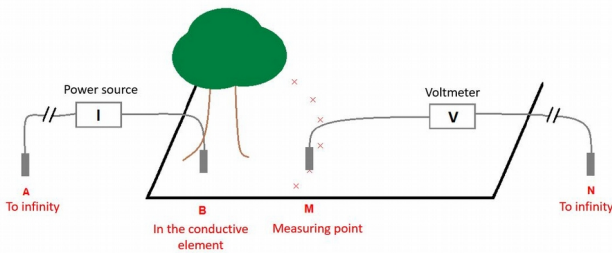


Figure 5: Principle of measurement by "grounding method"

Polarization effects in wood are caused by the differences in the mobility of ions across cell membranes, as a function of frequency, either through or around plant tissues (Figure 3). These results in the separation of charge carrier of different polarities (Zanetti et al 2015 [6]),

4.3 Root detection by acoustic tomography

One of the acoustic wave is the propagation, step by step, of a disturbance in a solid or fluid medium. The velocity of waves propagated depends on the nature and texture of the medium crossed (e.g. its elastic or viscoelastic properties, geometry). The means of excitation is a non-standard pulse source, i.e. a short blow to the ground using a mass. Thus, the wave produced disturbs the medium and propagates while spreading (Mary et al 2015, [5], Socco et al 2004 [10], Rinn 1999 [16]). The device is characterized by the geometric layout of receivers and the source. The receivers (wideband contact transducers of accelerometer-type) are at the base of the trunk. The source is positioned on the ground following a concentric grid. The number of points per angle unit defines the angular resolution. The recording of the signals is carried out synchronously on the receivers. The measurement is repeated several times in order to average and improve the signal-to-noise ratio. The acquisition time must be long enough to record all propagated wave trains and obtain complete time-frequency information. In order to at time t_0 the synchronous acquisition of the signals to the 4 receivers, another receiver is used next to the strike zone via a mass, or a dynamic hammer (integrated trigger).

When the disturbance encounters a root, the wave will find a dense medium that favors its propagation. If the root is at a short distance from the plumb of the blow, it will then act as a waveguide and the disturbance will then be registered mainly by the sensor located on the trunk in the same angular sector as the "excited" root. An analysis of the amplitudes and speeds of propagation also makes it possible to differentiate whether the wave has moved in the root or the ground.

The equipment used is the BOVIAR system which is composed of the TDAS-Soft acquisition software, the TDAS16' (16-bit Tomography Data Acquisition System) multi-channel acquisition unit, cables and a mass. The contact acoustic transducers used have a central frequency of 24 kHz. This device has the advantage of working at shallow depths (up to a few meters depending on the nature of the ground and the insonation frequency) and allows us a quick adjustment of the sampling rate, acquisition time and required gain. It therefore requires some preparation, apart from the meshing of the prospecting area (see figure 4). It is therefore particularly suitable for our purpose of locating the main running or woody roots.

5 Results

5.1 Electrical tomography

The areas of high resistivity observed on the profiles (red/purple) correspond to dense media such as rocks (limestone, granite) or the remains of foundations of old buildings (Figure 6). These hard elements constitute obstacles to the development of the roots and aerial part of certain trees. Conversely, the green and yellow areas are the most conductive (loose, drainage or flow area).

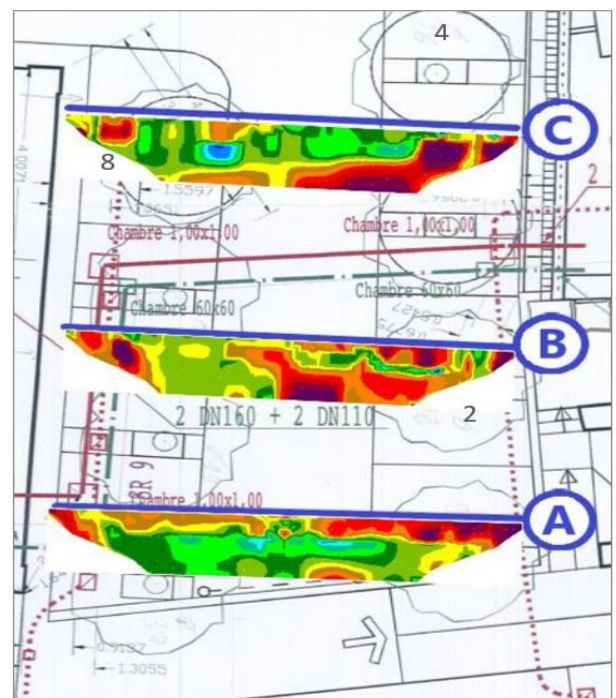


Figure 6: Sections (A, B, C) of electrical resistivity calculated and oriented according to the positioning of the trees (n° 1 to 8)

The protocol used was that of Wenner_alpha (identical spacing between electrodes) for 64 electrodes and current intensity 5 A maximum. An intensity of 20 mA was used, with a stack of 2-4 recordings. High resistivity areas are shown in red/purple; low resistivity areas are light green/bleu.

The electrical resistivity tomography allowed us to reveal the remains of an old foundation under this place at the corner of the left building, in particular near the establishment of the 8 "puny" shaft and the 4 . If tree 8 has a minor development compared to the others (lack of expansion of its root system, therefore of nutrients), tree 4 on the other hand has the advantage of being supplied, even weakly, with groundwater from Les Balmes. This would explain a root development with enough strength to lift the bitumen and circumvent obstacles. On the other hand, trees such as 2, 1, 3, 5 do not undergo constraints from the subsoil. Tree 8, and trees 7, 6 also, are close to underground networks (electricity, rainwater). A more thorough study of the tracing roots is necessary coupling acoustic and electric method, and first in forest environment to obtain a reference root system.

5.2 Electrical conductivity method by induced potential (grounding)

- Parc de la Torse (Aix en Provence) site

The device uses a Wenner protocol (with an injection of 32V at 55Hz). The arrangement of the electrodes follows the pole-pole configuration (cf. Figure 5) the injection zone is located at 180° on the mesh.

Only the half-space of roots reacts or is excited. It is necessary to change the place of current injection (0°, first, then 45°, 90°, etc.) to increase the precision of the results and to obtain information on the entire space around the tree. We obtained a 3D information. We represent here the projection on a plan (conductivity map)

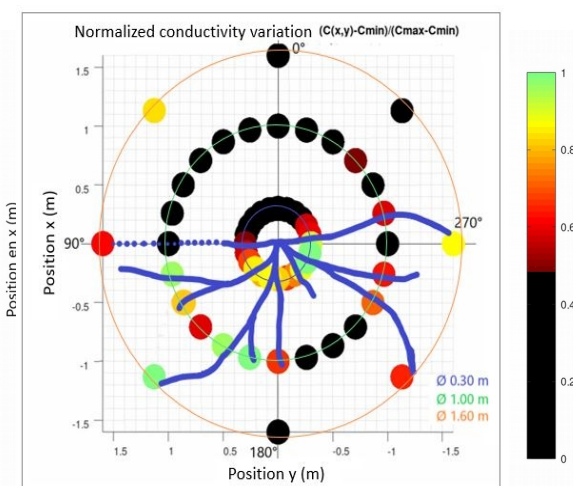


Figure 7: Conductivity map with a current injected at 180°

The conductivity data have been normalized in order to be able to compare the results between the 3 acquisition circles and to represent them on a same graph.

Note that conductivity depends on soil water content (climate) and seasons (sap flow).

$$C(x,y) = (C - C_{min})(C_{max} - C_{min})^{-1} \quad (1)$$

If the green color signifies that C(x,y)=1. Black color represents all values <0.5 . A color is attributed for all values >0.5. The conductivity is divided into 64 color intervals, of which 32 (C<0.5) are reduced to be black.

It is then possible to link the different measurement points (conductivity interval) and to obtain an estimate of the root expansion of the lime tree (blue lines, Figure 7) (Yard, 2021, [9]). The number of acquisitions can be increased to refine the results.

5.3 Acoustic method ground/trunk

- Subsidence Site (Lyon). Urban context

The acoustic method allowed to estimate the departures of the main roots of the 3 characteristic trees. The results are built on the maximum amplitudes of the signals, which gives an indication of the main roots directions (Figure 8). The scale of the values is not the distance but the amplitude of the signals, so they can only be interpreted to determine the directions of the roots and not their paths.

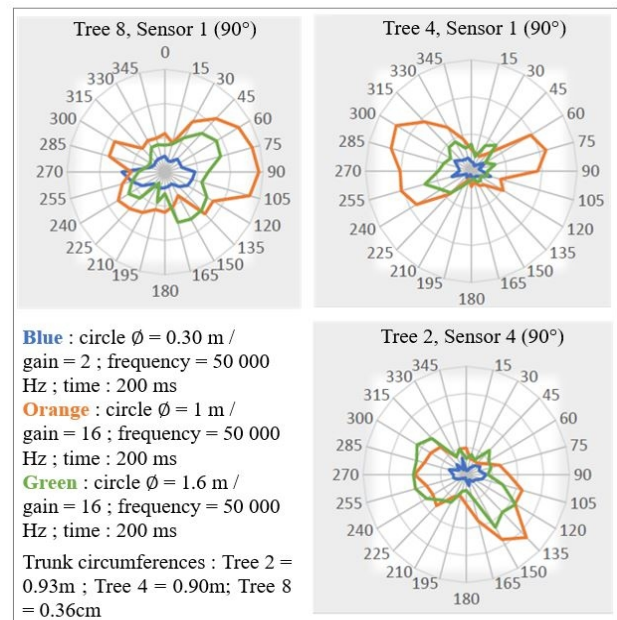


Figure 8: Representation of the acoustic amplitude maxima for the three characteristic trees chosen for their particular development in urban context (n° 2, 4 and 8)

- Forest parc site (Aix en Provence)

The setting up of the measurement system is identical: we draw concentric circles around the base of the tree of radius 0.3m, 1.0m and 1.6m, with an angular step of 15° while turning counter-clockwise. We arbitrarily position the origin of our circles and note its orientation to be able to represent

the results in space. In our case, the 0° origin is located in the Southeast (150°).

The good conditions of the mass is replaced

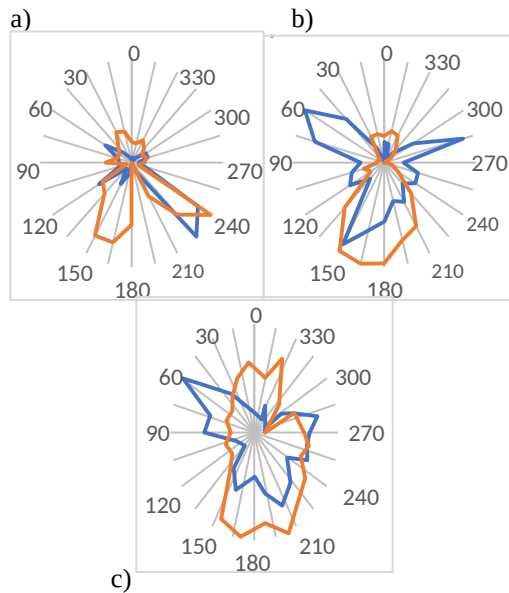


Figure 9. Blue line :maxima of amplitude, $|A_{max}|$; Red line: V velocity, on acquisition circle of ray: a) 0.3m, b) 1m, c) 1.6m

The experimental conditions due to the difference of the ground between an urban environment and a forest or peri-urban environment, required the replacement of the mass by a dynamic hammer with integrated a piezometer, allowing the 4 TDAS receivers to be triggered synchronously, with better accuracy (Figure 9). we can control the duration of the signal (<100ms), the gain necessary for each of the channels (4 receivers) and emit a short signal closer to a pulsed signal, but of lower amplitude than the mass.

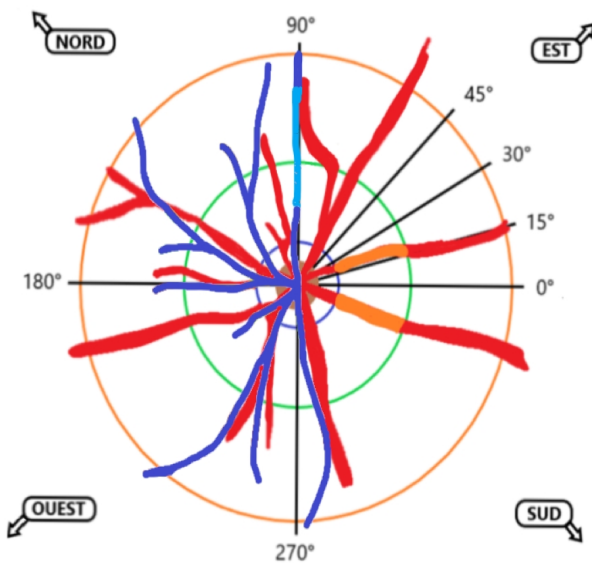


Figure 10: Root system of lime tree by acoustic method (red) and electrical conductivity, ground method (blue) lime tree in natural environment.

6 Interpretation & Conclusions

Electrical Resistivity Tomography (ERT) allowed us to reveal a very heterogeneous soil (water flow, conduits, rocky substrates, old foundations, etc.). The heterogeneity of the soil structure implies a weaker development of root and aerial biomass for trees hampered by underground elements.

The acoustic tomography method and the grounding method use very distinct and complementary processes concerning the acquisition conditions. Acoustic waves are mainly propagated by the heartwood, insulating part for the electric current which uses the sap of trees, and therefore the sapwood. However, although their support is different, the search for the path of the roots in the soil is complete. The acoustics will allow to characterize the major roots and the electricity to provide detailed information (e.g. rootlets).

Electrical investigation methods are sensitive to seasonal variations (sap flow, soil water content), while acoustic methods are more dependent on the density and texture of wood and soil.

The implementation of the acoustic method at a finer resolution was limited by the presence of the thick layer of bitumen to be drilled in urban context. The root volume could not therefore be evaluated at great depths, however it made it possible to estimate the presence and expansion of tracing roots at shallow depths and therefore to avoid these roots during soil excavation work and thus to preserve the sanitary and mechanical condition of trees that are essential in an urban context.

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