Advanced GPR Signal Processing Techniques for Root Detection in Urban Environments

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Abstract

Street trees are widely recognised to be an essential asset for the urban environment, as they bring several environmental, social and economic benefits. However, the conflicting coexistence of tree root systems with the built environment, and especially with road infrastructures, is often cause of extensive damage, such as the uplifting and cracking of sidewalks and curbs, which could seriously compromise the safety of pedestrians, cyclists and drivers. In this context, Ground Penetrating Radar (GPR) has long been proven to be an effective nondestructive testing (NDT) method for the evaluation and monitoring of road pavements. Besides, recent studies have explored the capability of GPR in detecting and mapping tree roots. The aim of this study is, therefore, to investigate the GPR potential in mapping the architecture of root systems in street trees. In particular, this research aims to improve upon the existing methods for detection of roots, focusing on the identification of the road pavement layers. In this way, different advanced signal processing techniques can be applied at specific sections, in order to remove reflections from the pavement layers without affecting root detection. This allows, therefore, to reduce false alarms when investigating trees with root systems developing underneath road pavements.

Introduction

Street trees in the urban environment play an active role for the wellbeing of the city. Benefits provided by street trees are typically categorised as environmental, economic or social.

However, street trees can also be source of issues in urban environments. In fact, one of the main causes of pavement degradation in an urban environment is the development of roots from street trees. This can affect road safety conditions, as roots can lead from minor to severe deformations and cracking of pavement. In this regard, poor design methods along with inadequate road maintenance can worsen decay conditions of the asset.

Besides, engineering standards and specifications for construction of road infrastructures inhibit root penetration. Therefore, tree roots are forced to grow at the interface between the pavement and the soil, attracted by the relatively high humidity which forms underneath the road surface. This creates a humidity gradient that further stimulates growth of roots, leading to more severe damage and disruption of the pavement surface.

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

Ground Penetrating Radar (GPR) is increasingly acknowledged to be a powerful non-destructive testing (NDT) method for imaging the subsurface structure and locating buried objects. GPR has already proven to be an effective inspection tool for road inspections, including the evaluation of pavement layer thicknesses and the assessment of damage conditions in hotmix asphalt (HMA) layers, load-bearing layers and subgrade soils. More recent applications can also be found within the context of assessing tree root systems.

Aims and Objectives

This research aims to demonstrate the effectiveness of GPR in providing a three-dimensional mapping of the root system architecture of urban trees under the road surface.

To achieve this aim, the main objective is to provide a dedicated data processing methodology for the automatic recognition and tracking of tree roots, especially in high-reflectivity areas e.g., multi-layer road pavement infrastructures. Furthermore, another important objective is to produce root density maps at different depths, in order to enhance interpretation of data in terms of local variations of roots concentration within the transition areas between natural soil and the pavement structure as well as at the interface between road structural layers.

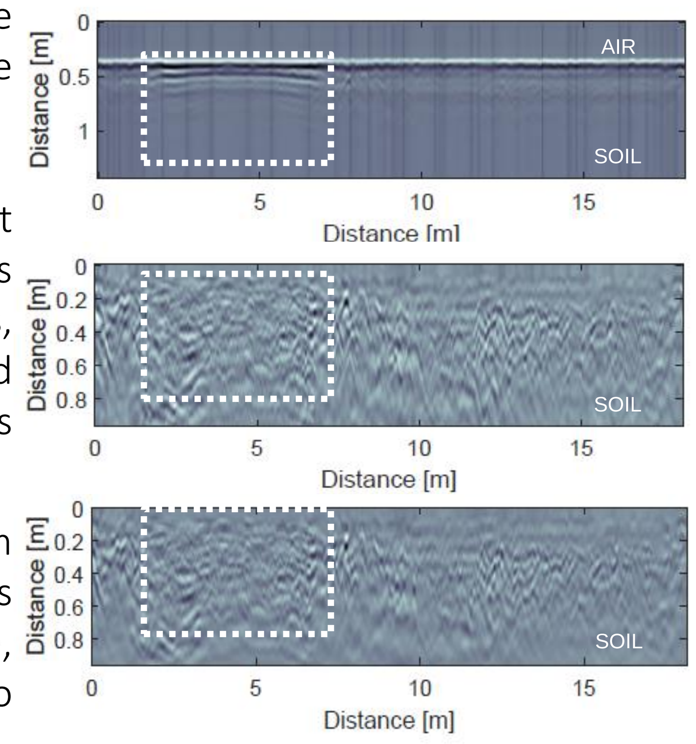
Methodology

The Signal Processing Algorithm

This stage of processing was performed to improve the quality of the raw data and avoid false interpretations.

The pavement results in repetitive reflections that dominate the C-Scan and mask potential reflections from roots and other targets of interest. To tackle this, a **Singular Value Decomposition (SVD) filter** was applied to the post-processed data in order to mitigate as much as possible the effects of the pavement.

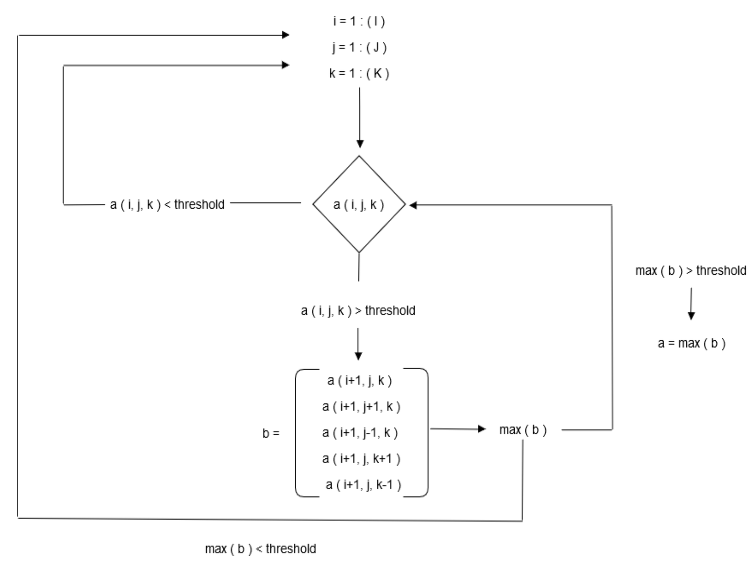
The reconstruction of the geometry of the root system requires the representation of the target to be as accurate and focused as possible. Therefore, **Frequency-Wavenumber (F-K) migration** was applied to GPR data to aid with the localisation of the roots.



Bscans (a) before processing, (b) after SVD, (c) after F-K migration. The dashed area indicates the location of the road pavement

The Root Tracking Algorithm

- *Target detection:* the amplitude values are compared with a predefined threshold value throughout the analysed domain.
- *Correlation analysis:* a possible correlation is sought between the targets identified in the previous step, based on their position in three-dimensional space.
- *Tracking of the root:* the algorithm follows the vertices of the hyperbolae, creating a vector that corresponds to a single root.
- *Reconstruction of root system architecture in the 3D domain:* vectors created at the previous step are positioned in a 3-D rendering of the tree root system



Root Density Estimation

A dedicated index was provided to obtain information about root density at the interconnection area (e.g. local changes of density). The domain was divided into reference volume units. The length of roots contained in a reference volume was then evaluated as follows:

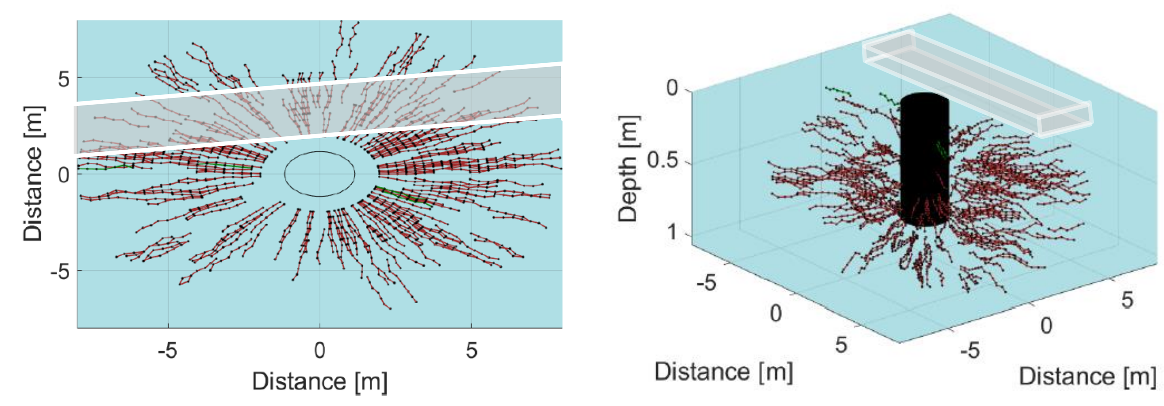
$$d = \frac{\sum_{i=1}^{N} L_i}{v}$$

where d is the density [m/m^3], N is the number of roots contained in a reference unit of volume [m^3], and L_i is the length of the root [m].

Results

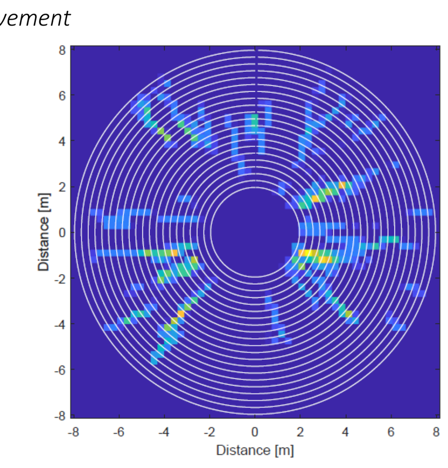
The application of the signal processing algorithm to the raw data allowed the signal-to-noise ratio to be increased and to enhance target detections (i.e. hyperbolae). Also, the efficiency of the SVD filter in removing both ringing noise and reflections from the pavement layers can be observed.

The application of the multi-stage data processing methodology allowed to locate targets in the 3-D domain and to automatically track their development.



Result of the application of the multi-stage data processing algorithm to the investigated tree in a 2-D plan view and in a 3-D rendering.The grey area and the parallelepiped indicate the location of the road pavement

The root density at different depths was then examined using the proposed index. The domain investigated was divided into reference volume units with dimensions of 0.3 m × 0.3 m × 0.1 m and subsequently analysed to estimate the total length of roots per reference unit.



GPR-derived root density map (density values are normalised).

Conclusions

This study reports a demonstration of the potential of ground penetrating radar (GPR) to detect tree roots growing underneath road infrastructures automatically. The primary aim of the study was to demonstrate GPR potential in providing effective threedimensional mapping of street trees' root systems, located under the road surface. A multi-stage interpretation algorithm was presented, aiming at reconstructing the patterns of tree roots using GPR. The proposed methodology utilises circular measurements with a radial expansion from the tree trunk. Initially, a pre-processing step is applied in which the ringing noise and the reflections due to the presence of a pavement are removed using a Singular Value Decomposition (SVD) filter. A frequency-wavenumber (F-K) migration is then applied to the filtered data in order to increase the overall signal to clutter ratio and to avoid misinterpreting hyperbola-sides as targets. Subsequently, a tracking algorithm is employed so as to unravel hidden patterns associated with roots. Lastly, the found roots are coherently expressed through continuous functions and the root density is analytically derived.

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This poster and work is dedicated to the memory of Jonathan West, a friend, a colleague, a forester, a conservationist and an environmentalist who died following an accident in the woodland that he loved.

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