Tree Roots Pose Reconstruction via GPR and 3D CNN

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Root system architecture (RSA) of trees is of great importance for analyzing the trees' health and ensuring root support to the trees. Investigating the topology of the root system also helps avoid roots destructing roads and other infrastructures. Traditionally, tree roots have been studied using destructive techniques, such as uplifting. Although these methods can provide direct, essential information, they are time-cost and labor-intensive and may hurt the tree roots system if wrongly performed, which would result in inaccurate results (Buczko, U. et al., *Plant Soil*, 316, 205, 2008.). Recently, non-destructive methodologies have been introduced in the field of tree roots survey tasks. Ground-penetrating radar (GPR) is a well-recognized, non-invasive geophysical technique for the detection of tree roots (Guo, L. et al., *Plant Soil*, 362, 2013.). To obtain the roots' architecture, the GPR generates processed radar profiles via multiple antennas positioned around the tree trunk and requires the operator's personal experience to manually connect root points between adjacent radar profiles, this process leads to inaccurate results when studying complex root systems (Zenone, T. et al., *Funct. Plant Biol*., 35, 1047–1058, 2008.). On the other hand, the GPR imaging processors always bring a 2D image with low resolution, which also causes inaccuracy in root pose estimation (Comite, D. et al., *IEEE Geosci. and Remote Sens. Mag.*, 9(4), 173-190, 2021.). To this end, we propose a method to transfer traditional tree roots radar images into easy-to-understand 3D poses, which may help understand the RSA of roots more efficiently.

In this study, we propose a convolutional neural network (CNN) based tree roots pose reconstruction method for GPR techniques. In this approach, several two-dimensional (2D) common-offset-GPR measurements are first performed parallelly above the ground surface on straight trajectories. Then the F-K migration method is used to image the 2D radar data, which transfers the hyperbolic radar signatures to a focusing point indicating the position and size of the tree root under the experiment. By combining all these migrated 2D B-scan data, we finally get a set of three-dimensional (3D) GPR C-scan data after imaging. Then the C-scans obtained via GPR measurements are processed via a CNN to retrieve the tree root pose. To train the CNN algorithm, a large set of C-scans is generated using an open-source 3D finite-difference time-domain (FDTD) simulator. The data set includes hundreds of C-scans obtained for the random realizations of realistic tree roots with different branching forms and ways of placement underground. The C-scans obtained by the FDTD simulator are scaled and resized before being included in the data set. The 3D radar image from the dataset is interpreted as a 3D tree root pose to train and test a designed 3D CNN. We obtain the training loss by calculating the error between the reconstructed pose and the ground truth, which is the l_2 distance between the locations of the joint points of tree branches. The ground truth for simulation data is manually labelled. The backward propagation is used to optimize the network. Our preliminary results show that the minimum testing error of the CNN algorithm is less than 40mm. The testing results demonstrate that the current methodology allows locating and pose reconstruction of buried tree roots.