Particle Level Set Tracking for Low Resolution X-ray CT Image Data of Plant Root Systems in Soil

Stefan Mairhofer ✉,
Tony P. Pridmore
School of Computer Science
Jubilee Campus, University of Nottingham,
NG8 1BB
stefan.mairhofer@nottingham.ac.uk

Brian Atkinson, John Atkinson,
Marcus Griffiths, Craig J. Sturrock,
Sacha J. Mooney, Malcolm J. Bennett
School of Biosciences
Sutton Bonington Campus, University of Nottingham, LE12 5RD

Abstract

LARS - a root segmentation method and software tool was developed to allow the recovery of fully-developed root systems of plants grown in soil. The method is built on a particle level set framework using a tracking-based strategy to follow root cross-section through low resolution X-ray micro computed (µCT) image data. The method was tested on image data of spring wheat plants that were grown outside under natural conditions and scanned at harvest stage.

1. Introduction

X-ray micro computed tomography (µCT) has become a versatile laboratory tool for soil and plant root studies, allowing among others the examination of roots in relation to different physical properties of growth media [1] including their effects on macro-pores [2], the investigation of root-root responses to inter- and intra-specific interactions [3], and the analysis of root hydraulic properties [4]. While for many of these studies the application of high-resolution scans is pivotal, it places restrictions on sample size and with it the developmental stage of the plant. However, when the focus of the research shifts towards plant maturity, larger columns have to be used which compromises the resolution of the data. This has implications for the recovery of root system information, in that the size of root cross-section is reduced to a few pixels. As a result there is less descriptive information representing root material, making it more susceptible to noise and image artefacts. In this lower resolution data, connectivity of individual roots is not guaranteed. Moreover, in order to ensure penetrability of X-rays through the larger columns, an increased energy needs to be applied, which in turn impacts image contrast [5]. All these attributes pose completely new challenges for the recovery of plant root systems from soil in X-ray µCT images. In this work we present a segmentation by

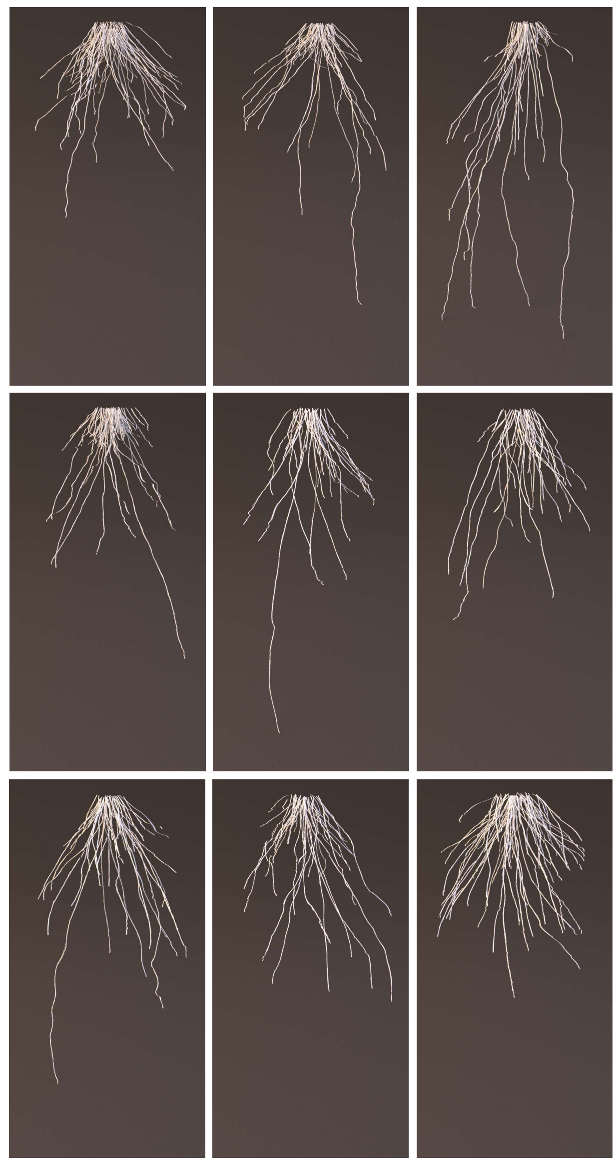

Figure 1: Recovered root systems of fully-developed wheat plants from X-ray µCT image data using LARS

tracking method (LARS – Large Aperture Root Segmentation) that addresses these difficulties and allows the recovery of fully developed soil-grown plant root systems by following root cross-sections through a low resolution X-ray µCT image stack.

2. Methods

LARS follows a tracking-based strategy built on the particle level set framework [6], which uses a combined Lagrangian/Eulerian scheme for the advancement of the moving interface. The advection of the particles assists the level set interface in conserving its area for under-resolved regions [6], which is particularly important when using the framework for boundary detection and tracking of small objects. The level set interface evolves based on an underlying vector field, which is defined as a gravitational pull towards features matching the root object's appearance model. This vector field allows the interface to bridge gaps as it evolves from one object's location to the next between images, while being attracted to the nearest candidate with the highest similarity. A vector field that is solely defined by orientations towards most likely target candidates, however, will violate the requirement of a solenoidal field [7]. It is therefore updated after each level set iteration by solving the pressure equation to form a divergence-free vector field that allows smooth propagation of the interface [8]. To reduce computational complexity, motion and variability is modelled by a Gaussian-Wishart distribution that defines the search-area in which features and the corresponding vector field are calculated [9]. An interface is evolved within an image until it best matches the target object and is continued across images thereafter to track a target object through a stack of images.

3. Conclusion

The presented method was tested on root systems of fully-developed spring wheat plants after reaching harvest stage. The plant were grown outside under natural conditions from early spring (March) through to early autumn, using columns of 100 cm height and 20 cm diameter filled with a mix of sandy loam and silver sand at a ratio of 70:30. The scanning of the sample took place in October. The image data was acquired at a resolution of 150µm using a custom-build GE v|tomex|L X-ray CT system. Root objects were manually initialised with a tracker in the first frame in which they were visible, and tracked until the column boundaries were reached. Some of the recovered root systems are shown in figure 1.

References

[1] Rogers, Eric, Daria Monaenkova, Medhavinee Mijar, Apoorva Nori, Daniel Goldman, and Philip Benfey. X-ray computed tomography reveals the response of root system architecture to soil texture. Plant Physiology, 2016

[2] Colombi, Tino, Serge Braun, Thomas Keller, and Achim Walter. Artificial macropores attract crop roots and enhance plant productivity on compacted soils. Science of The Total Environment 574: 1283-1293, 2017

[3] Paya, Alexander, Jesse Silverberg, Jennifer Padgett, and Taryn Bauerle. "X-ray computed tomography uncovers root–root interactions: quantifying spatial relationships between interacting root systems in three dimensions." Frontiers in plant science, 2015

[4] Tracy, Saoirse, Keith Daly, Craig Sturrock, Neil Crout, Sacha Mooney, and Tiina Roose. "Three□dimensional quantification of soil hydraulic properties using X□ray Computed Tomography and image□based modeling." Water Resources Research, 51(2): 1006-1022, 2015

[5] Ketcham, Richard, and William Carlson. "Acquisition, optimization and interpretation of X-ray computed tomographic imagery: applications to the geosciences." Computers & Geosciences 27(4): 381-400, 2001

[6] Enright, Douglas, Frank Losasso, and Ronald Fedkiw. "A fast and accurate semi-Lagrangian particle level set method." Computers & Structures 83(6): 479-490, 2005

[7] Sethian, James A. "Evolution, implementation, and application of level set and fast marching methods for advancing fronts." Journal of computational physics 169(2): 503-555, 2001

[8] Sussman, Mark, and Elbridge Gerry Puckett. "A coupled level set and volume-of-fluid method for computing 3D and axisymmetric incompressible two-phase flows." Journal of computational physics 162(2): 301-337, 2000

[9] Bishop, Christopher. Pattern recognition and machine learning. Springer, 2006.