Segmenting root systems in X-ray computed tomography images using level sets

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Motivation
The measurement of the three-dimensional shape of plant roots, or root system architecture (RSA), is of importance to genetic studies that identify connections between root traits and their genotypic control. There are various destructive methods for measuring root system architecture ("shovelomics"), as well as methods of growing plants such that their root systems are exposed and easily imaged. We explore the situation when a plant's roots are growing in a medium-filled pot and the pot is imaged with X-ray computed tomography (CT). An advantage of this methodology is that the root system is not manipulated or destroyed in the process of imaging. However, to assess the RSA, the root regions must be segmented from the non-root regions, which is the focus of this work.

Examples of X-ray CT images

We use a three-dimensional level set method, adapted to the root segmentation problem, to differentiate the root versus non-root regions.

- A small set of images (1-19, depending on the dataset) are initialized with squiggles representing root locations (Fig. 2).
- A narrow-band level set algorithm is used; the formulation is from Rousson and Deriche ([2], [3]) where it is assumed that the pixels are drawn from Gaussian distributions.
- Use occupancy grids to focus computational resources on active regions of the contour as well as prevent small details of the root from being smoothed away.

Approach

Initialization and Experimental Details

In Fig. 1, and scans are captured with a North Star Imaging (NSI) X5000 X-ray CT instrument. The instrument outputs high-resolution image stacks (largest dataset: 1803 × 2238 × 1805 pixels).

Plants are grown in different media, as shown in Fig. 1, and scans are captured with a North Star Imaging (NSI) X5000 X-ray CT instrument. The instrument outputs high-resolution image stacks (largest dataset: 1803 × 2238 × 1805 pixels).

Results and Conclusions

While this was a general method, if the medium and plant species are known, some features of both should be incorporated into the method to reduce runtime and increase segmentation accuracy.

Future work

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References

Table 1: Dataset and experimental details. Sixth column: number of initialization images used, seventh column: the number of iterations until convergence. Final column: method's total runtime, excluding the image load time.

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Initialization images</th>
<th>Iterations</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cassava in potting medium</td>
<td>5</td>
<td>169</td>
<td>3.02 hr.</td>
</tr>
<tr>
<td>Maize in expanded clay</td>
<td>11</td>
<td>12</td>
<td>25.26 min.</td>
</tr>
<tr>
<td>Soybean in expanded clay</td>
<td>1</td>
<td>80</td>
<td>8.03 min.</td>
</tr>
<tr>
<td>Maize in turface</td>
<td>2</td>
<td>40</td>
<td>9.10 min.</td>
</tr>
<tr>
<td>Cassava in potting mix</td>
<td>15</td>
<td>30</td>
<td>14.50 min.</td>
</tr>
<tr>
<td>Maize in surface</td>
<td>10</td>
<td>17</td>
<td>11.70 min.</td>
</tr>
</tbody>
</table>

Figure 1: Example of X-ray CT images, to show the variety of medium and root system shapes. From left to right, the species and growing medium is: cassava in potting mix, maize in turface, and soybean in expanded clay, respectively. Some root regions are indicated with a yellow arrow; not all root regions in each image are indicated.

Figure 2: Examples of X-ray CT initialization images. Images are marked by the user indicating root regions. We used the color red. 2a and 2c show image slices whose orientation are perpendicular to the ground plane, while 2b shows an image slice whose orientation is parallel to the ground plane.

Figure 3: Results of applying the method to three different species, with different root morphologies, in three different growing media.

The method was developed for general purpose use: for roots of any shape, in any growing medium. However, from a qualitative assessment, results were best from the cassava in potting mix result (Fig. 3c). The visibility of the maize roots in turface was a problem even for initialization, so it was not surprising that the root system recovery in that medium was truncated (Fig. 3b).