Generating High-Fidelity 3D Models of Individual Plants from Handheld Video Recordings

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Abstract. This paper presents a pipeline for extracting precise 3D reconstructions and graph representations of plants. By combining Neural Surface Reconstruction (Neuralangelo) with a robust graph extraction algorithm, our approach generates high-fidelity 3D models from handheld video recordings. These models are suitable for various downstream tasks, including the estimation of advanced plant features.

1 Introduction

Studying the three-dimensional spatial organization of plants at a macroscopic scale is crucial for understanding plant-environment interactions. This involves assessing leaf area, branch structure, and fruit positioning, with quantitative measures of biomass and leaf count. Measuring these features in plant biology is, however, still challenging since accessible 3D tools for macroscopic observations are currently unavailable. As a consequence quantitative assessments rely on 2D techniques or costly 3D methods like X-rays and electron microscopy [1, 3]. Developing a non-destructive method to assess live plant structures in 3D would greatly benefit ecological and agronomic research. Our approach simplifies the process of 3D reconstruction using consumer-level cameras, making it more accessible and easier to capture compared to traditional 3D scanning methods. This makes the technology more user-friendly and scalable, especially for end-users who may not have specialized technical expertise in 3D modeling or 3D scanning.

2 Methodology & Preliminary Results

An overview of our pipeline is given in Figure 1(a). An off-the-shelf mobile phone camera, specifically an iPhone XR, was used to record a video of the plant from all directions. To minimize occlusions, the camera was moved in a circular path around the plant, ensuring that all angles were captured. This video was input for a neural radiance fields-based 3D reconstruction technique. We selected Neuralangelo, which builds upon multi-resolution hash grid encoding, generating fine-grained details for tasks such as novel view synthesis. Furthermore, Neuralangelo incorporates numerical gradients for computing higher-order derivatives as a smoothing operation and avoid localities [4]. This method provides high-fidelity 3D reconstructions that capture intricate details of plant morphology, crucial for precise phenotypic analysis. The resultant 3D reconstruction (colorized mesh presentation) is then processed by a robust graph reconstruction algorithm based on topological thinning and a scale invariant pruning criterion originally designed for volumetric medical data [2], to compute a 3D graph representation. The graph is annotated with a variety of abstract geometric and morphological features, forming the basis for optional subsequent plant feature extractions. For instance, leaf counting is facilitated through roundness analysis, as illustrated in Figure 1(c), where the roundness of edge transitions between stems (high roundness) and leaves (low roundness due to their flat shape) is measured by the variation in distance from the center to the surface. This analysis enables the identification of leaves and facilitates the estimation of plant height, area, volume, and stem diameter.

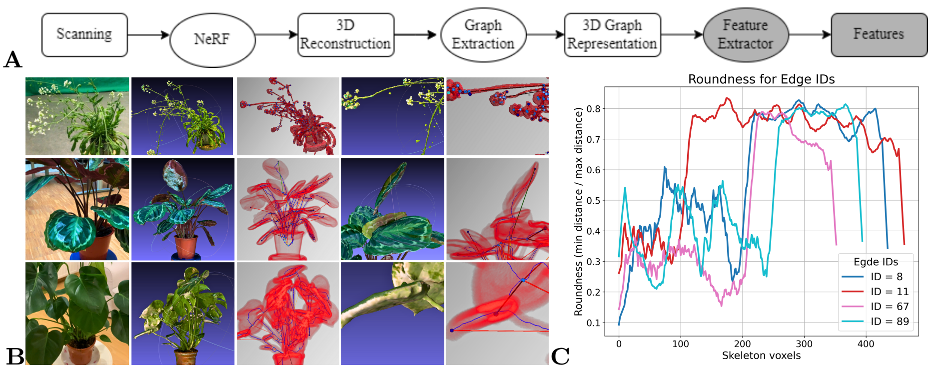

Fig. 1: (**a**) Pipeline of the implemented methodology. The square boxes represent input/output, the round boxes the algorithms, and the grey boxes future work. (**b**) Results of our proposed pipeline: 1st column: Real images; 2nd & 4th column: Extracted geometries (overview and close-up); 3th & 5th column: Extracted graphs within density volume (overview and close-up). (**c**) Roundness values for four transition edges.

To evaluate pipeline in the context of plant phenotyping we generated 3 reconstructions; *Capsella grandiflora, Calathea medallion roseopicta*, and *Monstera deliciosa* shown in Figure 1(b). As can be seen, Neuralangelo provides detailed 3D models and representative graphs can be extracted.

3 Conclusion and Further Work

We have developed a pipeline to extract 3D reconstructions and graph structures for plants from hand-held video recordings. These 3D reconstructions allow in-depth explorations of plant representations across various research and environmental settings, aiding in studying growth dynamics, adaptation strategies and crop improvement. Future work will focus on extracting the traits mentioned to enrich the pipeline.

References

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