Photometric Stereo data for Leaf Segmentation and Plant Phenotyping

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Continuous advances in computer vision (CV) have allowed for significant improvements in objective, accurate and fast image analysis. CV tools are being used in many different applications, one of them being plant phenotyping. However, key challenges in CV for plant phenotyping still need to be addressed. For example, two-dimensional (2D) imaging approaches are widely used due to their availability and relative ease of capture, but they cannot accurately represent features such as leaf curvature and movement (e.g. hyponasty), which can lead to erroneous data interpretation. Three-dimensional (3D) approaches overcome some of the shortcomings of 2D, but are frequently limited by other factors such as resolution, speed, availability and high cost. We addressed these issues by developing a novel affordable 3D plant phenotyping system based on the Photometric Stereo (PS) technique [1, 2].

Our validation results show that the PS system provides accurate plant area estimations and can also track leaf inclination angles throughout the diel (i.e. 24 hour) light and dark period, which is a useful tool for estimating the plant's circadian clock. To further understand plant growth dynamics, we aimed to automate the extraction of individual leaf area and angle information.

Automated individual leaf segmentation is a challenging task as leaves within a plant canopy tend to overlap, occlude, move and can be of different shapes and sizes. Leaf segmentation algorithms based on the traditional CV approaches showed that they may work in certain scenarios, but often cannot generalize to more than a few cases [3]. On the contrary, machine learning has already showed generalizing properties in many areas, including leaf segmentation, but requires large training datasets when training on conventional RGB images [4].

We proposed to train a neural network (NN) models [4, 5] for automated leaf labelling given the data from PS imaging – grayscale, albedo or normal map images. The provided data was presented as conventional 2D RGB images, so we could take advantage of already available NN architectures and pre-trained models. We have generated a hand-labelled dataset consisting of over 450 labelled images of wild-type Arabidopsis plants grown in different lighting and temperature conditions, which provided a variety of rosette architectures. Here we focused on plants grown in standard conditions (150 µmol m^{-2} s^{-1} and 22ºC). This dataset consisted of 230 samples that was split into a 80:20 ratio for training and validation datasets, respectively. Datasets typically are randomly split into training and validation datasets. Here, we chose plants in a specific manner, so each individual plant (and all its time-series images) appear in either the training or validation dataset.

We trained nine different models that involved both training the model from scratch and using transfer learning on the pre-trained models with the COCO dataset. We chose two different NN architectures to compare the results – RNN with recurrent attention and Mask R-CNN [4, 5]. Our preliminary results indicate that the best results were achieved using fine-tuned models based on the architecture from He et al. [5] on each set of image data (i.e. grayscale, albedo or normal map) - symmetric best dice (SBD) [3] score ranged from 0.806 (normal maps) to 0.814 (albedo). When trained from random weights, the values ranged from 0.758 (albedo) to 0.813 (grayscale). In comparison, [4] SBD score ranged only from 0.440 for normal maps to 0.560 using albedo and grayscale images. The experiments did not show a clear advantage for any image data type, but the results using the method from He et al. [5] were almost 30% more accurate when compared to the Ren et al. [4] approach.

We believe the new PS dataset will be useful for the plant imaging community and will help to solve the leaf segmentation challenge in the future. Subsequent work will involve leaf segmentation and study of Arabidopsis mutants, and leaf tracking algorithm development. The derived PS dataset will be made publicly available shortly.

References

[1] R.J. Woodham. Photometric method for determining surface orientation from multiple images. Opt. Eng., p. 139–44, 1980.

[2] G. Bernotas, L. C. T. Scorza, M. F. Hansen, L. N. Smith, K. J. Halliday, A. J. McCormick, M. L. Smith; "Photometric Stereo Technique Suitability Study for Plant Phenotyping", CVPPP, https://www.plant-phenotyping.org/CVPPP2017-programme, 2017.

[3] H. Scharr, M. Minervini, A. P. French, C. Klukas, D. M. Kramer, X. Liu, I. Luengo, J. M. Pape, G. Polder, D. Vukadinovic, X. Yin, S. A. Tsaftaris; "Leaf segmentation in plant phenotyping: a collation study" Machine vision and applications, 2016.

[4] R. Mengye, R. S. Zemel; "End-to-End Instance Segmentation with Recurrent Attention", CVPR, 2017.

[5] K. He, G. Gkioxari, P. Dollar, R. Girshick; "Mask R-CNN", ICCV, 2017.