Photometric Stereo Technique Suitability Study for Plant Phenotyping

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The dynamic quantification of growth traits is critical for building accurate modelling tools to predict plant behaviour under different growth environments, and consequently in designing strategies to improve plant health and overall yields. We are interested in a light-regulated mechanism called the shade avoidance response (SAR), which appears in high-density planting and results in elongated stems, increased leaf movement (hyponasty) and reduced yields [1]. Most of the reported plant monitoring systems focus on two-dimensional (2D) images; however, 2D imaging techniques cannot represent a complex three-dimensional (3D) plant structure. 3D data acquisition systems may overcome some of the drawbacks of 2D imaging, but their applicability in practice is still often limited due to their affordability, availability, resolution and speed, ultimately requiring new methodologies to be investigated. Therefore, we examine and present an unexplored Photometric Stereo (PS) technique suitability study for examining SAR in *Arabidopsis thaliana*. PS is a 3D data acquisition technique that observes the object under at least three different lighting conditions and computes a Surface Normal (SN) map [2]. Our developed PS system uses a machine vision Near-InfraRed (NIR) monochrome camera and two alternative types of illumination composed of four visible (5700K) and four NIR (940 nm) LEDs. Preliminary results have shown that the visible light preserves better details at the plant surface, however, NIR illumination is chosen as it does not interfere with the plant growth during diel growth tracking. Due to one of the PS assumptions, we bootstrap the original PS calculations with a light field compensation model based on the inverse-square law to obtain better reconstruction results. The obtained SN map is complimentary to the 2D image and can be used for 2D projected area loss compensation for more accurate plant area measurements as well as leaf angle estimations. We validated the accuracy of the system in three stages: (i) angle and area evaluation of known sized object positioned at varying angles, (ii) angle measurement of an *Arabidopsis* leaf at varying angles and (iii) *Arabidopsis* rosette area measurements. A known sized object was imaged at every 5-degree angle increments in range from 0 to 45 degrees. The Mean Absolute Error (MAE) of angle estimation was 0.89°, while the Mean Relative Error (MRE) of the compensated area was 1.01%. The developed system demonstrated the MRE of 5.76% for rosette area assessment and leaf angle was estimated with a MAE of 9.03^o. The error for leaf angle estimation was relatively constant for all angles tested, meaning it can be used as a normalization factor improving leaf angle accuracy in future measurements. The preliminary results reveal that the developed system is as accurate as most of the state-of-the-art systems in terms of object area and surface angle estimations [3, 4]. Currently, the system is being used to track plant diel growth using *Arabidopsis* wild type and phytochrome mutants in different light and temperature conditions. The extracted dynamic rosette growth trait information will allow us to gain a new understanding of how different light and temperature can impact on plant growth architectures and therefore in yield potential. Future work will focus on image processing and tracking of individual leaves. We believe that the developed methodology will have a great impact on the plant biology community due to the affordability and portability of our 3D phenotyping system.

References

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