EVALUATING FLIGHT PATH STRATEGY FOR UAV-BASED PHENOTYPING OF INDIVIDUAL MUSKMELON PLANT IN GREENHOUSE ENVIRONMENTS

Tian-Yi Lu, Jing-Heng Lin, Kuan-Chen Lin, Ta-Te Lin[*]

Department of Biomechatronics Engineering, National Taiwan University, Taipei, Taiwan, ROC.

*Corresponding Author: m456@ntu.edu.tw

ABSTRACT

Unmanned Aerial Vehicle (UAV)-based phenotyping is an emerging non-invasive method for high-throughput trait measurement in controlled environments. This study examines how UAV flight trajectory affects reconstruction fidelity and trait accuracy for muskmelon and grape plants in a GPS-denied greenhouse. Two strategies - circular loop and vertical hop - were flown using a UAV with RGB-D SLAM navigation, capturing data with a RunCam Thumb Pro. Data were processed through a GLOMAP structure-from-motion pipeline with 3D Gaussian Splatting. Reconstruction quality was assessed using Peak Signal-to-Noise Ratio (PSNR) and Structural Similarity Index Measure (SSIM), while plant height and canopy span were derived from point-cloud geometry. The vertical hop achieved higher SSIM (0.913 vs. 0.897) with comparable PSNR (19.923 vs. 19.954 dB) and yielded lower trait errors (height MAE: 7.0 cm; span MAE: 4.0 cm) than the loop (8.4 cm; 6.8 cm). Vertical scanning therefore enhances structural fidelity and measurement accuracy, underscoring the importance of trajectory design for UAV phenotyping in greenhouses.

Keywords: UAV, Plant Phenotyping, Smart Agriculture, Visual SLAM, Gaussian Splatting

INTRODUCTION

UAV-based phenotyping has enabled efficient and non-destructive measurement of crop traits, offering valuable tools for precision agriculture. Muskmelon, with complex canopy structures and environmental sensitivity, pose challenges for phenotypic assessment. In GPS-denied environments such as greenhouses, UAVs depend on SLAM for autonomous navigation and accurate data collection. While sensors and processing techniques have evolved, the role of UAV flight paths in ensuring reliable 3D reconstruction and trait extraction remains underexplored. (Yang et al., 2017; Roth et al., 2018).

This study evaluates how UAV flight trajectories affect 3D reconstruction and trait accuracy of muskmelon and grape plants in greenhouses. By comparing circular loop and vertical hop paths, it aims to identify flight path designs that improve phenotyping reliability in GPS-denied conditions.

MATERIALS AND METHODS

The study was conducted in a greenhouse with muskmelon and grape plants. A quadrotor UAV equipped with an RGB-D camera and onboard SLAM executed two trajectories: a circular loop around each plant and a vertical hop in discrete upward steps, as shown in Fig.1.
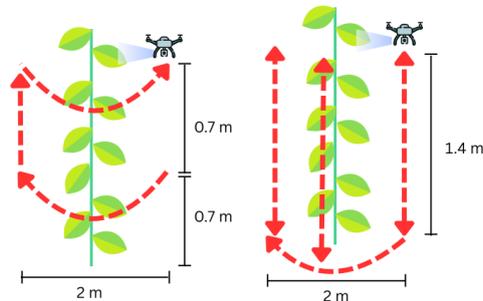

Fig.1 Schematic diagram of UAV flight path designs: (left) circular scanning and (right) vertical scanning

4K video was captured using a RunCam Thumb Pro. Frames were processed through a GLOMAP-based structure-from-motion pipeline with 3D Gaussian Splatting to create dense point clouds. Canopy span was then estimated from convex-hull projections, and height was determined by projecting points onto the stem axis and locating the highest point. Ground-truth measurements of height and width were used for comparison, and Mean Absolute Error (MAE) was calculated.

RESULTS & DISCUSSION

The vertical hop outperformed the circular loop overall, though the metrics revealed a tradeoff. The circular loop reconstructions had slightly higher PSNR (19.954 dB vs. 19.923 dB), indicating better pixel-level fidelity, whereas the vertical hop achieved higher SSIM (0.913 vs. 0.897), reflecting more accurate structural geometry. Since phenotyping depends more on structural fidelity, the SSIM advantage of the vertical hop is more relevant. This is confirmed by trait extraction, where the vertical hop reduced error in height (7.0 vs. 8.4 cm) and canopy width (4.0 vs. 6.8 cm), making it the more effective trajectory.

CONCLUSIONS

This study demonstrates that UAV flight path significantly influences the accuracy of 3D plant reconstruction and phenotypic trait measurement in greenhouse conditions. While circular loop enhance visual reconstruction fidelity, vertical hops reduce trait measurement errors. These findings provide actionable guidelines for UAV mission planning in precision agriculture.

REFERENCES

Roth, L., Y. He, and J. K. Schueller. 2018. Effect of UAV imaging angles on 3D reconstruction accuracy in horticultural phenotyping. *ISPRS J. of Photogrammetry and Remote Sensing* 142: 218-227.

Yang, G., J. Liu, C. Zhao, Z. Li, Y. Huang, H. Yu, and H. Yang. 2017. Unmanned aerial vehicle remote sensing for field-based crop phenotyping: Current status and perspectives. *Frontiers in Plant Science* 8: 1111.