# EVALUATION OF HIGH-THROUGHPUT 3D RECONSTRUCTION METHOD FOR PLANTS AND ITS APPLICATION TO TRAITS FEATURE EXTRACTION

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## ABSTRACT

2D images are widely utilized to monitor and evaluate plant growth, capturing the dynamic and multi-directional nature of plant canopies remains difficult, emphasizing the need for 3D monitoring integrated with plant phenotyping systems.This study aims to introduce a high-throughput plant phenotyping system using 3D plant shape model reconstructed from a dataset of 2D plant images from multiple camera poses. A robot autonomously gathered data by recording video footage of plants from various viewpoints, ensuring comprehensive canopy coverage. This systematic data collection was foundational for building detailed 3D representations. The collected images were then utilized to train and evaluate several photorealistic 3D reconstruction techniques based on computer vision and deep learning called Neural Radiance Fields (NeRF) and 3D Gaussian Splatting. Reconstructed complex plant shape and texture were evaluated image quality metrics such as PSNR, SSIM, and LPIPS. As the results, 3D Gaussian Splatting indicated the superior score for reconstruction quality and speed. Further, we investigated the potential on quantitative plant feature analysis using 3D reconstructed plant models. By applying 3D data processing techniques, we succeeded in extracting the real-scale plant traits information. This result suggests the possibility of non-invasively extracting phenotypes from image information.

**Keywords:** Plant phenotyping, Neural Radiance Fields (NeRF), Gaussian Splatting, spatial data, data-driven agriculture.

## INTRODUCTION

Monitoring plants with 2D images presents challenges in capturing the dynamic and multi-directional nature of canopies. While recent research has introduced 3D techniques, NeRF and 3D Gaussian Splatting (3DGS), its potential for analyzing plant organs is still underexplored. Given these challenges, the primary objectives of this research were twofold: first, to introduce a high-throughput plant phenotyping system capable of generating a detailed 3D plant model reconstructed from a dataset of 2D plant images; and second, to thoroughly investigate the potential of this system for quantitative plant feature analysis, focusing on segmenting plant features like leaves and extracting precise geometric data from these segmented 3D models using advanced computer vision methodologies

## MATERIALS AND METHODS

The study involved collecting 700 multi-view images of cucumber plants using an autonomous robotic system. These 2D images underwent a multi-stage pre-processing pipeline: the Depth Anything (DA) model for background removal, the YOLOv11 model for detecting individual leaves and generating bounding boxes, and the Segment Anything Model (SAM) for precisely isolating leaf masks within those bounding boxes. This comprehensive process resulted in a refined dataset containing only images of leaves. This refined dataset, combined with pose data derived from Structure from Motion (SfM), was then used to train the NeRF and 3DGS model. Subsequently, point clouds were extracted from the 3DGS model to reconstruct the detailed geometry of leaves within the canopy, facilitating quantitative plant feature analysis.

## RESULTS & DISCUSSION

Table 1 Quantitative Performance Comparison of NeRFs and 3DGS.

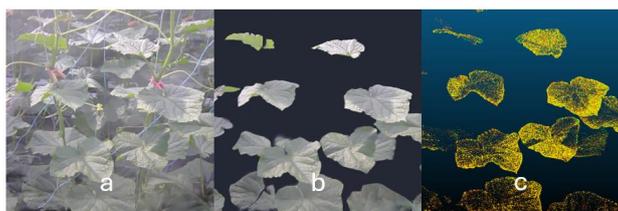| Models | PSNR | SSIM | LPIPS |
| --- | --- | --- | --- |
| Instant-NGP (NeRF) | 19.77 | 0.70 | 0.32 |
| Nerfacto (NeRF) | 18.44 | 0.68 | 0.35 |
| 3DGS | 24 | 0.87 | 0.21 |



Fig.1 Rendered Non-Segmented (a), Segmented (b) and Exported (c) Leaves.

The pipeline demonstrated high effectiveness: the DA model successfully removed complex backgrounds from the canopy. The YOLOv11 model accurately detected leaf locations, achieving a mean Average Precision (mAP@0.5) over 96%. Following this, the SAM precisely produced isolated leaf masks. These masks were crucial for creating an intrinsically segmented 3DGS model. From this segmented model, isolated point clouds of individual leaf organs were successfully extracted (Figure 1). This outcome proves the pipeline's high potential for extracting target plant organs and highlights its utility for detailed plant growth diagnosis. Furthermore, 3DGS exhibited superior scores for reconstruction quality compared to NeRF (Table 1). The successful extraction of real-scale plant trait information from these 3D models underscores the possibility of non-invasively extracting phenotypes from image data.

## CONCLUSIONS

The developed pipeline effectively extracts plant organs using a 3DGS, enabling non-invasive plant trait analysis and detailed growth diagnosis. Future research explores analyzing specific plant organs beyond leaves and develops more advanced methods to analyze geometric data from the segmented 3D models for a wider range of plant growth diagnoses.

## REFERENCES

Pham, D. T., et al., 2025, High-throughput 3D reconstruction of plants and its application to plant feature segmentation, Smart Agricultural Technology, 12, 101063.