Affordable high-throughput processing of handheld camera images of container plants to phenotypic data

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Can we phenotype many container plants with 3D traits automatically with an affordable solution?

Problem

3D reconstruction workflow is time-consuming because it is not automated, and built-in tools to process multiple image sets do not exist. Point clouds require processing to extract phenotypic traits data.

Approach

Design an image acquisition system that is easy to set up and operate. Develop a 2-part pipeline: (1) Automatically process images to 3D point clouds via API of commercial Structure-from-Motion (SfM) software Agisoft Metashape Professional. (2) Use Python to analyze point clouds and export phenotypic traits.

Experiment and methods

A. Setup: A temporary image acquisition system [Figure 1] was set up on the platform of a Phenospex PlantEye F500 laser scanner. Plants were moved in groups of 3 individuals to the imaging station and photographed. The image acquisition system consisted of: a black groundcover sheet, eight 12-bit coded targets, and a camera calibration sheet. The image acquisition system occupied a 90cm x 180cm area. Plants were spaced on bricks 50 cm apart on center in one row, in order of increasing plant ID.

B. Imaging: A Canon EOS Kiss X7 camera was used to capture RGB images of plants in JPG format. The maximum resolution of 5184 x 3456 pixels was chosen. Aperture-priority setting and f/6.3 were used. The camera was handheld above plants at a height of approximately 100 cm from the base platform. Images were captured from 4 angles parallel to the plant row. Approximately 30 to 50 images per camera angle were captured. The process was conducted 8 times.

C. Reference data and Ground truth: Reference point cloud [Figure 2], plant height, and projected leaf area measurements were obtained using a dual-unit PlantEye F500 laser scanner and proprietary HortControl software. Plants were scanned in groups of 3 individuals immediately following imaging in (B). For ground truth, a meter stick was used to measure maximum plant height.

D. Measurement: The proposed pipeline was used to generate 3D point clouds and execute phenotypic traits calculation [Figures 3, 4].

Pipeline

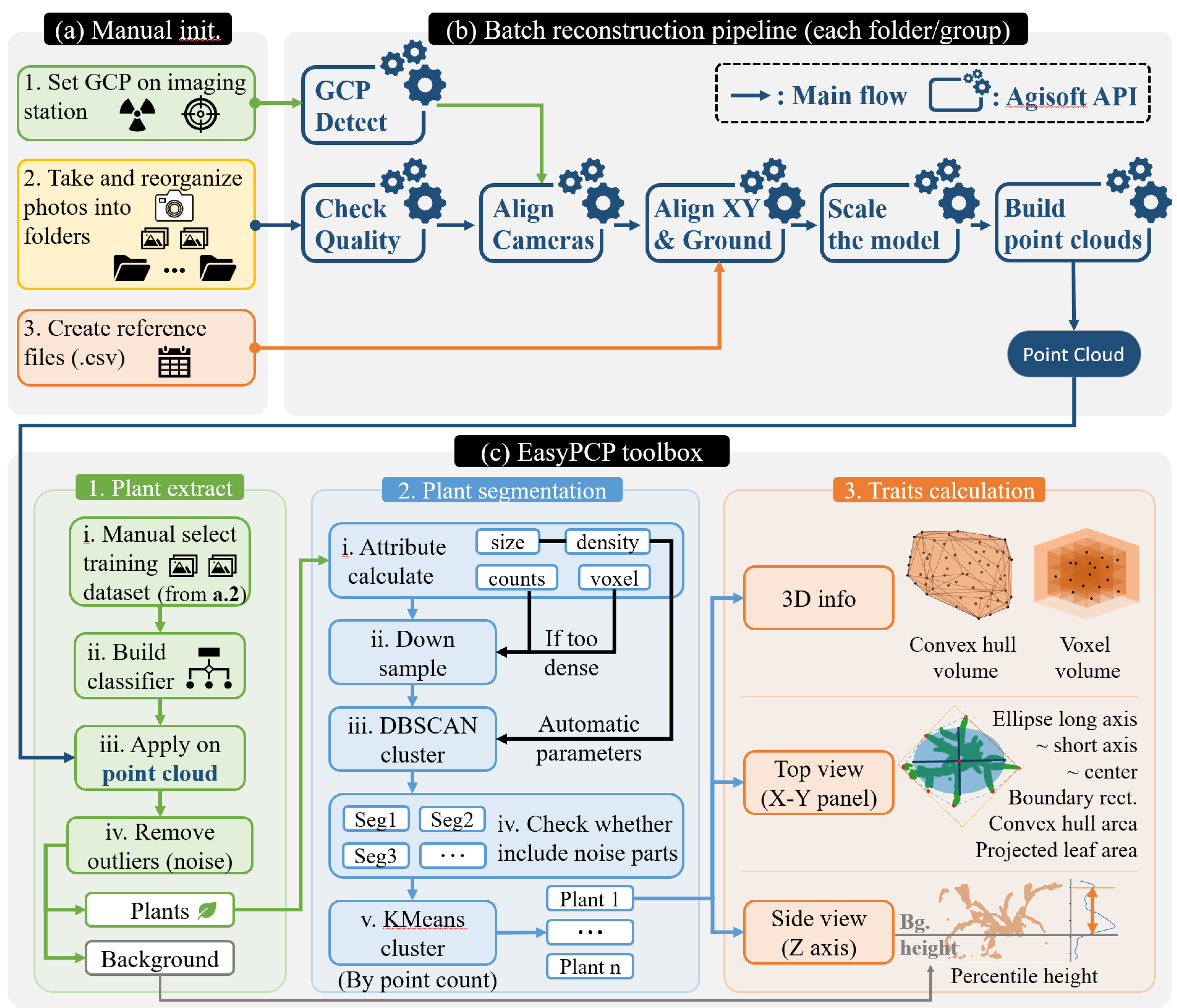

Figure 3. The full pipeline, beginning with setup of imaging station and ending with output of plant phenotypic traits.

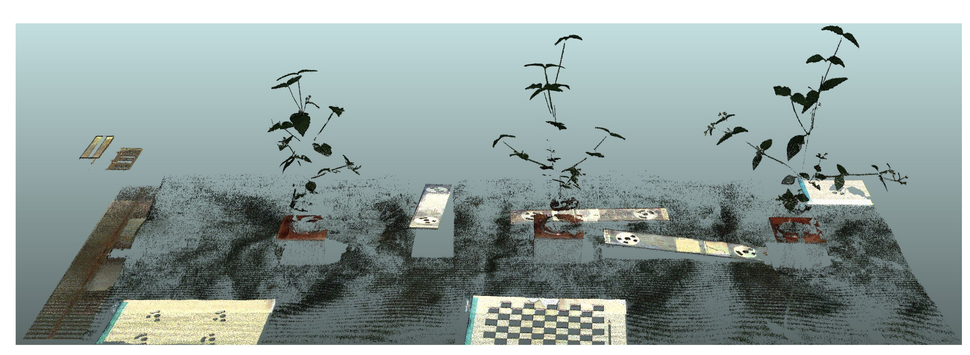

Figure 2. The 3D point cloud produced by PlantEye laser scanner.

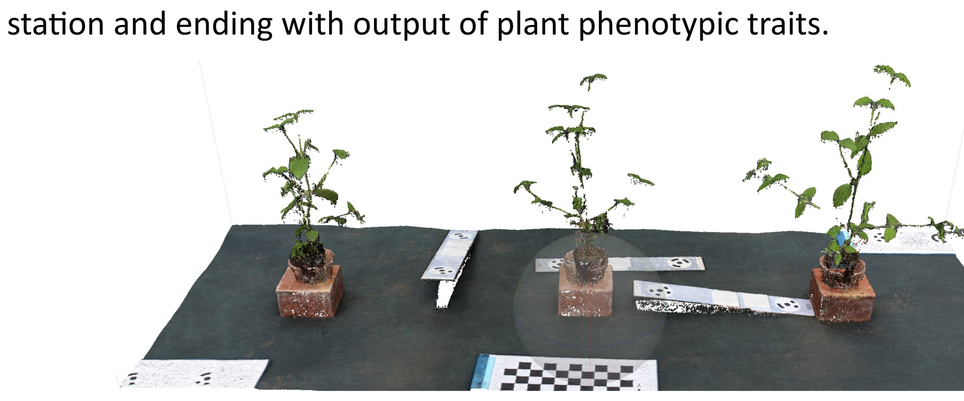

Figure 4. The 3D point cloud generated automatically by Agisoft Metashape.

Image acquisition system

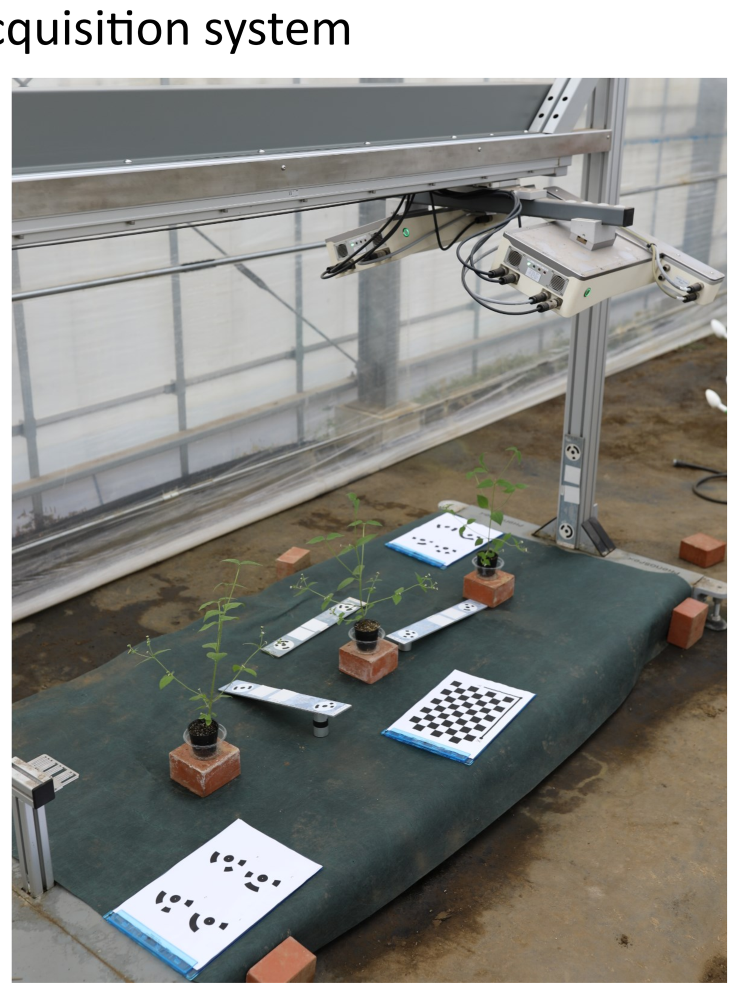

Figure 1. The image acquisition system, including coded targets and camera calibration sheet, set up on the platform of the PlantEye F500 laser scanner.

Validation

Figure 7. EasyPCP Classification.

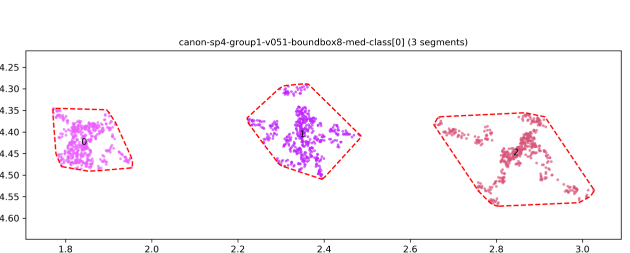

Figure 8. EasyPCP Segmentation.

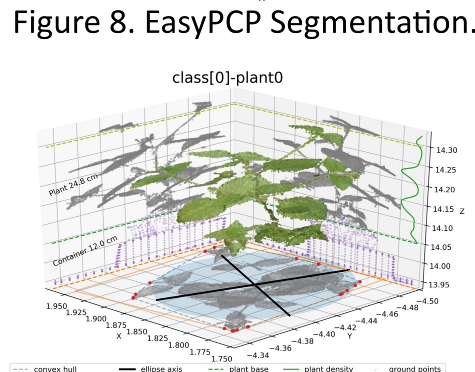

Figure 9. EasyPCP Measurement.

Results—Validation dataset

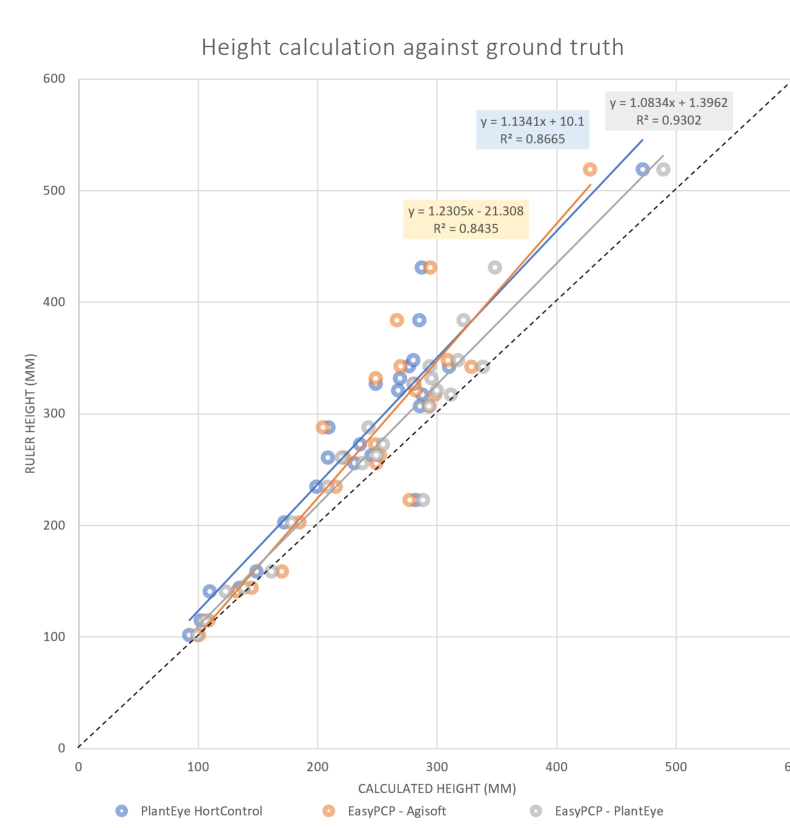

Figure 10. Height measurement from SfM using EasyPCP and laser scanner using Planteye HortControl against ground truth from manual ruler measurement.

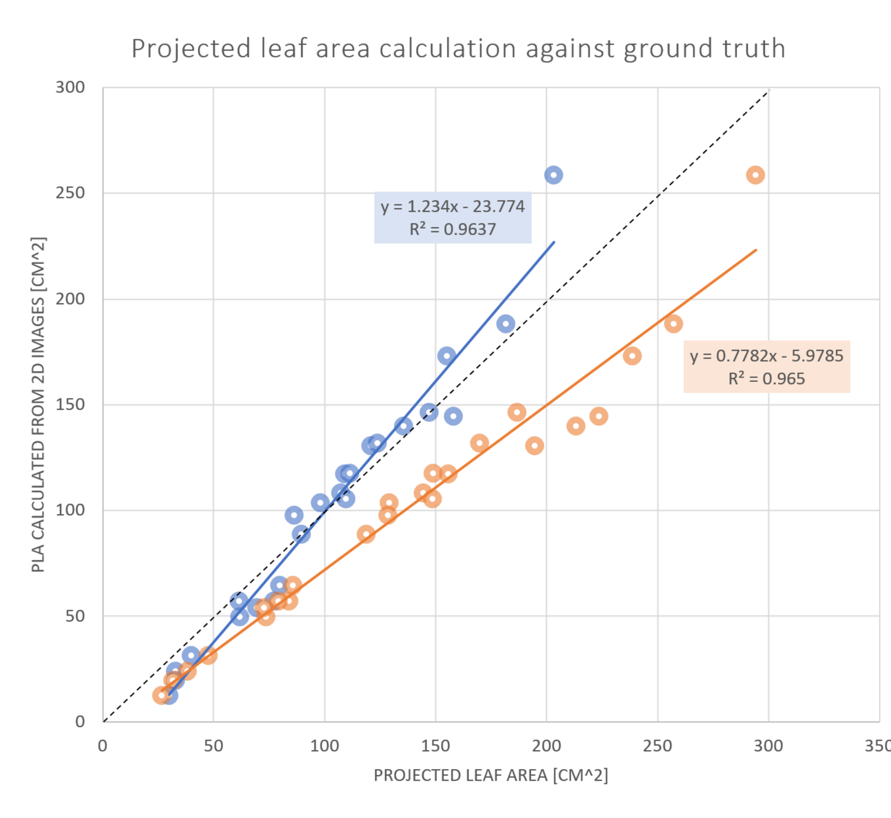

Figure 11. Projected leaf area measurement from SfM using EasyPCP and laser scanner using Planteye HortControl against ground truth from traditional 2D PLA measurement.

Accuracy evaluation

3 precision scale bars [Figure 5] individually calibrated to 0.1 mm accuracy (Cultural Heritage Imaging, USA) were installed at approx. 0°, 6°, and 12° angles for the purpose of validating the point cloud scaling accuracy in 3 dimensions [Figure 6], but were not used in the SfM process.

Figure 5. CHI precision scale bar.

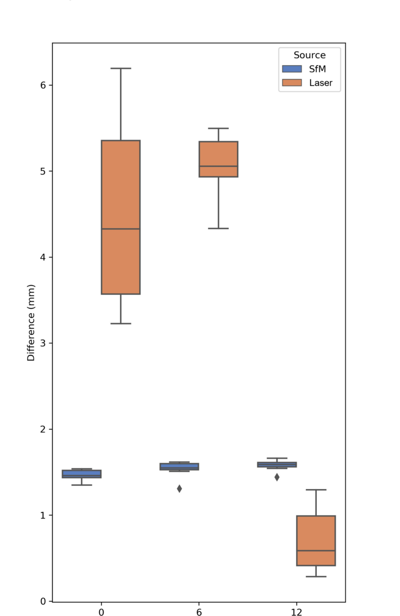

Fig.6. Accuracy comparison of SfM and PlantEye for different scale bar angles.

Application example: High-throughput phenotyping

216 greenhouse container plants [Figure 12] were imaged in 36 groups of 6 individuals in a single session. To reduce imaging time, 20 photos per group were taken from overhead view only. All imaging work was completed within 4 hours.

The 36 image sets were automatically processed to point clouds [Figure 13] and phenotypic data was extracted automatically [Figures 14, 15].

Fig.12. 216 container plants for application of high-throughput phenotyping.

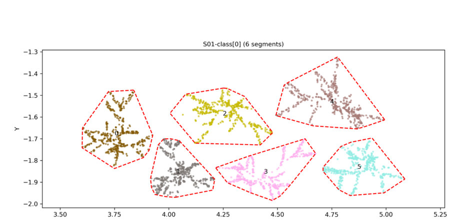

Figure 14. Successful segmentation.

Figure 13. The 3D point cloud generated automatically by Agisoft Metashape.

Results—Application dataset

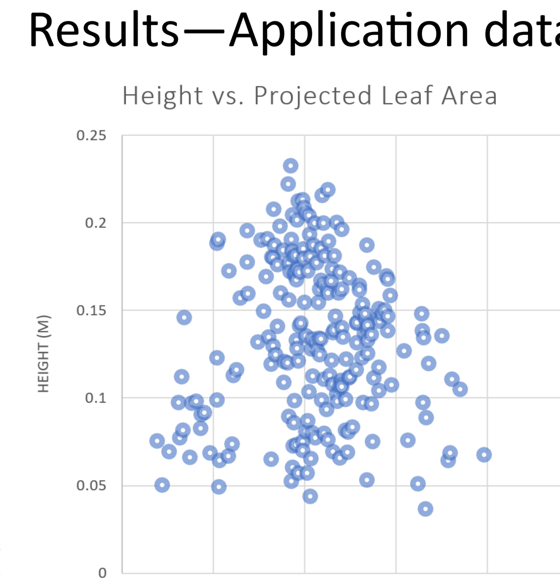

Fig.15. 216 plants data were collected.

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Conclusion

With JPEG images of adequate resolution, sharpness and overlap >80 %, a high-quality 3D point cloud can be produced automatically with minimal configuration.

Phenotypic traits can be measured from point cloud automatically using "EasyPCP" Python script.

Plant height r^2 > 0.84 and projected leaf area r^2 > 0.96 and indicate that accuracy is acceptable.

Challenges

Classification: Result depends on training data

Segmentation: Finding the best DBSCAN parameters

Future work

Analyze more traits e.g. leaf number, total leaf area. Improve accuracy.