3D Plant Phenotyping

Zachary Bram and Brady Pramberg

3D Plant Phenotyping

Problem Statement

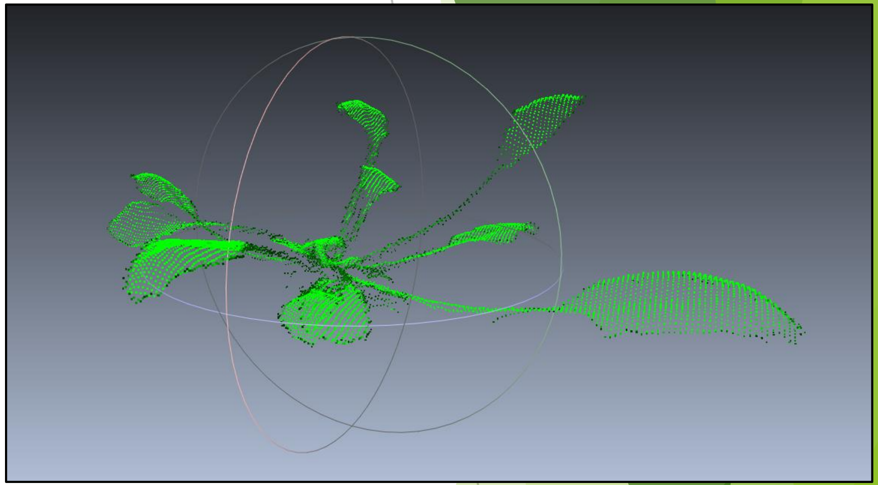
- Current methodology is to capture plant data using 2D images taken with LemnaTec Scanalyzer. This data is then analyzed to compute phenotypes.
- **Problem Statement:** Plants exist in 3D world, by using 2D images for phenotyping, we lose a whole dimension of accuracy
- **Solution:** Apply computer vision techniques to compute 3D phenotypes of plants from 2D image sets

3D Plant Phenotyping
Objectives

- Develop computer vision based algorithm within Matlab to compute 3D phenotypes
  - Convex Hull
  - Plant biomass
- Compare the 3D results with the same phenotypes calculated from 2D images
  - Goal is to have increased accuracy
- Perform experimental analysis: plot results from daily images to track plant growth

3D Plant Phenotyping

Related Work



- Purpose: analyze fragile plants without damaging them
- 3D plant-reconstruction
  - Accurate and non-damaging phenotyping method
  - Plant roots that are thin and delicate in nature can be analyzed using 2D images
  - Disassemble plants into disjoint parts to 3D scan and reconstruct
- We use computer vision to generate a 3D convex hull for analyzing plant phenotypes

3D Plant Phenotyping
Dataset

- Images taken from five different angles, 36° apart
- Imaged once daily for 20 days

0°

36°

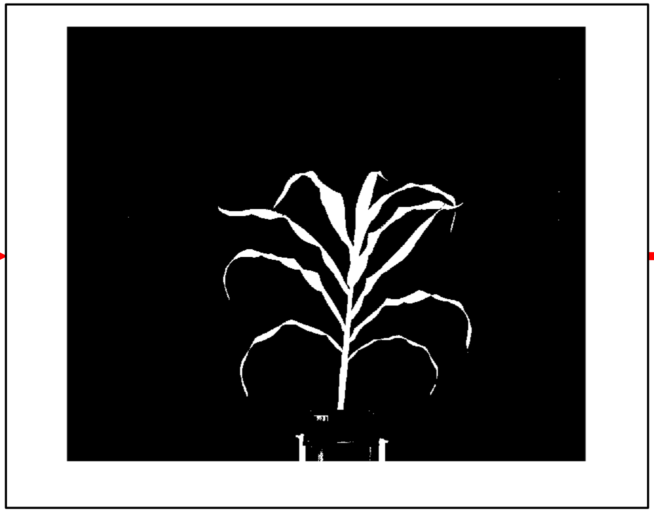
72°

108°

144°

3D Plant Phenotyping
2D processing - Generate mask

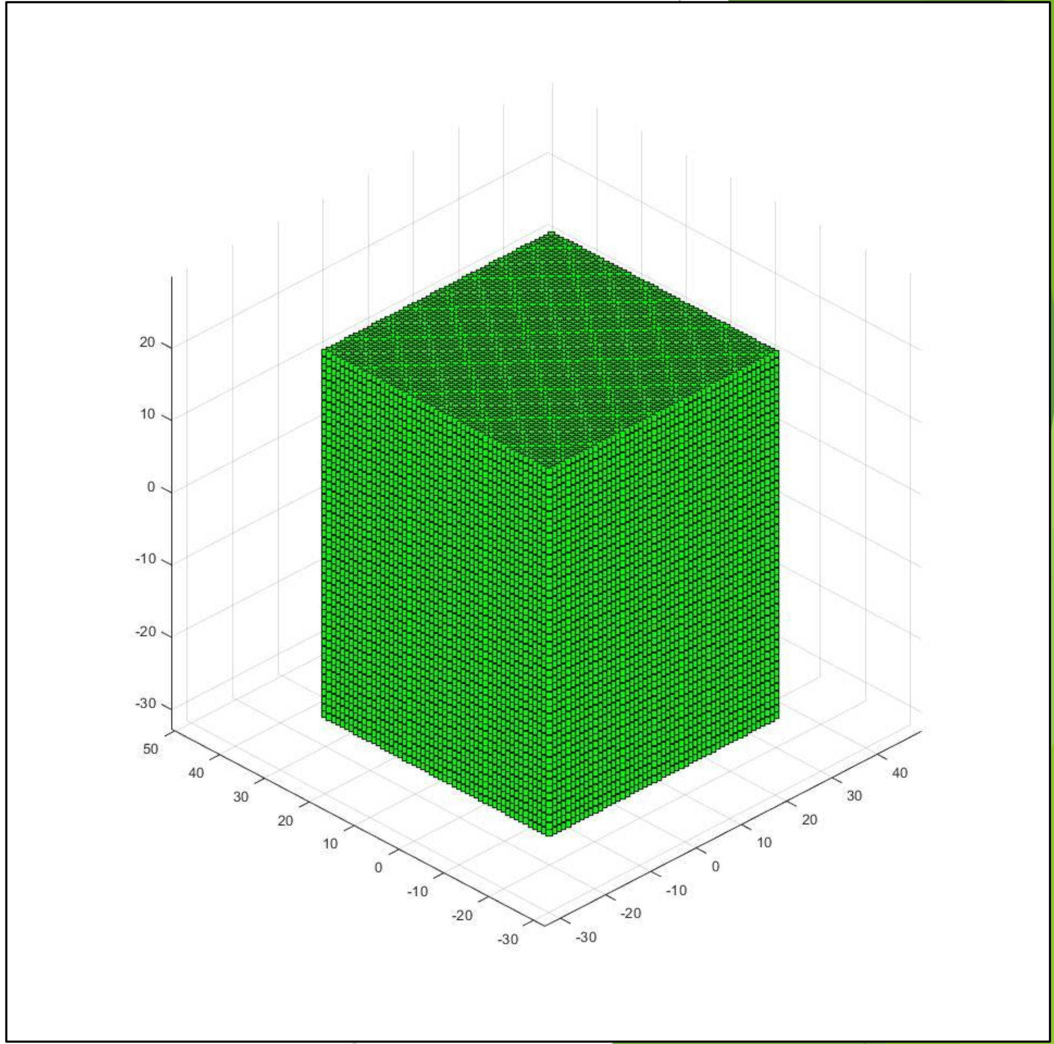
- Background subtraction to extract plant
- Binarization
- Morphological Dilation to ensure no components "missed" by not being connected



3D Plant Phenotyping
3D processing - Voxels

- Voxels: 3D equivalent of a pixel
- (x, y, z) coordinates
- Custom function written to create grid
- Must be small in size relative to image
  - 100x100x100 grid has 1 million points = lots of memory

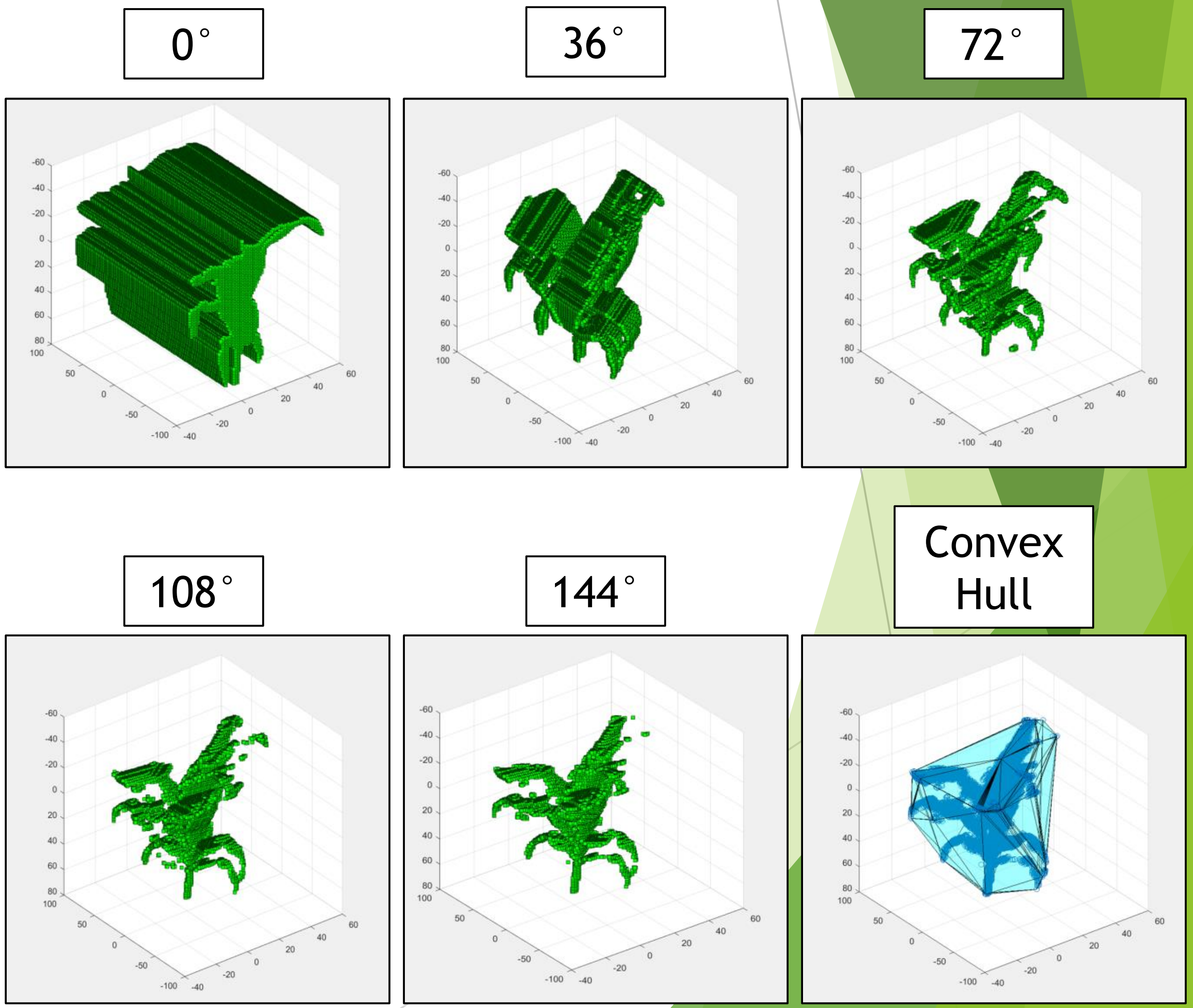
Voxel grid



3D Plant Phenotyping

3D Processing - Space carving

- Project 2D mask onto 3D voxels
- “Carve” away voxels not within mask
- Images show carving using 5 angles
- Last image shows final 3D convex hull



Sample values for day 20

3D Plant Phenotyping
3D Processing - Phenotypes

- Convex Volume

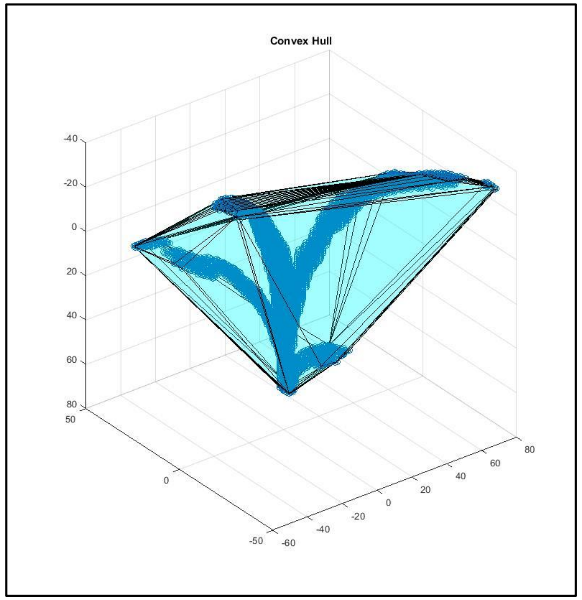
$$V_{C-H}$$

  - Volume within convex-hull

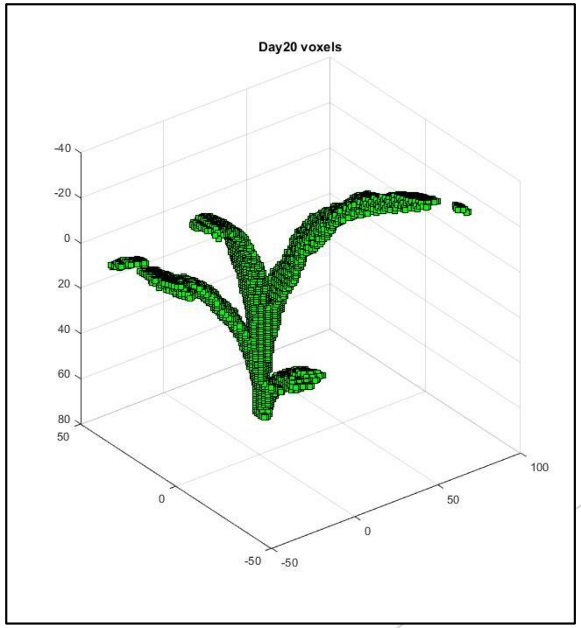
- Plant Biomass

$$P_m = \frac{N_{voxel,C-H}}{V_{C-H}}$$

  - Number of plant voxels in the convex-hull divided by volume of convex-hull



$$V_{C-H} = 154908$$

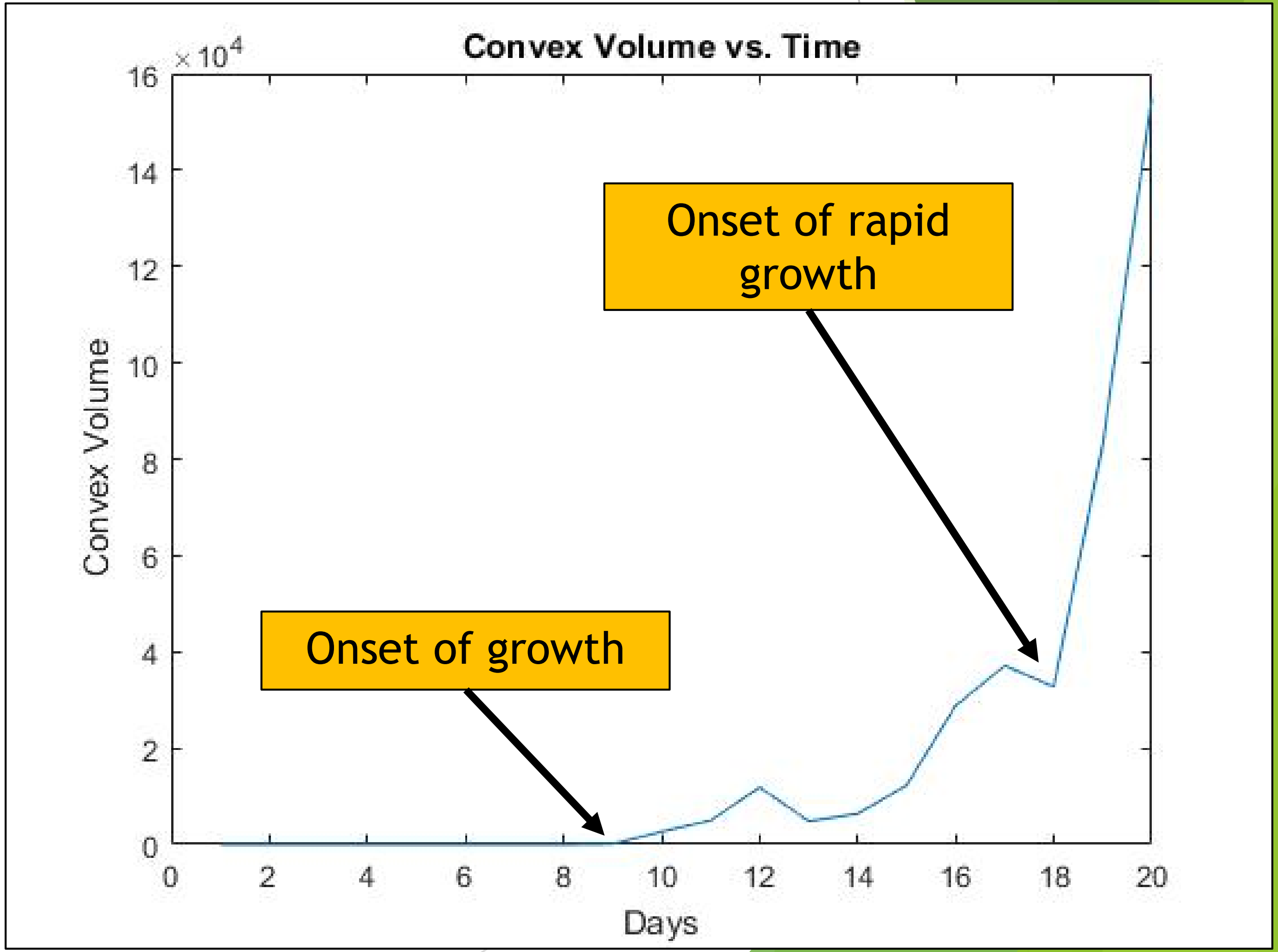


$$P_m = \frac{10148\ voxels}{154908} = 0.0655$$

3D Plant Phenotyping

3D Plant Growth – Convex volume

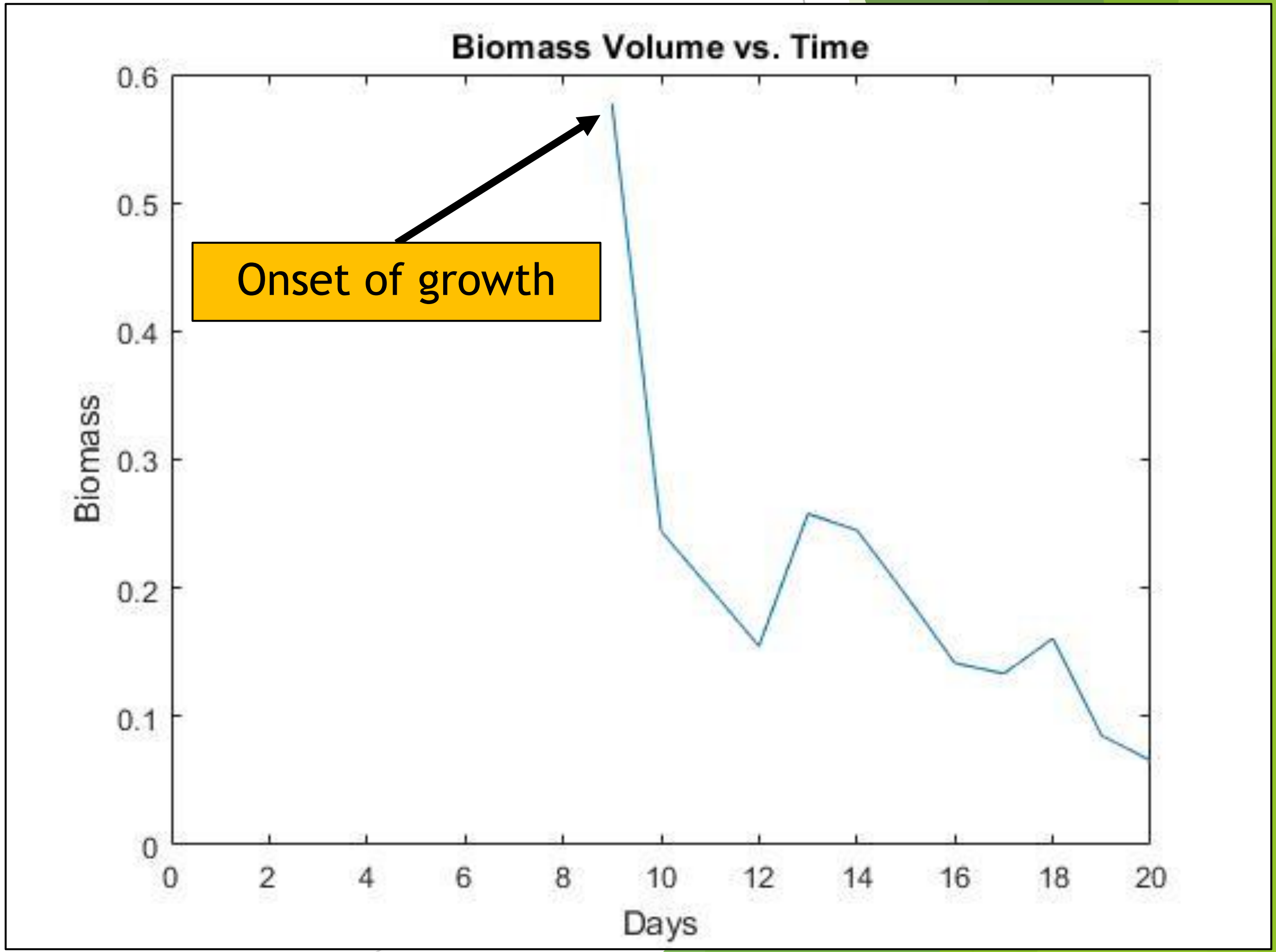
- Growth plotted over 20 days
- Plant has no visible leaves until day 9
- Grows drastically from days 18-20



3D Plant Phenotyping

3D Plant Growth – Plant biomass

- Growth plotted over 20 days
- Plant has no visible leaves until day 9



3D Plant Phenotyping

2D Phenotyping - Evaluation Approach

- **Problem:** Plants do not face camera in optimal position
  - Sample images taken from day 20
- **Experiment:** Measure 2D phenotypes of each angle for 20 days and compare

Day 20

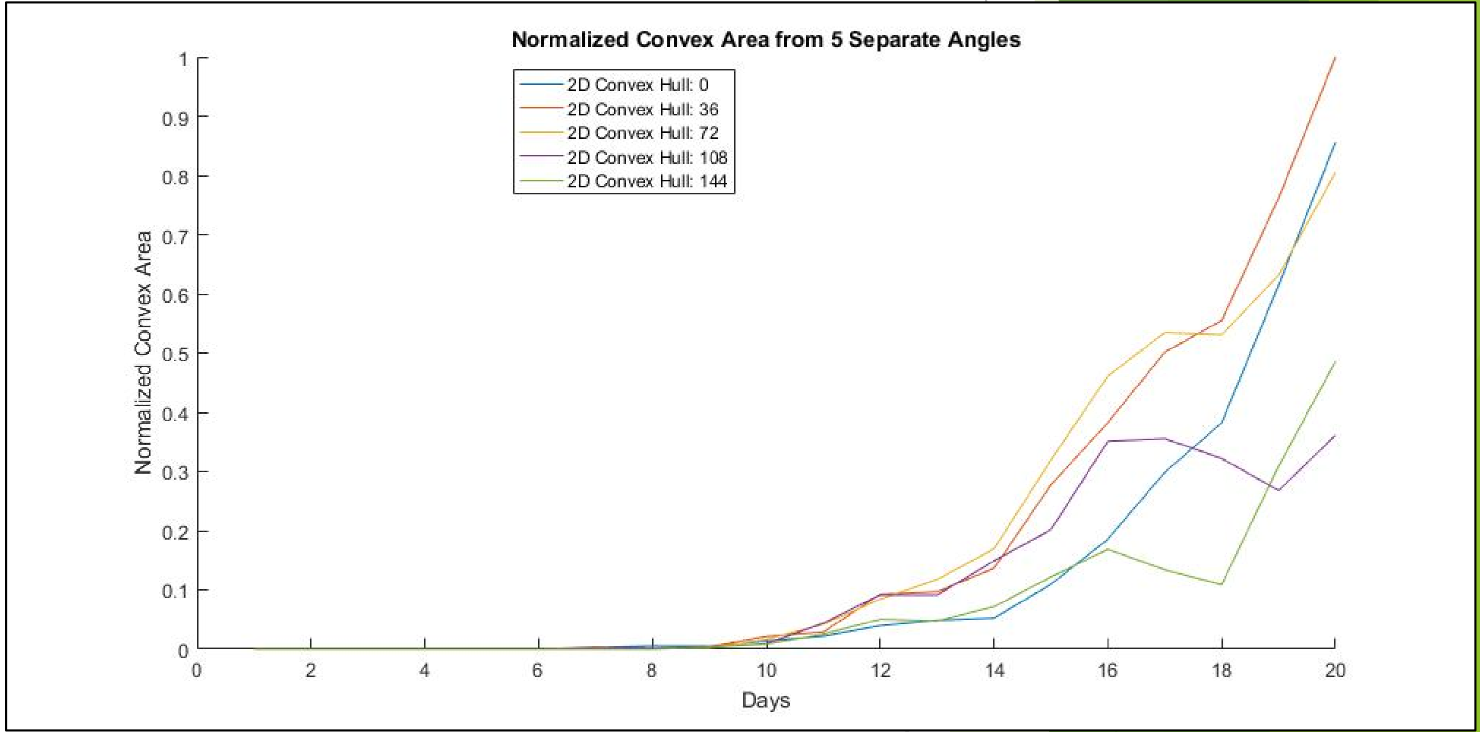
0°

108°

3D Plant Phenotyping

2D Phenotyping – Normalized convex area

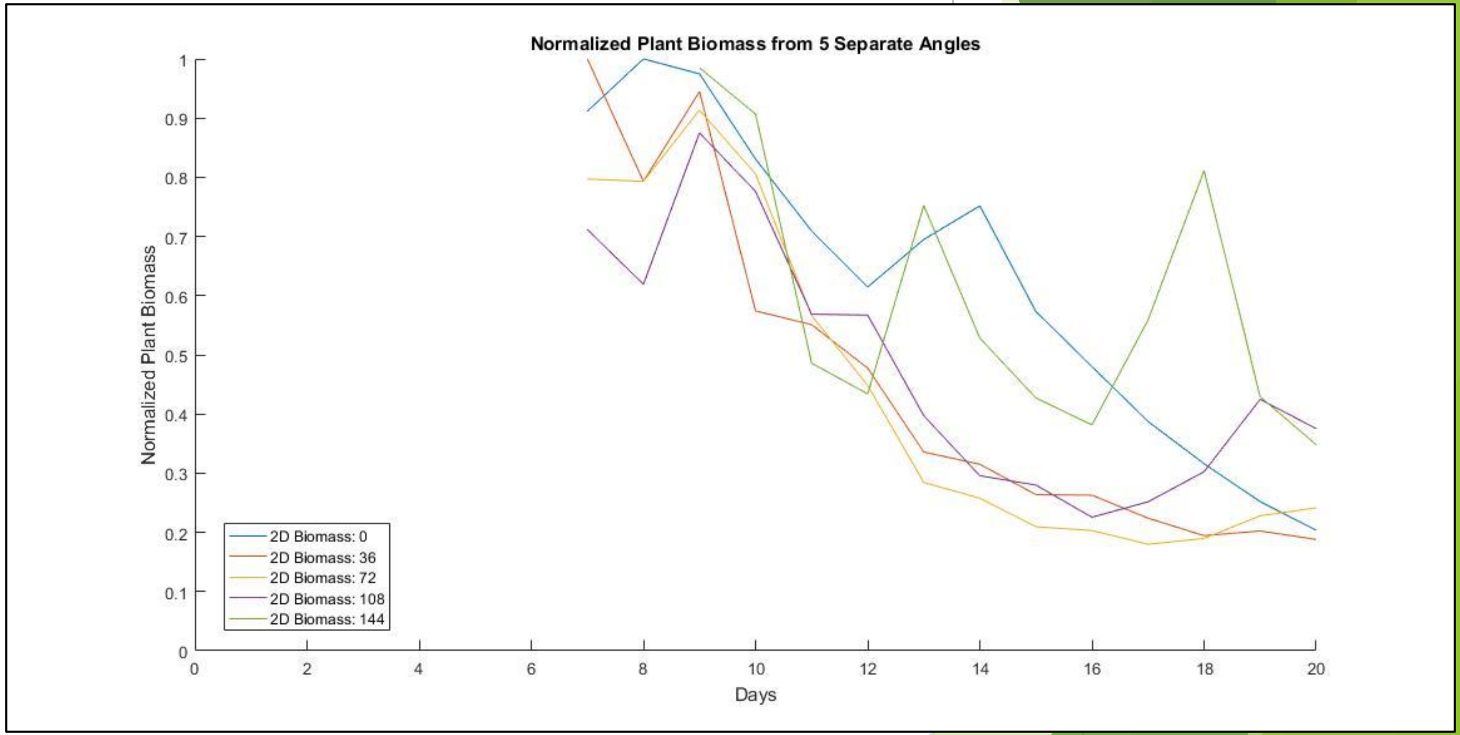
- Normalized convex area
  - Divide by convex area of view most orthogonal to camera
- Results:
  - 108° view was 36% lower than 36° view
  - 36° view showed no growth past day 16



3D Plant Phenotyping

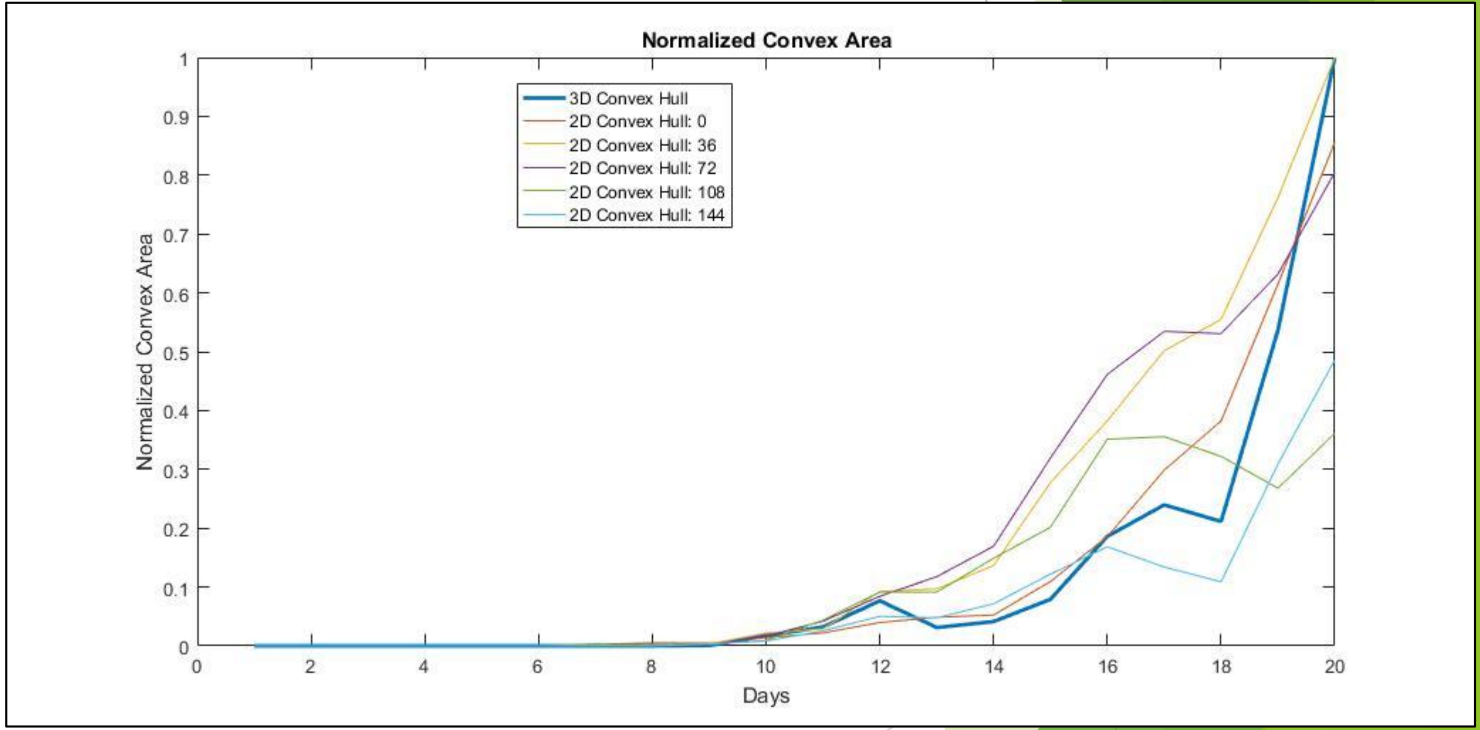
2D Phenotyping – Normalized plant biomass

- Normalized plant biomass
  - Divide by biomass of view most orthogonal to camera
- Results:
  - 108° view was 100% higher than 36° view



3D Plant Phenotyping
Comparison – 2D/3D normalized convex area

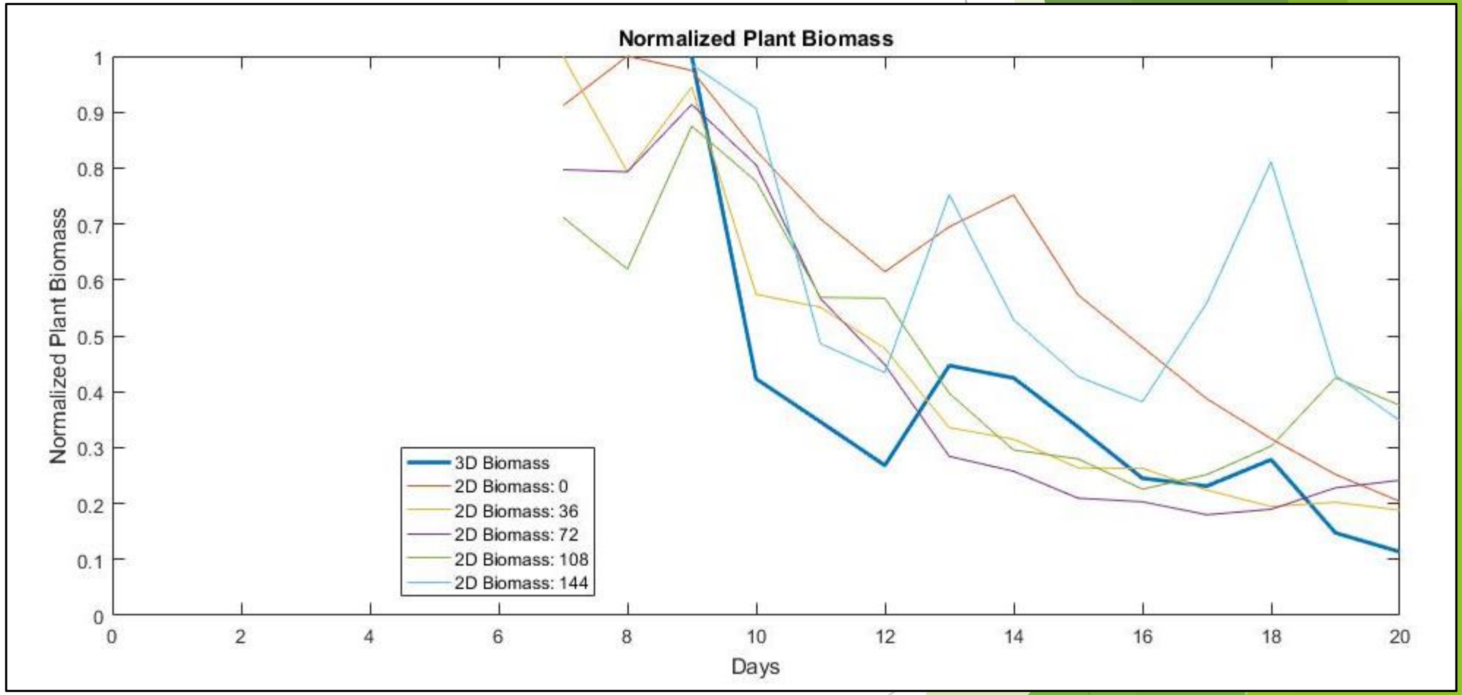
- Results:
  - Some views followed 3D results closely
  - 108° and 144° views have very high errors



3D Plant Phenotyping

Comparison – 2D/3D normalized plant biomass

- Results:
  - Some views followed 3D results closely
  - 108° and 144° views have very high errors



3D Plant Phenotyping
Evaluation

- 3D phenotyping is preferable
  - Takes more time to image and process
  - More accurate
    - No dependency on orthogonality of plant to camera
- 3D phenotype accuracy can be improved with more views
  - 5 views gave rough voxel model
  - 10+ should be used for experimental purposes

3D Plant Phenotyping
References

- Zheng, Ying, Steve Gu, Herbert Edelsbrunner, Carlo Tomasi, and Philip Benfey. "3D Reconstruction of Small Plant From Multiple Views." 2014 ASABE Annual International Meeting (2014): n. pag. Web. 8 Feb. 2017.
- Yin, Kangxue, Hui Huang, Pinxin Long, Alexei Gaissinski, Minglun Gong, and Andrei Sharf. "Full 3D Plant Reconstruction via Intrusive Acquisition." Computer Graphis Forum 34 (2015): 1-13. 2015. Web. 15 Feb. 2017.

Questions?