PhD Thesis Presentation

Studies on 3D-based plant phenotyping by multi-scale data fusion

マルチスケールデータ融合による植物表現型の３次元計測に関する研究

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2023

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CONTENT

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01

Introduction

1.1 General background

Accurate and comprehensive data collection helps effective decision-making in agriculture

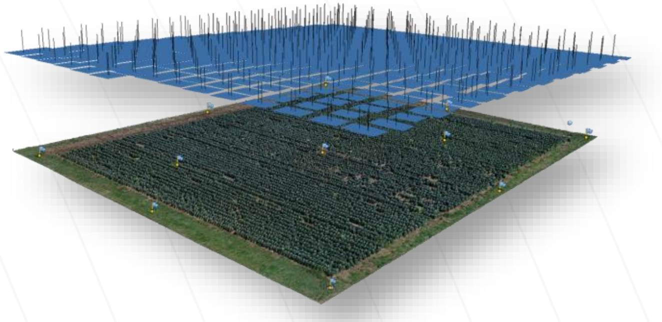
Traditional approach hard to meet such demand

High-throughput phenotyping technologies

[1] https://www.forbesindia.com/fbimages/900x600/proportional/jpeg/blog/wp-content/uploads/2023/01/Agriculture-is-a-potential-solution-to-meet-food-and-climategoals.jpg

1.2 Limitation of existing methods

Aerial approach
(distance to object > 5m)



Survey entire farmland efficiently

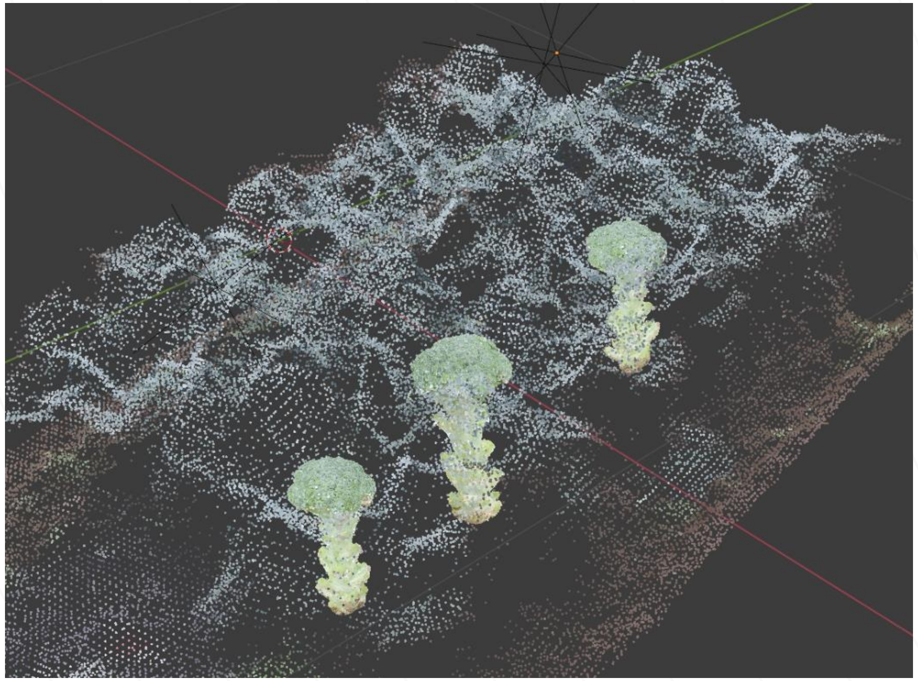
Low quality of organ structure

Close-range approach
(distance to object < 2m)

Obtain better organ structure

Low efficiency for surveying entire farmland

1.3 Research objective



Can we obtain **high-quality** organ structure of entire farmland **efficiently** by **fusing both approaches**?

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02 Close-range 3D pipeline

2.1 Background

Traditional close-range 3D phenotyping pipeline

Image collection | 3D reconstruction | Organ 3D model | Traits calculation

2.2 Challenge

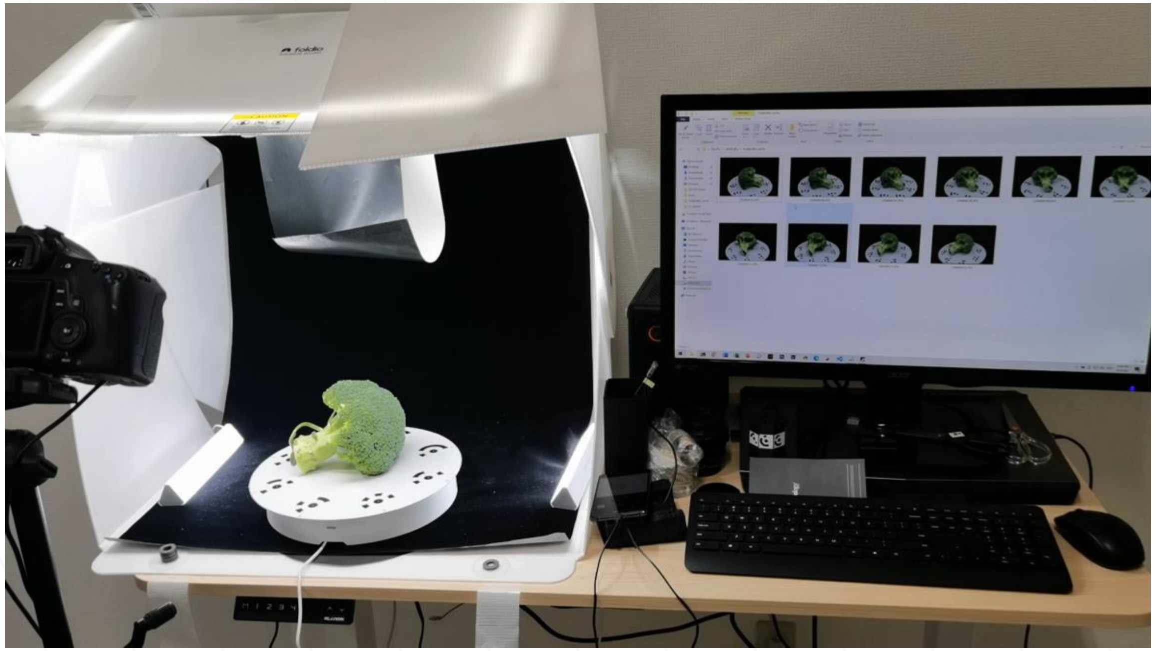
Traditional method cannot obtain complete organ structure

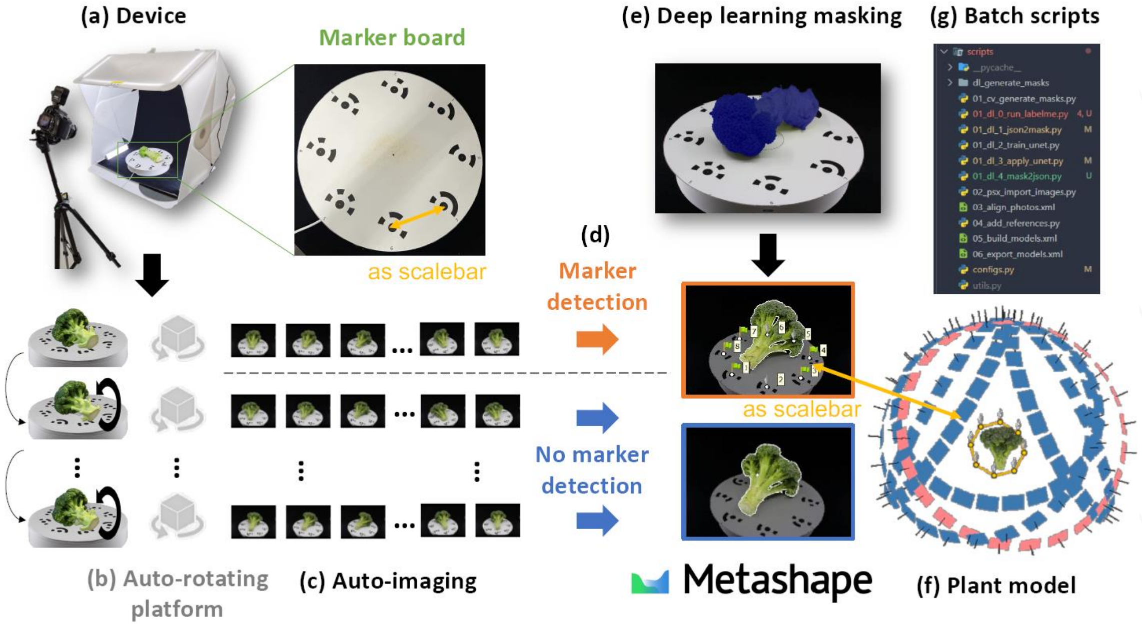
Obtained

Expected

2.3 Solution

Implement an automatic data collection and 3D reconstruction pipeline



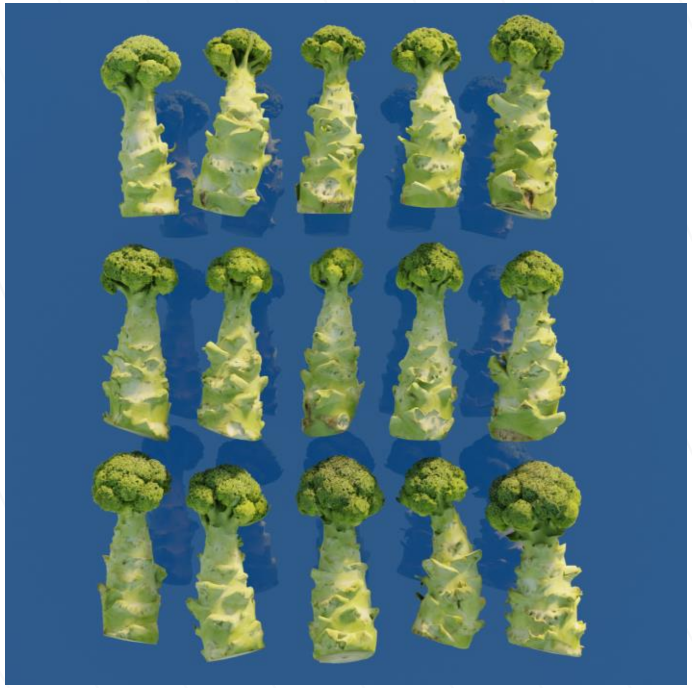


Automatic image collection

Dual rotation reconstruction pipeline

2.3 Results - obtained high-quality 3D model

Real world photo

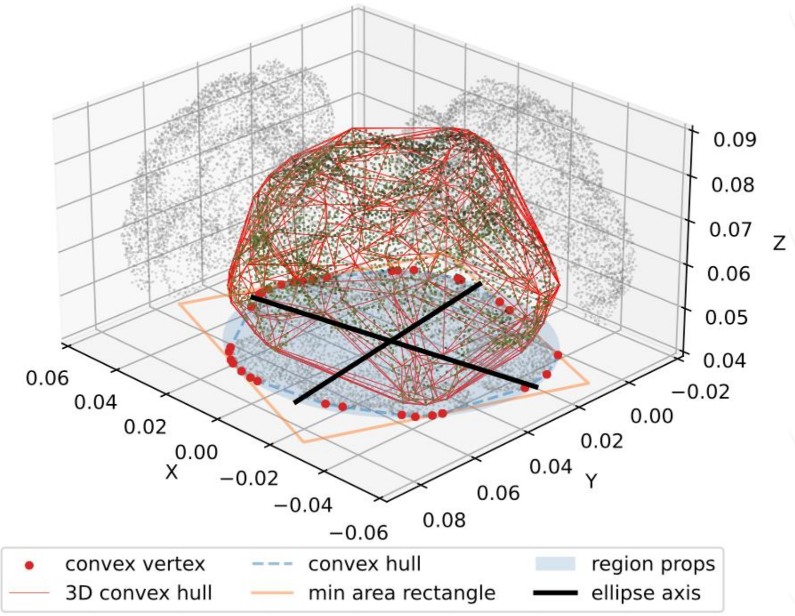


Obtained 3D model

Data pool of 3D high-quality broccoli heads

2.3 Results - 3D data processing

Calculate 3D-based morphological traits



Visualization

	Traits	Unit
1D	Crown/head height (m)	m
	Center point (x, y)	m
	Centroid point (x, y)	m
	Roundness	-
2D	Minimum area rectangle (width, length)	m
	Ellipse axis length (long, short)	m
	Ellipse orientation	degree
	2D convex area	cm^2
	Projected area	cm^2
3D	3D Convex volume	cm^3
	3D Concave volume	cm^3

Final output traits list

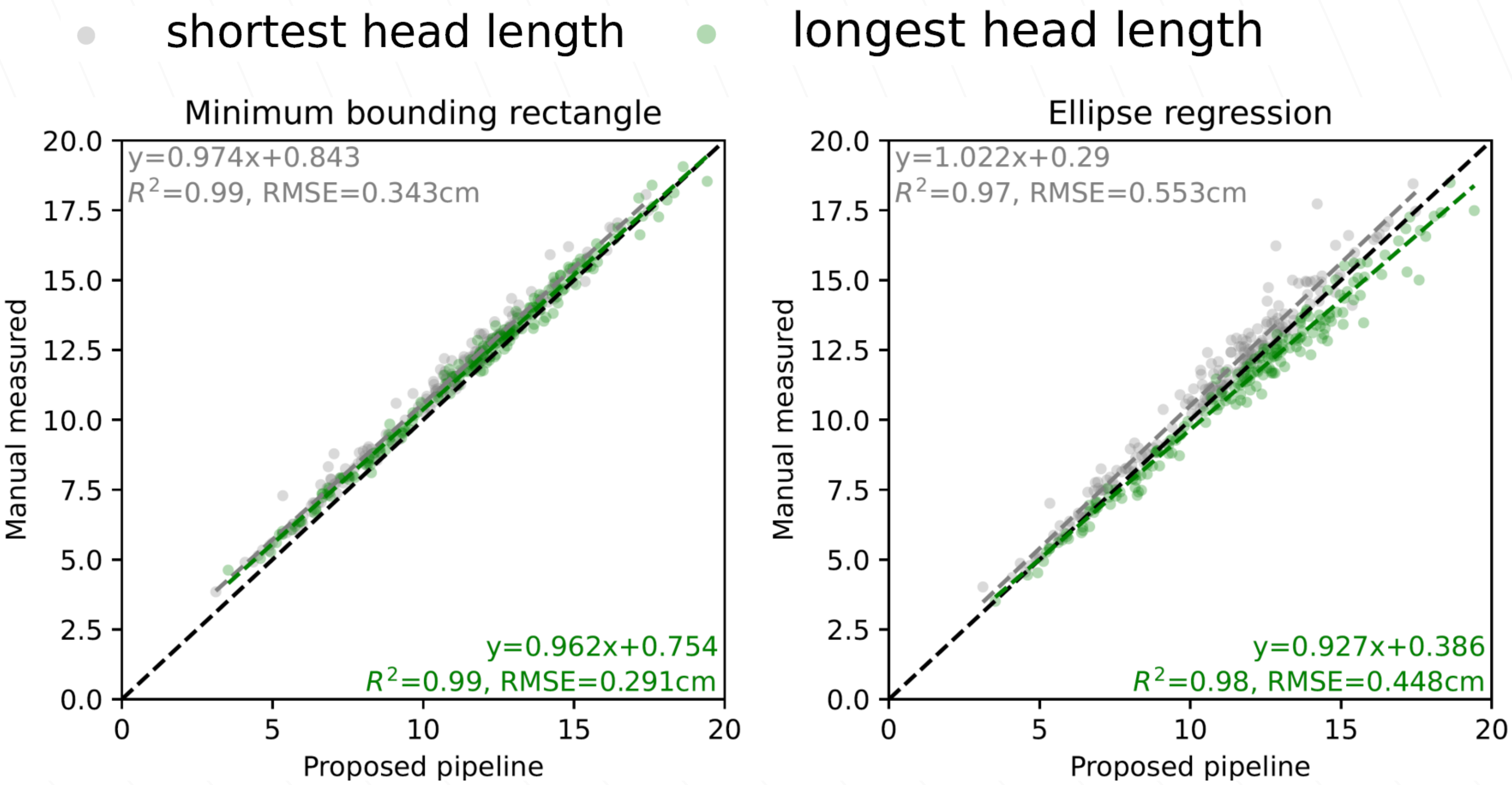
Head 3D data pool

As model attributes

2.3 Results - traits accuracy validation

Compare the shortest and longest length

(hard to do manual measurements for 2D and 3D traits)



2.4 Conclusion

- Obtained the **high-quality** and **complete** 3D models
- Calculated the **3D-based traits** and validated **accuracies**
- Built a **data pool** for high-quality broccoli head 3D models

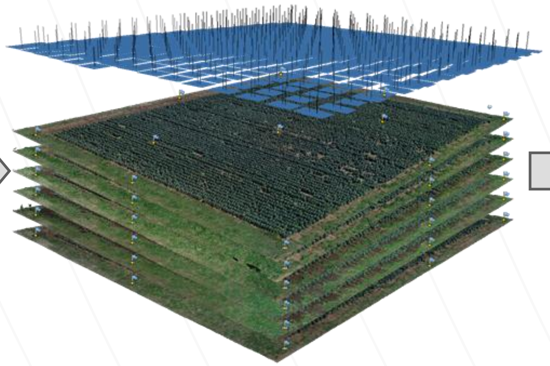
03

Aerial 3D pipeline

3.1 Background

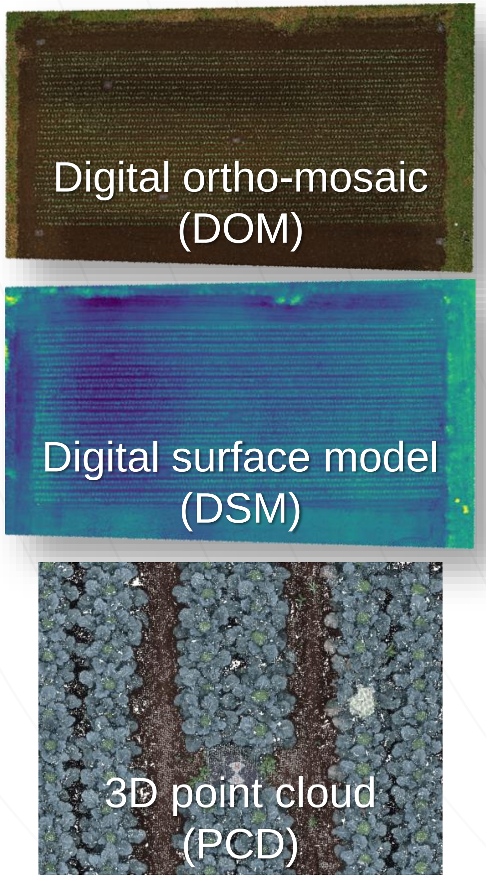
Traditional aerial phenotyping pipeline

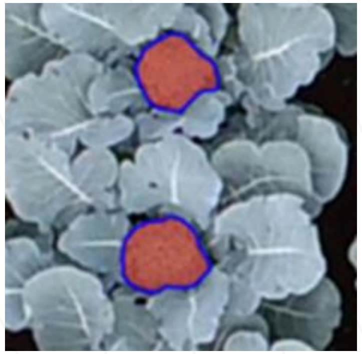
Collect raw UAV images



3D reconstruction

Metashape





Organ segmentation

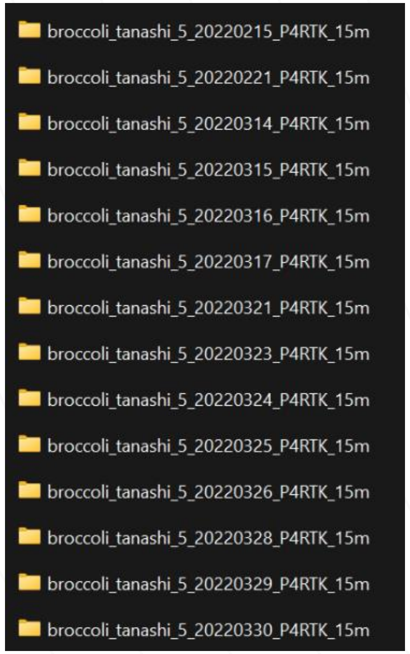
Morphological traits calculation

3.2 Challenges

1. Need to analysis huge amount of image data

(difficult to process in time)

Just for 1 ha

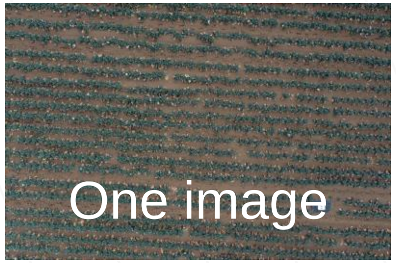


Large amount of time-series data
(38 flights in 2022)

One flight

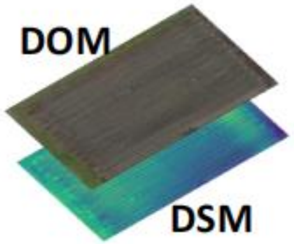
200+

raw images
(2.7GB+)

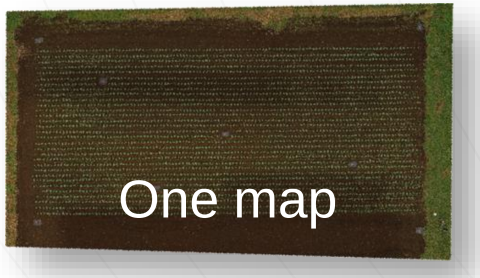


5742 x 3648 pixels

200 x 20 billion
=
4 trillion pixels
per flight



(1GB+)



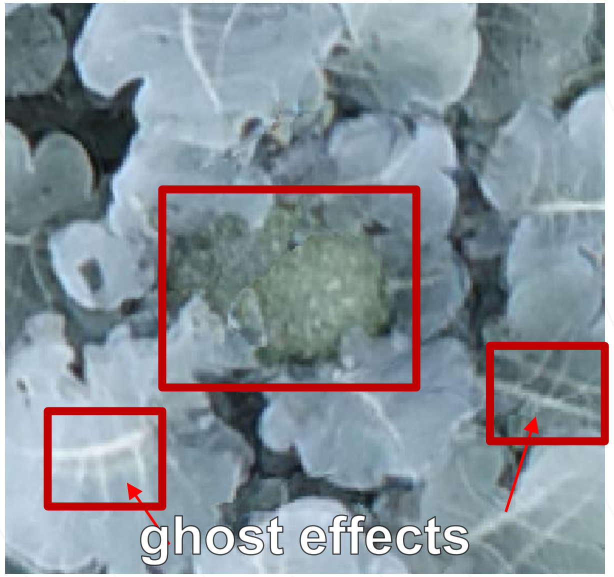
19572 x 17664 pixels

0.3 trillion
pixels
per flight

3.2 Challenges

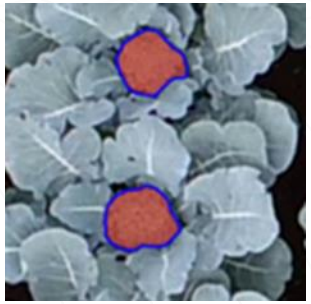
2. Hard to achieve the quality for organ-level analysis from aerial reconstruction

3D canopy model
(PCD)



2D field map
(DOM)

3.2 Challenges



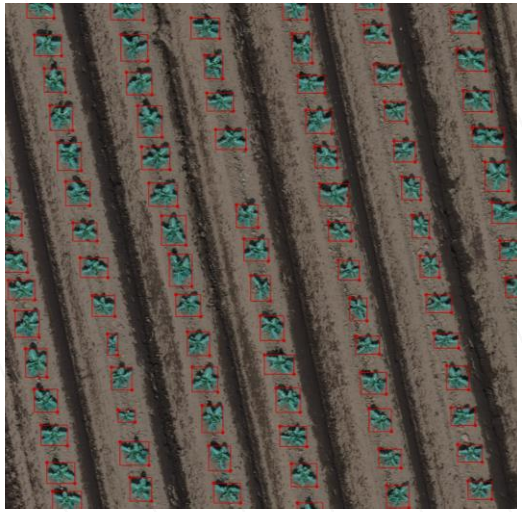
3. Complex natural environment conditions makes segmentation tasks difficult
(deep learning needs large number of training data)

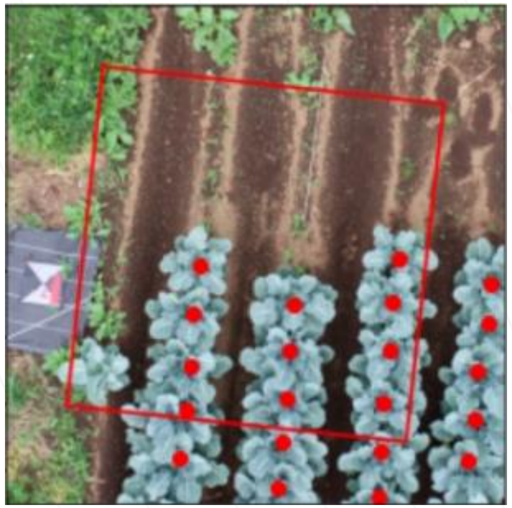
Huge differences between time, sunlight, soil condition, growing stage, cultivars

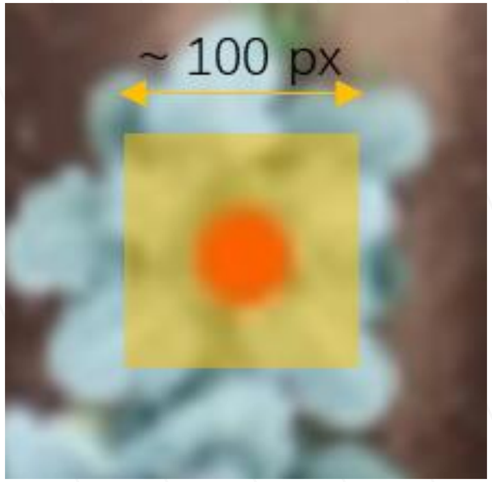
3.3 Solutions for analyzing huge amount of image data

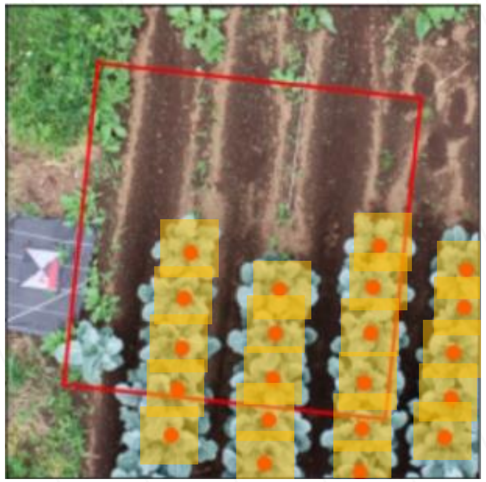
Temporal data fusion

narrow the processing regions by using prior knowledge of agriculture









Broccoli head position is almost the same as its seedling position

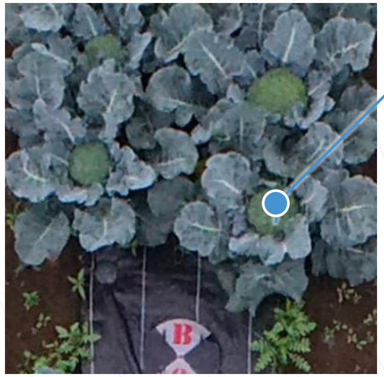
Narrow the processing area around the seedling area

(100 x 100) pixels x 3000 count = 30 billion pixels per flight ~ one raw image
per crop
5742 x 3648 ~ 20 billon pixels

3.3 Solutions for not enough aerial quality

Spatial data fusion

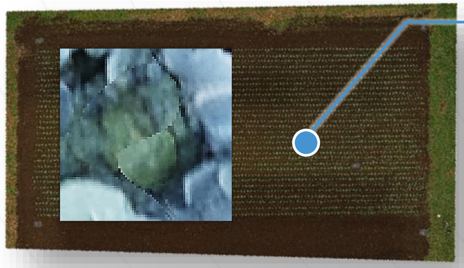
combine raw images (pixel coordinates) with field maps (geo coordinates)



(2341,1492)

Pixel coordinates

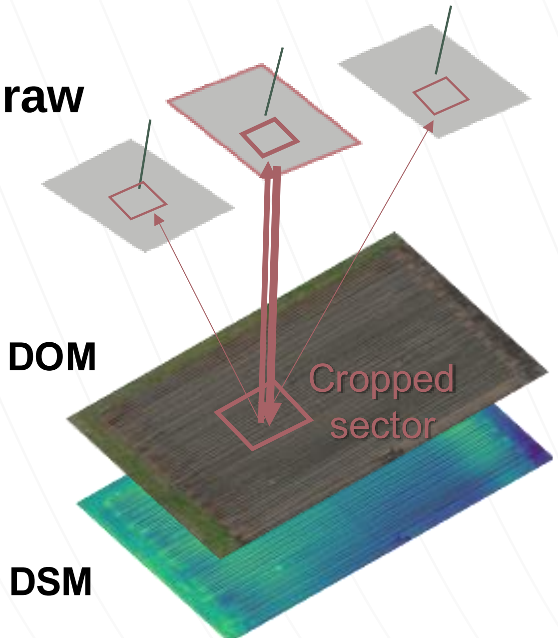
Better quality
Lacks spatial context

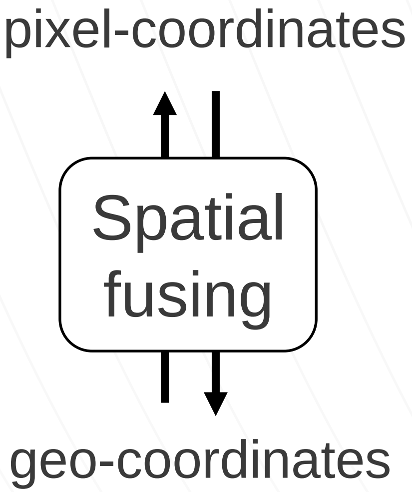


(35.7393N,139.5414E, 96.34m)

Geo coordinates

Lower quality
Has spatial context





EasyIDP Public

A handy tool for dealing with region of interest (ROI) on the image reconstruct mainly in agriculture applications

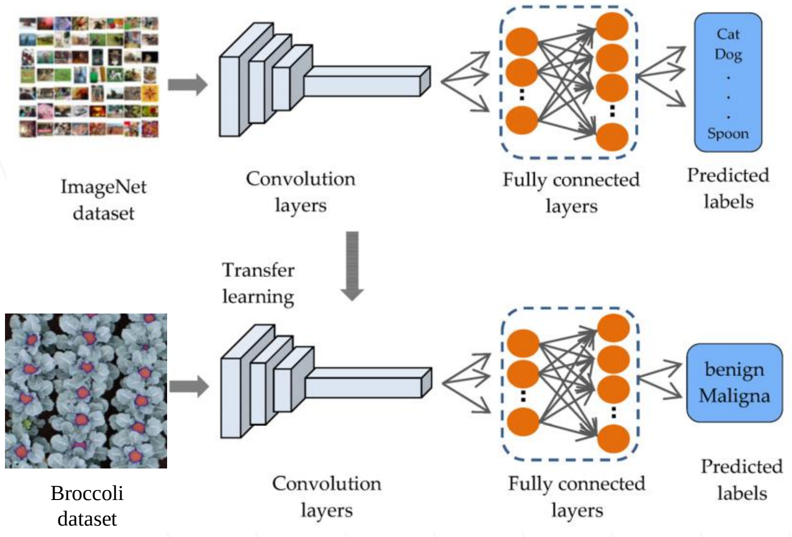
Python 31 MIT 3 26 0 Updated last month

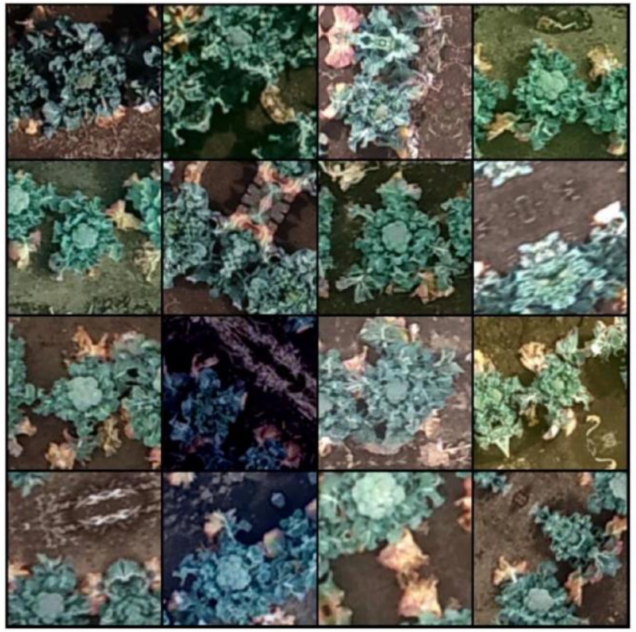
3.3 Solutions for lacking training data

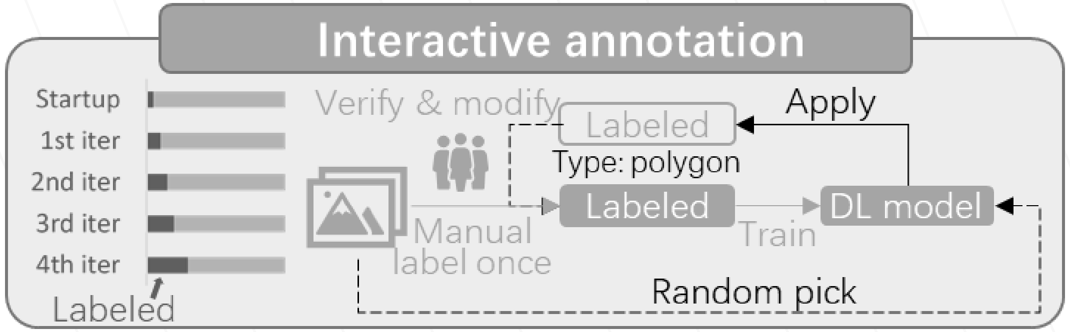
Deep learning data fusion

low labor cost for training data annotation

pre-trained models



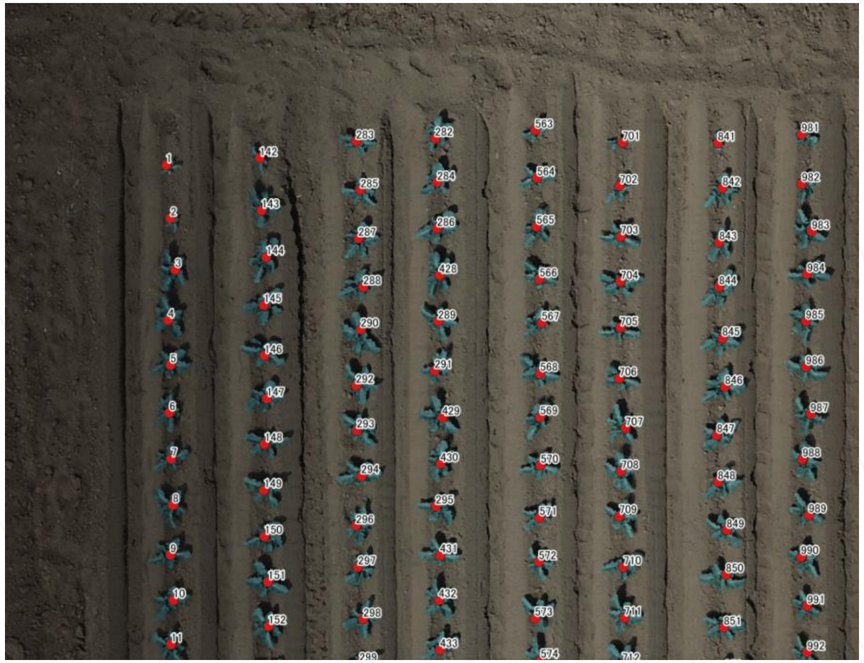




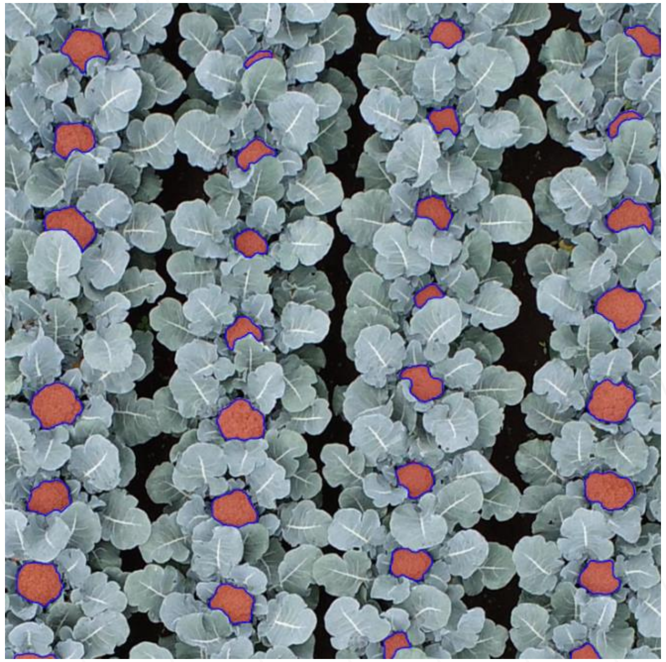
(a) Transfer learning (b) Data augmentation (c) Active learning

3.4 Results – temporal & spatial data fusion

Seeding detection by pre-trained Yolo v5



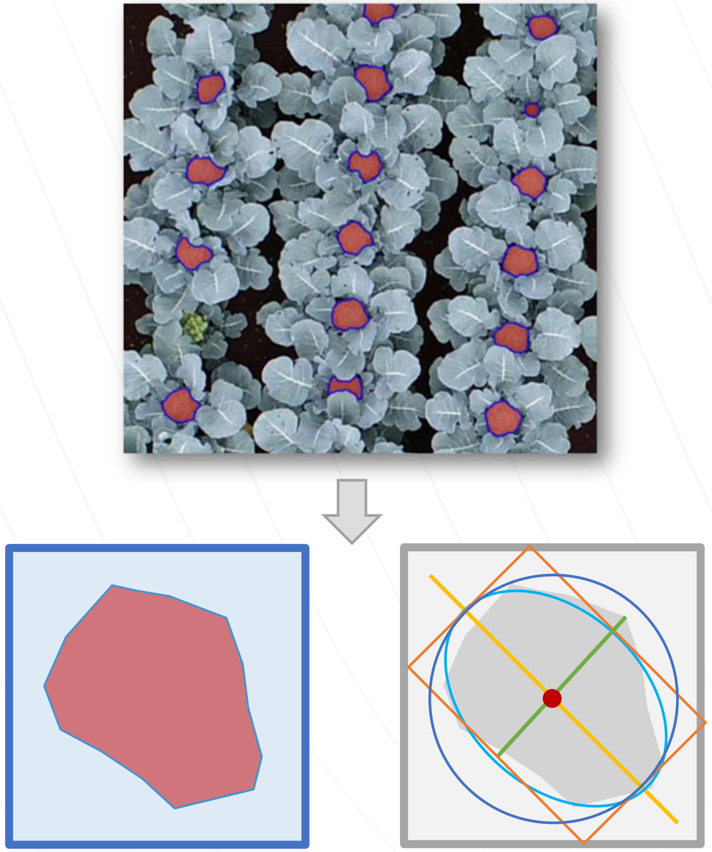
Temporal (time-series) data fusion during growing stages



Head Segmentation results

3.4 Results - traits calculation

For each broccoli head

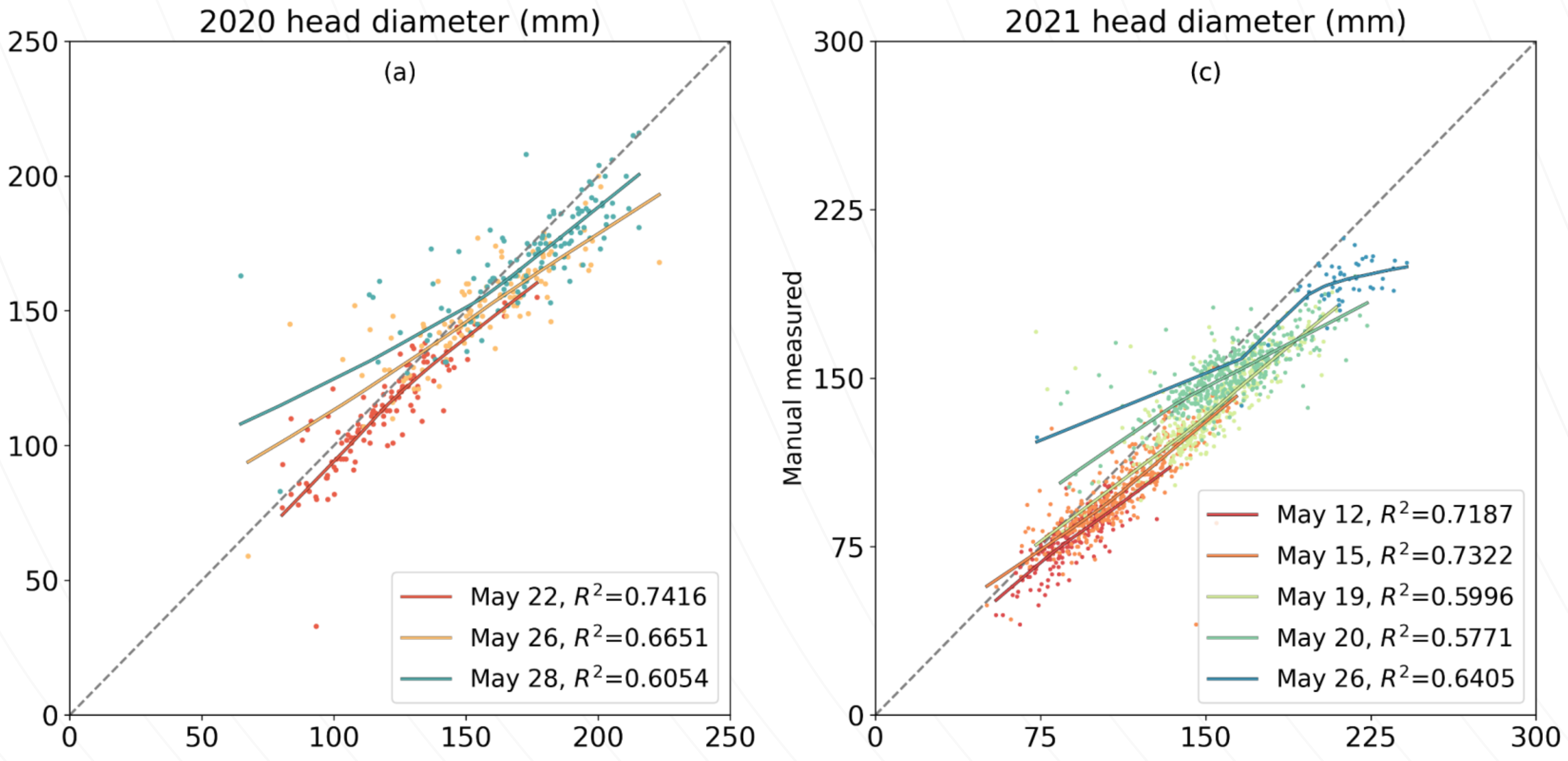


- Minimum area rectangle max/min side-length
- Equivalent diameter
- broccoli center points
- Eccentricity, circularity
- Major axis length
- Minor axis length
- Area, perimeter
- Convex area

3.4 Results - traits accuracy validation

Has acceptable correlation with manual measured head size

Y: Manual field measured



X: Aerial measured

3.5 Conclusion

- Developed temporal data fusion method with prior knowledge of agriculture to dramatically save the computation cost
- Developed spatial data fusion to improve the organ-level image quality
- Developed deep learning data fusion to decrease the workload of training data annotation for head segmentation
- Improved 2D-based traits of broccoli head and validated by manual measurement

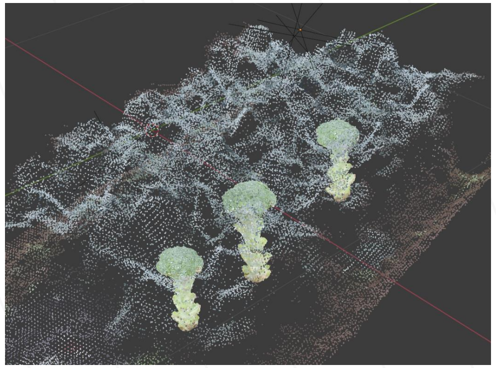
04 Cross-scale data fusion

4.1 Background

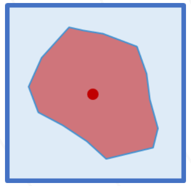
Part 2: close-range 3D pipeline

Part 3: aerial 3D pipeline

Part 4: cross-scale data fusion



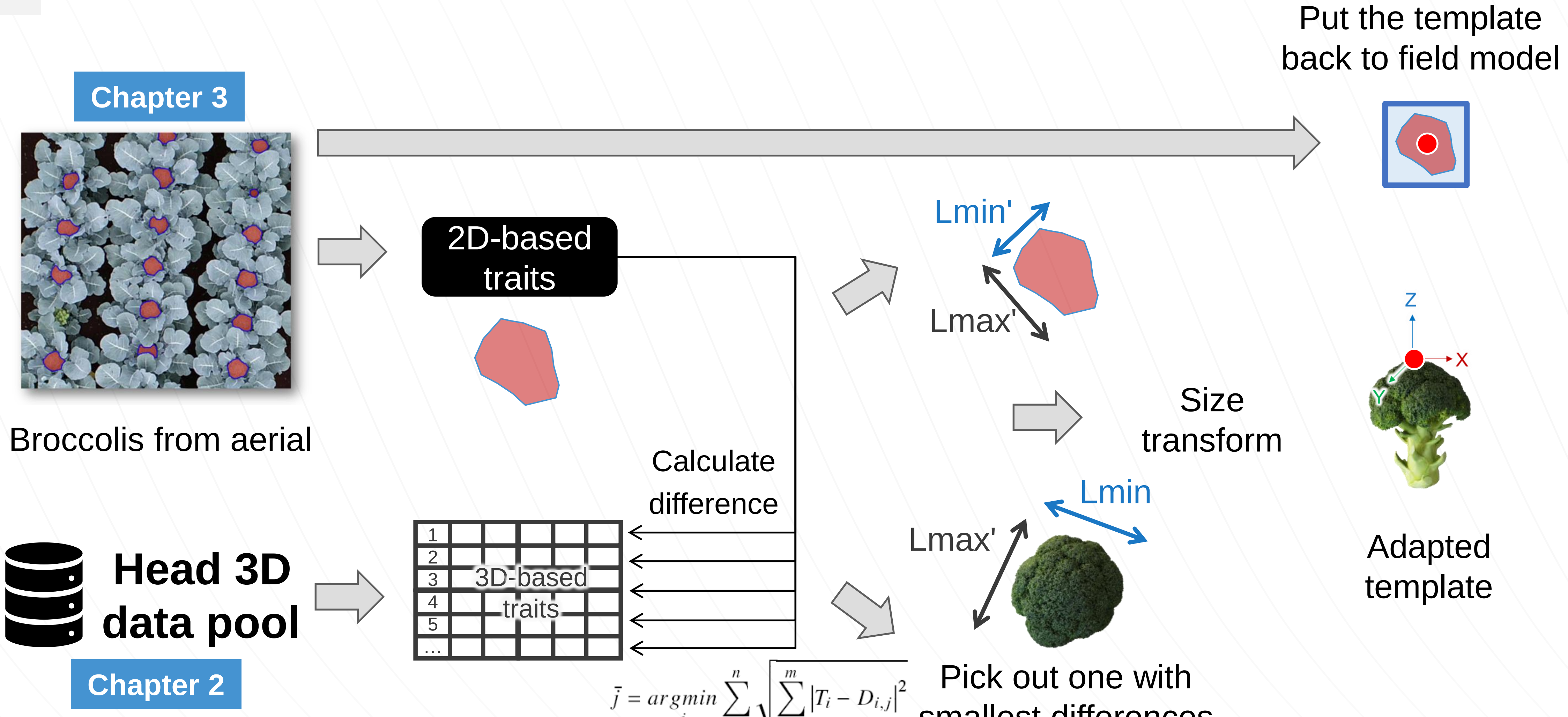
Head 3D data pool



Head shapes & positions in entire farmland

High quality head models of entire farmland

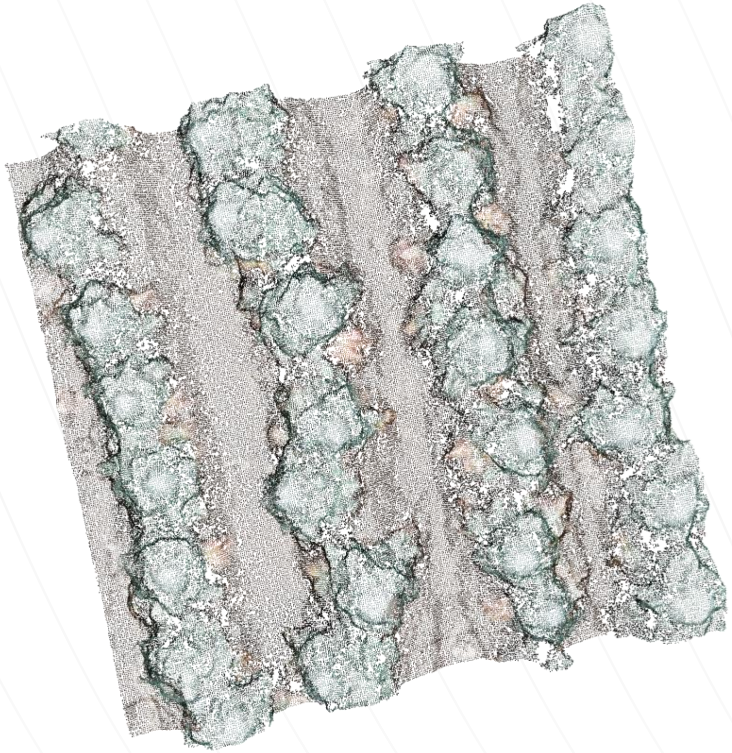
4.3 Solutions for cross-scale data fusion



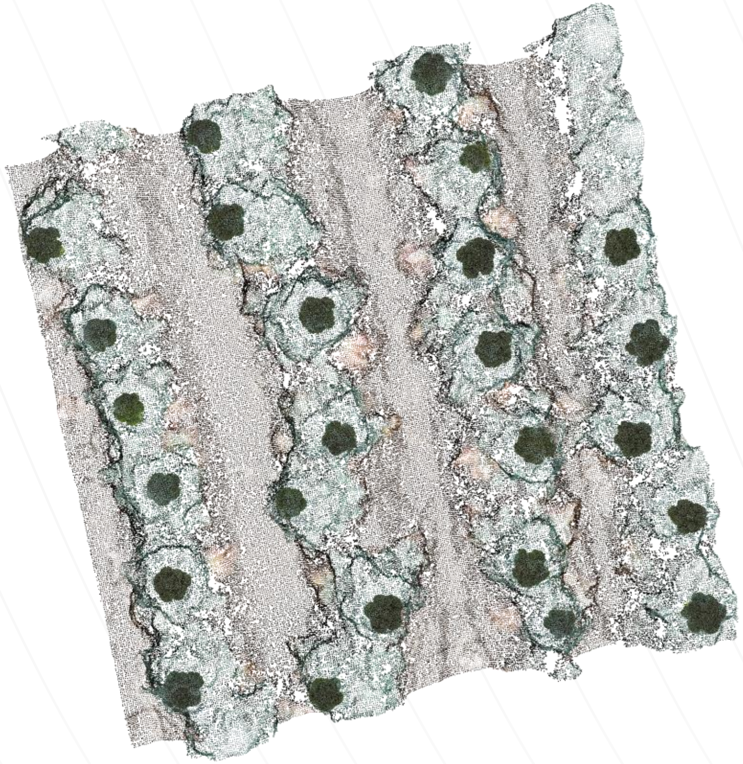
$$\bar{j} = \underset{j}{argmin} \sum_{i}^{n} \sqrt{\sum_{i,j}^{m} |T_i - D_{i,j}|^2}$$

4.4 Results - cross-scale data fusion

Aerial segmentation results

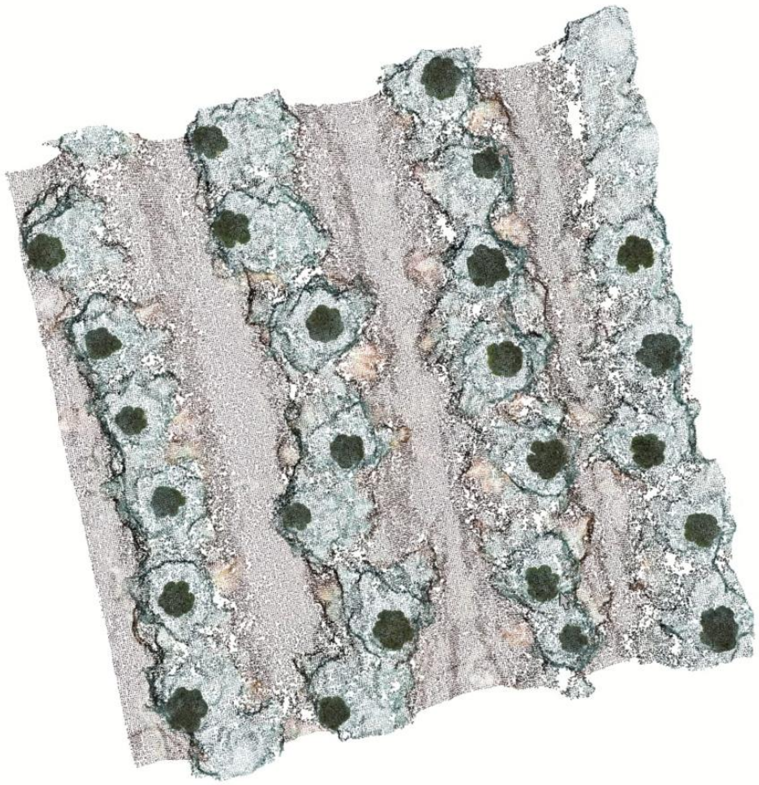


Aerial field 3D models



Data fusion results

4.4 Results - cross-scale data fusion



4.5 Conclusion

- Calibrated the shape errors caused by occlusion
- Selected the calibration model automatically by Auto-ML
- Developed data fusion workflow to place the best match from close-range data pool back to aerial field model

05

Conclusion

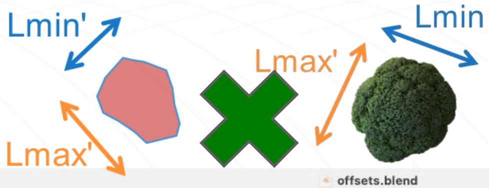
5.1 Highlights

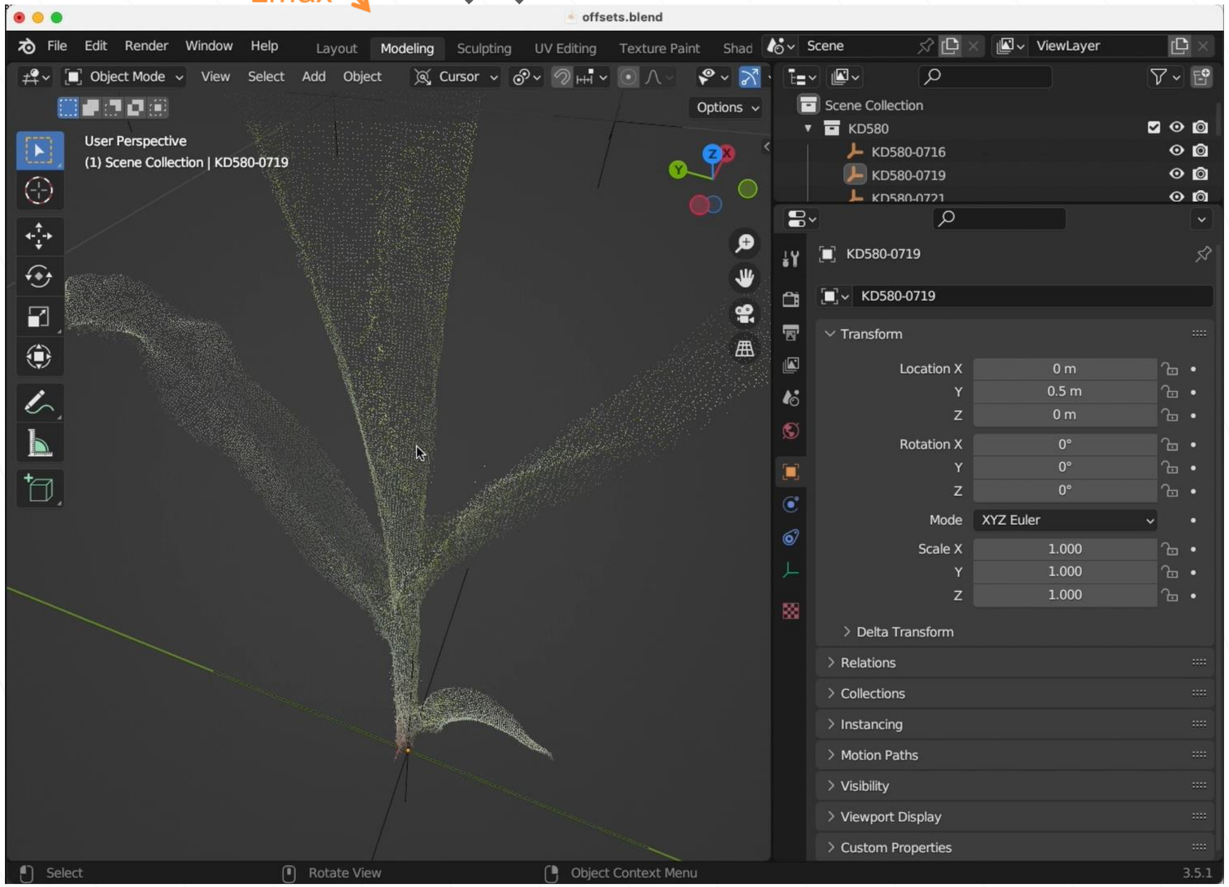
Chapter 2 Built a close-range high-quality data pool with 3D-based morphological traits for 189 broccoli heads

Chapter 3 Decreased the aerial image processing workload and improved the organ-level accuracy by temporal and spatial data fusion

Chapter 4 Developed aerial & close-range data fusion to place high-quality 3D models back to field.

5.2 Future work





Explore the deep learning 3D reconstruction approach, like NERF [1] **(faster and better quality)**

Improve the data fusion approach by procedural modeling for complex plant structures

[1] https://www.matthewtancik.com/ner

Achievements

Journals

Wang, H., Duan, Y., Shi, Y., Kato, Y., Ninomiya, S., Guo, W., **2021**. EasyIDP: A python package for intermediate data processing in UAV-based plant phenotyping. *Remote Sensing* 13, 2622. https://doi.org/10.3390/rs13132622 **(Published)**

Wang, H., Tang, L., Nishida, E., Fukano, Y., Kato, Y., Guo, W., Drone-based harvest data prediction can reduce on-farm food loss and improve farmer income *Plant Phenomics*. **(Under review)**

Wang, H., Tang, L., Nishida, E., Fukano, Y., Kato, Y., Guo, W., Virtual broccoli farmland by drone-based phenotyping and cross-scale assimilation. **(In preparation)**

Conferences

Wang, H., Tang, L., Nishida, E., Fukano, Y., Kato, Y., Guo,W. July 3-5, **2023**. Virtual broccoli farmland by fusing close-range and aerial phenotyping, Fifth International Workshop on Machine Learning for Cyber-Agricultural Systems (MLCAS2023), Sarabetsu village, Hokkaido, Japan. **(Oral)**

Wang, H., Tang, L., Nishida, E., Fukano, Y., Kato, Y., Guo, W. Sept 27-30, **2022**. Estimate Optimal Harvest Time by Cross-scale Assimilated Digital Broccoli Farmland, 7th International Plant Phenotyping Symposium: ”Plant Phenotyping for a Sustainable Future”, Wageningen, Netherlands. **(poster)**

Wang, H., Tang, L., Nishida, E., Fukano, Y., Kato, Y., Guo, W. July 20-22, 2021. Cost-efficient broccoli head phenotyping using aerial imagery and SfM-based weakly supervised learning, The 8th International Horticulture Research Conference, Nanjing, Jiangsu, China. **(poster)**

Wang, H., Kato, Y., Guo, W., June 3-4, 2021. EasyIDP: A python package for intermediate data processing in UAV based plant phenotyping, 超分野植物科学研究会の第１回研究集会 2021, Zoom online, Tokyo, Japan. **(poster)**

Wang, H., Kato, Y., Guo, W., May 22, 2021. EasyIDP: A python package for intermediate data processing in UAV based plant phenotyping, 農業情報学会 JSAI 2021 年次大会, Zoom online, Tokyo, Japan. **(poster)**

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2023

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