Precision Crop Load Management for Apples
From Pruning to Fruitlet Thinning

Long He

2022 Mid-Atlantic Fruit and Vegetable Convention

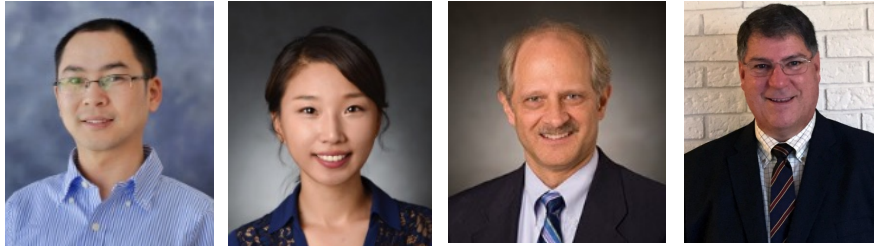February 2nd, 2022

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Background Information

Project Team

- Graduate students: Magni Hussain, Xinyang Mu, Rashmi Sahu, Omeed Mirbod
- Undergraduate students
- Grower collaborators

Project Support

❑ **State Horticultural Association of Pennsylvania (SHAP)**

- ▪ Apple detection and sizing
- ▪ Targeted thinning for apples

❑ **Precision Crop Load Management for Apples (USDA-SCRI)**

- ▪ Cornell-lead (Dr. Terence Robinson)
- ▪ Machine vision and actuating system (PSU)

❑ **Robotic Green Fruit Thinning (USDA-AFRI)**

- ▪ PSU team
- ▪ Robotic system development

Background Information

❑ **Imaging Acquisition System - MOOG**
- ▪ Four cameras + artificial lights
- ▪ Detect crop buds to fruits
- ▪ Deep learning models

Crop Load Management Operations

- Branch pruning
- Branch reconstruction
- Buds counting

- Blossom thinning
- Artificial Pollination
- Flower detection

- Green fruit thinning
- Green Fruitlet detection

Good Production
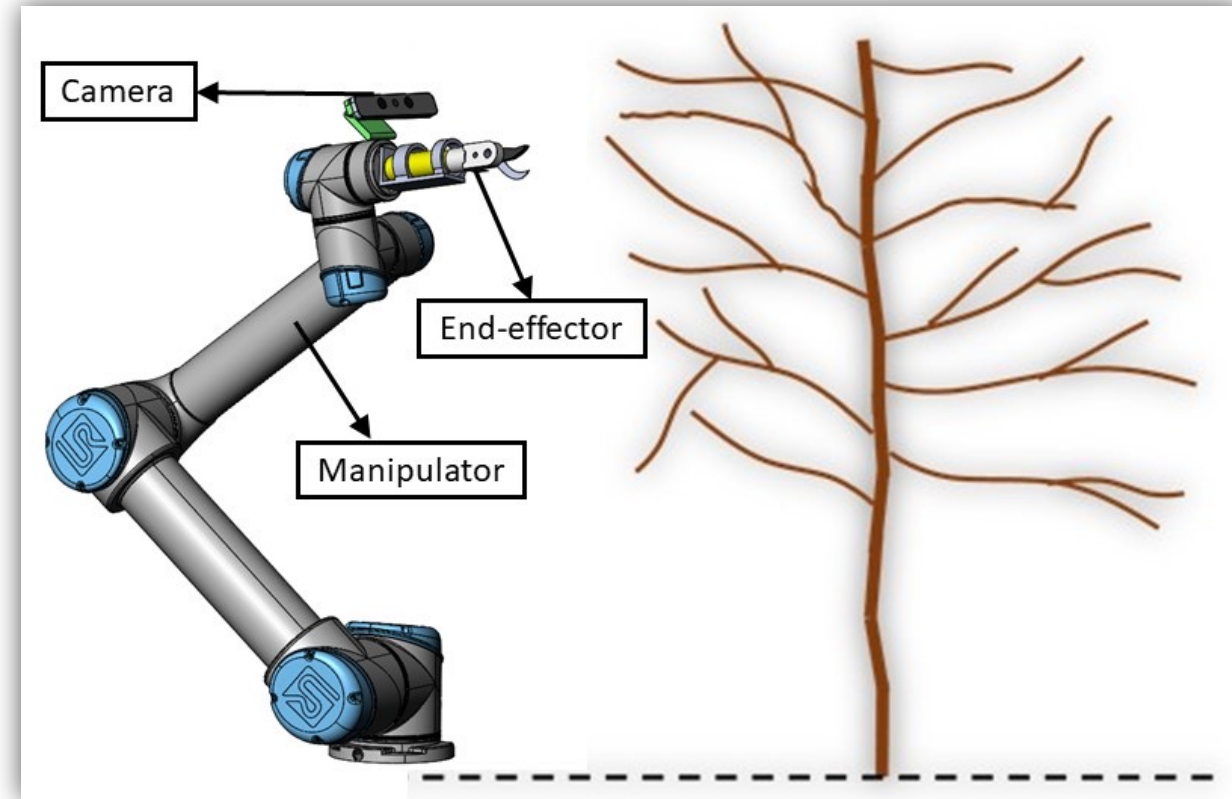*Nice Fruits*

Branch Pruning for Apple Trees

- Manual pruning
- Orchard platform to increase efficiency
- Skilled worker

- Mechanical pruning (Hedging)
- Increase working efficiency
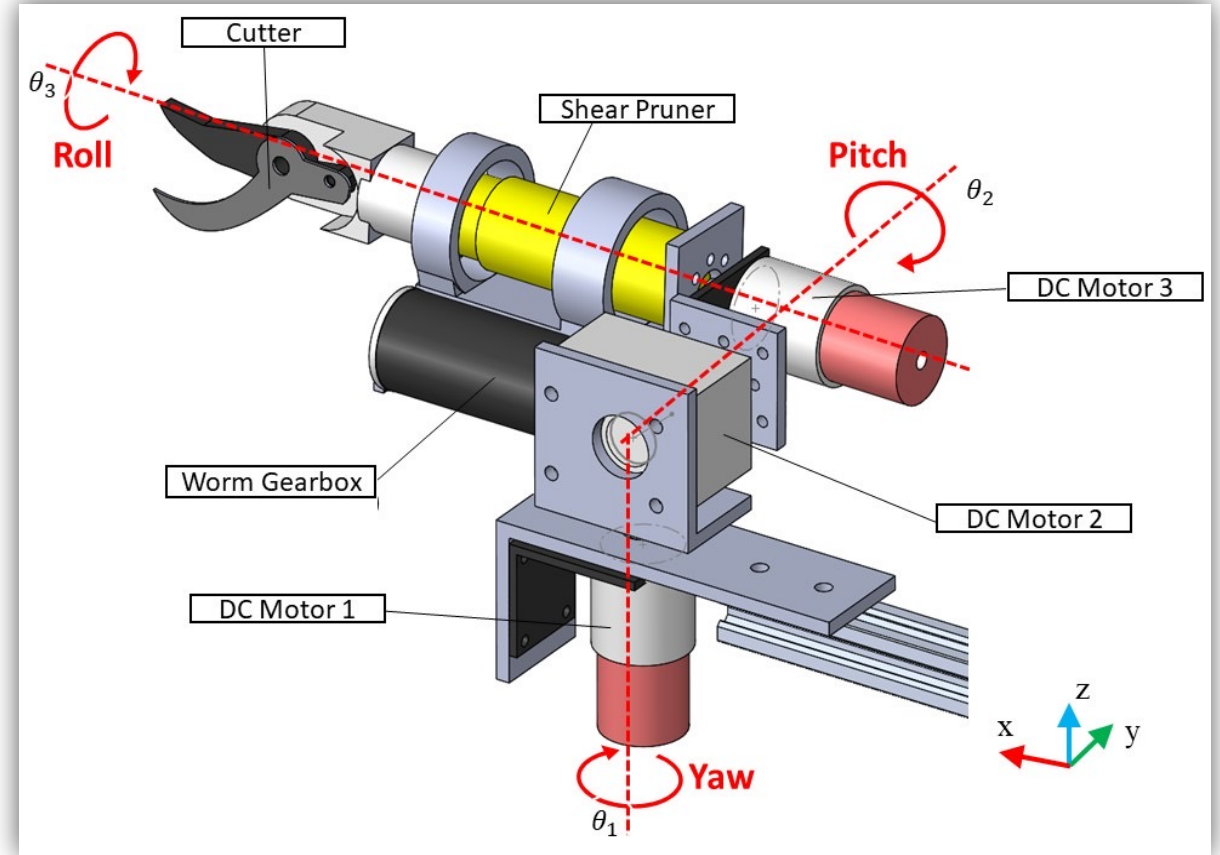- Non-selective

Robotic Pruning (Selective Pruning)

- Machine vision system → 3D tree reconstruction

- Manipulation system → Robotic arm and end-effector tool for pruning branches

Cutting force and orientation measurement

Cutting mechanism design

❑ **Field Test of Two Prototypes**
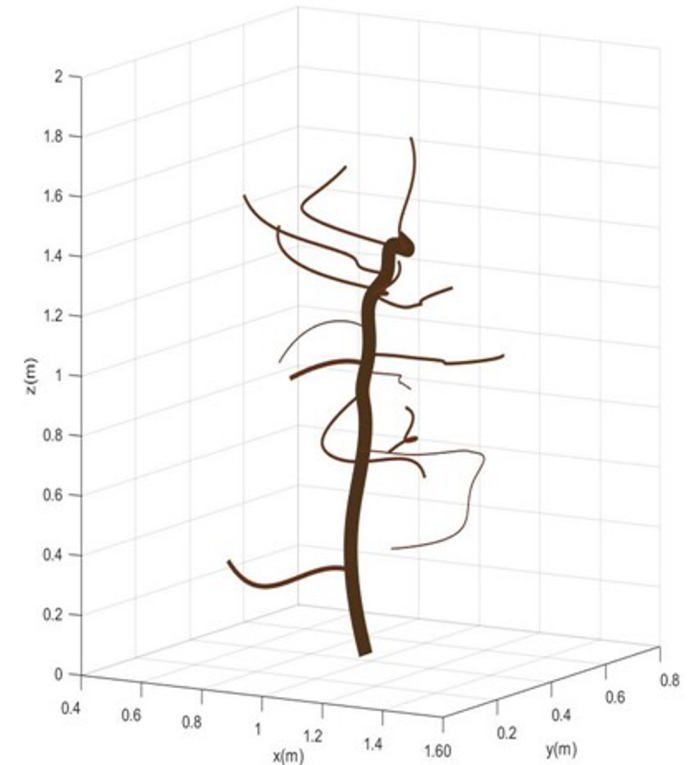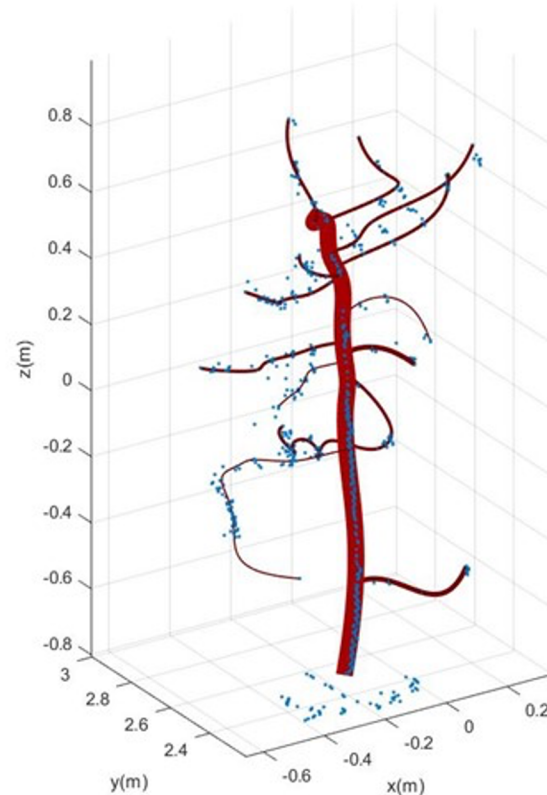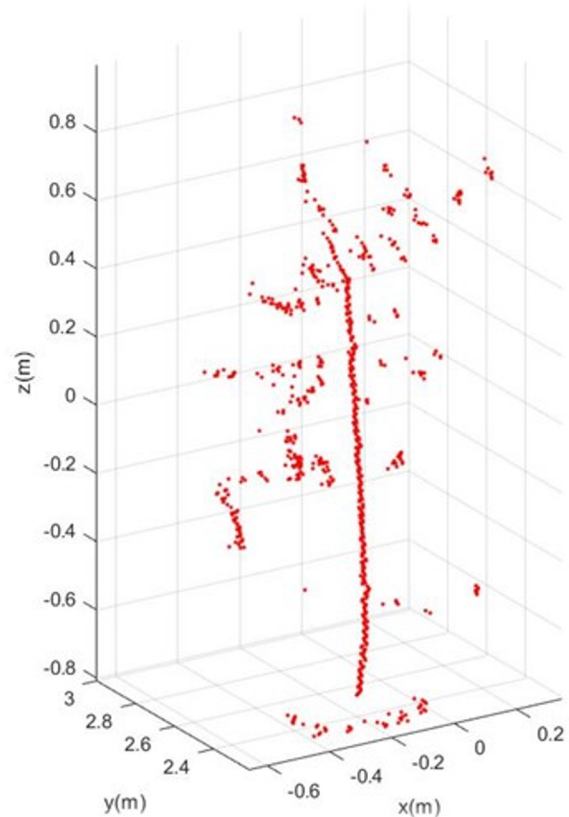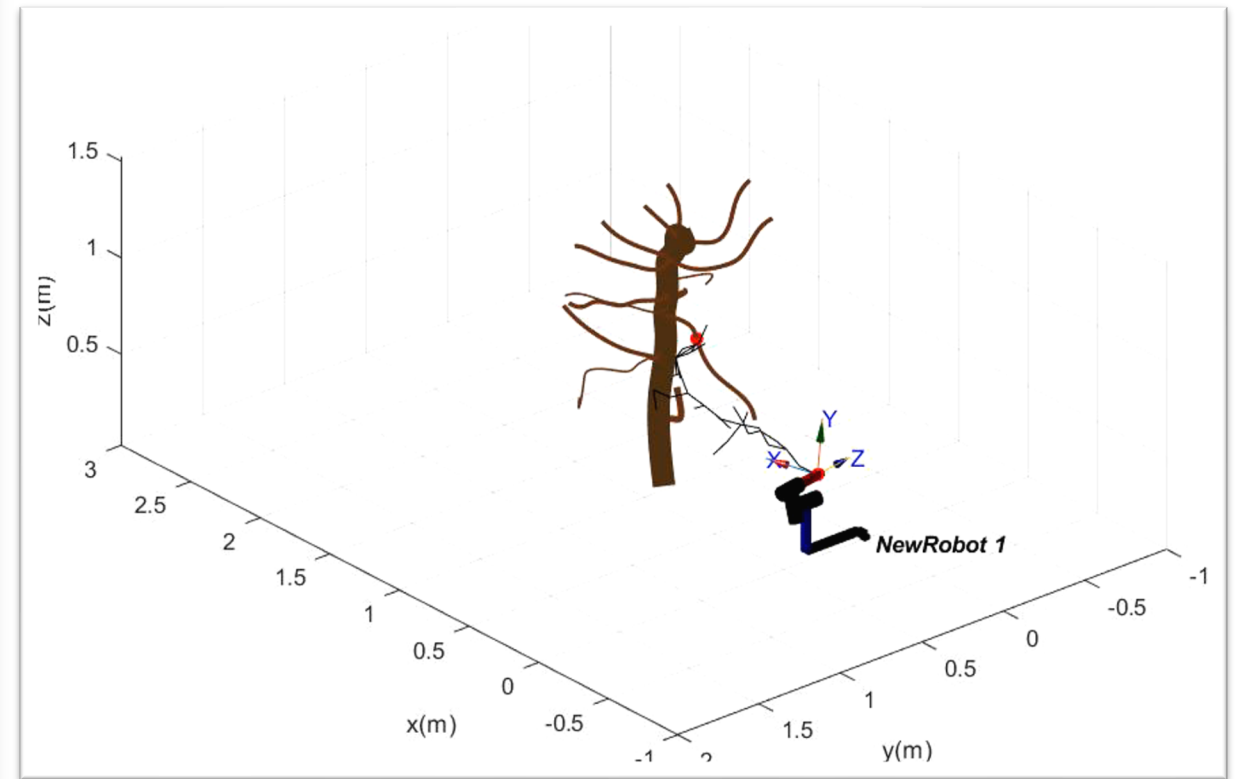
Branch Pruning for Apple Trees

❑ **Tree Model 3D Reconstruction**

- Trunk and Branches were segmented → 12 primary branches
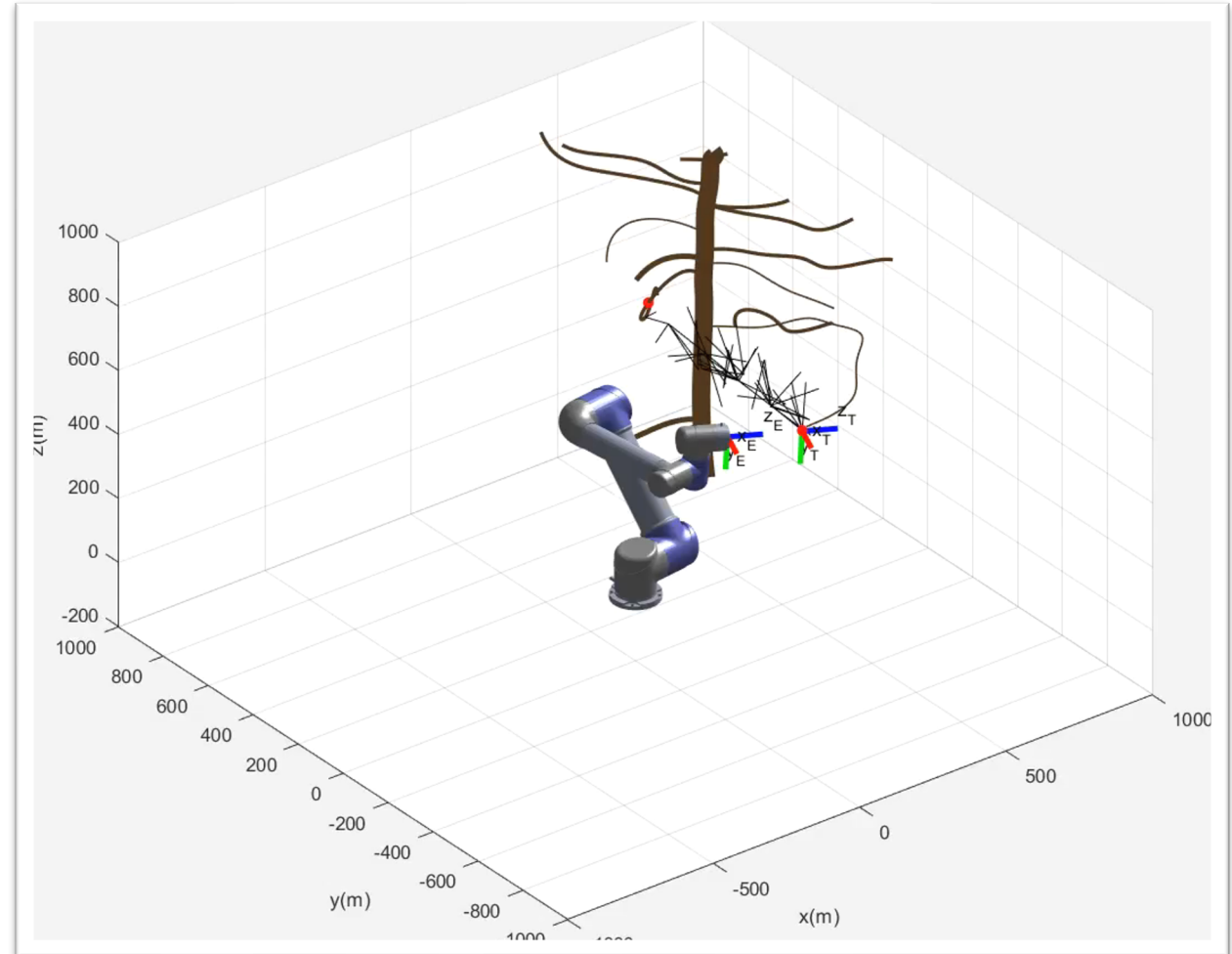- LiDAR coordinates to path planning environment coordinates

❑ **Cartesian Robotic System**

❑ **Six-Degree Freedom Robotic System**

CL Management at Flower Stage

❑ **Precision Pollination**

  - Target king flowers
  - Flower density maps

❑ **Precision Blossom Thinning**

  - Identify flower clusters
  - Flower development stages (percentage)
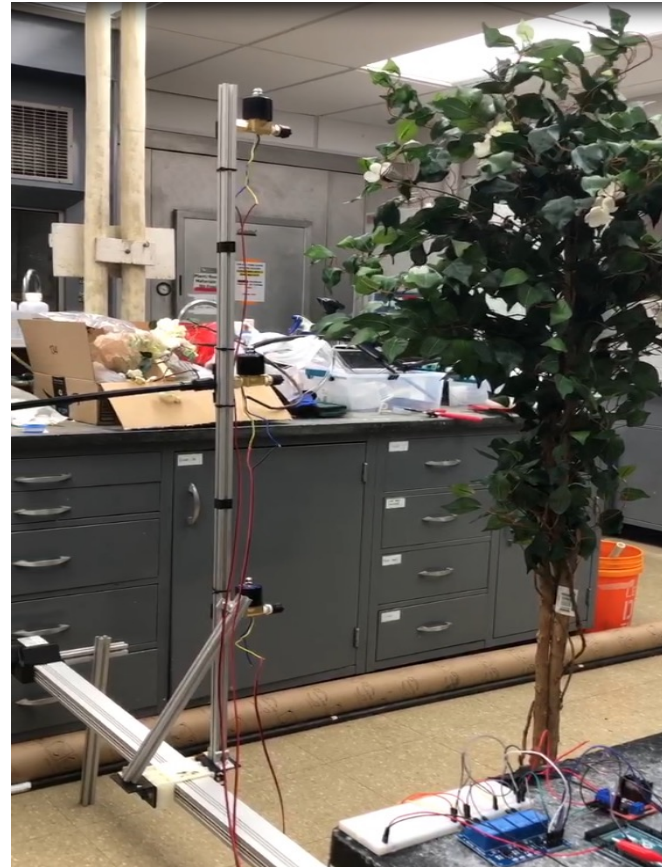 - Initial date of Pollen Tube Growth Model
  - Targeted Spraying

❑ **Flower Detection Using Deep Learning Models**

❑ **Preliminary Study on Targeted Spraying**

Precision Green Fruit Thinning

❑ **Investigation of Different Thinning Methods**

Thinning Methods	Fuji (smaller canopy)		Golden Delicious	
	Ave. fruit weight/tree (lb)	Ave. fruit No./tree	Ave. fruit weight/tree (lb)	Ave. fruit No./tree
Airblast sprayer	26.7	37.2	22.7	50.2
Handheld sprayer	23.0	32.0	43.4	93.6
Hand thinning	36.1	51.4	101.4	254.8

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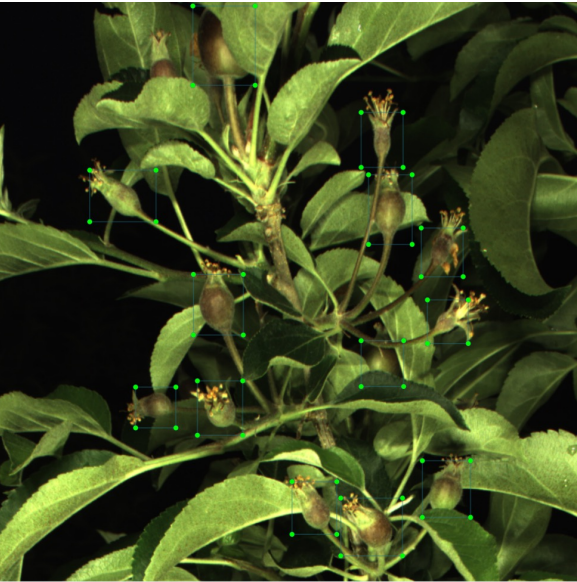## ❑ **Precision Green Fruit Thinning**

- Machine vision system for green fruit detection

- Targeted chemical thinning

- Robotic green fruit thinning
  - Fruit removal method
  - End-effector design
  - Integration of machine vision system
  - Robotic system control (path planning)

Precision Green Fruit Thinning

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❑ **Image Acquisition System – Tree Level (Dr. Dana Choi)**
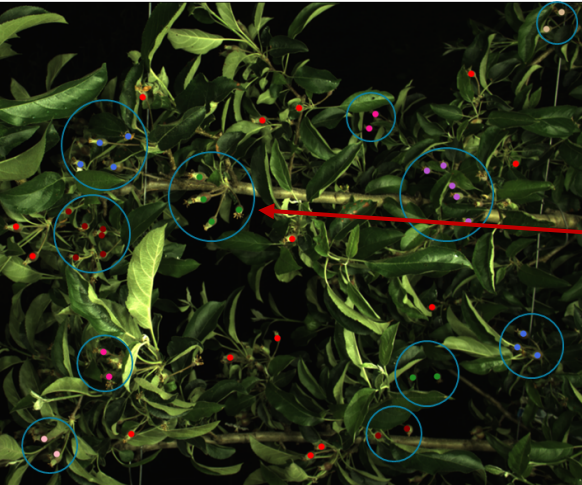
Green Fruit counting
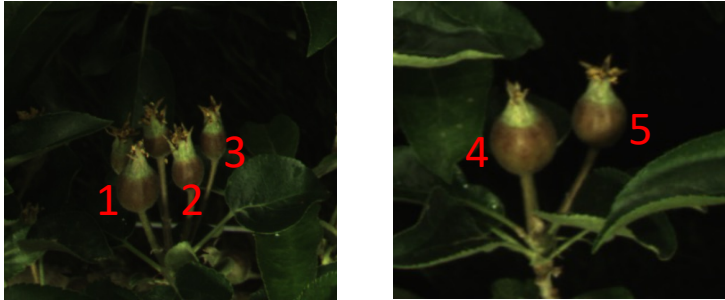
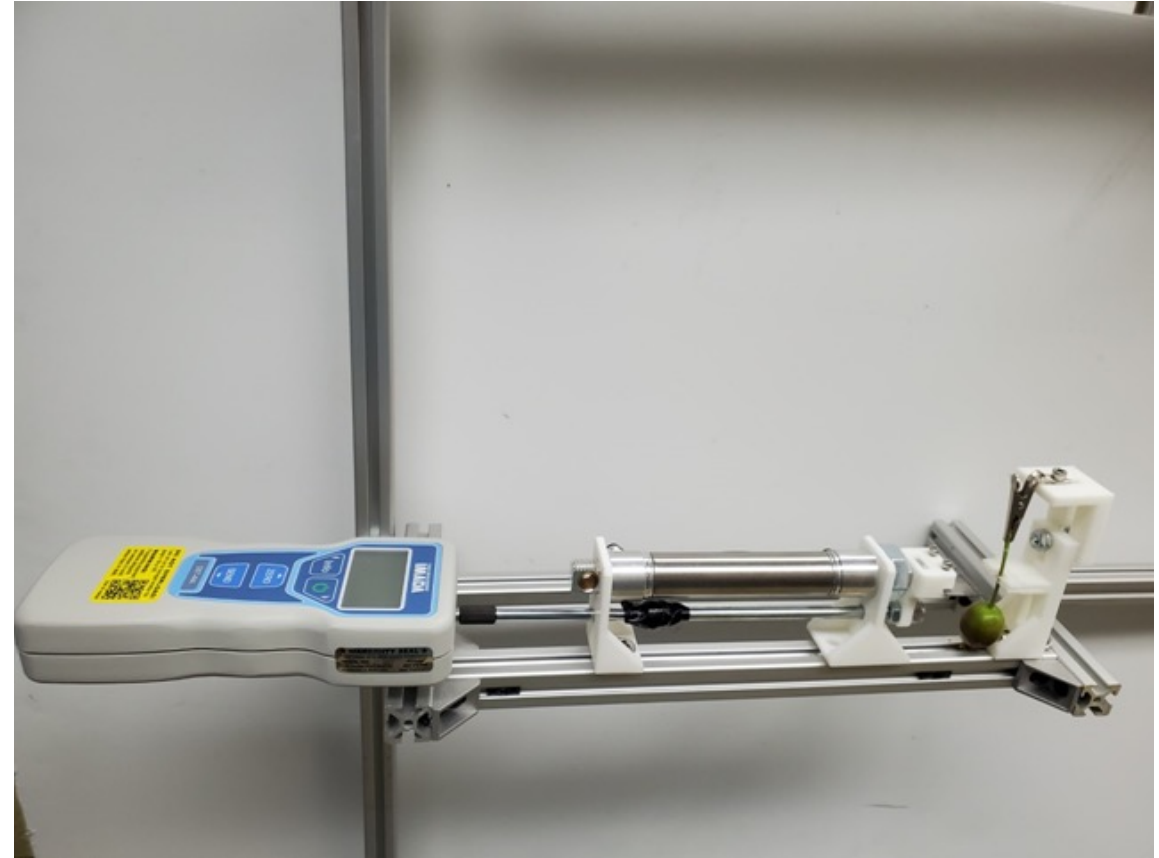| Fruit Count	Precision	Recall	F1
206	0.98	0.8	0.88

Fruit cluster identification
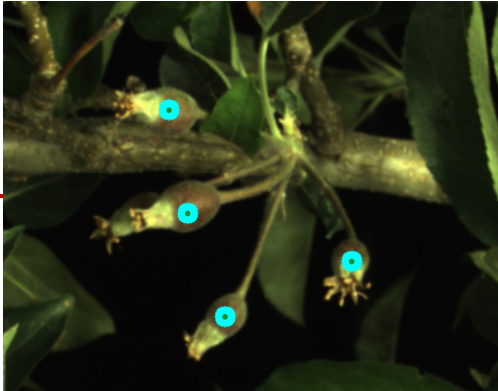
Green Fruit Detection for Robotic Thinning

❑ **Green Fruit Removal Dynamics**

Pulling

Stem cutting

Precision Green Fruit Thinning

❑ Green Fruit Removal Force and Location

Cultivars	Stem Cutting Force (N)	Spur-End Pulling Force (N)	Fruit-End Pulling Force (N)	Pulling Detached Location (%)	
				Fruit-end	Spur-end
Fuji	36.3	20.5	26.6	28%	72%
Golden Delicious	37.1	19.5	23.7	50%	50%
GoldRush	27.5	19.1	23.5	60%	40%
Overall	**33.6**	**19.9**	**24.8**	**42%**	**58%**

Precision Green Fruit Thinning

❑ **Green Fruit Detection for Robotic Thinning**

- **Implementations**
  - Handheld
  - Robotic manipulator

- **Fruit samples**
  - 50 Fuji
  - 50 Golden Delicious
  - 50 GoldRush
  - 25 GoldRush for robotic manipulator test

Precision Green Fruit Thinning

❑ **Green Fruit Removal Results**

Tests	Cultivars	Total No. Fruits	Removed Fruits	Success Rate
Handheld prototype	Fuji	50	47	94%
	Golden Delicious	50	48	96%
	GoldRush	50	45	90%
Robotic arm prototype	Golden Delicious	25	23	96%

Conclusion

- ❑ **Crop Load Management Operations**
  - ▪ Branch pruning
  - ▪ Blossom pollination/thinning
  - ▪ Green fruit thinning

- ❑ **Sensing System for Precision Crop Load Management**
  - ▪ Machine vision system for buds/flowers/fruits detection
  - ▪ Deep learning algorithm development
  - ▪ Decision support system

- ❑ **Robotic Crop Load Management**
  - ▪ Robotic mechanism development – pruning and thinning
  - ▪ Targeted spraying system for thinning

Thank you!

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