NRI: INT: COLLAB: Distributed co-Robots for Strawberry Harvesting (Award Number: NSF #1924622, #1924662, #1924640, 9/1/2019-8/31/2024)

PI: Yunjun Xu, University of Central Florida

Co-PI: Reza Ehsani, University of California, Merced

Co-PI: Manoj Karkee, Washington State University

Background and Motivation

- Harvesting is a major cost of production in many fruit and vegetable crops, especially in strawberries.
- There has been a big decline in strawberry production recently in the US (since 2014) due to a labor shortage.
- Many greenhouse robots have been designed for harvesting (e.g., in Northeast Asian countries).
- Field robots emerge in industries, but mainly monolithic large systems.

- **The vision is to reduce the harvesting labor cost via the integrative small co-robot system that could work reliably and efficiently for longer hours and under varying environment conditions.**
- Easier to transport
- No single-point-of-failure
- Very low downtime impact
- Easily adaptive to field variations
- High platform flexibility

Conceptual Picture of the Co-Robot System

- Small harvesting robots scouting throughout a field.
- Accurate vision processing and cooperative picking.
- Delivering the full basket to the collection station
- Human monitoring via a GUI.
- Decentralized scheduling for row allocation.

- Harvesting robot design and integration
- Extensive experiments in commercial farms.
- Cost analysis and evaluation

Row Allocation & Small Harvesting Robots:

- Row allocation
  - In Monte Carlo simulations, the proposed decentralized algorithm (auction based) gives the same solutions as a benchmark algorithm in most of the cases, with a much smaller computational cost [1].
  - The algorithm is scalable.

  [1] M. Mapes and Y. Xu, "Row Allocation Negotiation for a Fleet of Strawberry Harvesting Robots," ***ASME Letters in Dynamic Systems and Control***, Vol. 2, Issue 3, July 2022, pp. 031007 (1-7).

- New vision-based motion control
  - Achieved a 100% success rate in minimum time row transition.
  - A new vision based optimal row transition algorithm was developed.

  [2] Q. Li, and Y. Xu, "Minimum-time Row Transition Control of a Vision Guided Agricultural Robot," ***Journal of Field Robotics***, May 01, 2022, Vol. 39, Issue 4, Page 335-354.

- New harvesting experiments
  - High accuracy in picking strawberries in open field conditions (five different scenarios, >600 picking attempts).
  - Average 7.5 seconds per fruit.
  - 94.0% to 37.5% of the success rate in five different scenarios.
  - Identified key issues causing those failed cases (mechanical, vision, or height estimates).
  - Conduct visual inspection of the post-harvesting quality (right after harvesting and 24 hours after harvesting).






Image Processing for Strawberry Canopy

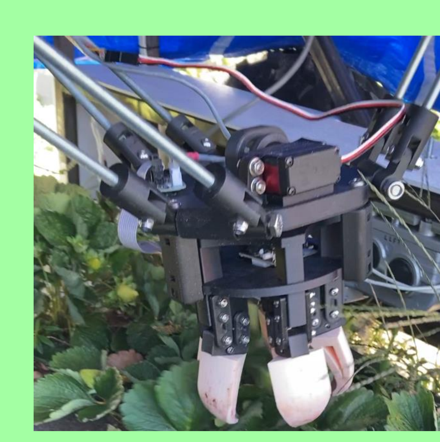
- Machine vision systems (including image processing) in detecting strawberry canopy components in field environment is challenging due to variable outdoor lighting, occlusion of desired parts by foliage and other parts of the canopy, and clustering of strawberries and stems.

- The objective of this study is to develop a robust machine vision system for detecting, localizing and estimating ripeness of strawberries and detecting other canopy components integrating various techniques such as
  - Controlled lighting conditions
  - Exposure fusion technique
  - End-to-end deep learning approaches
  - Analysis of strawberry edge curvature

- Detection accuracy (lab experiments): mAP 89.32% (training)
  80.20% (testing)

Cooperative Parallel Robot Arm:

- Harvesting mechanism is one crucial subsystem affecting the speed of strawberry. Three main components: a mechanism to squeeze stems, an arm to pick a strawberry, and a slider to transfer harvested fruit to a storage unit.
- A delta robot-arm has been built to pick and harvest fruits.
- A gripper has been designed to squeeze stems for efficient strawberry detection and harvesting. The gripper is shown on the right.
- The workspace of the end-effector looks like an elliptical cone, where all the points located inside it represent reachable positions for the end-effector of the robot.
- Lab experiments: 90.9% success (grasping) and 78.8% success (harvesting)



Planned Tasks in the Proposal

Tasks	Xu (UCF)	Ehsani (UCM	Karkee (WSU)	Year 1	Year 2	Year 3	Year 4
1. Decentralized row allocation algorithm	●			■	■		
2. Image processing for strawberry detection			●	■	■		
3. Cooperative parallel robot-arm picking mechanism		●		■	■		
4. Harvesting robot innovation and integration	●	●	●	■	■	■	■
5. Cost analysis						■	■
6. Evaluation	●	●	●		■	■	■

- **UCF**:
  Harvesting robot platform design
  Harvesting robot manufacturing and integration
  Graphical user interface design and programming
  Guidance, navigation, and control software design and programming (including the cooperative row allocation algorithm)
  Software integration and testing
- **WSU**:
  Strawberry canopy images acquired and used in training deep learning networks
  Integrate machine vision system with a strawberry harvesting robot
- **UC Merced**:
  Gripper/end effector design
  Arm design; basket design; integration with the harvesting robot.

Intellectual Merit

- **Decentralized Row Allocation among Harvesting co-Robots**: Partially inspired by human picker strategies, a decentralized, scalable row allocation algorithm will be investigated for harvesting robots to achieve a consensus.
- **Machine Vision for Strawberry Identification**: Integrated multi-exposure fusion, curvature analysis, and hierarchical image processing, supported by an end-to-end deep learning technique, will be investigated
- **Cooperative Parallel Robot-Arm-based Picking Mechanism:** The combination of a single degree of freedom robot arm, a parallel delta robot-arm and a conveyer belt system will be investigated
- **Engineering Tasks and Integration:** Robot scouting control, robot design innovation, visual servoing algorithm, GUI, evaluation and cost analysis

Broader Impacts

- Attainment of such a system will have a significant positive impact on the long-term sustainability of the U.S. strawberry industry
- Results will benefit other strawberry operations such as weed control and disease detection, as well as harvesting activities in other specialty crops facing a similar labor shortage issue.
- Benefit many UG/G students at three universities
- Hands-on projects attracting K-12 students.
- GUI which can help growers/users with disadvantages.
- Results have been and will continue to be published in journals and conferences.

2023 NRI PIs' Meeting

May 1-3, 2023 | Arlington, Virginia

Award IDs: #1924622, #1624662, #1624640