NRI: INT: COLLAB: Distributed co-Robots for Strawberry Harvesting (Award Number: NSF #1924622, 9/1/2019-8/31/2023)

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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 (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 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

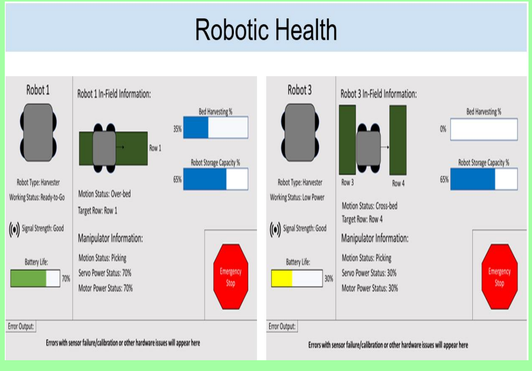
Conceptual Picture of the Co-Robot System

- Small harvesting robots scouting throughout a field.
- Accurate vision processing and cooperative picking.
- Delivering the full basket to the collocation 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

Distributed Row Allocation:

- To ultimately compete with human pickers in speed, cooperative robots are needed.
- Similar to human pickers, co-robots will work in a decentralized fashion.
- A three-layer algorithm will be developed for the distributed row allocation.
- The algorithm will be scalable, efficient/fast, no-confliction, and simple.
- Many practical issues will be considered: field conditions, robot information, etc.
- Many engineering tasks are also involved (guidance, navigation, and control, visual servoing, end effector design, etc.) and the PI's group has many preliminary results.



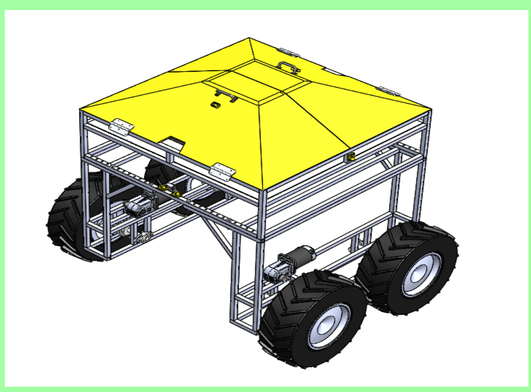


Image Processing for Strawberry Canopy

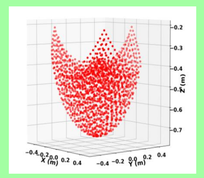
- Machine vision systems (including image processing) in detecting strawberry canopy components in field environment is challenging due to variable outdoor lighting, occlusion of desired parts by foliage and other parts of the canopy, and clustering of strawberries and stems.

- 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

- About 150 images of strawberry canopies were collected as a preliminary dataset
  - Preliminary analysis shows a detection accuracy of 87.5%

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 prototype of a gripper is shown here.
- 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.
- This design will not only save time by decreasing unnecessary long-distance movements of the whole arm, but also avoid any damage to fruits during the harvesting process.



Planned Tasks

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

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 Impact

- 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 such as tomatoes and blueberries.
- Benefit more than 5000 students at three universities
- Hands-on projects attracting K-12 students.
- GUI which can help growers/users with disadvantages.
- Results will be published in journals and conferences.

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