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

PI: Yunjun Xu, University of Central Florida

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

Co-PI: Manoj Karkee, Washington State University

Challenges to be Addressed and Their Significance

- Harvesting is labor intensive, and the associate cost is high for many fruit and vegetable crops
- Due to labor shortage, strawberry production in the US decreases.
- Existing harvesting robots are for greenhouse applications, or mainly monolithic large systems for field conditions

- **We are developing an integrative co-robot (small robots) system that can work effectively in harvesting and lower the cost**. The advantages include
  - Convenient for moving the robot around
  - There will be no single-point-of-failure issues
  - Robot design is adaptive to farm environment variations

Overall Structure of the Co-Robot System

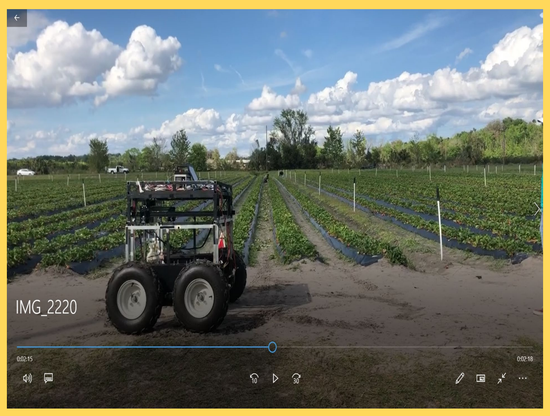
- The scouting robots are small.
- Efficient computer vision and cooperative picking.
- A GUI for growers/users
- Row allocation via a decentralized, auction based algorithm

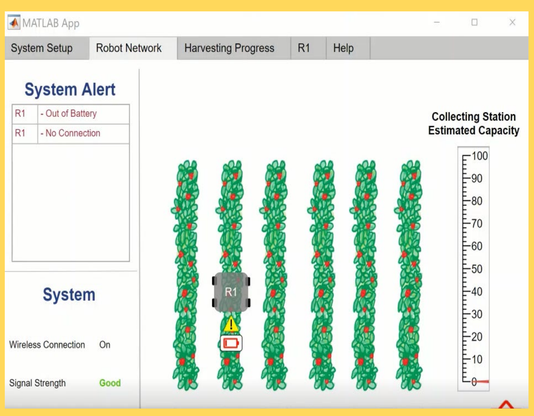
Also,

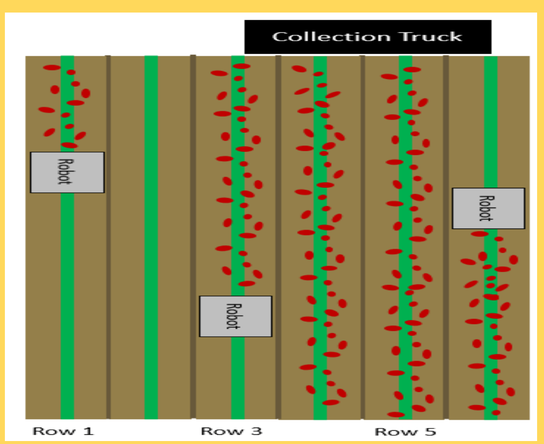
- Enhanced design for harvesting robots
- Cost analysis will be conducted.

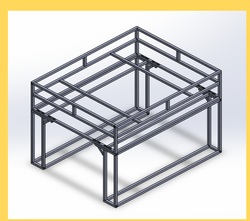
Distributed Row Allocation:

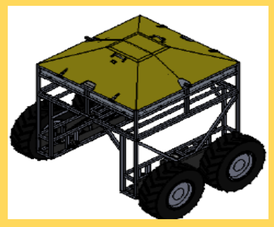
- We are developing a three-layer decentralized, and auction-based scheduling algorithm for a group of small harvesting robots.
- We are developing a graphical user interface to enable growers/users to effectively use the integrated co-robot system.
- We are developing a new learning-based controller to have efficient cross-bed motion controls, and field experiment is ongoing.
- We are redesigning the scouting robot according to the new requirements.

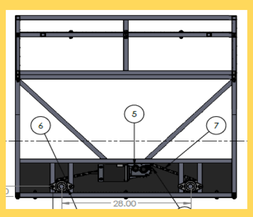


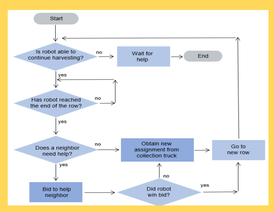






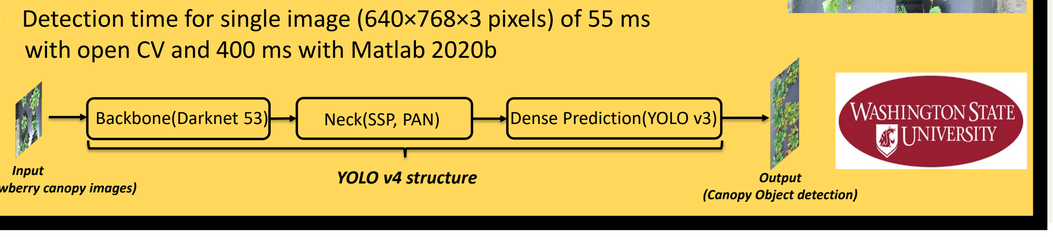






Object Detection in Strawberry Canopy

- To provide the presence, location and maturity of strawberries in field condition
- You-Only-Look-Once (YOLO) v4 was used as deep learning model to detect canopy objects into 5 groups.
  - *Flower, and Immature, Nearly Mature, Mature and Overripen Berries*
- 1,400 canopy images were collected using an RGB-D sensor (ZED Camera) in commercial fields to train the model
- Preliminary analysis based on 100 test canopy images shows:
  - A mean Average Precision (mAp) of 87.8% with mature fruit
  - F1 score of 0.85
  - Detection time for single image (640×768×3 pixels) of 55 ms with open CV and 400 ms with Matlab 2020b

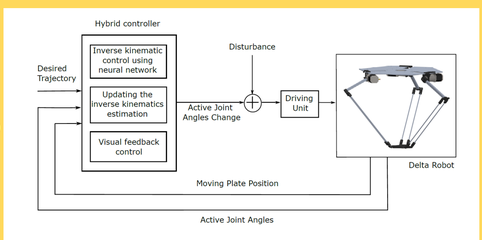


Cooperative Parallel Robot Arm:

- After a target strawberry location is determined, we can move the end-effector based on a planned motion trajectory tracking. However, as the robot reaches and interacts with a dense crop, the location of the target strawberry can change, which leads to an unsuccessful harvesting.

- To address this challenge in designing the picking mechanism, a hybrid control system is used. This control system helps the robot to interacts within a dense crop. To achieve this goal, neural networks and visual feedback control are combined to overcome the limitations of each individual technique.

Location of the strawberries is acquired → A desired path is defined based on the least obstacles possible on the trajectory



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**:
  Redesign the harvesting robotic platform based on the existing one.
  New algorithms in row scheduling and controls in cross-bed and over-bed motions.
  Many engineering tasks associated with the research thrusts.

- **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

- We anticipated that the new integrated co-robot system will significantly increase the efficiency and lower the cost in strawberry harvesting.
- Results will benefit other operations in strawberry fields or other specialty crops.

- Many UG and G students have participated in this project at three universities.

- Hands-on projects attracting K-12 students.

- We anticipate the GUI will help growers/users, especially those with disadvantages.

- Publications, we have submitted journal and conference papers.

2021 NRI & FRR Principal Investigators' Meeting
March 10-12, 2021

Award ID#: #1924622