Robotics, Computer Vision, and Machine Learning for Precision Agriculture

Project Title: Robot Swarms and Human Scouts for Persistent Monitoring of Specialty Crops

Project Award #: 2015-67021-23857

Penn Engineering GRASP LABORATORY · UC MERCED University of California · USDA

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Goal

Use robots and data-driven learning to:

1. Produce semantic maps of farm objects
2. Estimate yield
3. Monitor health

Methodology:

- ***Detect fruits:***
  - ➢ Initial: data-driven deep neural network based object detection
  - ➢ Advanced: improve detection with context information (context extraction → context-based ROI selection → task-specific back-end analyzers)
- ***Data-association:***
  - ➢ Initial: track fruits in 2D
  - ➢ Advanced: represent fruits as 3D landmarks and match their projections with detections in the image
- ***Mapping***
  - ➢ Initial: average 3D locations of corners around fruit detections
  - ➢ Advanced: use fruits as features in SfM, directly reconstruct a map of fruits

Data collection

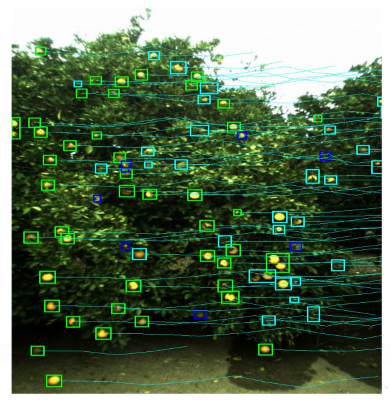
Detecting, tracking, counting and mapping

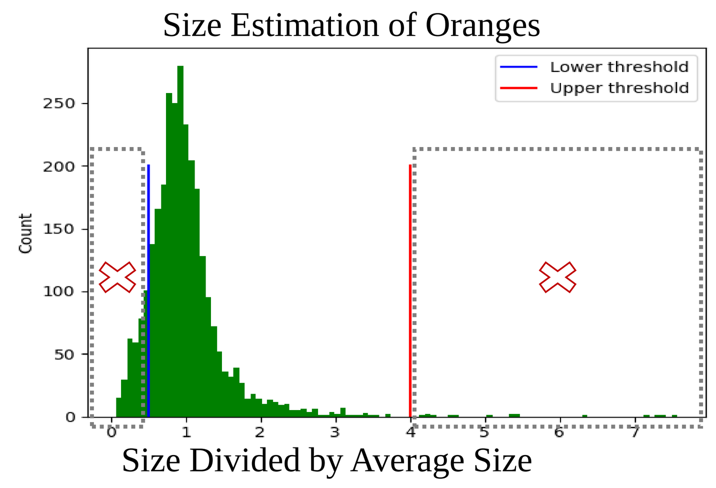
Challenges in fruit counting:

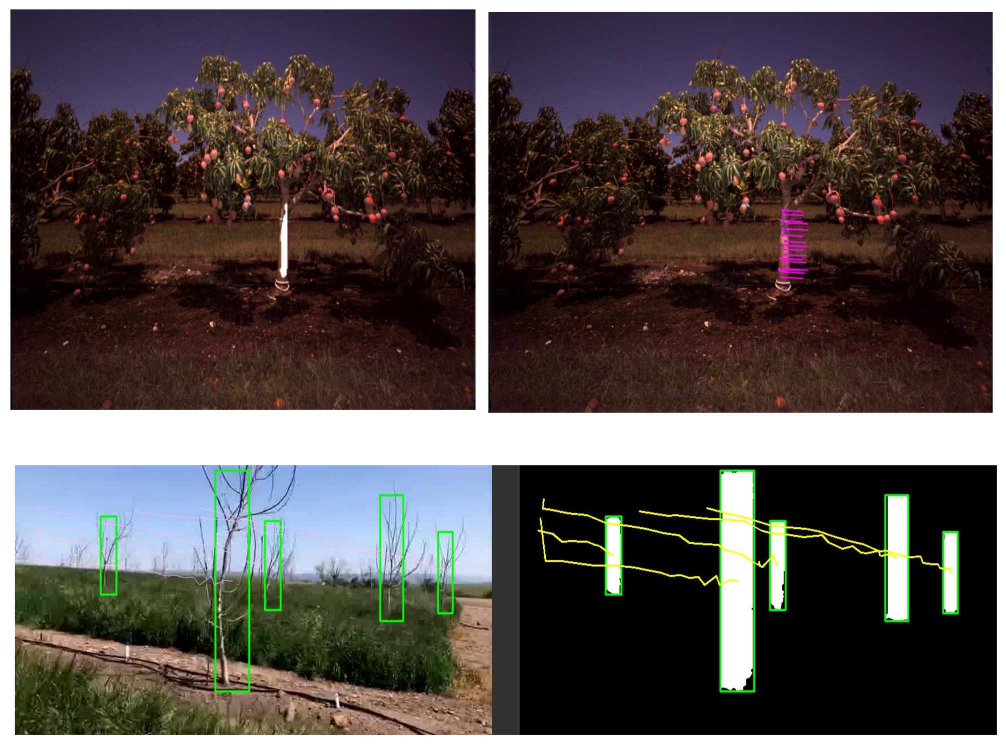
1. Data association across frames ⟹ Object tracking algorithm
2. False detections ⟹ 3D-size-based rejection
3. Double tracking ⟹ 3D-location-based rejection
4. Counting non-target fruits ⟹ 3D-distance-based rejection

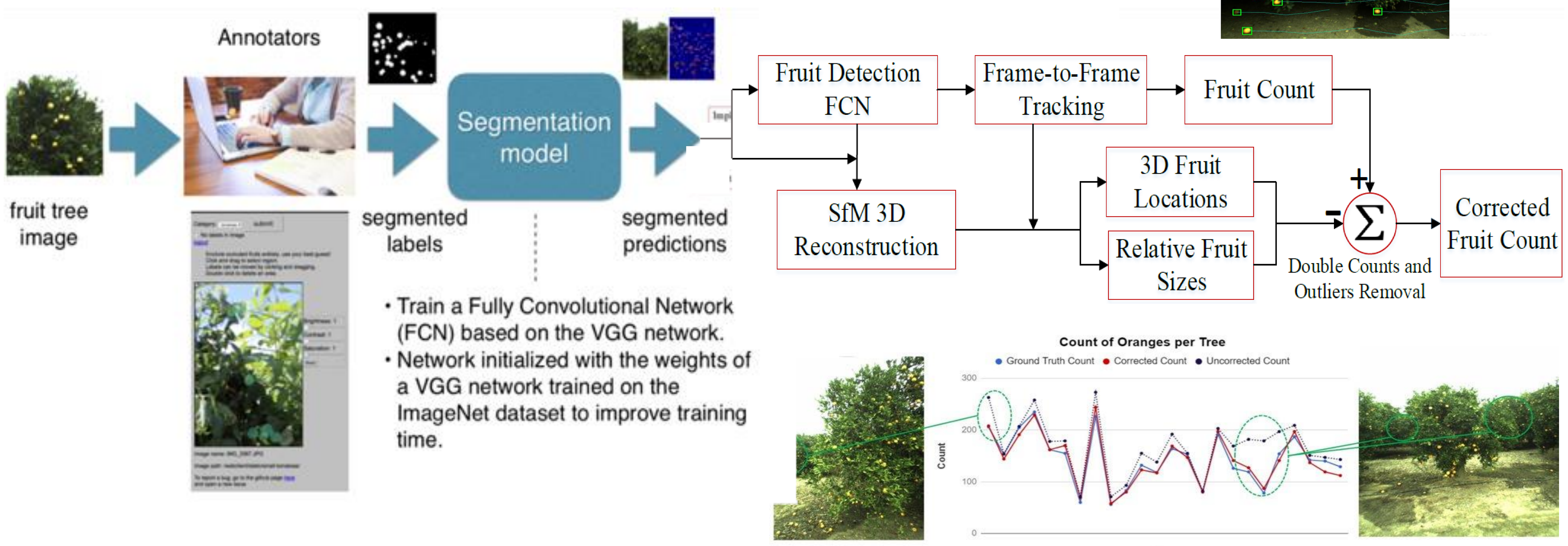
Our solutions:

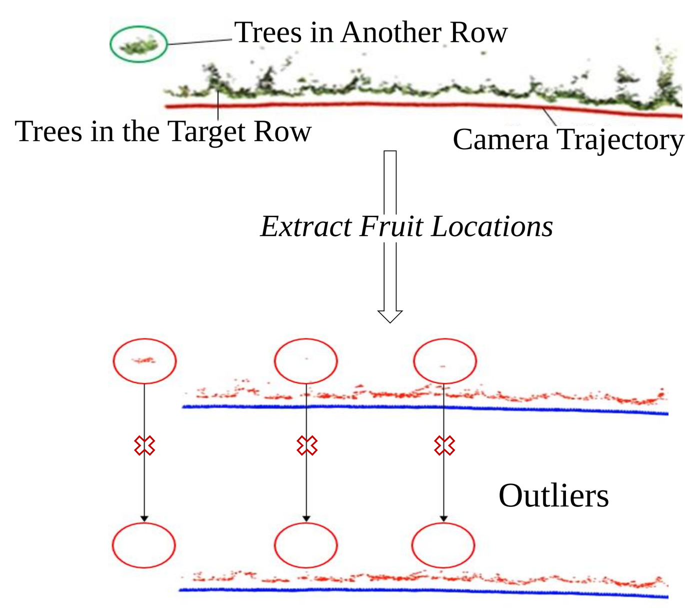
- Object tracking algorithm
- 3D-size-based rejection
- 3D-location-based rejection
- 3D-distance-based rejection

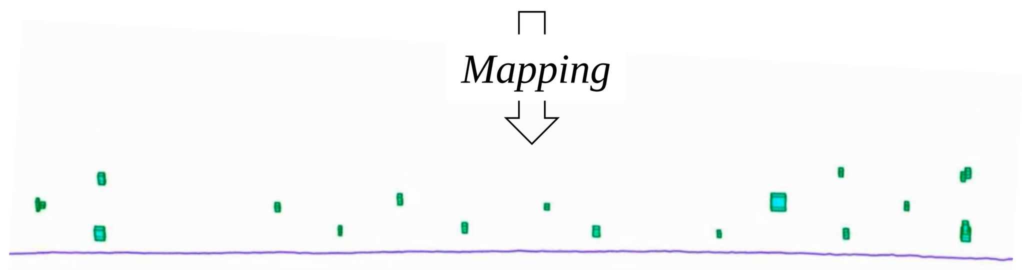








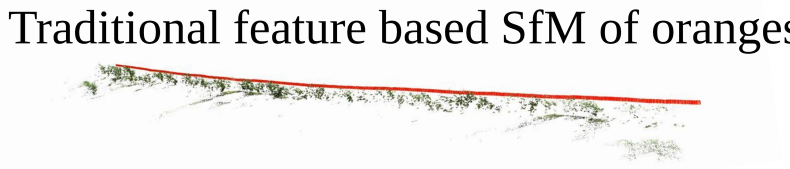




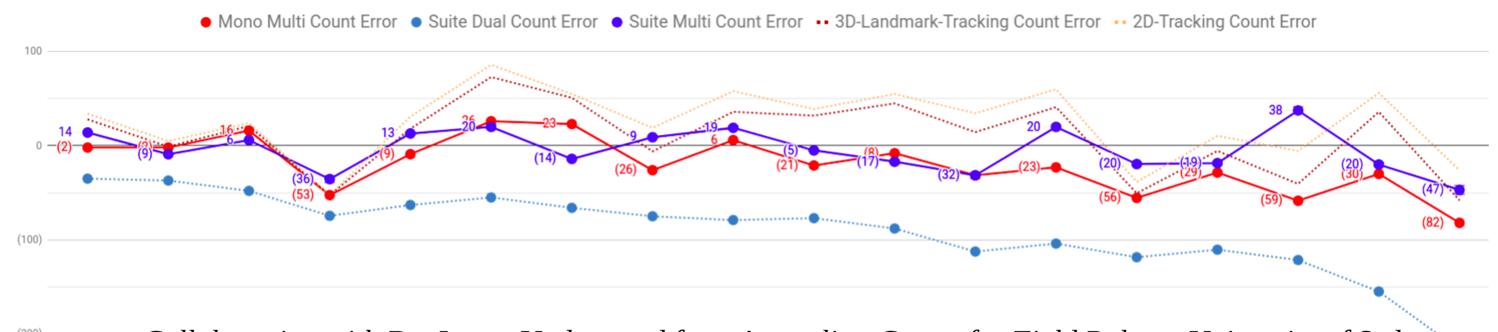
Every trunk is represented as a 3D bounding box

Recent Results: SfM using semantic features & data association with landmark representation:

Traditional feature based SfM of oranges:



Semantic feature based SfM of mangoes:

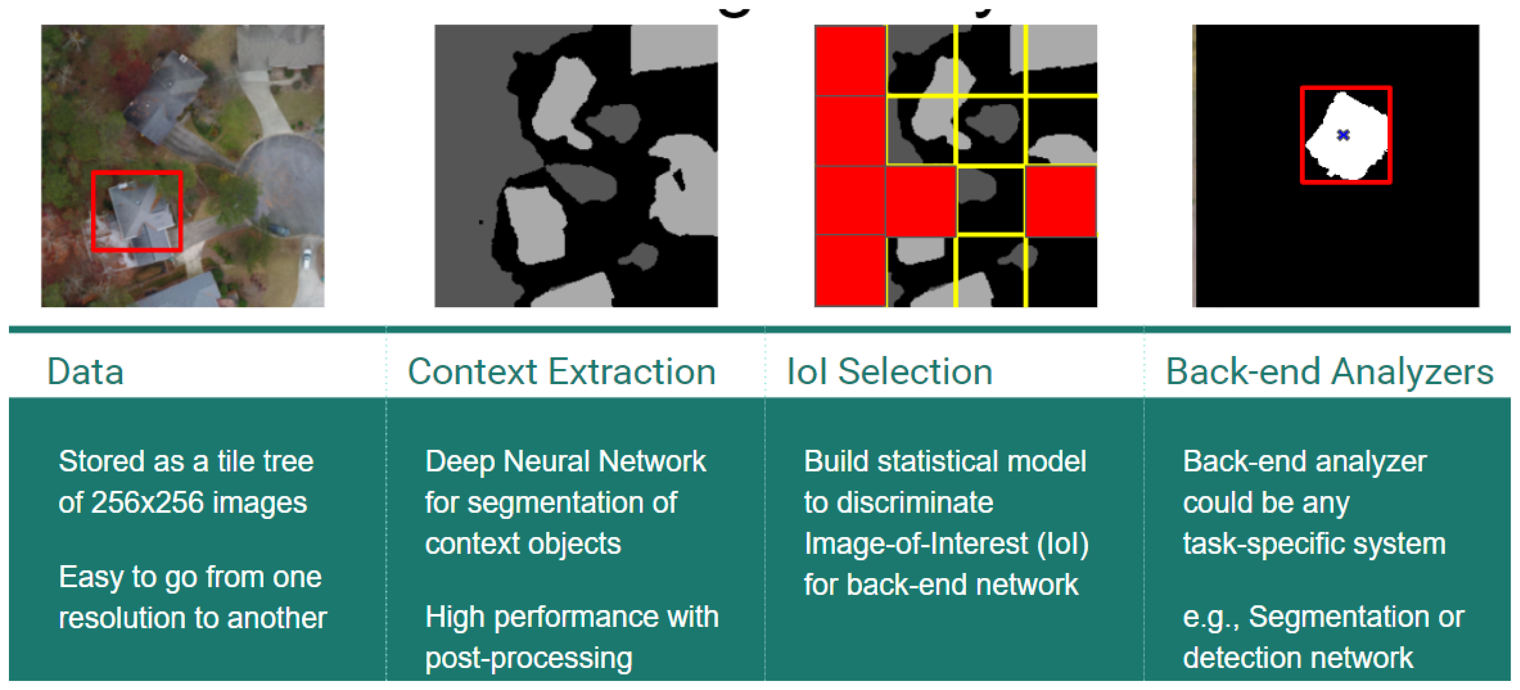


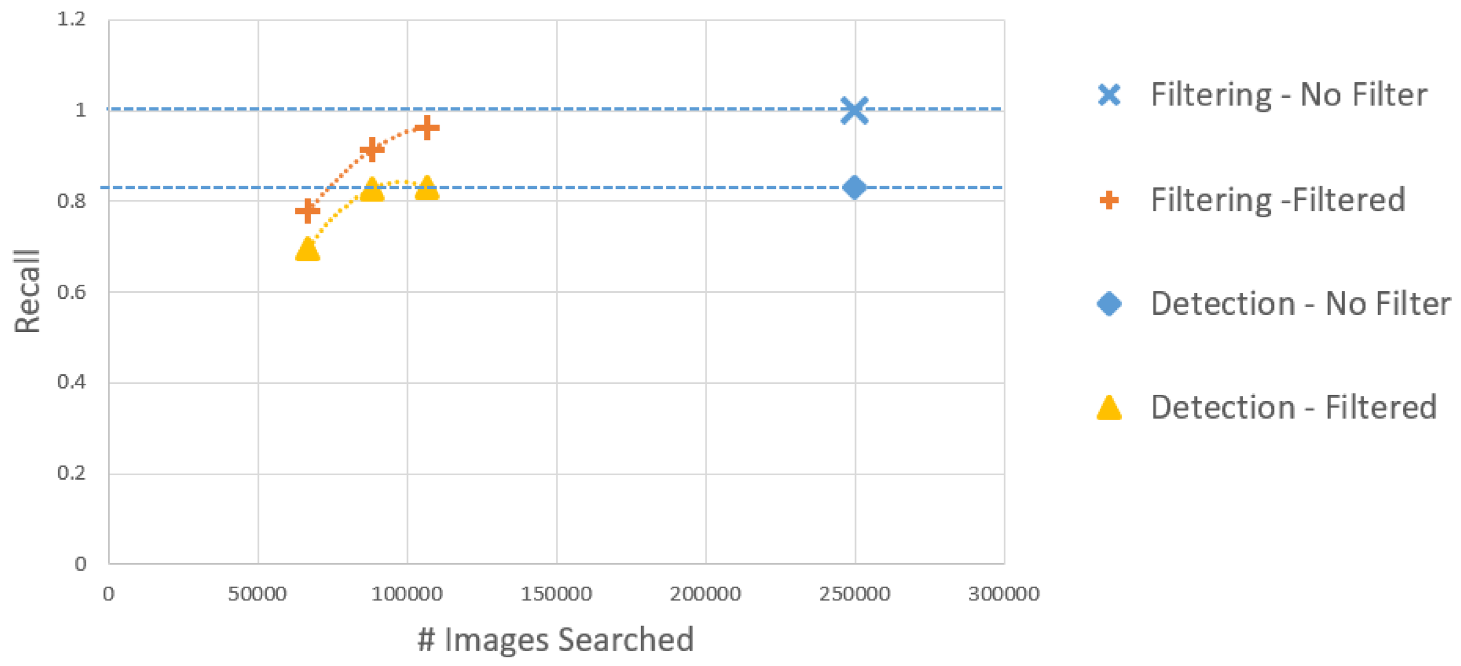
Collaboration with Dr. James Underwood from Australian Centre for Field Robots, University of Sydney

Monocular camera based pipeline achieves comparable performance to sensor-suite (3D Lidar, GPS/INS, camera) based approach. But the monocular camera is:

1. Cheap
2. Lightweight with small form factor
3. Widely accessible (commodity hardware)

Context based image analysis





- **Publications:**
  - ➢ X. Liu, S.W. Chen, C. Liu, S.S. Shivakumar, J. Das, C.J. Taylor, J. Underwood, and V. Kumar. Monocular Camera Based Fruit Counting and Mapping with Semantic Data Association. ICRA 2019 (under review)
  - ➢ Xu Liu, Steven W. Chen, Shreyas Aditya, Nivedha Sivakumar, Sandeep Dcunha, Chao Qu, Camillo J. Taylor, Jnaneshwar Das, and Vijay Kumar, "Robust Fruit Counting: Combining Deep Learning, Tracking, and Structure from Motion", accepted in International Conference on Intelligent Robots and Systems (IROS) 2018.
  - ➢ Daniel Orol, Jnaneshwar Das, Lukas Vacek, Isabella Orr, Mathews Paret, Camillo. J. Taylor, Vijay Kumar, "An aerial phytobiopsy system: Design, evaluation, and lessons learned," 2017 International Conference on Unmanned Aircraft Systems (ICUAS), Miami, FL, USA, 2017, pp. 188-195.
  - ➢ Lukas Vacek, Edward Atter, Pedro Rizo, Brian Nam, Ryan Kortvelesy, Delaney Kaufman, Jnaneshwar Das, Vijay Kumar, "sUAS for deployment and recovery of an environmental sensor probe," 2017 International Conference on Unmanned Aircraft Systems (ICUAS), Miami, FL, USA, 2017, pp. 1022-1029.
  - ➢ Steven W. Chen, Shreyas Skandan, Sandeep Dcunha, Jnaneshwar Das, Chao Qu, Camillo J. Taylor, Vijay Kumar, "Counting Apples and Oranges With Deep Learning: A Data-Driven Approach," in IEEE Robotics and Automation Letters, vol. 2, no. 2, pp. 781-788, April 2017.
  - ➢ Reza Ehsani, Dvoralai Wulfsohn, Jnaneshwar Das, Ines Zamora Lagos, "Yield Estimation: A Low-Hanging Fruit for Application of Small UAS," in ASABE Resource: Engineering & Technology for a Sustainable World, July 2016, pp. 16-18.
  - ➢ Reza Ehsani and Jnaneshwar Das, “Yield estimation in citrus with SUAVs,” Citrus Extension Trade Journals, pp. 16-18, 2016.
  - ➢ Suproteem. K. Sarkar, Jnaneshwar Das, R. Ehsani and V. Kumar, "Towards autonomous phytopathology: Outcomes and challenges of citrus greening disease detection through close-range remote sensing," 2016 IEEE International Conference on Robotics and Automation (ICRA), Stockholm, 2016, pp. 5143-5148.
  - ➢ Jnaneshwar Das, Gareth Cross, Chao Qu, Anurag Makineni, Pratap Tokekar, Yash Mulgaonkar, Vijay Kumar. "Devices, Systems, and Methods for Automated Monitoring enabling Precision Agriculture," In IEEE International Conference on Automation Science and Engineering (CASE), 2015.
- **Patent:**
  - ➢ Systems, Devices, and Methods for Robotic Remote Sensing for Precision Agriculture, V.Kumar, G. Cross, C. Qu, J. Das, A. Makineni, Y. Mulgaonkar (U.S. patent, 2017)US20170372137.
  - ➢ Systems, Devices, and Methods for Agricultural Sample Collection. D. Orol, L. Vacek, D. Kaufman, J. Das & V. Kumar; (provisional patent filed, July 2017).