Robotic Apple Harvesting in Washington State

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Presentation Overview

- Motivation
- Working environment
- Design objectives
- Hand picking analysis
- System design
- Preliminary field testing results
- Future work
- Questions
Research Motivation

- **Washington State fresh market apple industry in 2014**
  - 2.7 million metric tons of apples valued at $1.84 billion USD\(^1\)
  - Accounted for 70% of U.S. apple production
- **The WA fresh market apple harvest requires**
  - Employment of 30,000 additional workers
  - An estimated cost of $1,100 to $2,100 USD per acre per year\(^2,3\)
- **Labor costs are rising and there is increasing uncertainty about the availability of farm labor**
- **Lack of mechanical harvesting for fresh market apples is a significant problem**

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Long-term Goal: Reduce dependence on the labor force for fresh market tree fruit harvesting
Working Environment

- Commercial apple orchard located in Prosser, WA
- Highly unstructured environment
- Modern cultivation systems with formal tree architectures
- “Fruit Wall” concept simplifies the task
Design Objectives

- Cycle time < 6 sec
- Detachment success > 90%
- Fruit damage < 10%
- Pick multiple apple varieties
- Modular design that is cost-effective

**Our Approach:** An ‘undersensed’ design that executes look-and-move fruit picking, is mechanically robust to position error, and replicates the human picking process
Initial Design Development: Manual Apple Picking

• Fruit is grasped with a spherical power grasp\(^4\) with the index finger applying pressure against the stem
• No dexterous manipulation of the fruit with the fingers
• To separate the apple from the branch, the hand moves the fruit in a pendulum motion

‘Undersensed’ Hand Picking

- Are there effective methods to pick fruit that do not require fruit orientation and stem location?

Representative Hand Picking Data
Mechanical Design

- Custom design
- 7 degrees of freedom
- Modular configuration (Dynamixel Pro actuators)
End-Effector Design

- Underactuation provides shape-adaptive grasping
- Passively compliant joints enhance robustness to position error & unplanned collisions
- Grasping is executed in an open-loop manner
- Fabricated with additive manufacturing

Experimental Setup

VIDEO

ROBOTIC APPLE HARVESTING
Vision Performance

Actual vs. Recovered Image
Vision Accuracy:

Total # of Images = 54
Total Fruit Manual Count: 193
Total Fruit Identified: 193
Identification Accuracy = 100%

Total Fruit in Workspace = 150

Average Fruit per Image = 4
Average Vision Time per Image = 6.3 s
Average Vision time per Apple = 1.7 s
Picking Results

• 127 of 150 fruits attempted were picked (approximately 85%)
  – 8/127 – No stems
  – 33/127 – Spur attached to fruit
  – 86/127 – Stems attached to fruit

• Misses fall into the following five general categories
  1. Poorly thinned branch (aka “fruit pendulum”) – 7 instances
  2. Finger grabbed adjacent obstruction – 3
  3. Position and/or calibration error – 8
  4. Fruit slipped from grasp – 2
  5. Previous fruit stuck in hand - 3

• No obvious evidence of bruising

• Ideal fruit location is 3 – 6 in away from the trellis wire
Picking Time

- Mean picking time – 6.01 sec/per fruit
  - 1st fruit in a cycle: 6.22 sec
  - Remaining fruits in a cycle: 5.84 sec
- Each task in the picking sequence was segregated into an individual function and timed
  - Motion planning computation: 0.15 sec
  - Approach: 2.14 sec
  - Grasp: 1.5 sec
  - Removal: 1.23 sec
  - Fruit release: 1 sec
Future Work

• Higher level decision making based on detection of trunks and trellis wires

• Grasp planning based on visual input

• Tactile sensor integration for detection of stem break, missed fruits, etc.
Questions???