ROBOTICS FOR SPECIALTY CROPS: PAST, PRESENT AND PROSPECTS

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Introduction

- Specialty crops:
  - Fruits and vegetables, tree nuts, dried fruits, horticulture, and nursery crops (including floriculture).
- In 2007, the value of farm-level production totaled $50.1 billion, representing more than one-third of the value of U.S. crop production.

Production challenges

- A workshop titled "Engineering Solutions for Specialty Crop Challenges," was held April 24-25, 2007 in Arlington VA.
- Representatives from various specialty crop industries and from several federal agencies planned and organized the meeting.
- Attendees included federal program managers, specialty crop industry producers and representatives, and researchers, educators, and outreach specialists from numerous universities.

Production challenges

- Three major industry concerns were identified:
  - Product quality
  - Environmental footprint
  - Labor cost and availability

Engineering advances needed

- Attendees anticipated that the following engineering advances and technologies are needed:
  - improved and readily available sensors to increase knowledge of plant growing conditions and product quality
  - more efficient application/use of water, nutrients, and chemicals
  - automated systems that can reduce costs of harvest and cultural practices
  - better economic models and decision support systems that can improve production and management decisions.

Robotics - mechatronics

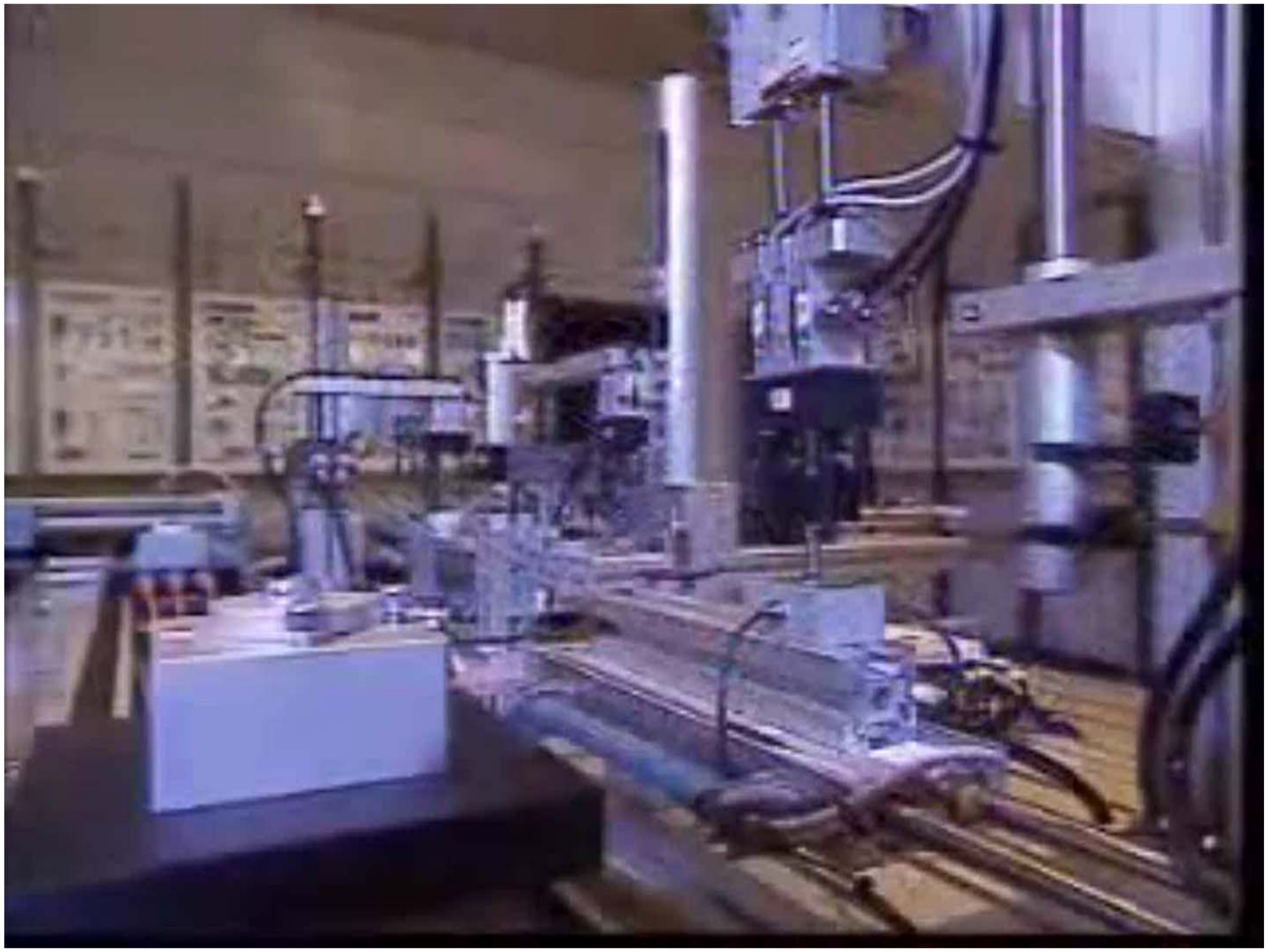
The marriage of mechanical devices with electrical and computational systems is referred to as ‘robotics’ or ‘mechatronics’.

Agricultural robots

- An agricultural robot incorporates three basic components*:
  1. A sensing system to measure important physical and biological properties of the agricultural system
  2. decision-making capabilities for processing information from the sensor system to determine how the agricultural system should be manipulated
  3. actuators to manipulate the agricultural system accordingly.

*Harrell, R.C., Slaughter, D.C., Adsit, P.D., 1988. Robotics in agriculture. In: Dorf, R.C. (Ed.-in-Chief), International Encyclopedia of Robotics Applications and Automation. John Wiley & Sons, Inc., New York, pp. 1378–1387.

Industrial robots vs. Ag robots



Grain crops 'robotics'

Ag robots for specialty crops

- Large ‘lag’ with respect to industrial and commodity crop robotics.
- Such systems may offer solutions for
  - improved and readily available sensors to increase knowledge of plant growing conditions and product quality (SENSING)
  - more efficient applications/use of water, nutrients, and chemicals (APPLICATION)
  - automated systems that can reduce costs of harvest and cultural practices (MANIPULATION).

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SENSING

A new era in remote sensing of crops with unmanned robots.
Pablo J. Zarco-Tejada, J. A. J. Berni, L. Suárez, and E. Fereres
17 December 2008, SPIE Newsroom. DOI: 10.1117/2.1200812.1438

Sensing for specialty crops

- NEED: periodic and on-demand sensing of plant growing conditions and product quality
  - Data for plant, soil, environment and fruits.
- Major applications
  - Disease detection
  - Yield estimation
  - Water stress detection
  - Fruit ripeness estimation.

Sensing for specialty crops

- Two major approaches
  - Sensor networks
    - Periodic and on demand data
    - Large number of simple, low-cost, static sensors
    - Issues of energy, calibration, ruggedness, communication
  - Robotic scouting
    - On demand data
    - Mobile units carry complex, expensive instruments
    - Issues of autonomous and safe operation.

Robotic scouting: UAVs

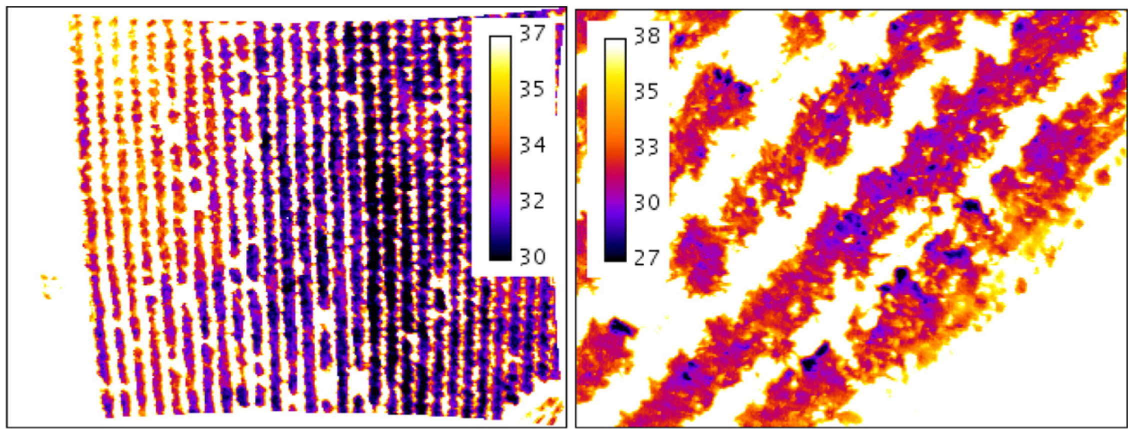
- Aerial imaging



- UAV cost: from ~ $7k to $100k.
- Flight height ~ 100 – 2000 ft.
- Resolution ~ 1-10 inch/pixel.

Robotic scouting: UAVs

- Data on demand (photos, NDVI, thermal, multi-spectral).
- Example:



Thermal images (expressed in °C) acquired with a helicopter UAV over a peach orchard showing water-stress spatial variability (left), and within-crown thermal differences as a function of stress (right)

- Camera cost: from $100 to $15k or more.

Robotic scouting: UAVs

- Issues
  - Cost
  - Automatic take-off & landing still not robust
  - Trained operator required
  - In USA, the FAA has not allowed operation yet
  - Legal issues (safety, privacy)
  - Product integration
    - Data interpretation
    - Decision making.

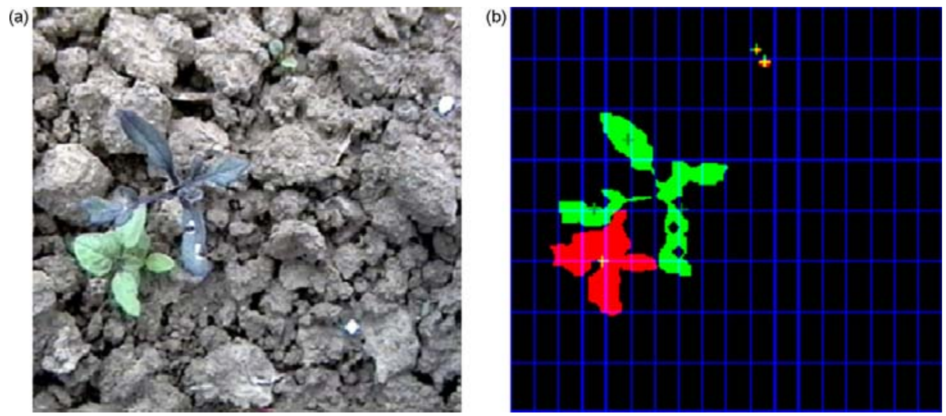
APPLICATION

Precise applications for specialty crops

- NEED: more efficient application/use of water, nutrients, and chemicals
- Focus on pesticide spraying
- Two major approaches:
  - Vision based
  - Seed map based

Vision based spraying

- Weeds are detected using computer vision



- Micro-spraying is performed on weeds; precision up to 0.5 inches;
- Issues: the lack of robust weed sensing technology is the main limitation.

Vision based spraying

- Precision spraying can be performed by
  1. A robotic implement on a tractor
  2. A special-purpose mobile robot
- A recent start-up is focusing on (2) and uses vision and machine learning; venture capital has been invested.

Seed map based spraying

- Location of plant seeds is recorded with sub-inch accuracy (seed map)
- Inter-plant space is sprayed based on seed map
- Issues:
  - High equipment cost for RTK GPS
  - Localization robustness
  - An “open-loop” approach
  - Only at research level (UC Davis, Danish Inst. Of Agricultural Science)

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MANIPULATION

Manipulation for specialty crops

- NEEDS: Automated
  - Mechanical weeding
  - Pruning
  - Thinning
  - Harvesting
  - Nursery transplanting
- Robotic harvesting is the “Holy Grail” of agricultural robotics.

Robotic harvesting

- Technical feasibility has been shown for apples, citrus, strawberries, and other crops.

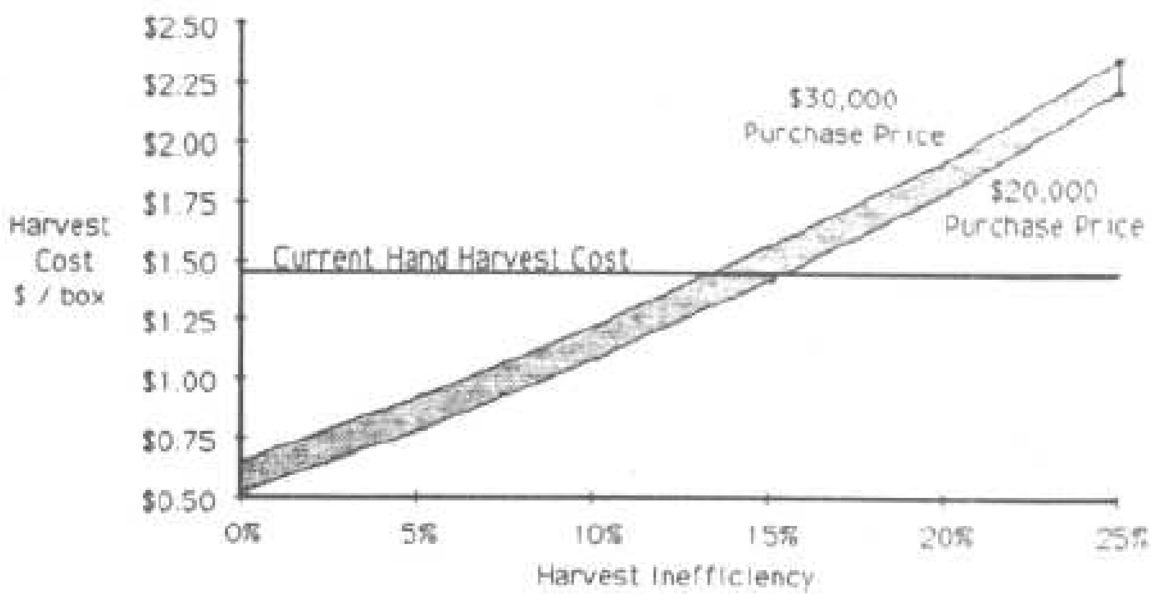
- Closed-loop approach: visually detect fruit, reach it and grasp using visual feedback.

Robotic harvesting

- Technical issues:
  - Un-harvested fruits (harvest inefficiency)
    - Not detected; not reached; dropped - bruised
  - Picking throughput (fruits/sec)
    - ~ 5 sec/fruit; human is ~ 1 sec/fruit
- Financial issues
  - Robot picking cost (human is ~ 1c/fruit)
  - Seasonal utilization
  - Segmented market

Robotic harvesting

- Economic study for citrus (1989)



- Lack of updated studies.

Robotic fruit harvesting prospects are positive

- Labor issue is becoming critical
  - Increased cost; harvest loss risk
- Cost of robotic manipulators is falling
  - From $100k to $10k or less
  - Massively parallel -> high throughput
- Cost of computing is low and power is tremendous
- Robotics theory has matured

Robotic fruit harvesting prospects are positive

- Renewed funding interest
  - Washington Apple Commission plans major effort
  - Venture capitalists are looking into agriculture
    - BlueRiver

    - Harvest Automation

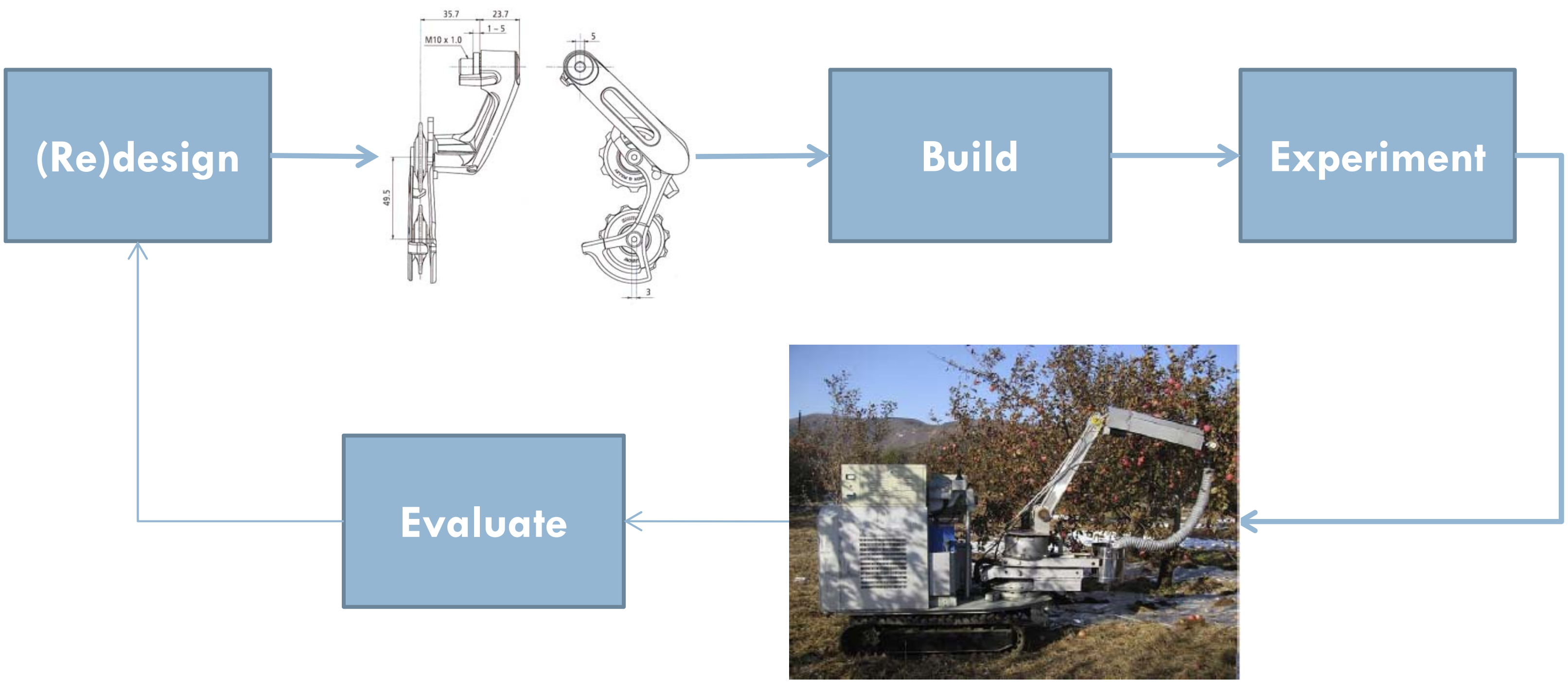
Why are we still at the prototype level?

Major obstacle

The cost of designing and testing robotic fruit harvesters is very high.

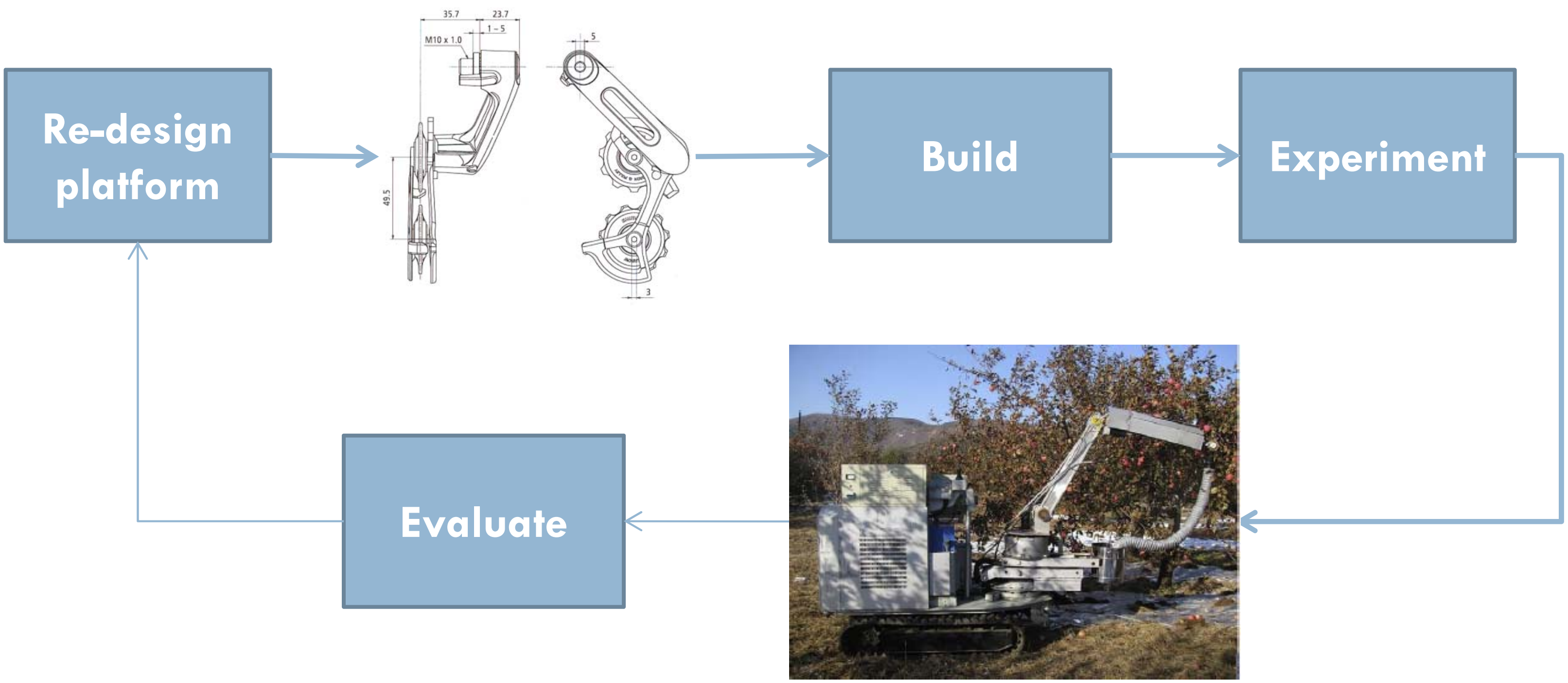
Current development cycle

- Design, build, evaluate…



Limitations

- Development cycle : “Re-design, build, evaluate”
  - cycle relies on actual harvesting tests
  - costly & slow (~1 cycle/year).



More limitations

- Experimental evaluations are not readily transferable to different

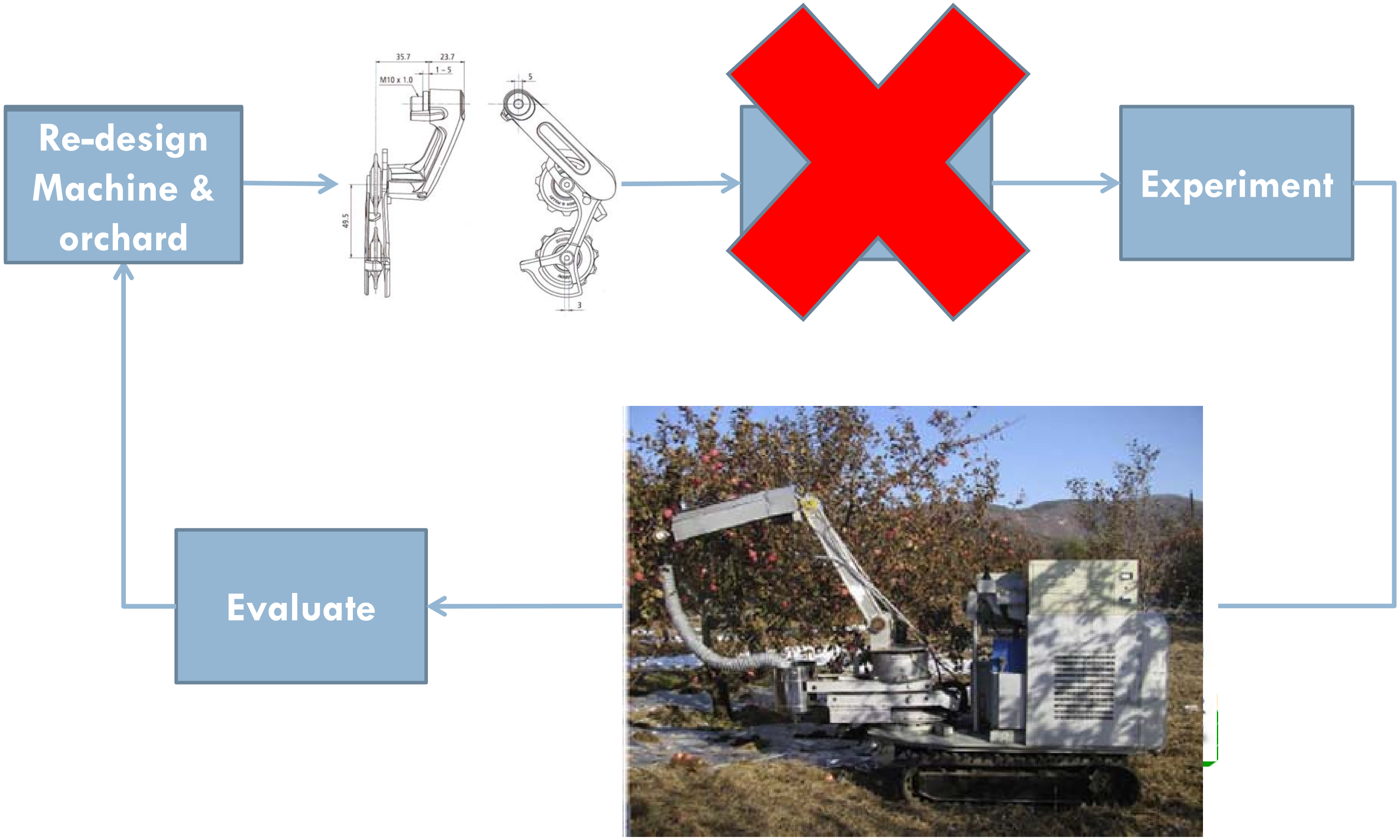
Machines

Training systems & orchard layouts

Productivity of mechanized systems

- Depends on the interactions of several factors:
  - Tree canopy shape and fruit distribution
  - Orchard layout
  - Machine design: geometry, size, structure, kinematics, dynamics, mobility
  - Fruit transport and logistics.

'Digital harvesting'



‘Digital harvesting’ simulator

Tree training system & orchard layout

3D fruit distributions

Machine kinematics

Design tool

Funding sources for 2012

Canning Peach Mechanization Research Fund

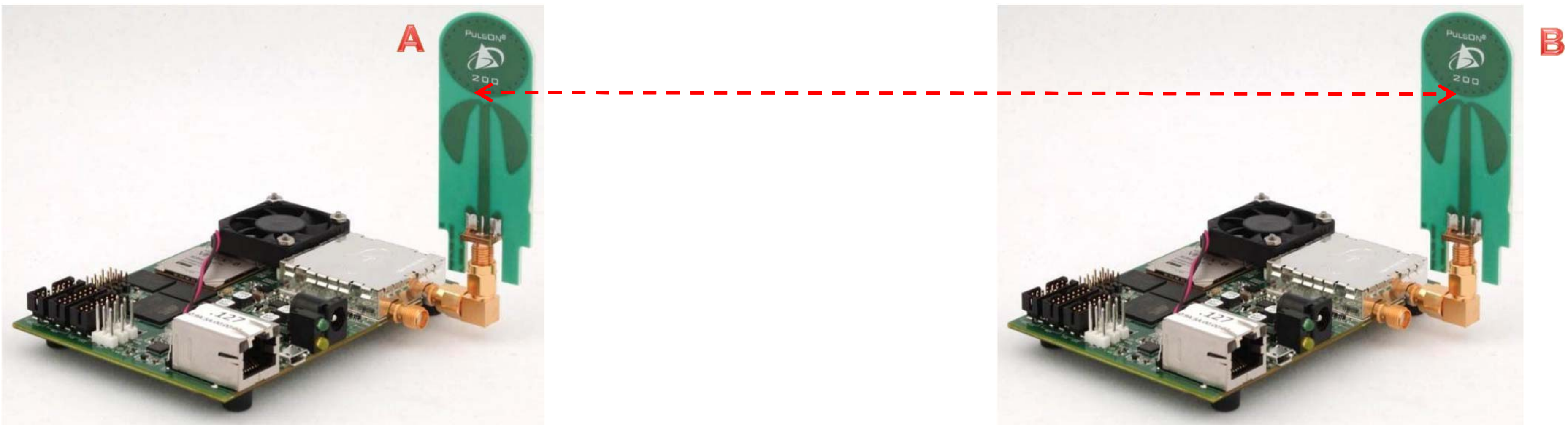
California Pear Advisory Board

Measuring fruit locations

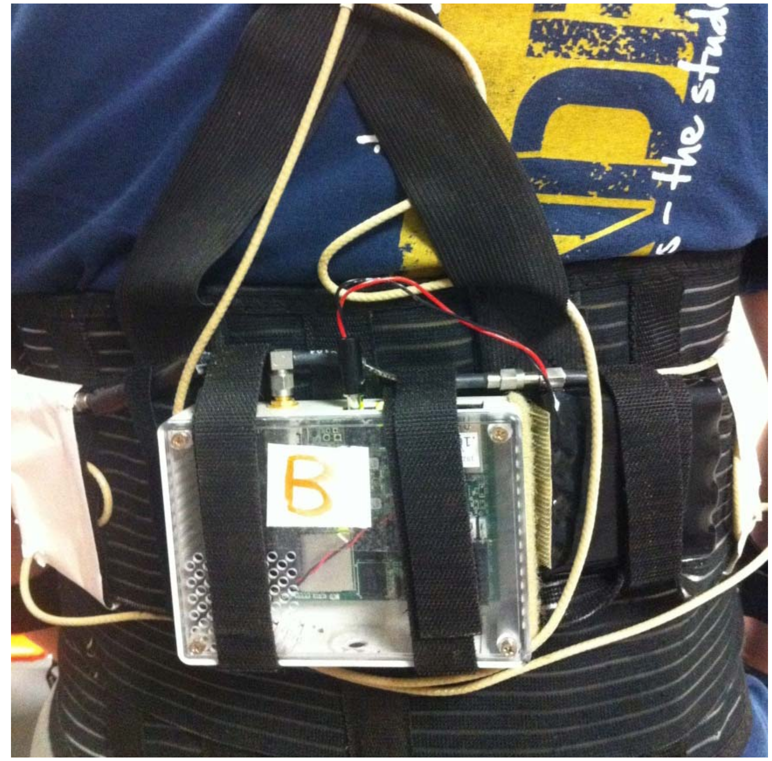
- Existing approaches: very few reported
  - String & plumb bob (1966)
  - Manipulator & inverse kinematics (1991)
  - Surveying with theodolite (1994)
  - 3D vision (2000)
- Measurement rates <1fruit/minute.

Main idea: track picker’s hand position

- Use ranging devices & trilateration



Wearable devices



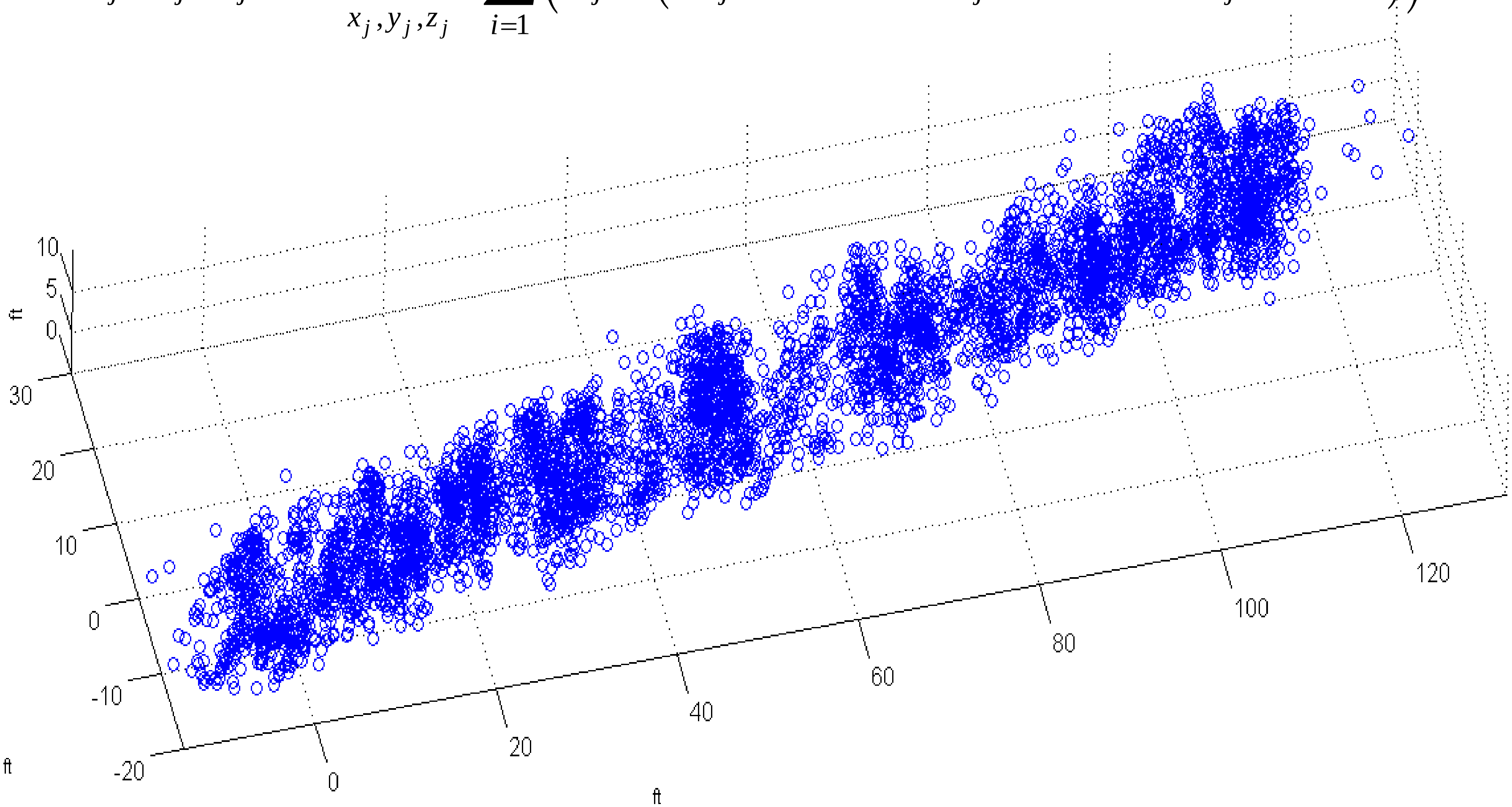
Trailer with radio beacons

Methodology

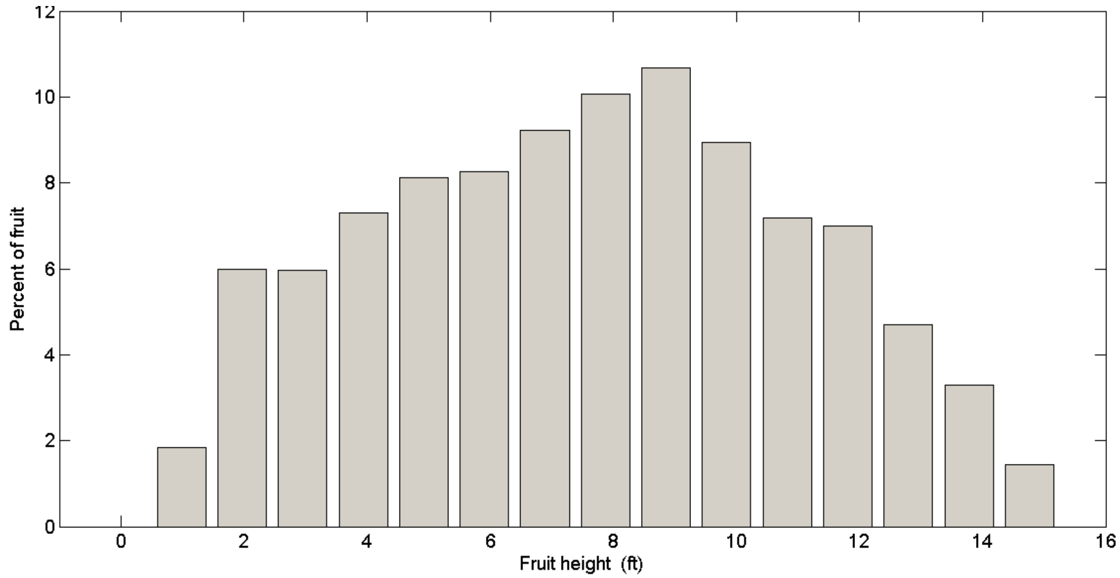
Ruddick Ranch (8/21/2012)
15 Bartlett pear trees

Fruit locations in the canopies

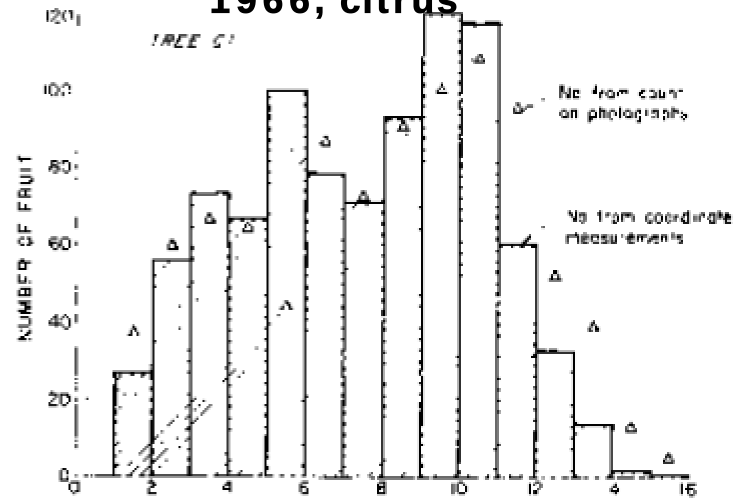
$$(x_j^*, y_j^*, z_j^*) = \underset{x_j, y_j, z_j}{\arg\min} \sum_{i=1}^{4} \left(\hat{r}_{ij}^2 - \left((x_j - bx_i)^2 + (y_j - by_i)^2 + (z_j - bz_i)^2 \right) \right)$$

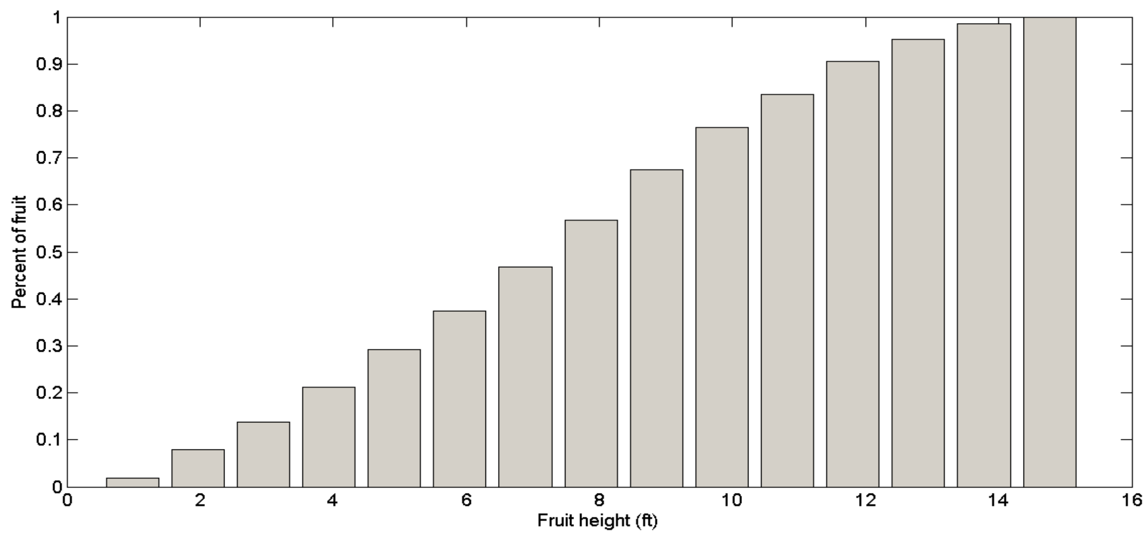


Fruit height distributions



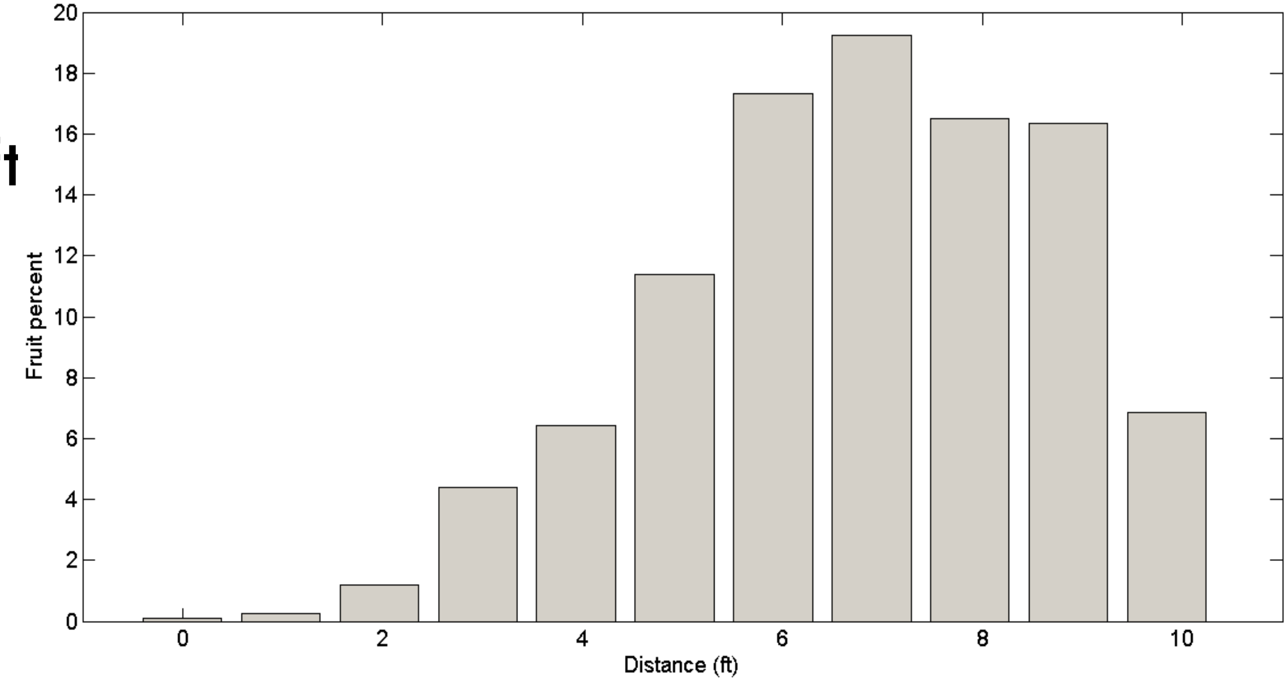
1966, citrus





Fruit horizontal distances from row centers

- $E(d) = 6.74$ ft, and $\sigma = 1.88$ ft

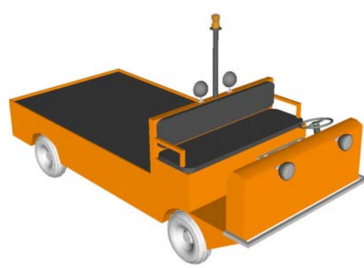


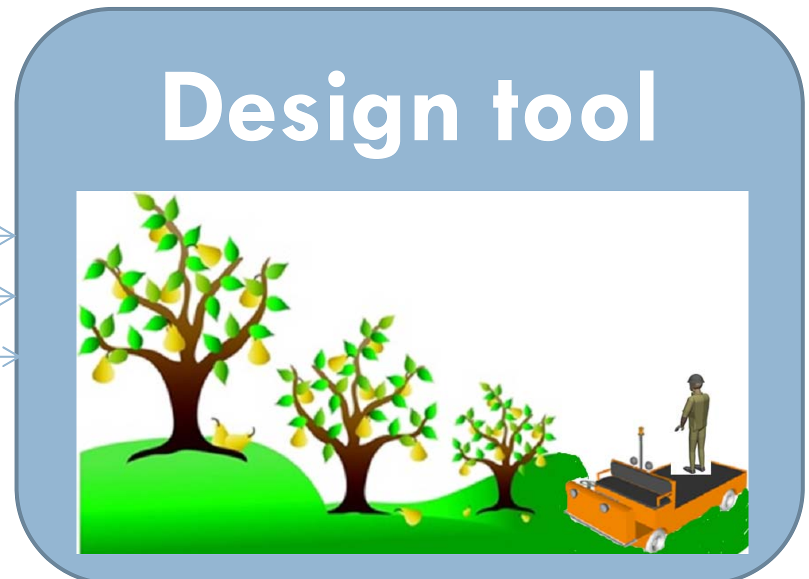
2013: To be continued…

Tree training system & orchard layout

3D fruit distributions

Machine kinematics





Worker kinematics

THANK YOU!

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