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Future Mechanical Improvements and Robotic Harvesting of Fresh Fruit

Remaining Profitable in the Face of Canker and Greening- Prospects for Mechanical Harvesting
April 6, 2006

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Presentation Outline

- Mechanical Harvesting Enhancements
  - Machine system utilization and optimization
  - Multiple shift harvesting (24 hr/d)
  - Autonomous navigation
- Robotic Harvesting of Citrus
  - Gripper development
  - Harvesting arm development
  - Sensors and controls development

Mechanical Harvesting Enhancements

- The optimal economic return on any automation or mechanization system occurs when all resources in the system are properly sized, and being utilized to their maximum productive capability.
- Bottlenecks at any component of the system can cause other components to operate less efficiently, impact the overall performance and thus economic viability of the individual components, as well as the overall system.

Mechanical Harvesting Enhancements

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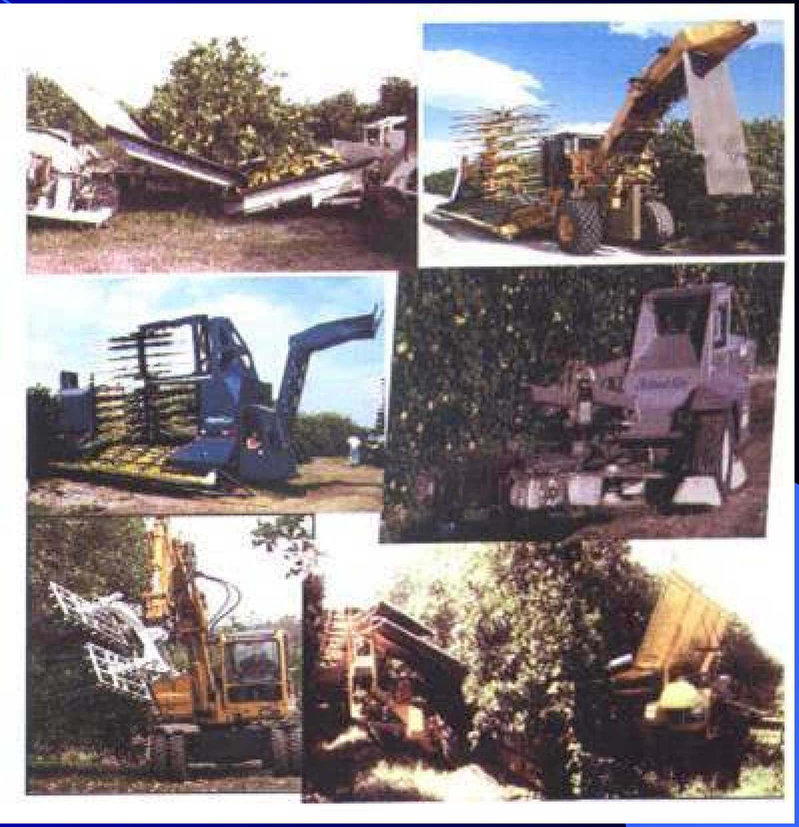
- Citrus harvesting is a complex system that involves several interdependent operations
  - Grove preparation and equipment relocation
  - Harvesting equipment operations
  - Goats which transport fruit to roadside
  - Gleaners
  - Processor's load allocations & capacity
  - Transportation to processors
- Each of these sub-systems must work together in an efficient manor for the whole systems to be optimal

Mechanical Harvesting Enhancements

- Which mechanical harvesting approach is best for a given application ?
  - Continuous Canopy Shake and Catch
  - Canopy Shake and Pick up
  - Trunk Shake and Catch
  - Trunk Shake and Pick up
  - Or maybe even robotic systems
- This will likely depend on system throughput, system cost, operating cost, load allocation, block size, and grove conditions



Mechanical Harvesting Enhancements

- Systems analysis tools commonly employed in industrial automation applications can answer complex systems questions in agriculture. Some examples are:
  – Grain harvesting, hauling, drying and storage
  – Dairy parlor design, automation and production
  – Robotic seedling transplanting
  – Cattle production and operations

Mechanical Harvesting Enhancements

- By combining stochastic resource utilization modeling tools with an economic model, the citrus industry would have a tool that could help decision makers in purchasing the right harvesting equipment, planning harvesting and load allocations, planning for maintenance, and ultimately optimizing their harvesting profitability.
- We are exploring the potential for developing such a resource modeling/economics tool.

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Mechanical Harvesting Enhancements

- An understanding of the complete harvesting process from tree to processor opens up possibilities for new harvesting methods to be evaluated in simulation: such as, multiple shift harvesting.
- Could harvesting efficiencies and thus harvesting cost be improved if the harvesting machines were able to operate at full capacity, much like the grain combines do in the mid-west?

Mechanical Harvesting Enhancements

- Exploring potential for multiple shift harvesting
  - Potential Advantages
    - Increased labor productivity
    - Reduced fixed cost per field box
    - Improved profitability for growers and harvesters
  - Challenges
    - Load allocations and processor capacity
    - Increased complexity of overall harvesting operation
    - Safety during nighttime harvesting

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Mechanical Harvesting Enhancements

- The adoption of mechanical harvesting must be a WIN-WIN situation.
  - Growers need to realize harvesting cost savings, while maintaining overall crop value
  - Harvesting companies must be profitable, which means they must efficiently adapt to different field conditions
  - Trucking companies must be able to handle the logistics of a new scheme of load allocations
  - Processors must be able to adapt the way loads are allocated, fairly compensating growers for crop value, while maintaining their own profitability
  - Gleaners must be appropriately compensated

Vehicle Guidance in Citrus Groves

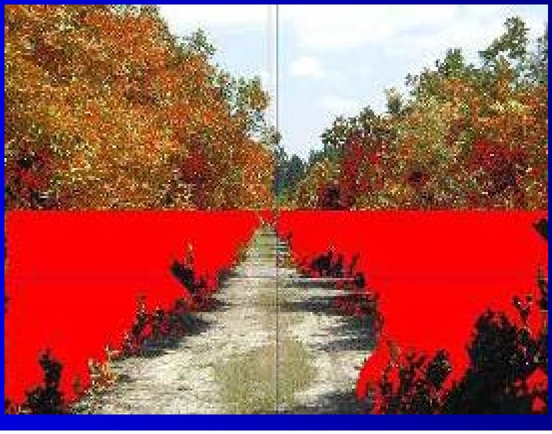
- There are numerous potential applications for autonomous vehicle guidance
  - Relieve operator of steering and speed control responsibilities in CCSC system, which could improve catch efficiency and reduce operator fatigue.
  - Improve cycle rate for TS&C systems by reducing re-positioning inefficiencies
  - Numerous other application in citrus: mowing, scouting, spraying, and so on.

Vehicle Guidance in Grove

- Machine Vision and laser radar based guidance algorithms have been developed and tested on a vehicle, which can autonomously navigate on a test track, as well as in a grove alley.
- We are developing fully autonomous capabilities that will be able to navigate through the grove, without human intervention.

Grove Image Before Processing

Grove Image After Processing



Tractor with Guidance Equipment

Robotic vs Mechanical

Robotic Citrus Harvester

- Flexible to change
- Fresh or processed fruit
- Lower labor productivity gain
- Cost per throughput higher

Mechanical Citrus Harvester

- Not flexible
- Processed fruit applications
- High labor productivity gain
- Cost per throughput lower

Potential Economic and Value Added Benefits of Robotic Harvesting Systems

- Automated fresh fruit harvest
- Late Season Valencia
- Small block size, or small load allocations
- Selective harvest versus once over harvest
- In-field sorting & grading (reduce pack out cost)
- Accurate yield monitoring
- Clean loads
- Scouting for weed and disease

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Automated Citrus Harvesters

- Obstacles
  - Detection of occluded fruit
  - Removal of interior fruit
  - Harvesting cycle rate
  - Capital cost of equipment
  - Maintainability
  - Grower acceptance

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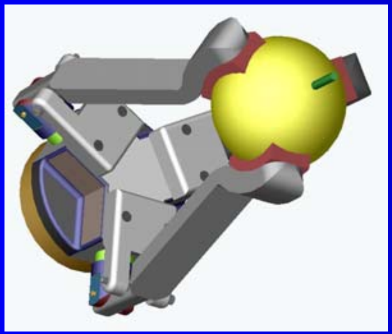
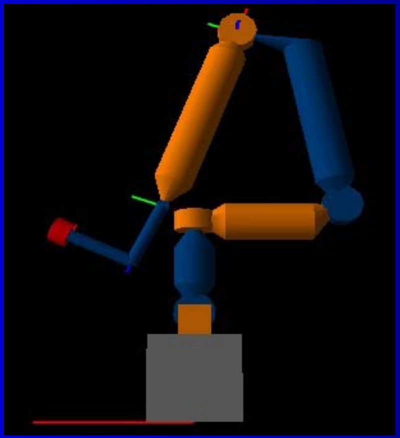
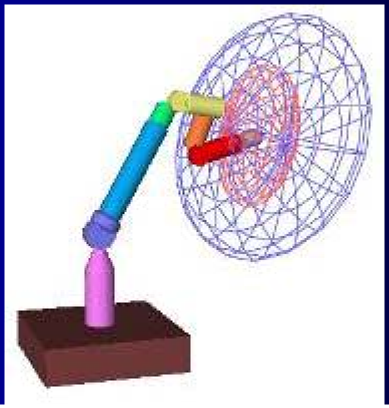
Automated Citrus Harvesters

- Primary Research Areas
  - End effector development
  - Manipulator arm development
  - Sensing technologies
  - Target identification & tracking
  - Manipulator control
  - Machine intelligence
  - Computer resources

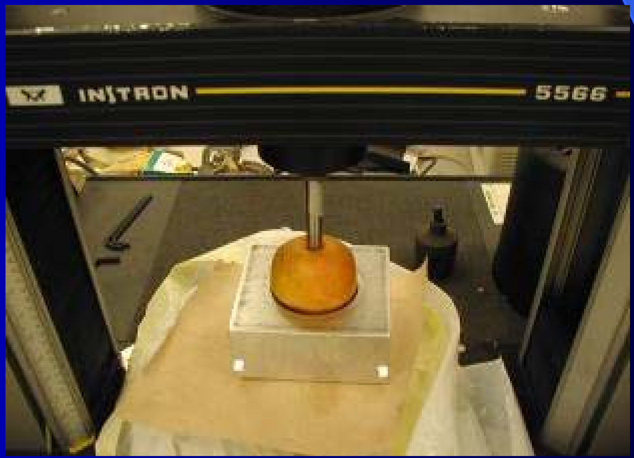






Physical Properties Studies

- We are conducting physical properties test on oranges to determine the optimal fruit removal cycle.
  - Bursting and puncture pressure test
  - Bruising
  - Fruit removal mechanics



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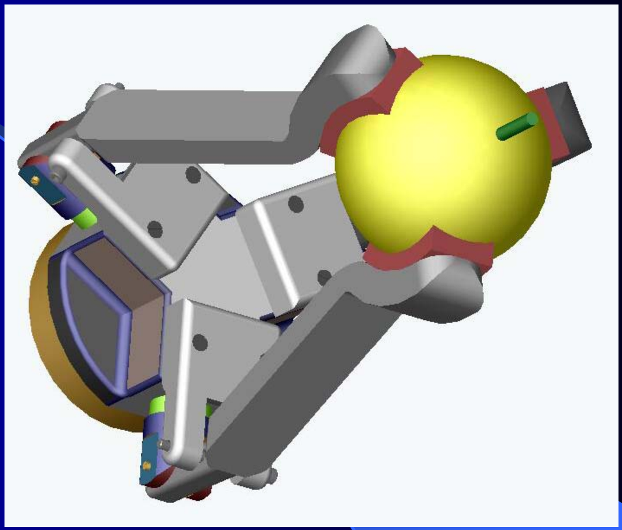
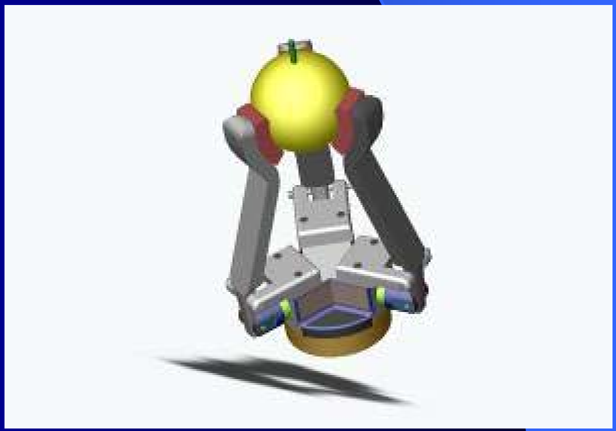
End-Effector Development

- A phase I end effector has been developed and is operational.
- Phase II end effector has been designed.
- Phase II end effector fabrication is nearly completed.





Robot Manipulator Development

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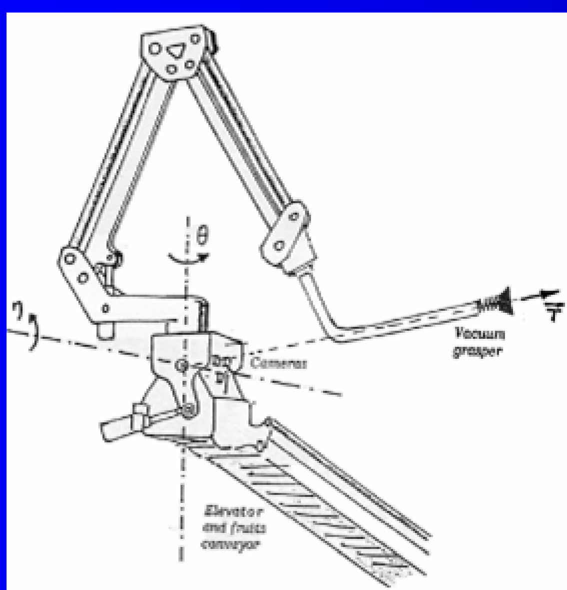
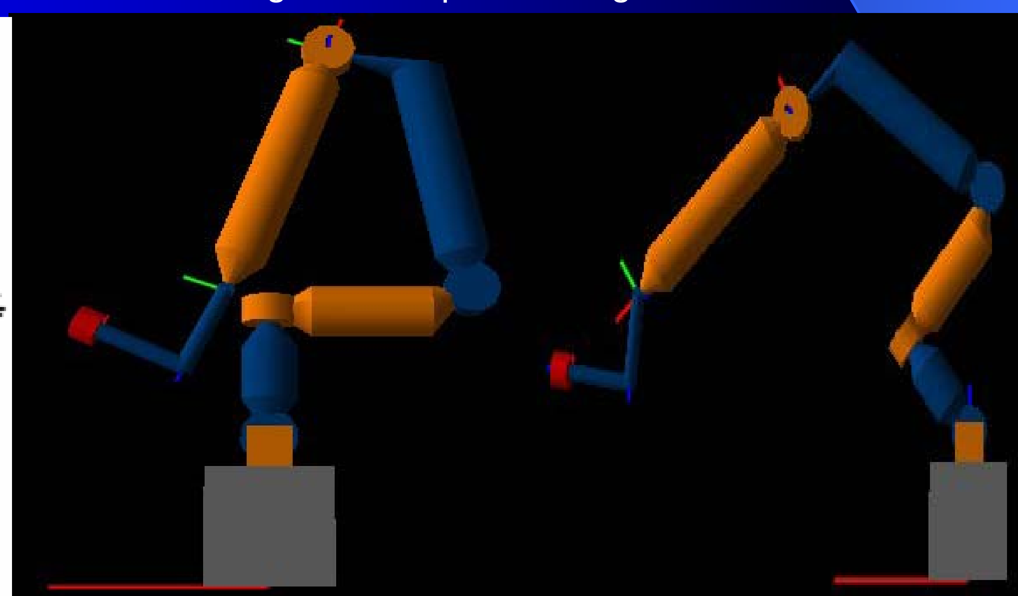
- Kinematic and dynamic modeling studies have been completed
- Manipulator dexterity analysis has been completed
- Structural and mechanical design is underway
- Electrical and control design is underway.
- Prototype arm fabrication, assembly and testing is planned

MAGALI & EUREKA geometric model showing different pose configurations





Sensory Systems Development

- Fruit detection using traditional CCD color camera, and other novel sensing technologies are being explored.
- Range estimation using ladar, ultrasonic and novel image processing technology
- Canopy surface mapping

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Fruit Detection Accomplishments

- Image Processing
  - Distinguish fruit from leaves and branches
  - Robust under varying light conditions
  - Distinguish clusters
  - Identify target and track fruit during harvesting

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Robot Servo-Control

- Integrated machine vision with manipulator control of 7 DOF robot arm

- Integrated and tested 2D image recognition algorithms and range to target estimation.

- Developed climate controlled field laboratory, and conducted preliminary harvesting trials

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Harvesting Research Accomplishments

- Harvesting systems
  - EOF developed
  - Field lab completed
  - Harvesting arm integrated with vision
  - Oranges picked
  - Modeling and design of new arm
  - Canopy mapping effort begun
- Vehicle guidance in the grove
  - Successfully navigate aisle way
  - Enhancing control and sensing
  - Working toward total autonomy