# An Autonomous Orchard Spraying System: Mission Planning and Control

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*Intelligent Technologies for Future Farming*
*DaNet Thematic Workshop*
*Horsens, Denmark, 27 March 2003*

# Outline

- **Background**
- Autonomous Vehicles for Agriculture
- Orchard Spraying System
  - Vision
  - Physical Hardware
    - Actuators
    - Sensors
    - Vehicle Electronics
  - System Software
    - Path-Tracking Algorithms
    - Mission-Planning Strategy
    - User Interface
  - Implementation Issues (Safety and Localization)
- Conclusion

# Utah State University

Located in Logan, Utah, USA
80 miles North of Salt Lake City

18,000 students study at USU's Logan campus, nestled in the Rocky Mountains of the inter-mountain west


CSOIS is a research center in the Department of Electrical and Computer Engineering

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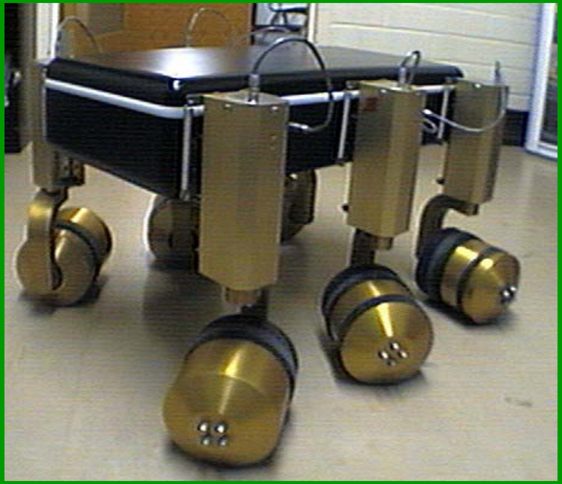
# Some Robots Built At USU

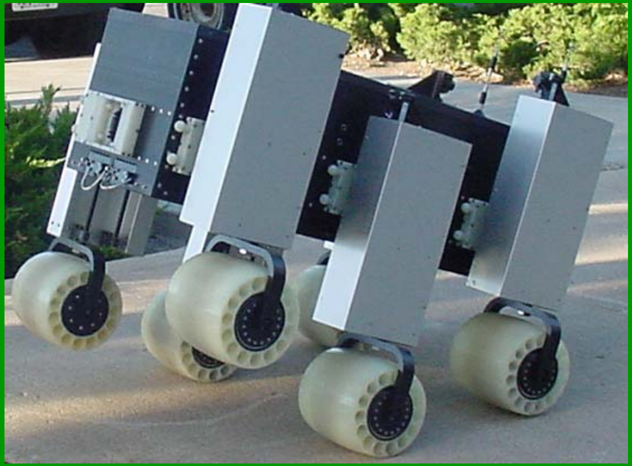
T1



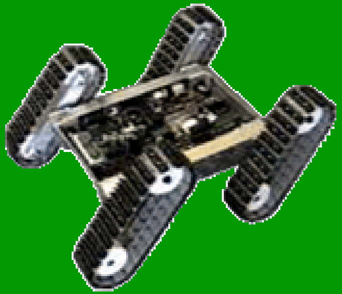
T2

ODIS

T3



## Some Vehicles Built At ASI



# Autonomous Vehicle Technology

- Autonomous vehicles are enabled by advances in:
  - Vehicle concept and mechanical design (actuation)
  - Sensors (e.g., GPS) and perception algorithms
  - Vehicle electronics (vetronics)
  - Control
  - Planning
  - User Interface
- Also important is the application.
- Today we will discuss the application of agriculture.

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# Autonomous Vehicles for Agriculture

- Arguably, there are two options for deploying vehicles for computer-controlled precision farming:
  1) Retrofit or redesign existing vehicles for autonomous operation:
     – All-terrain vehicles (ATVs)
     – Tractors
     – Trucks
  2) Design new vehicles, unrestricted by ergonomics
- We have focused on the former, while recognizing that the latter may be more efficient.

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# Two Autonomous Triton Predators Cooperatively Accomplishing a Spraying Mission

# Another Retrofit Project

- Automate a large field tractor for autonomous operation under computer control.
- Provide the automated tractor with obstacle detection and avoidance capability.

## Curved Path Following


Barrel
50’
Pond
Tractor

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# A Second Automated Tractor Project: Orchard Spraying

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# Vision

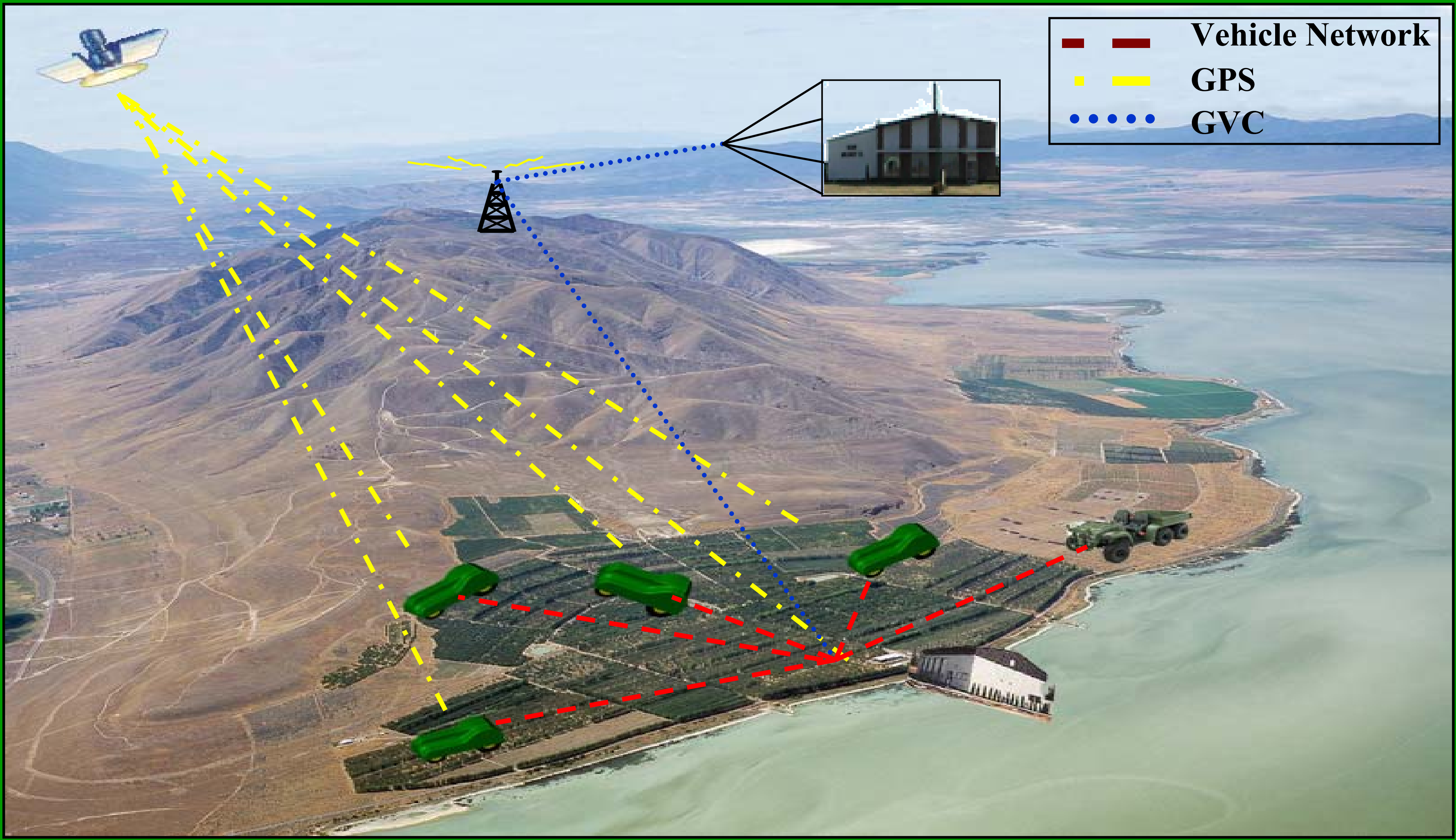
**Objective:**

Using an aircraft or satellite-derived GIS map of the region, user-assigned field tasks are performed using optimized intelligent path and mission planning.

**Applications**:

- Coordinate Space-Air-Ground GIS Data Base Building
- Optimally Manage Traditional Field Operations
  - Planting
  - Spraying
  - Harvest
- Optimally Manage Site-Specific Field Operations
  - Strategic Soil Sampling
  - Spot Chemical Application

# Orchard System



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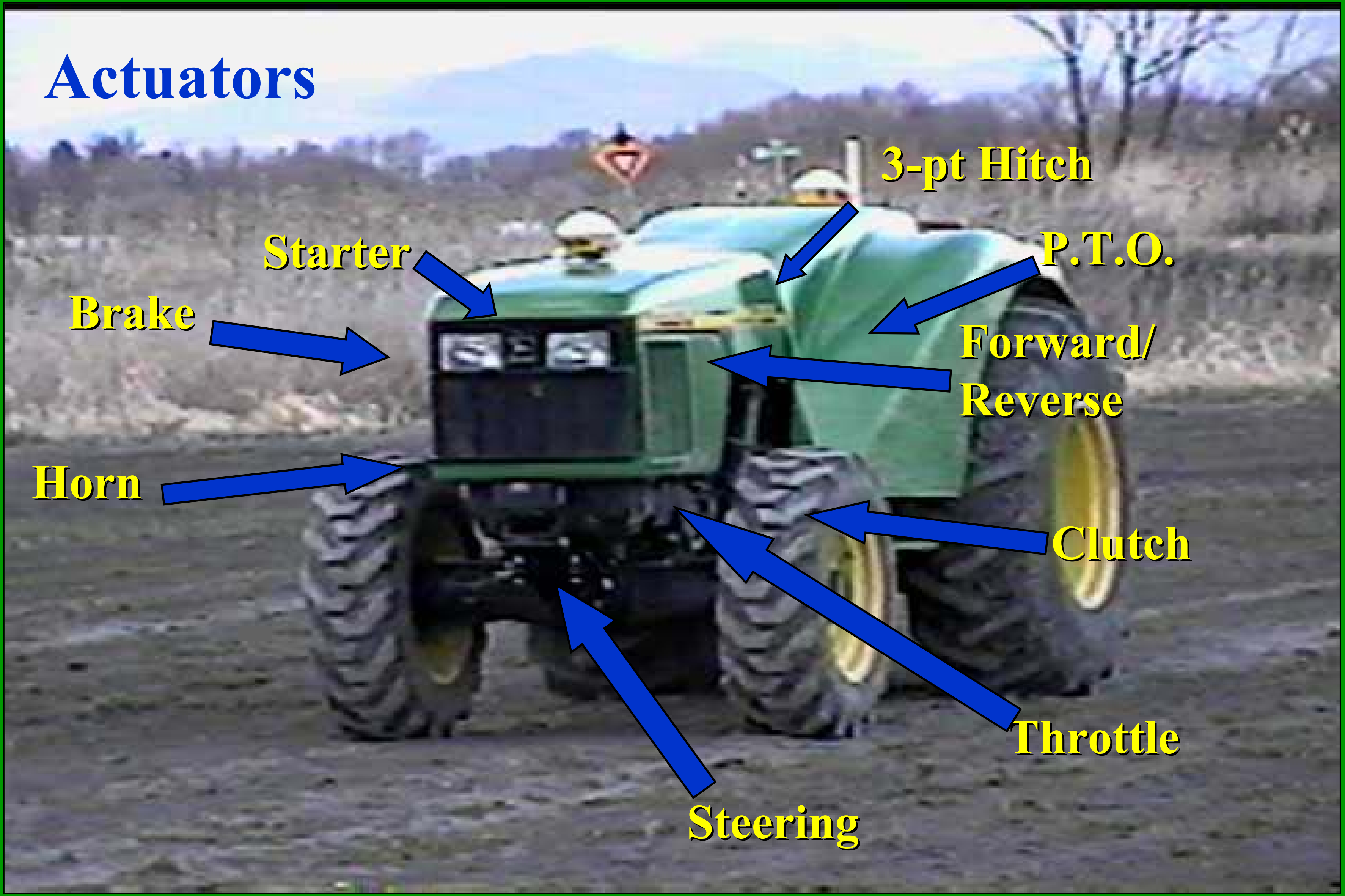
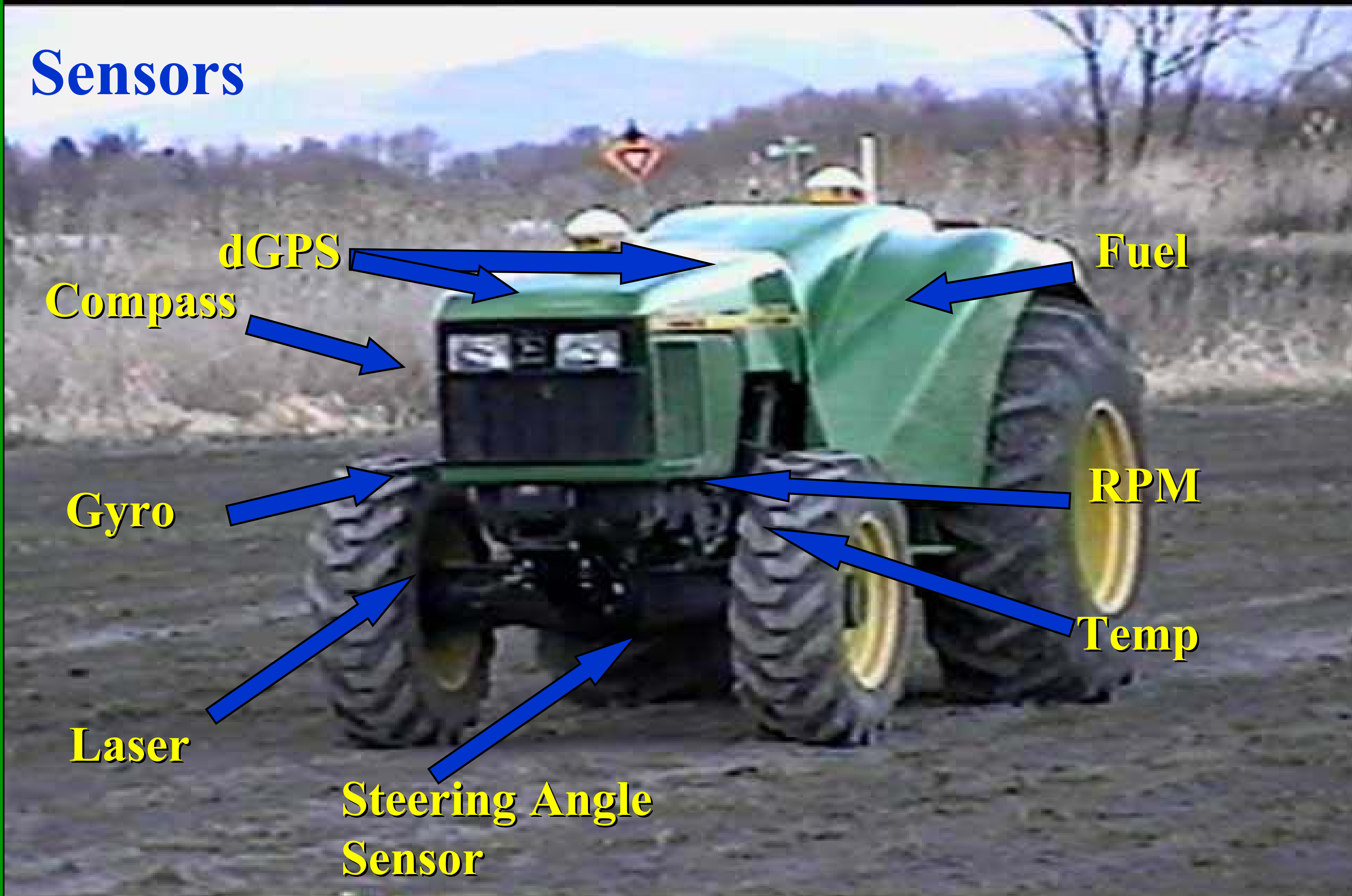
# Actuators


3-pt Hitch
Starter
P.T.O.
Brake
Forward/
Reverse
Horn
Clutch
Throttle
Steering

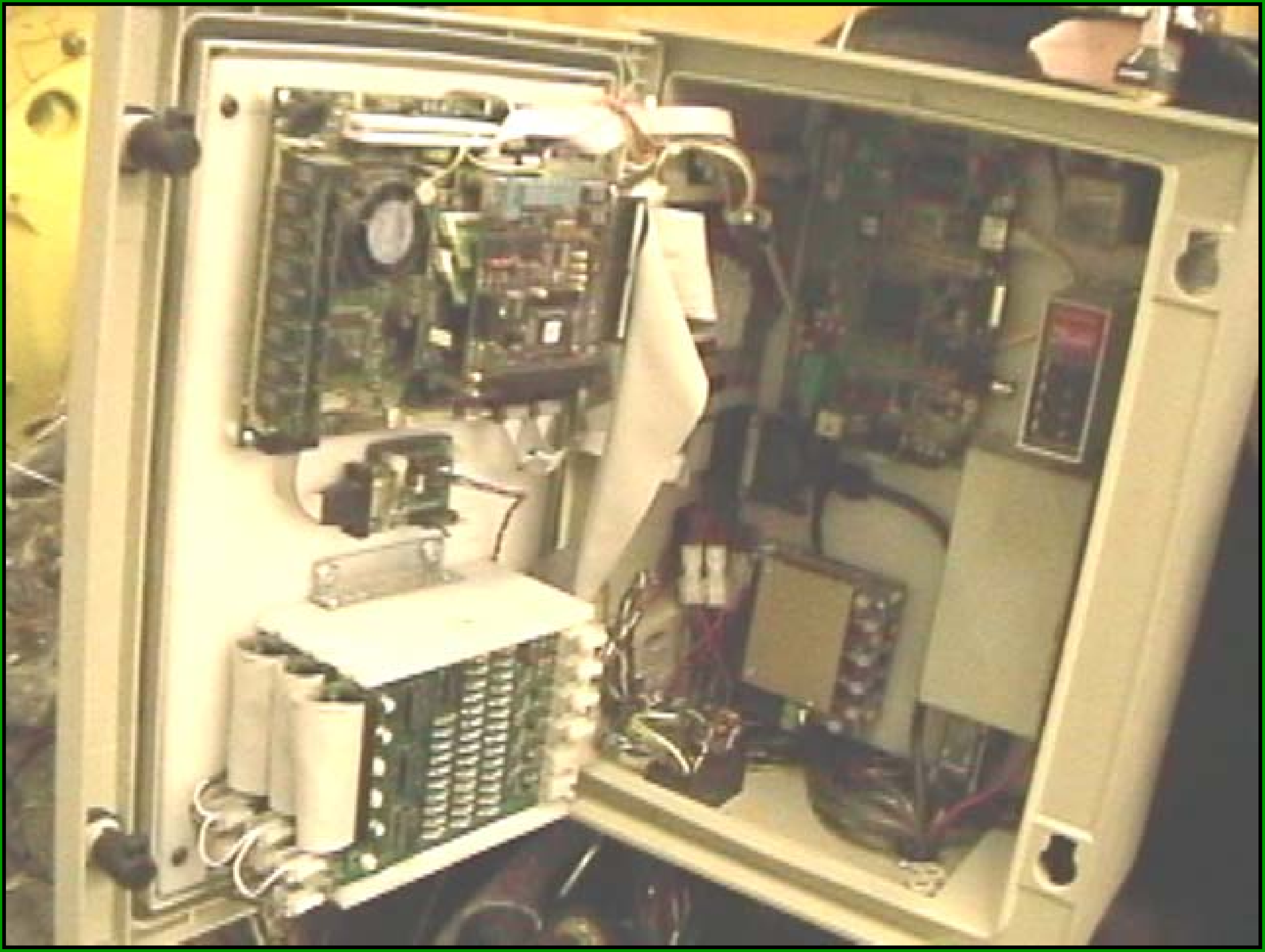
# Sensors


dGPS
Fuel
Compass
Gyro
RPM
Temp
Laser
Steering Angle Sensor

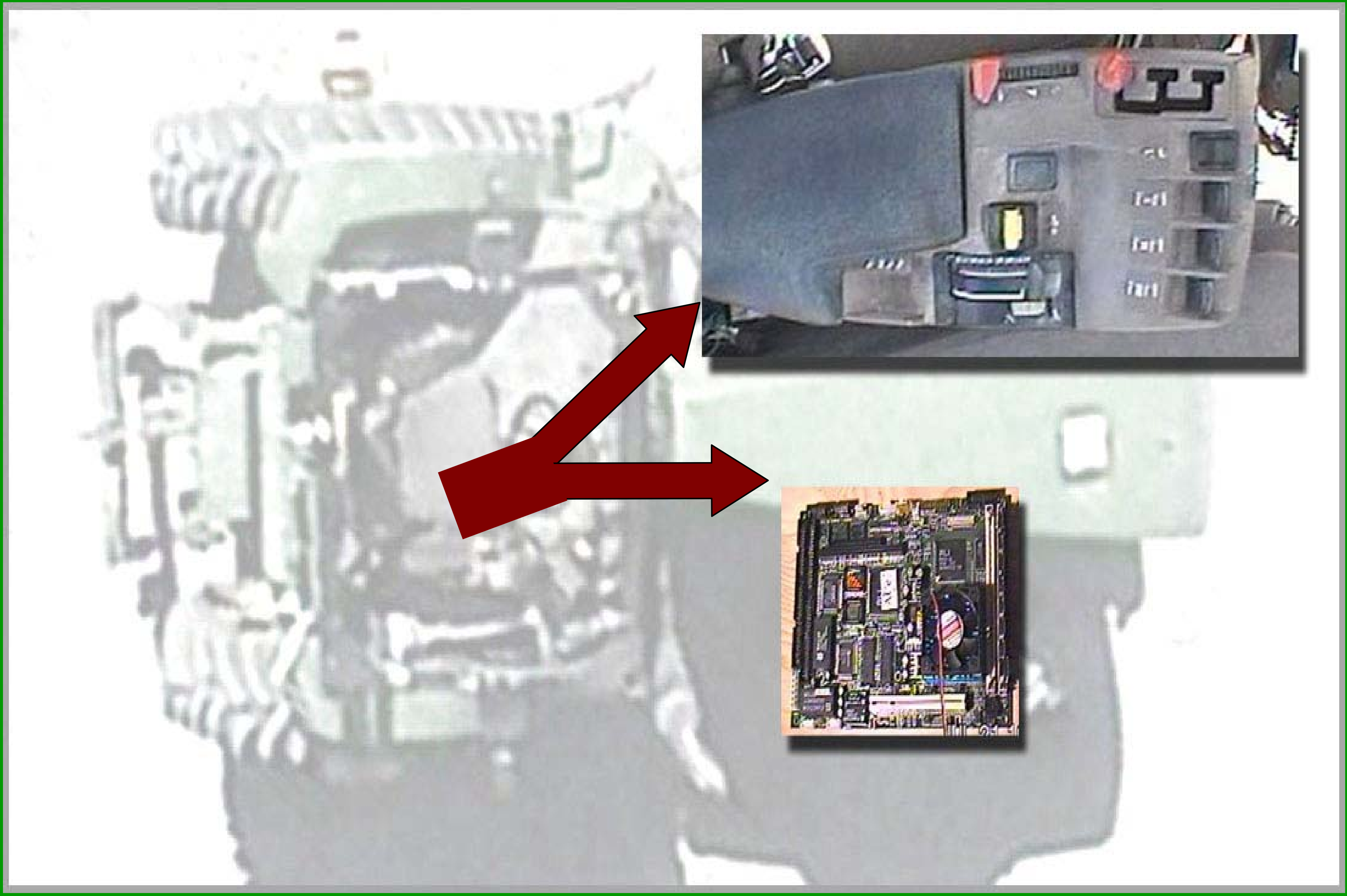
# Vehicle Electronics

## Electronics in Sealed Enclosure

- Computer
- Electronics
- W-LAN
- RF radio
- Power supply
- Electro-hydraulic controller

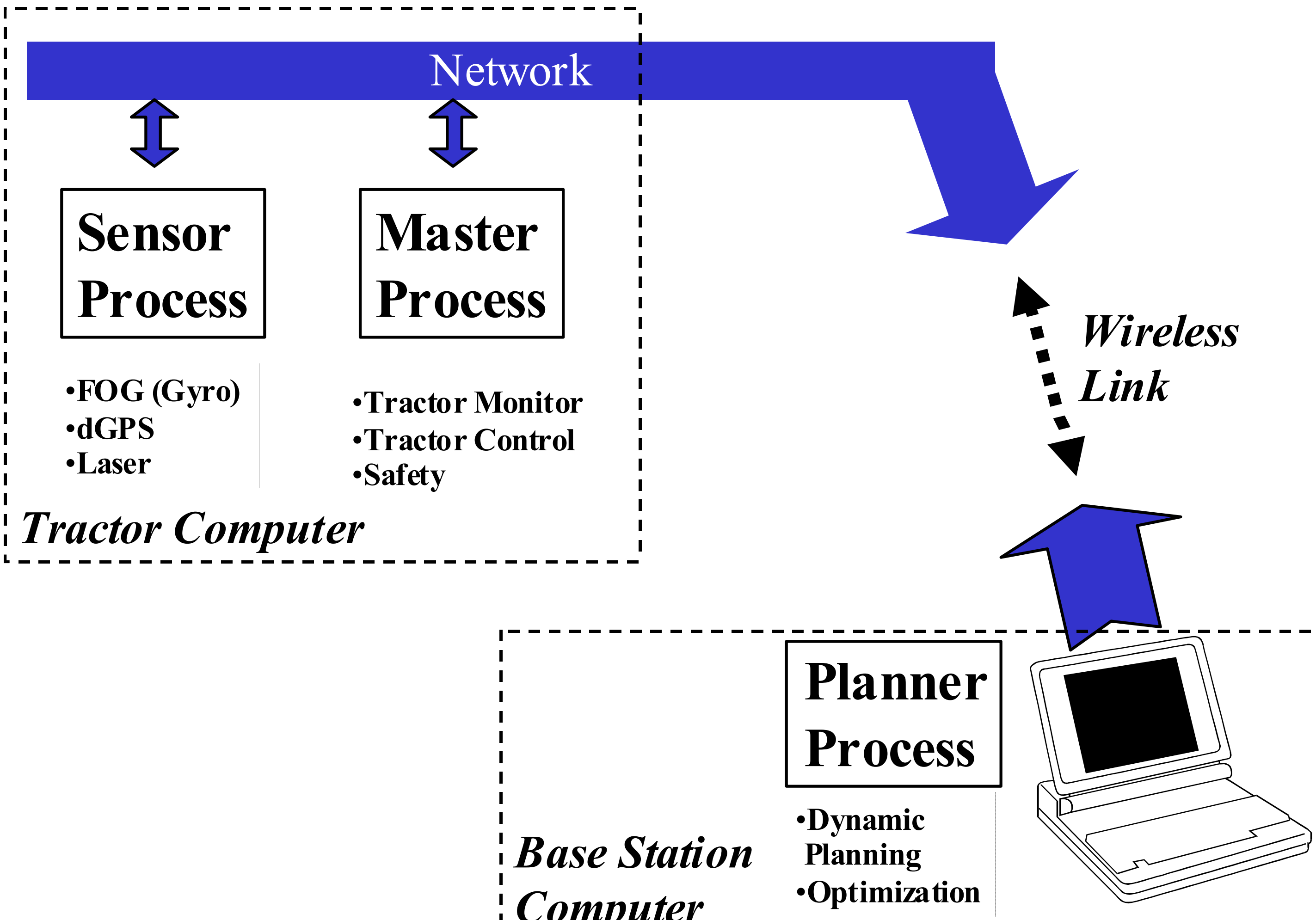


# Tractor Bus Interface



# Computer System

## System Diagram



# Communication

Tractor Status

Mission Directives

Emergency Stop
dGPS Correction

- Wireless network
- Redundant radio

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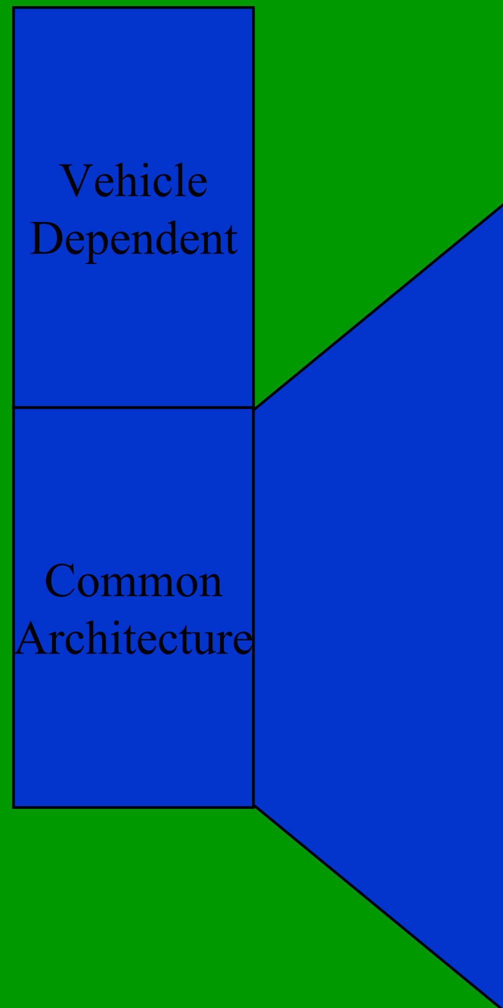
# Software Architecture

- Object oriented design
  (Code reuse)
- Compatible with industry communication infrastructure
- Compliant with industry design processes and standards
- Easily extended to multi-vehicle scenarios

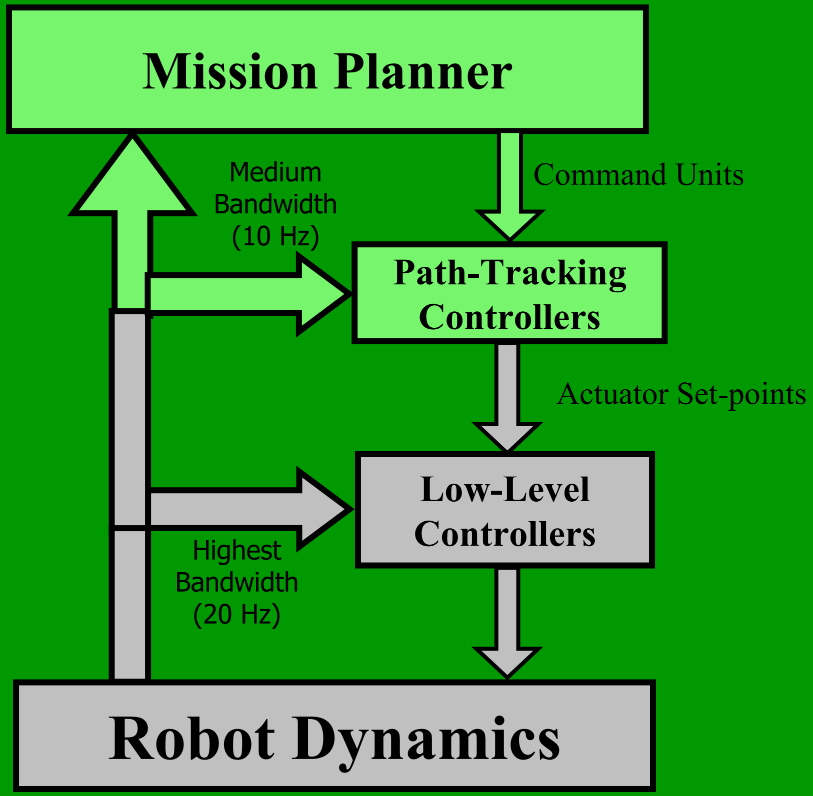



# Onboard Software

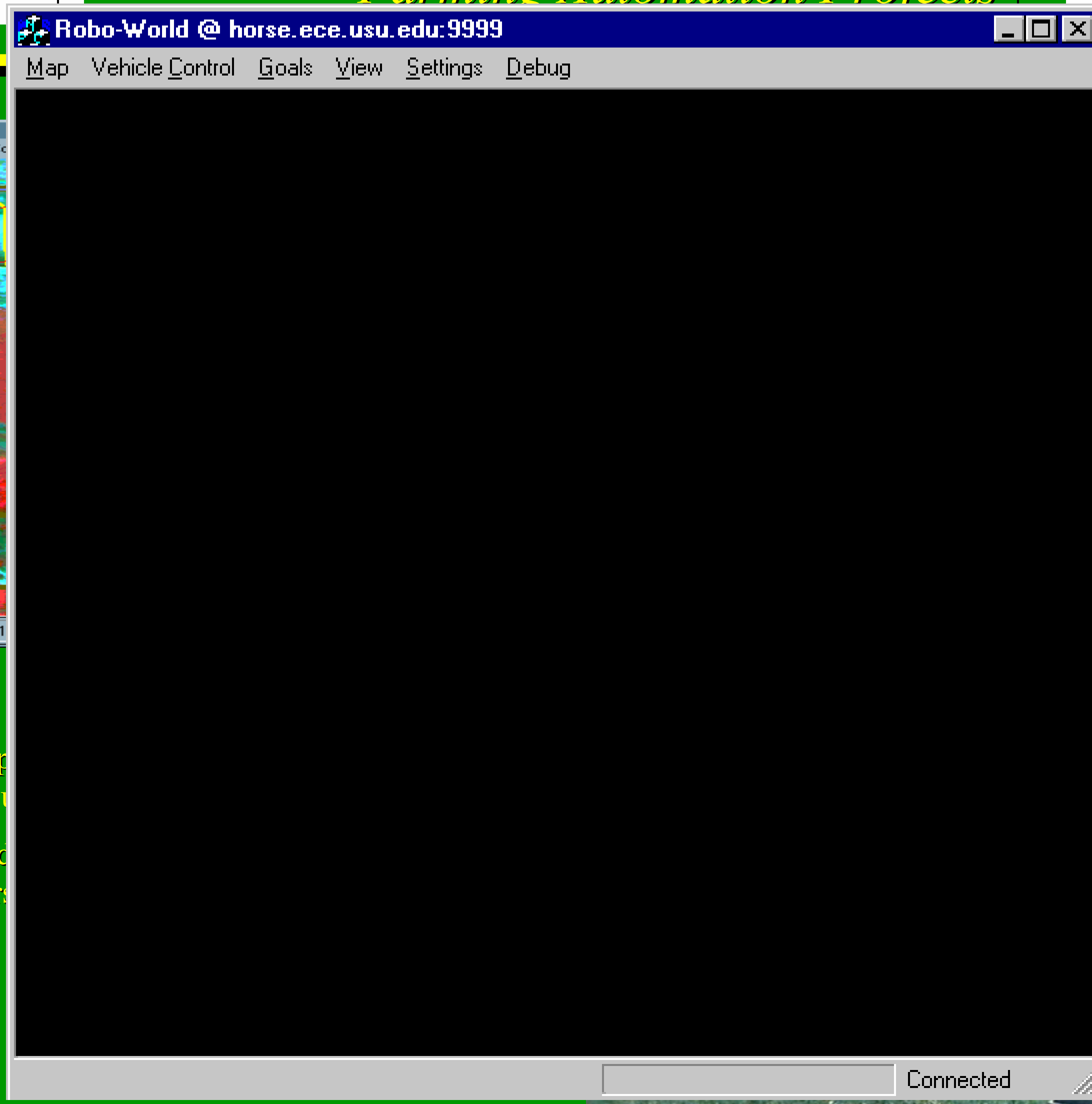
- CSOIS RTOS running over Linux on Intel
- Serial port peripherals

- Commercial automotive operating system with calibration and emulation capabilities (Infineon or Motorola processors)
- J1939 CAN peripherals where possible

# Mission Planning and Control



# Farming Automation Projects

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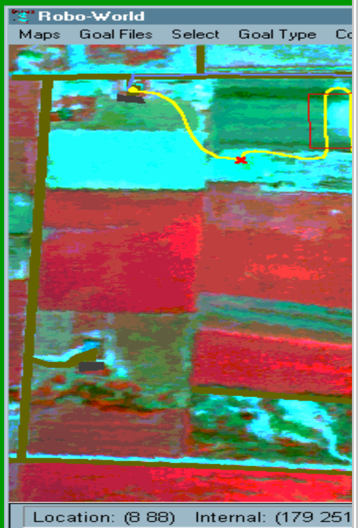
mission and path




- Technology develop
controlled vehicles
- Prototypes equipped
chemical applicator

# Mission and Path Planning

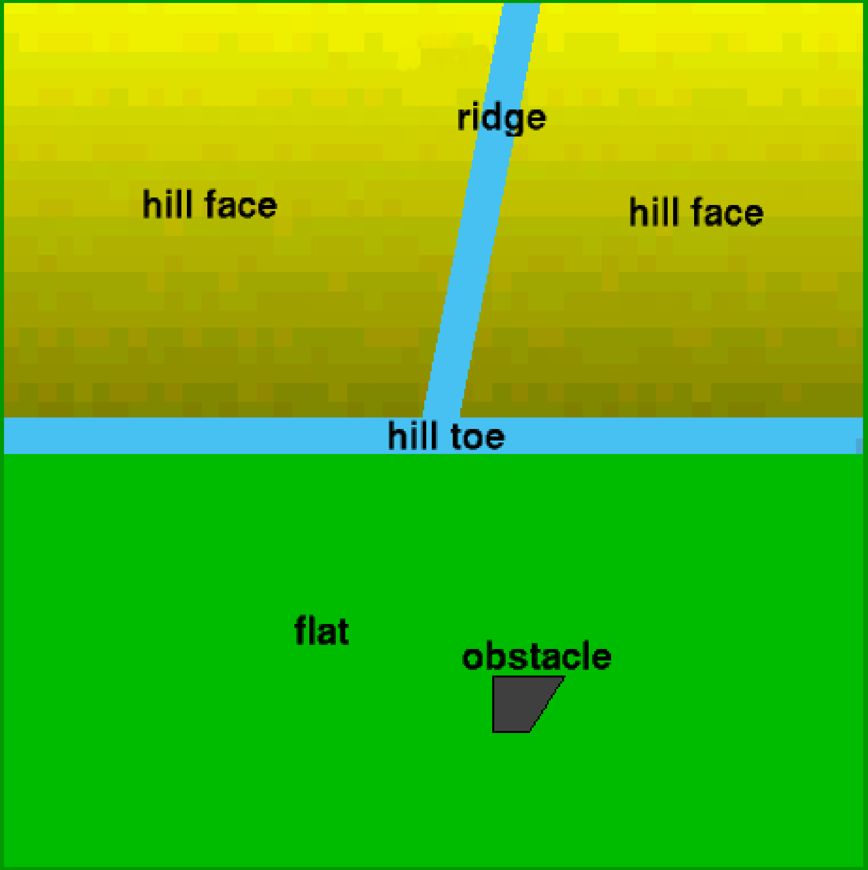
- Enable high-level task-centered control, using goals input by the user:
  - **Visit** tasks (photograph, take sample etc)
  - **Sweep** tasks (treat or sample rectangular region)
  - Field **harvest** task (arbitrary region & coordinated off-loading)
- Optimize overall task achievement
- Dynamically adapts to environment and task conditions
  - Vehicle break-down, obstacles
  - New tasks during execution

# Approach

- Represent alternative paths as a dynamically built network (graph)
- Costs of paths determined by cost model based on terrain types and vehicle characteristics (costs of turning, etc.)
- General optimization of paths (shortest path)
- General optimization of task assignment (travelling salesperson problem)
- Also optimize over possible:
  - sequence of multiple fields
  - paths in each field

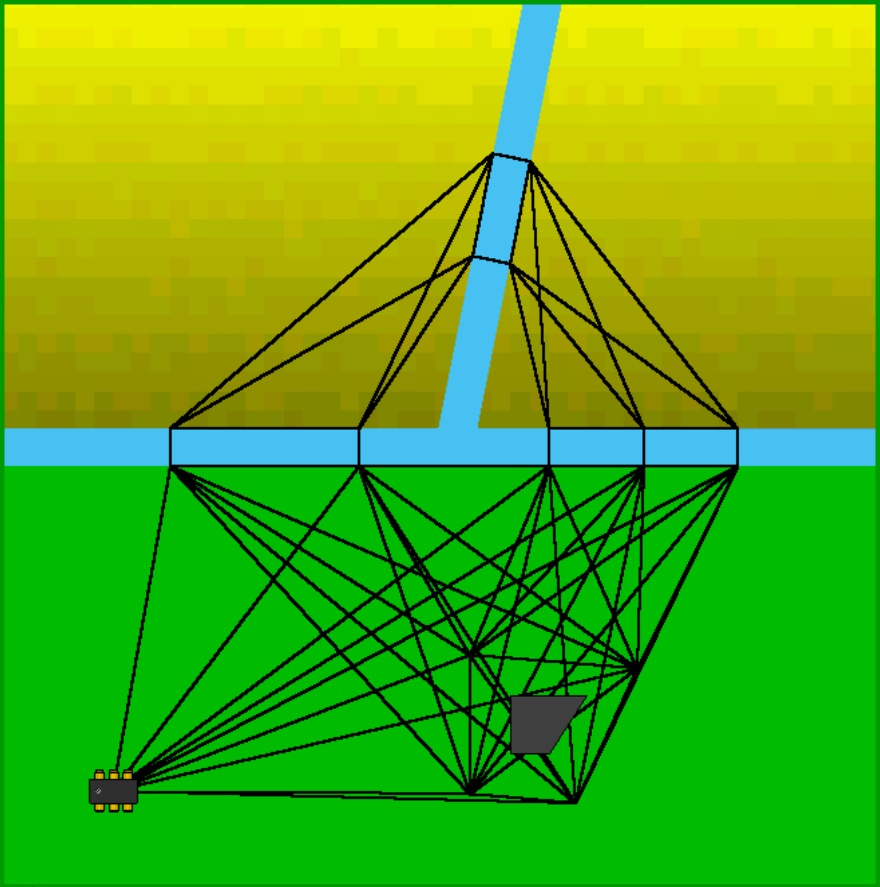
# Example: Mobility Graph

## Map Characterized by Terrain Objects



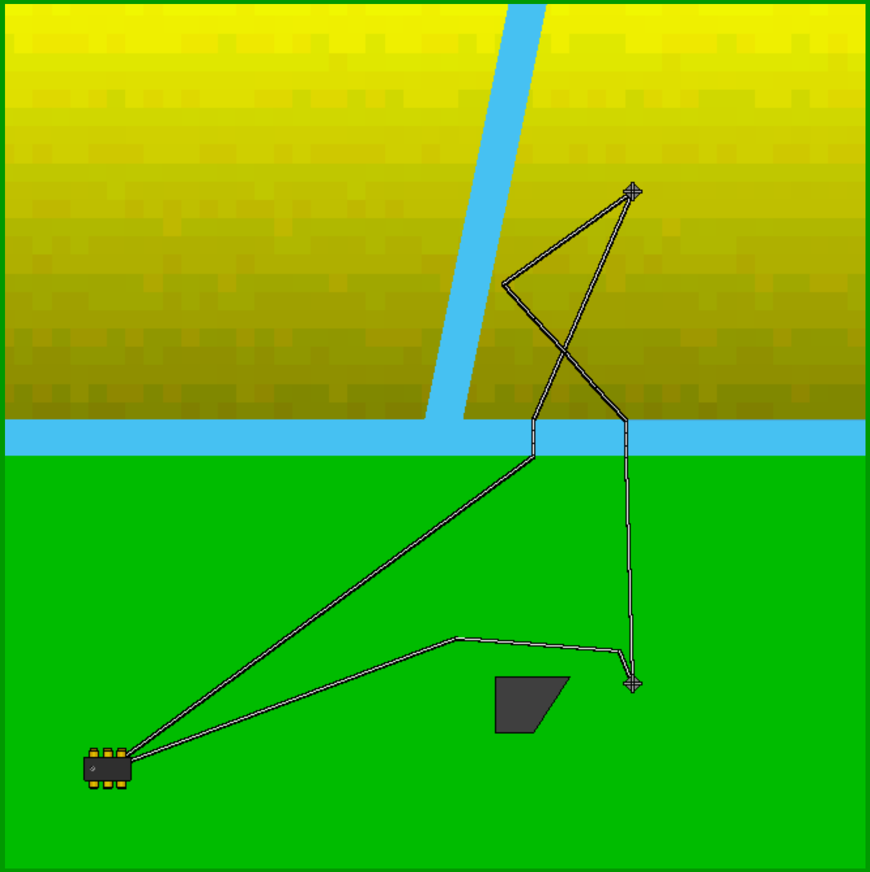
# *Example: Mobility Graph*

## *"Reasonable" Paths Through Terrain Objects*



# Example: Mobility Graph

## Planned Path with Two Visit Goals



# *Mission and Path Planning Extensions*

- Utilize roads, depots, and refilling stations in planning
- Command right and left spray nozzles independently
- Dynamic re-planning to refill the sprayer
  – Refill and resume from where it left off
  – Refill and re-plan the entire mission

# Path Tracking Control

**Steering commands are computed from orthogonal path deviations**

**Steering corrections are made until tractor is on and following the desired path**

# Path Tracking Strategies

- Fundamental for behavior generation
- Can be broadly classified into two groups
  1. Time trajectory based (temporal)
     - Desired path is parameterized into time-varying set-points
     - Locus of these set-points follow (in time) the desired trajectory (in space)
  2. Spatial
- We have implemented a variety of each type of controller on our robots, but have found spatial techniques to be better

# *Spatial Path Tracking Control Law: The ε-Controller ($C_ε$)*

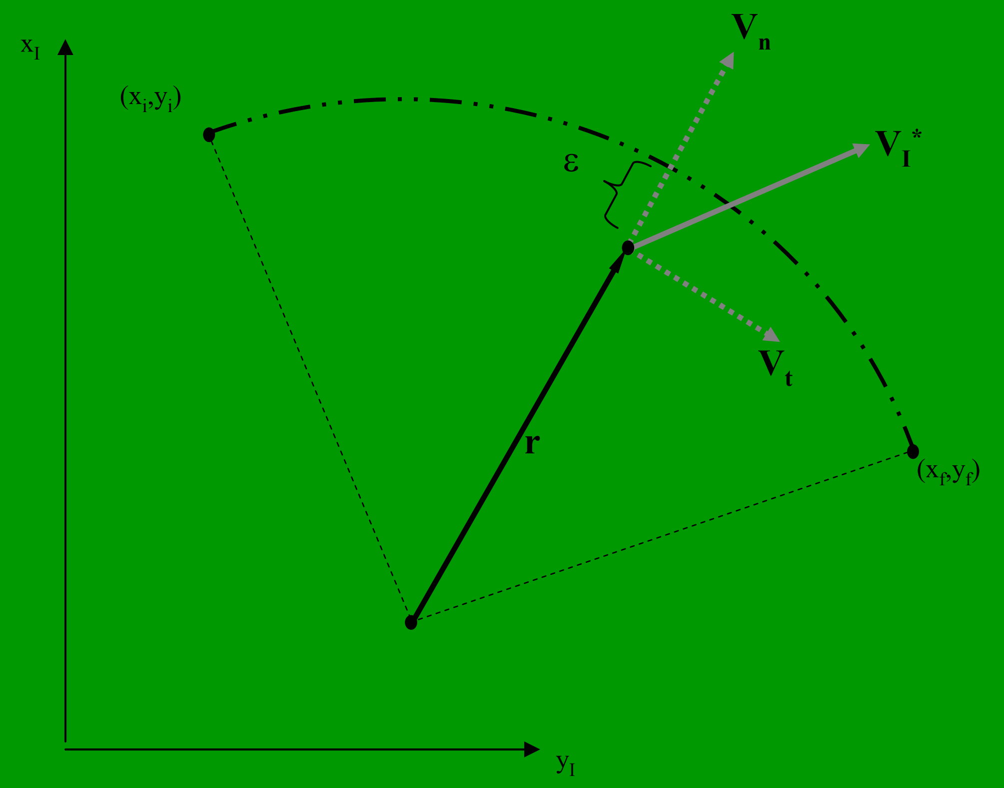
- Based completely on static inputs – the geometry of the desired path
- All desired paths are composed of either arc or line segments
- Real time variations of the desired speed ($V_d$) along the paths are allowed
- Uses only the current position ($\chi$) of the robot as the feedback variable
- References to time are avoided in the controller development

# The Control Strategy

- Compute separately the normal and tangential velocities:

$$||\mathbf{V}_n|| = f(\varepsilon)$$

$$||\mathbf{V}_t|| = V_d - ||\mathbf{V}_n||$$



# User Interface

# Orchard Spraying Example

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# Safety Scenarios

- We need to halt the vehicle if:
  - Tractor leaves field boundary or deviates from path
  - Unavoidable obstacle within given threshold
  - Communication disrupted or lost
  - d-GPS dropout corrupts position information
  - Computer failures occur
  - Emergency stop button
  - Vehicle halt computer command
  - Mission complete
- Some safeguards include
  - Sensor suite for detecting vehicle path obstructions
  - Redundant radio link to protect against wireless communication dropout or corruption.
  - Use of odometry to complement/supplement dGPS

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# Awareness Issues

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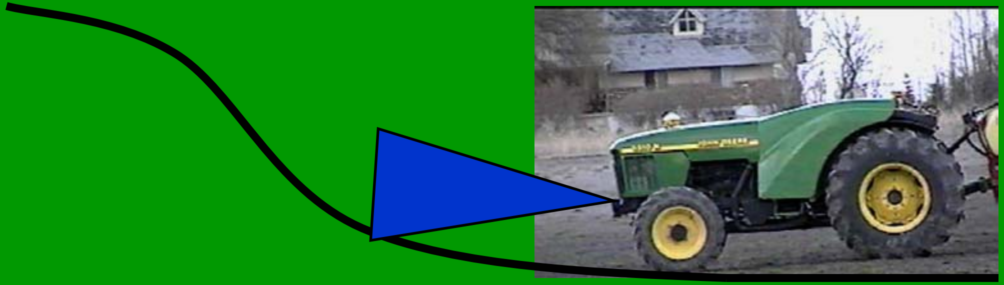
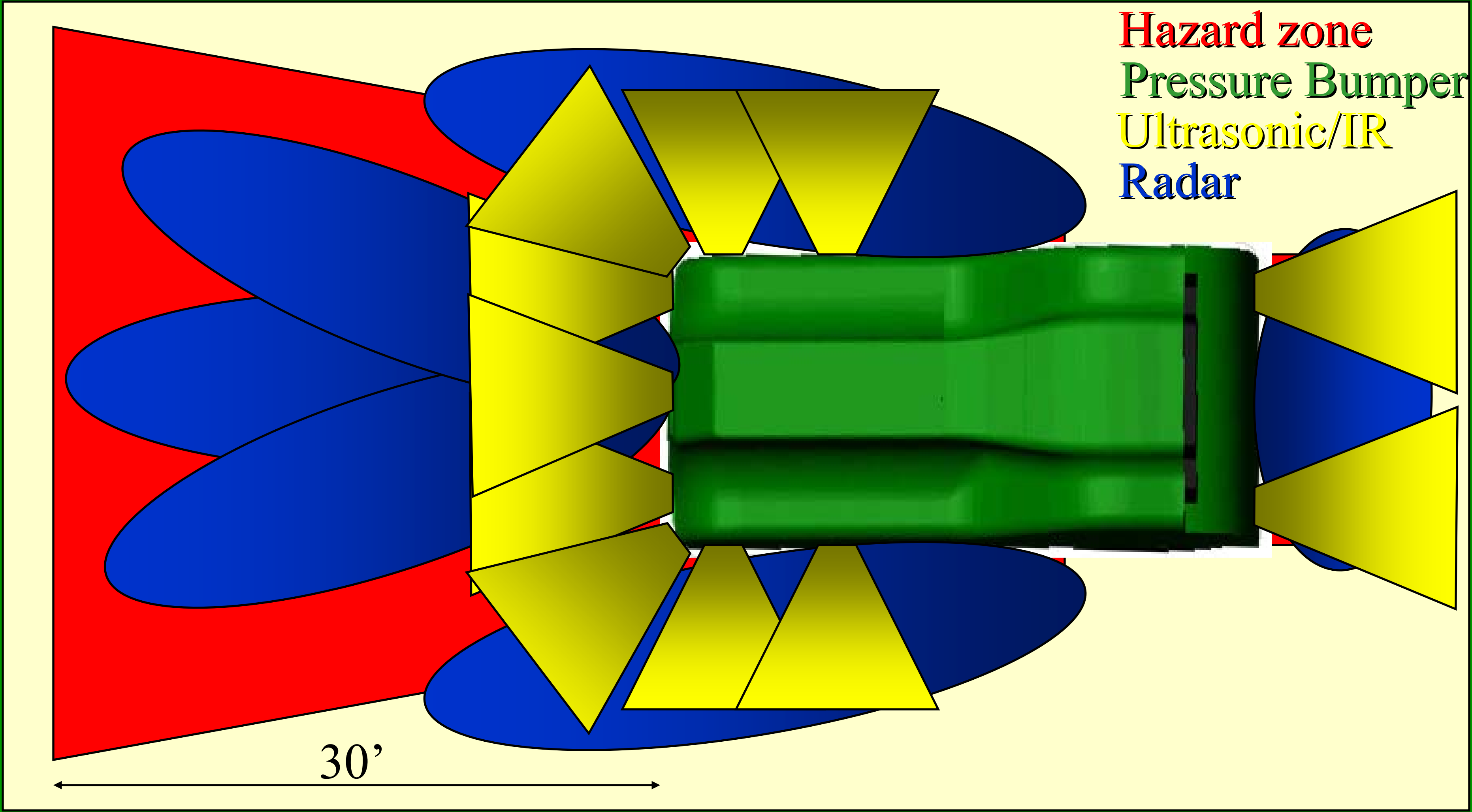


# 3 Tiered Proximity Detection



# Operational Lessons

- 200+ hours in the McMullin Orchard
- 800 acres of cherries, peaches, apples, & pears
- Orchard owner/manager is very cooperative
  - Cost is the key to owner acceptance
  - Safety is important
  - No problem accepting the technology if it works
  - Very interested in EPA report generation
- Localization (where am I?) is a key issue

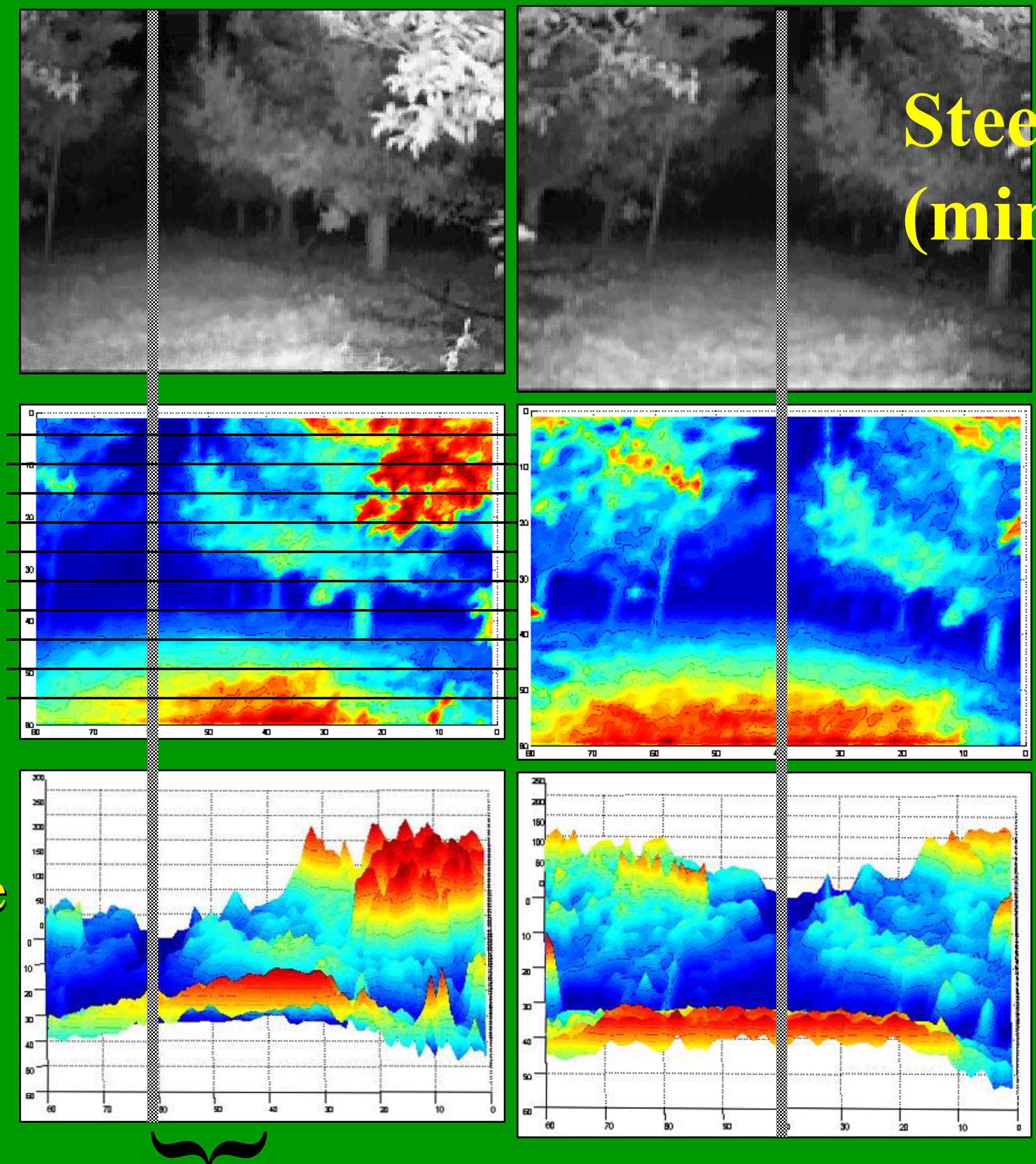
# Localization Issues

- Poor Radio Communications
  - High power antennas
  - Lower Frequency
- Intermittent GPS
  - Dead-reckoning
  - Reactive positioning
    - Hole-following with range data
    - Row sensing with laser

Infrared

Range map

3D range Map



Error

## Steer to the hole (minimize error)

**Pro:**

- Sensor independent
- Fast
- Simple

**Con:**

- Environment dependent

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