SAND2013-6287C

WATCHDOGS

Project Mentor: Bob Mata, Senior Manager, 6620

Original Objective

Develop an autonomous swarm of vehicles capable of:

- Providing surveillance for a section of the Kirtland Air Force Base
- Patrolling in an unpredictable manner
- Reporting significant anomalies to a central outpost

CONCEPT DESIGN

Wandering
Autonomous
Tactical
Clever
Heavy
Duty
Operatives
Giving
Surveillance

The Mechanical Team

Designs the mobile platform that transports the sensors.

Design Process

- Generated concepts: legged, tracked, and wheeled vehicles
- Selected one concept: buy and modify an ATV
- Refining design: Make the Can-Am Commander autonomous

Can-Am Commander Electric

Non-Pneumatic Tires

A flat tire is a significant risk. The probability of occurrence is high and it would require human interaction to fix. Non-pneumatic tires, made of a rubber tread around a polymer web, will continue to function even after being punctured.

Vehicle Dynamics

Allows the vehicle to avoid dynamic instability and deal with sudden changes in the environment.

- **CarSim -** Simulating the vehicle on the terrain allows us to identify paths that the vehicle can and cannot traverse.

- **On-Board System -** Real time calculations adapt for objects and environmental conditions unseen in simulations. For example, in a rain storm the coefficient of friction changes rapidly rendering the simulated model invalid.

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The Mechanical Team

Drive By Wire

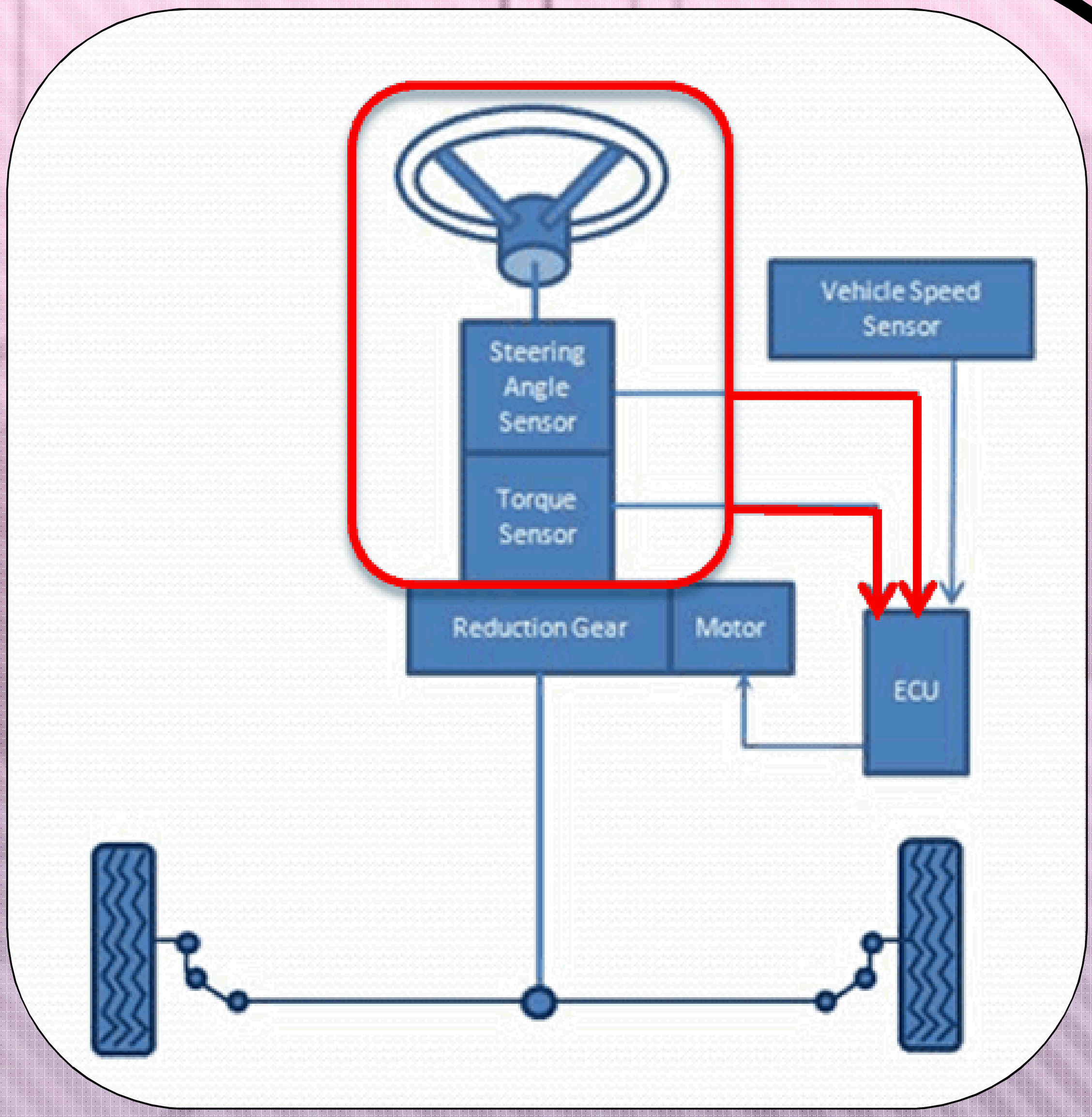
To make the vehicle autonomous, electronic controls will replace the driver's physical movements.

Accelerating - Use the existing intelligent throttle control

Braking - Push on the master cylinder with a linear actuator and measure the pressure in the brake lines to create a feedback loop.

Steering - Send inputs to the existing electronic power steering system to turn the wheels.

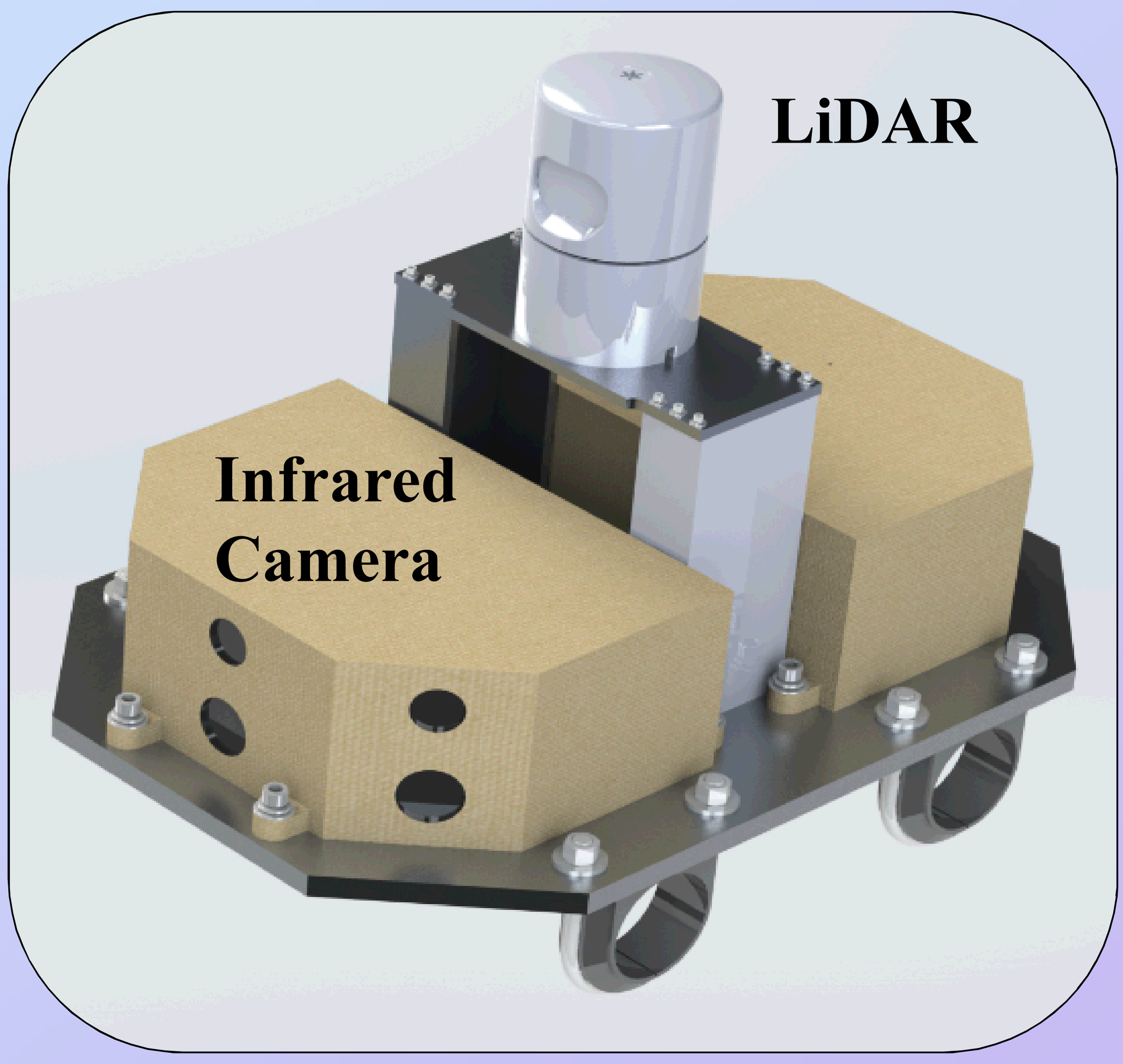
Shifting park to drive - Connect to the existing sensor and controller.



Attach the Sensors

The sensors and other electronic equipment must be attached to the vehicle where they will be most effective.

- **LiDAR and IR cameras -** Designed a mount to attach these key sensors to the top of the Commander's chassis.



- **Radar -** Mount the short range radars on the trailer hitch and the front winch.

- **On-board computer -** Protect the computer from the elements while keeping it cool using liquid cooling and fans.

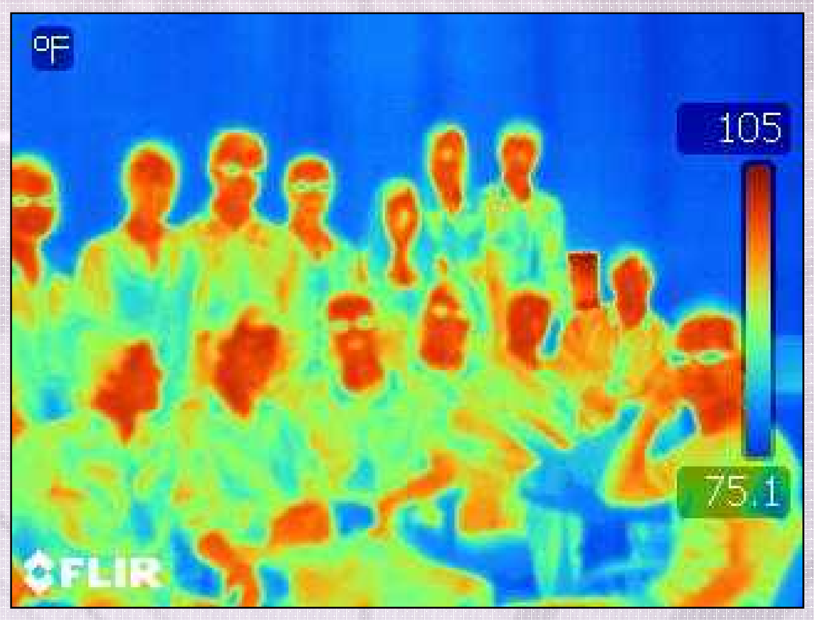
The Electrical Team

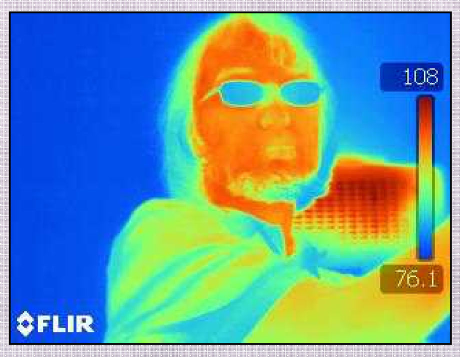
The electrical team is tasked with the responsibility to select the different sensors needed for the UGV, determining the power source used for the vehicle, determining how the vehicles communicate with each other and the base station, and selecting the on-board computer system.

Thermal Camera

Captures heat signatures and translates to imagery.
Used for human detection system.

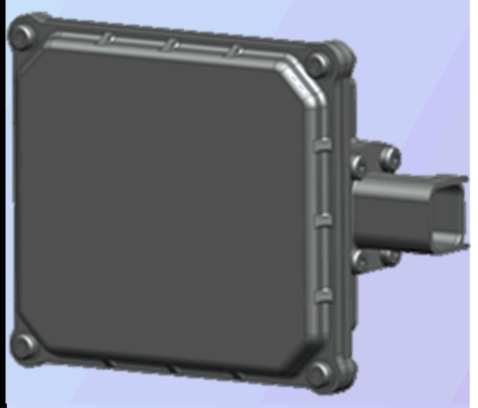
Capabilities:
- Full 360 degree HFOV
- Weather-hardened
- 1920x480 stitched image resolution
- 100m human detection range

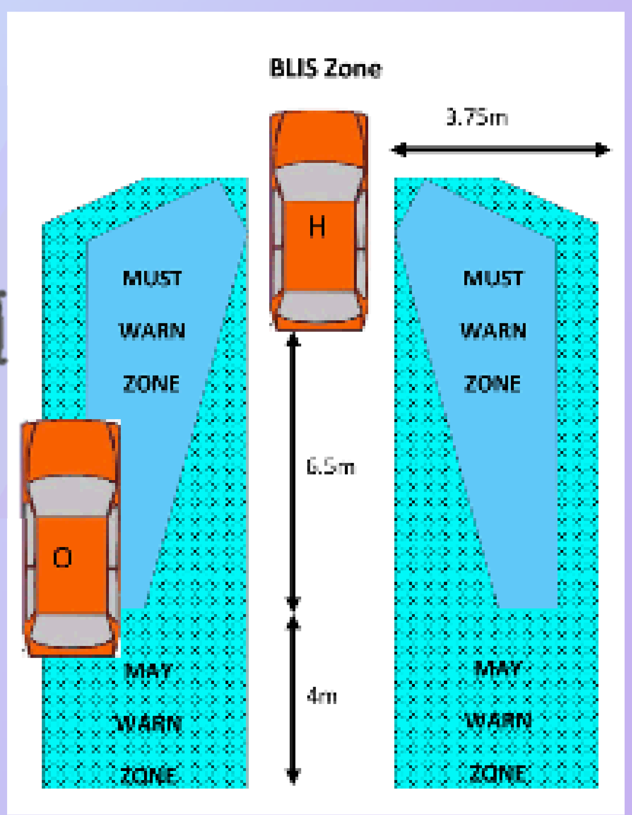




RADAR

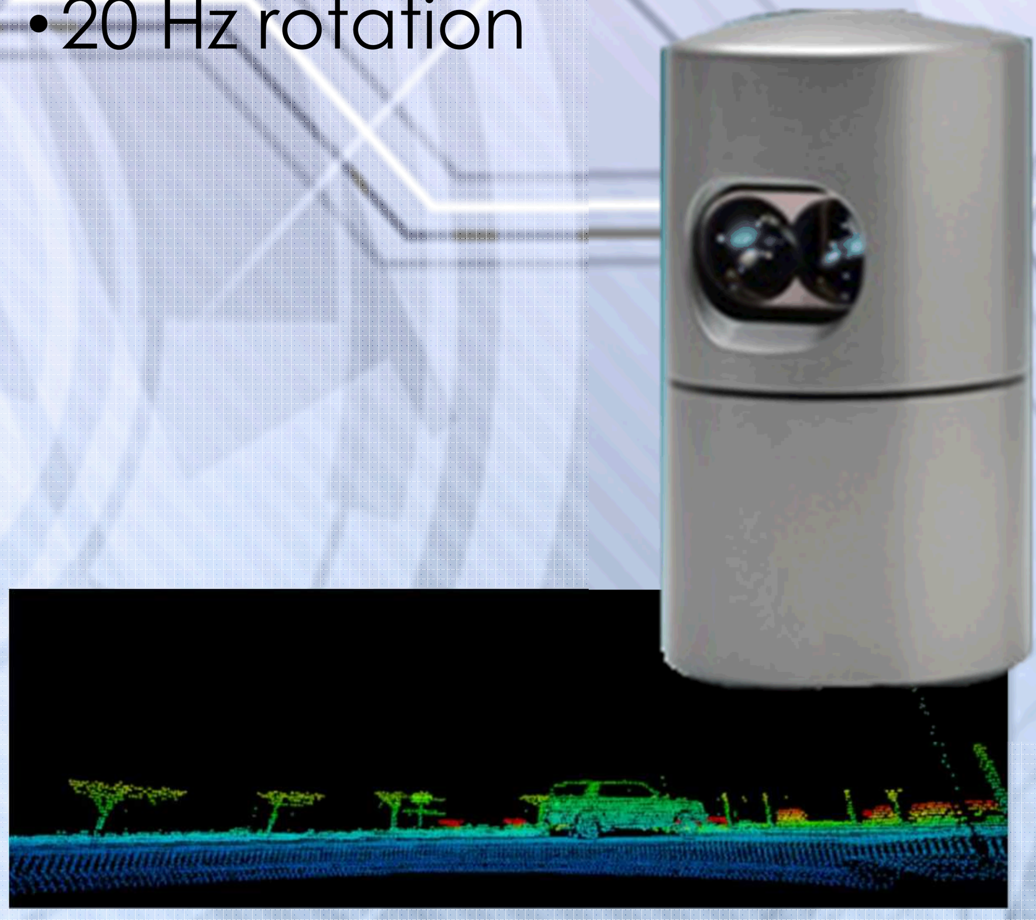
Short range radar mitigates the blind spot of the LiDAR. Used for obstacle and collision avoidance.
Capabilities:
- Rear and side detection
- 0.5m minimum range
- 80m maximum range
- +/-75 degree horizontal field of view each
- 76.5GHz





LiDAR

3D mobile mapping for obstacle avoidance and autonomous navigation.
Capabilities:
- 360 degree
- 700,000 data points/s
- 905nm wavelength
- 3D
- 32 data collecting lasers
- 20 Hz rotation

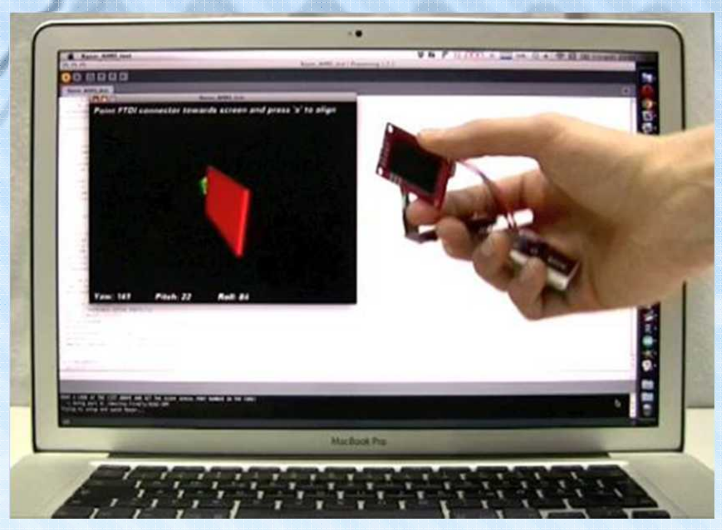


Unattended Ground Sensors

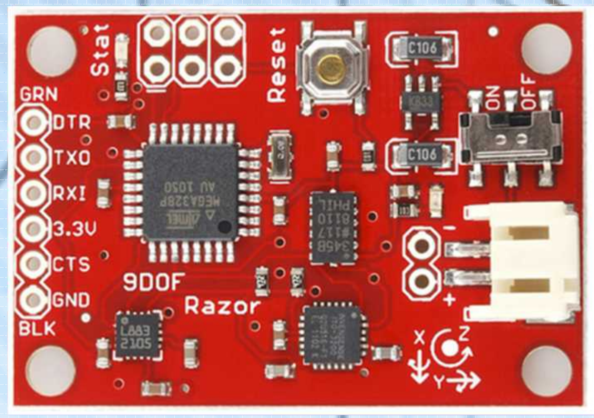
Alert autonomous vehicles to possible threats for further investigation by seismic activity
Capabilities:
- 1 mile range
- Perimeter placement
- Signal processing distinguishes activity

IMU

Measures heading, acceleration, and orientation



Capabilities:
- 3 degree compass
- 3 degree accelerometer
- 3 degree gyroscope



The Electrical Team

Red Teaming

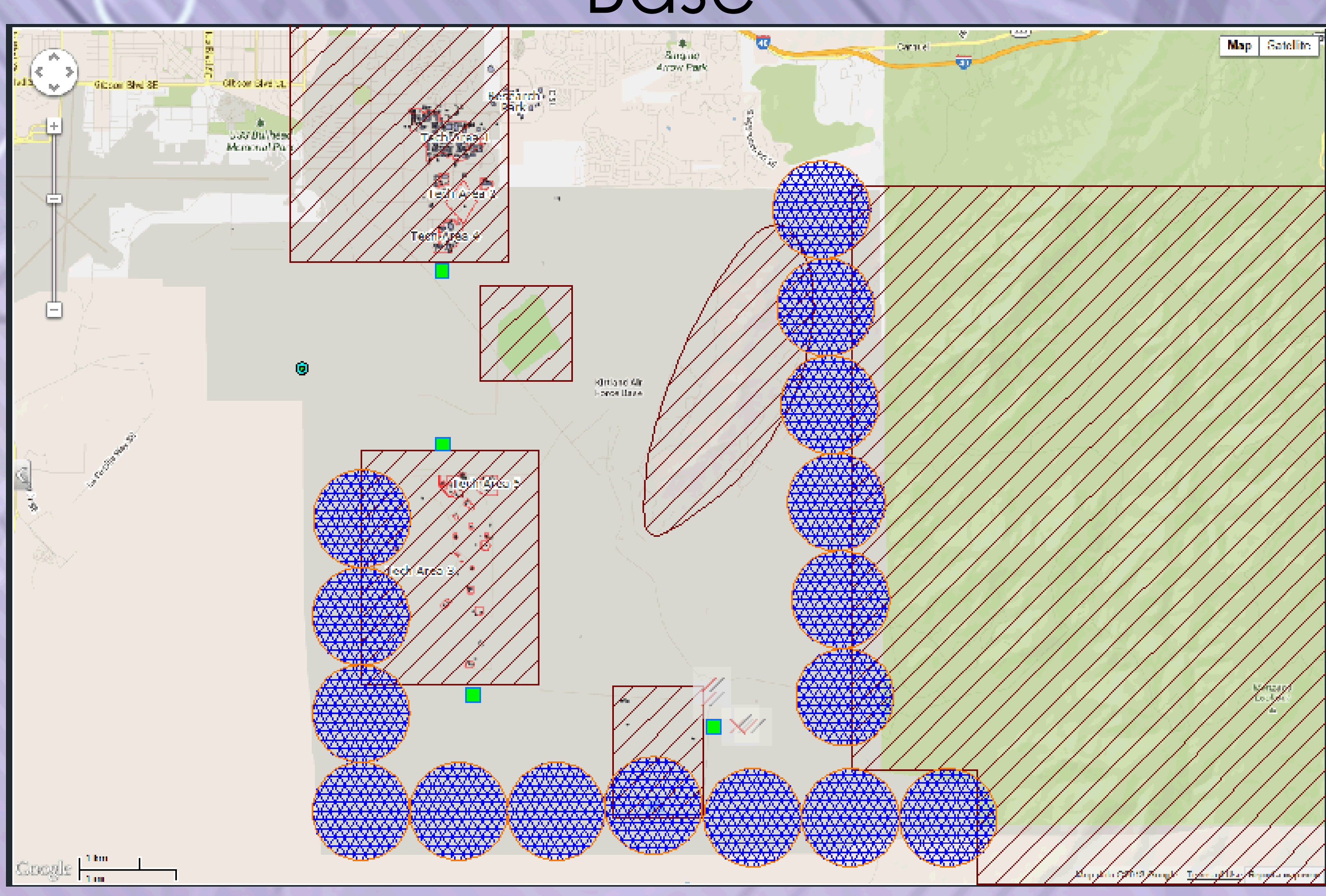
Troubleshooting our system to decrease threats to our vehicle

Issues found:
- No view of Z-plane
- Frequency jamming
- Reverse engineering of system
- Network tapping
- Rogue agent

Solutions
- Frequency hopping
- Electrical potting
- Encryption
- Periodic check-ins
- Tripwire alerts

Land Map

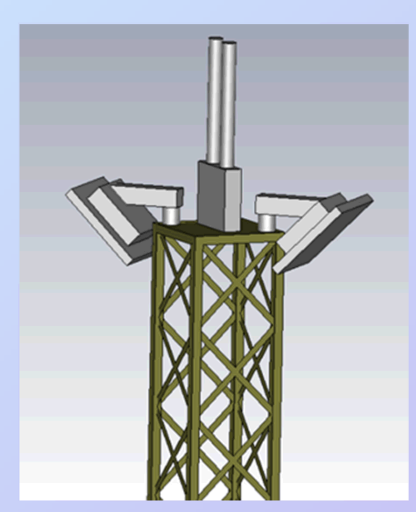
Area map of Kirtland Air Force Base

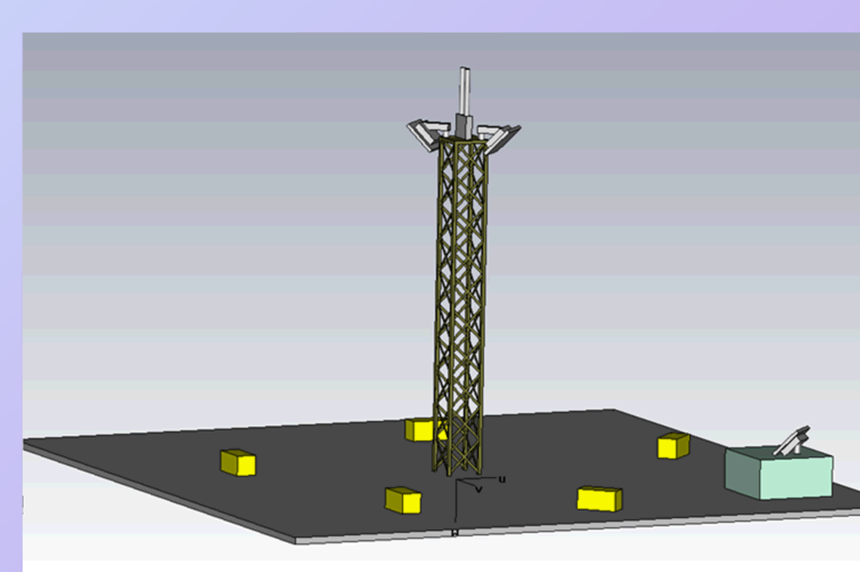


Telemetry

Communication between the vehicles and the command center is important, especially during a threat detection.

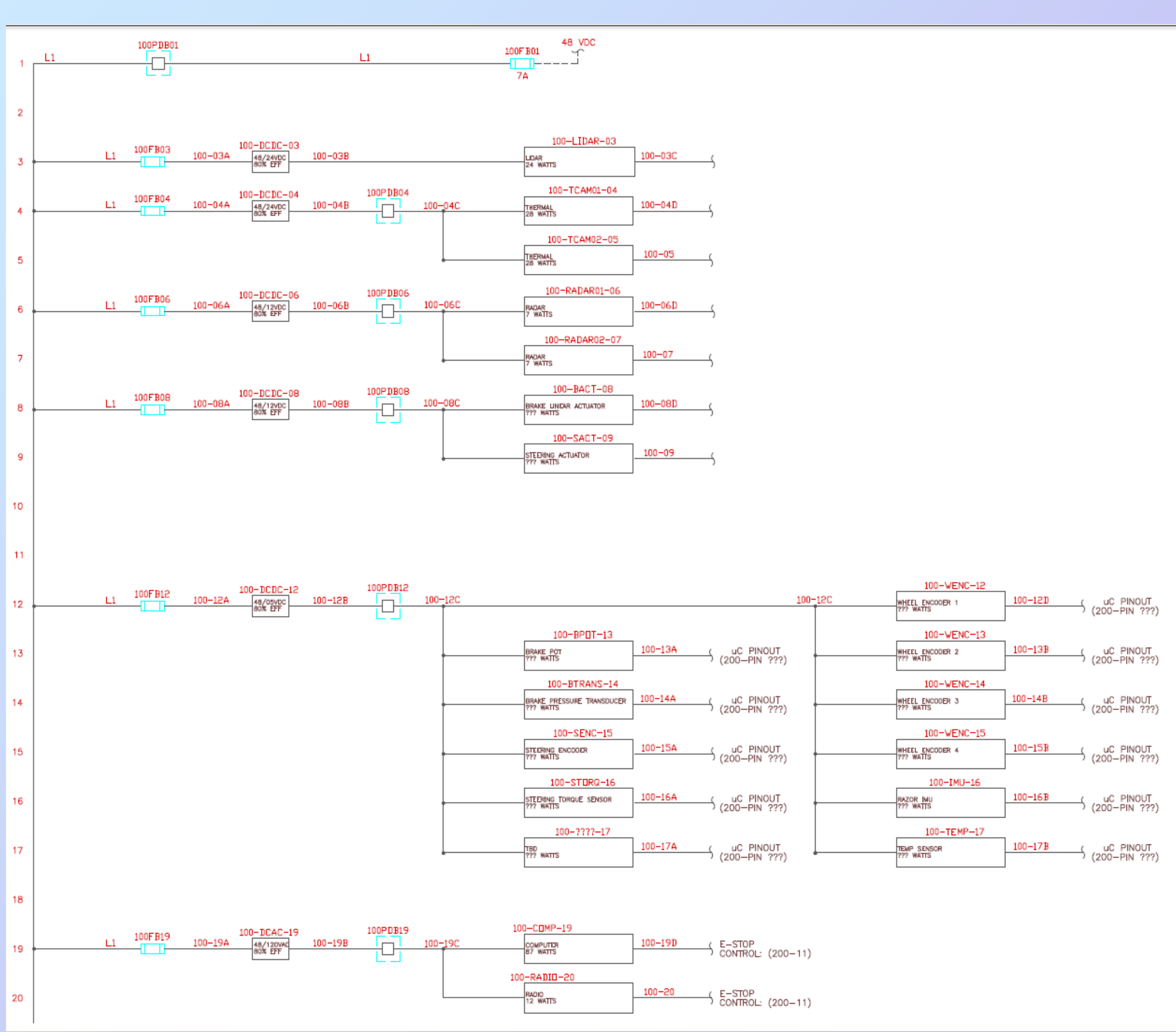
Capabilities:
- Point to multi-point
- Directional antenna on vehicle
- 2x directional + 1 Omni on command tower





Power System Layout

Main power source is 48VDC, which is split to power to the entire system.



Plugless Power

Wireless magnetic induction allows for easier implementation of autonomous charging

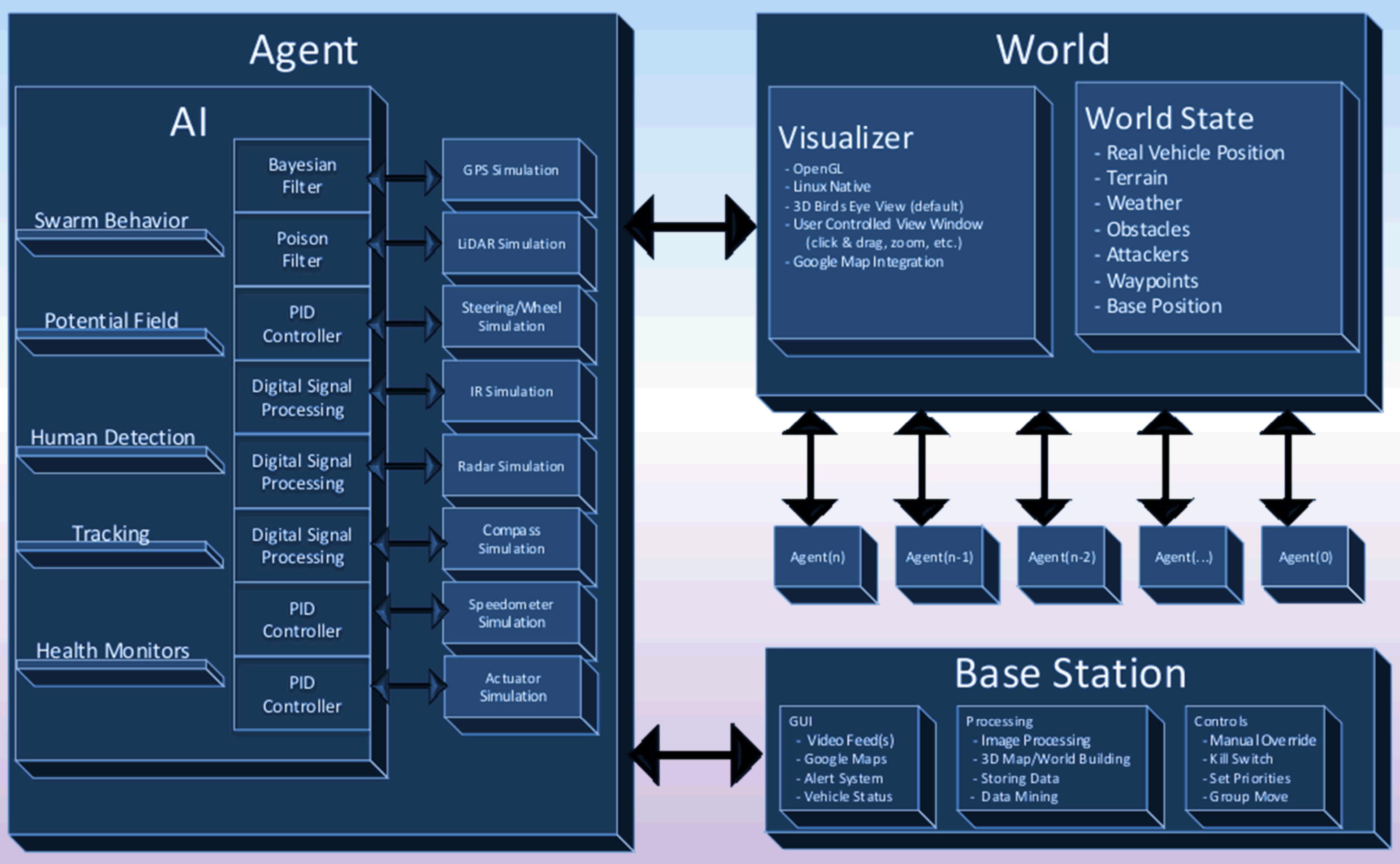
Capabilities:
- 240VAC charging
- Wireless
- Level 2 charging
- Available for ATV by 2014

The Computer Science Team

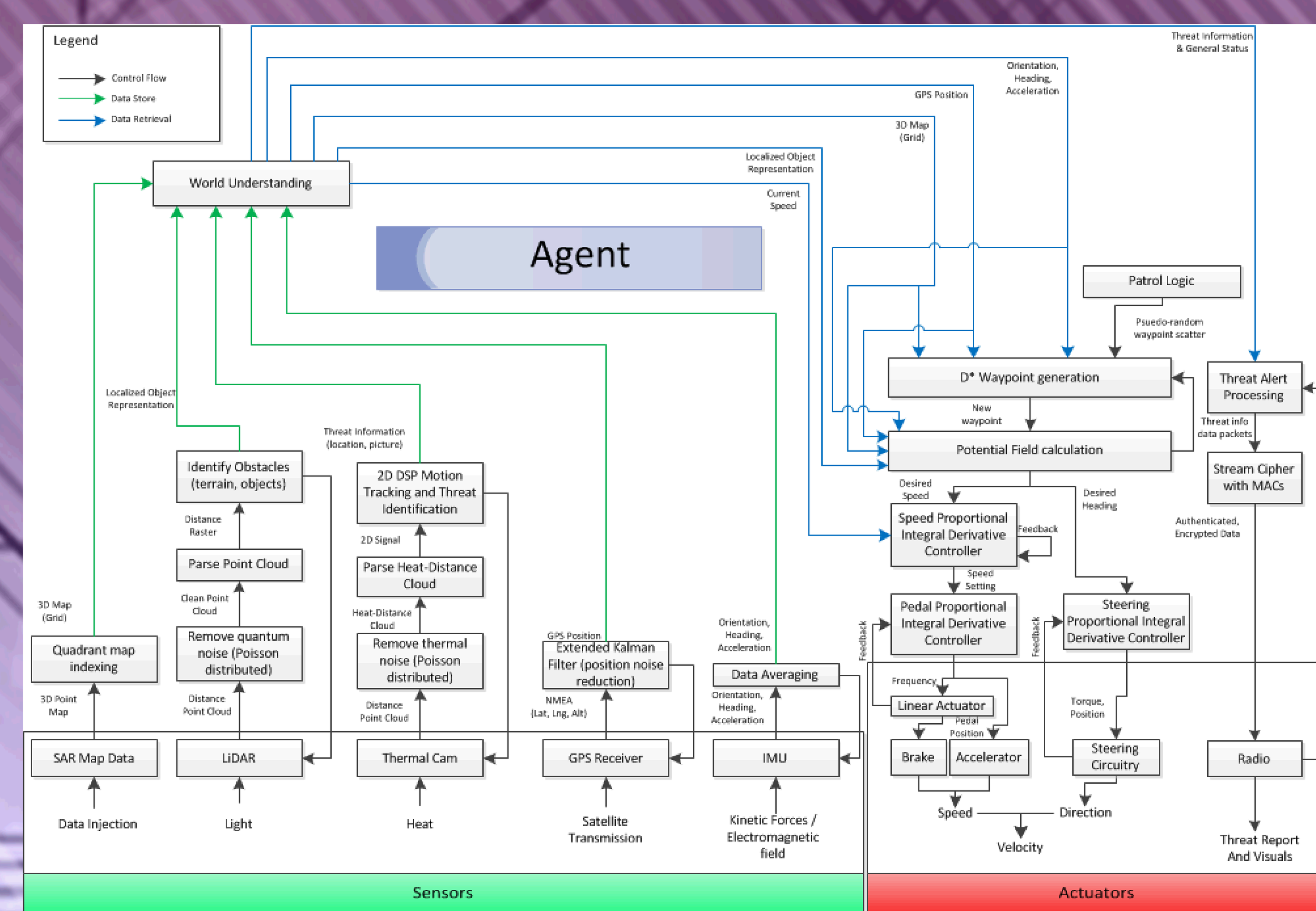
Software Architecture

The iSAFE software team was tasked with planning and developing the software for an Autonomous Surveillance Vehicle. We created a simulation framework to enable early development (pre-hardware) and to facilitate testing later. Virtual sensors and actuators, smoothing of motor movement, and basic robot navigation have been implemented as well. We expect development to be complete by the end of Summer 2015.

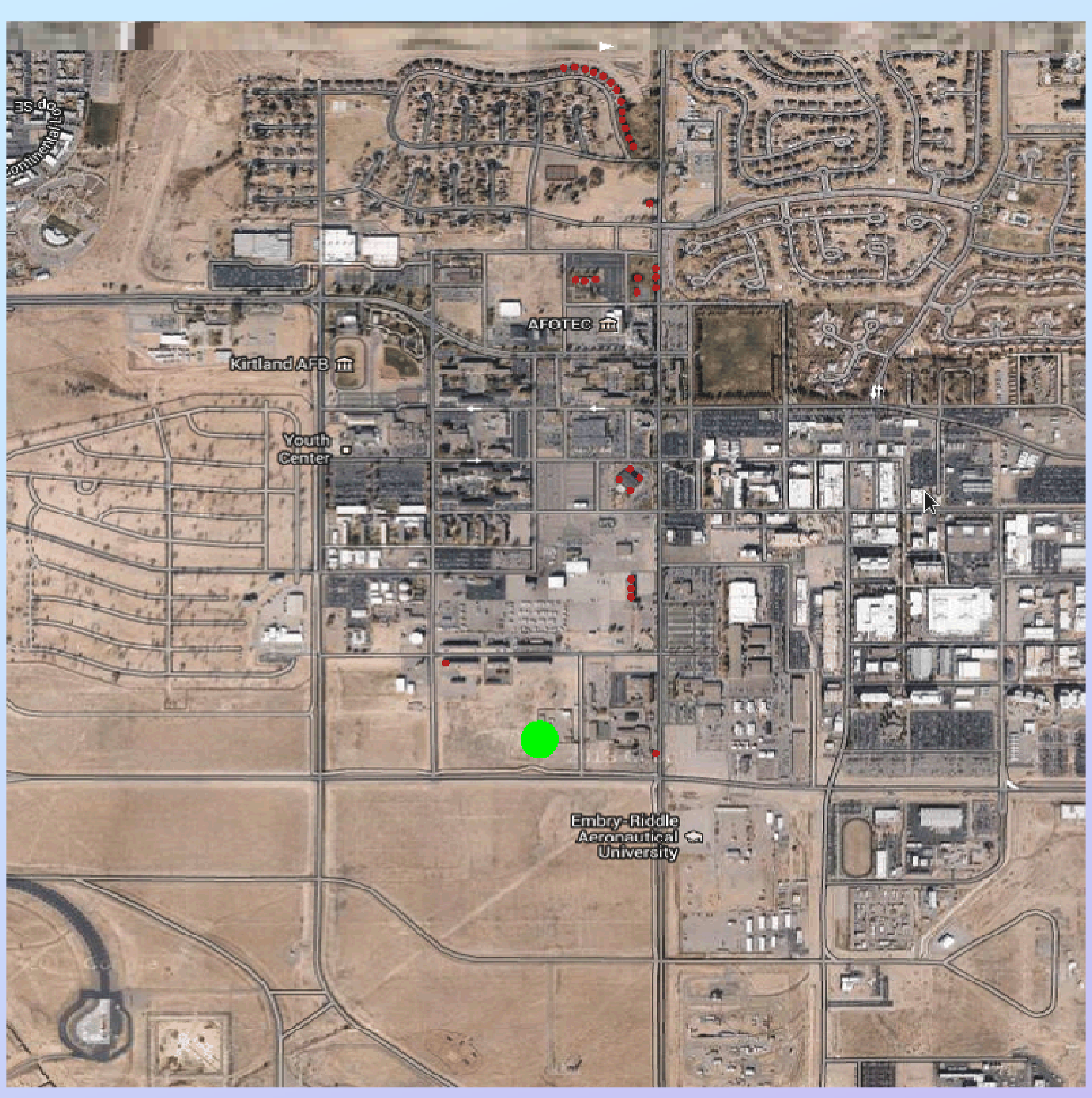
Code Structure



Control Flow



Simulation



Visualization

- 3D aerial view visualization
- Waypoint and obstacle display
- Limited Google Maps integration

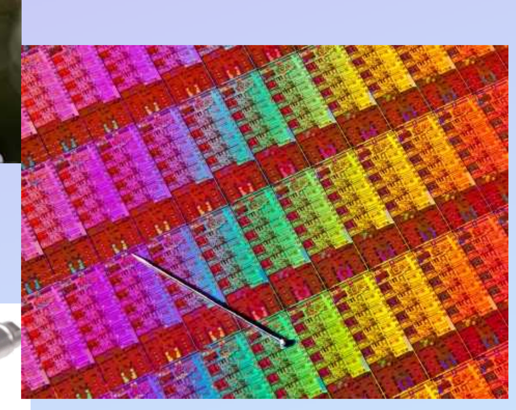
Simulation

- Provides input to virtual sensors
- Performs actuator simulations
- Contains virtual world

Hardware Visualization

Sensors

- Simulate interface between on-board computer and sensors
- Duplicate sensor output format
- Add realistic noise based on statistical distributions
- Integrate with simulation



Actuators

- Simulate interface between on-board computer and actuators
- Simulate timing, speed, and force
- Simulate error scenarios (wheel slip, actuator slip, external forces, etc.)
- Integrate with simulation

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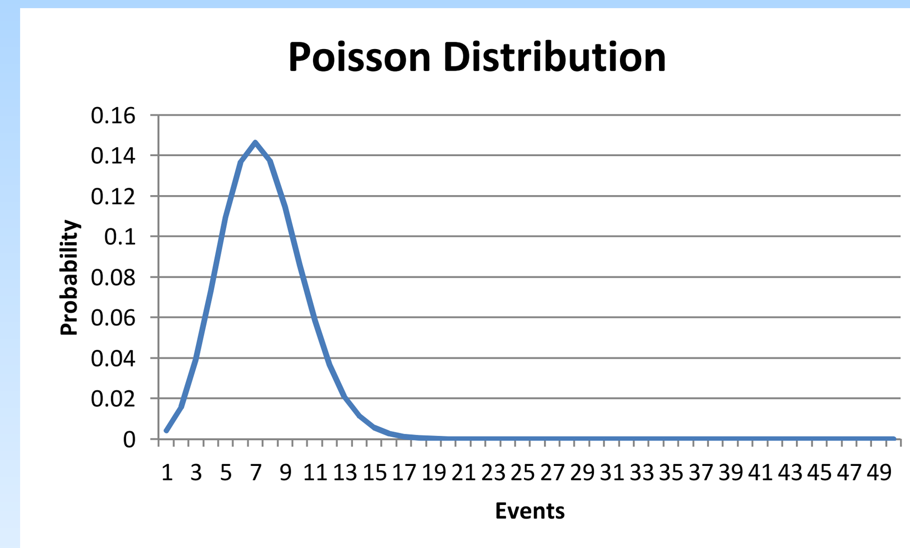
The Computer Science Team

Artificial Intelligence

Artificial intelligence methodologies are required on four distinct levels: pseudo-random path planning, navigation, fine motor movement, and hardware noise removal. For our coverage of patrol areas, we plan to run a genetic algorithm which will give us a measurably reasonable patrol route while preserving non-determinism. Once a patrol route with waypoints has been defined, we use the D* search algorithm to find a more refined path taking into account new data from LiDAR and terrain difficulty. The finer, localized movements of the robot are controlled by the use of potential fields, which generate a small path vector for foot-by-foot movement using obstacles and waypoints as input. Finally, motor movement and sensor noise are mitigated by the use of PID controllers and other techniques.

Sensor Noise Mitigation



LiDAR
Noise: Poisson Distributed
Mitigation: Quantum noise averaging

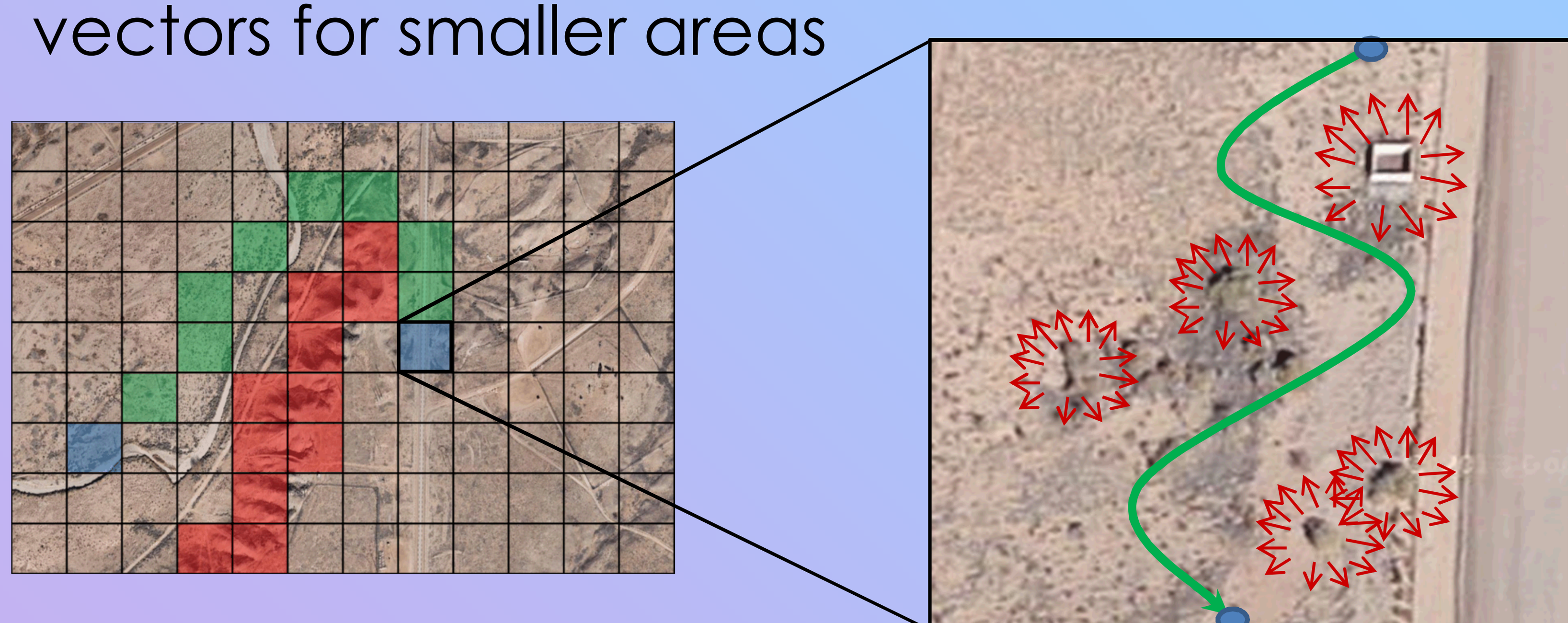
GPS
Noise: Gaussian Distribution
Mitigation: Extended Kalman Filter

IMU
Noise: Progressive error
Mitigation: Averaging and control feedback

The noise to common sensors is well-studied, and can be accurately represented by various statistical distributions. Techniques to mitigate this noise are also known and quite powerful.

Navigation

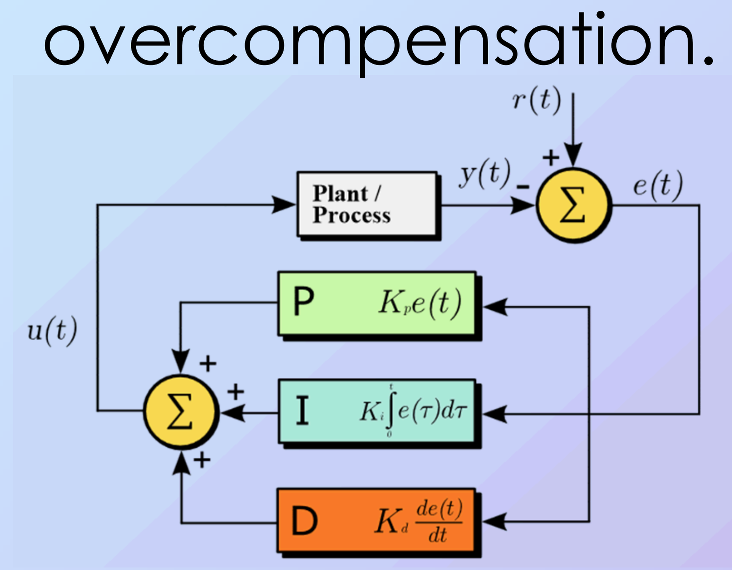
Assignment of potential fields to waypoints and obstacles allow us to create navigation vectors for smaller areas

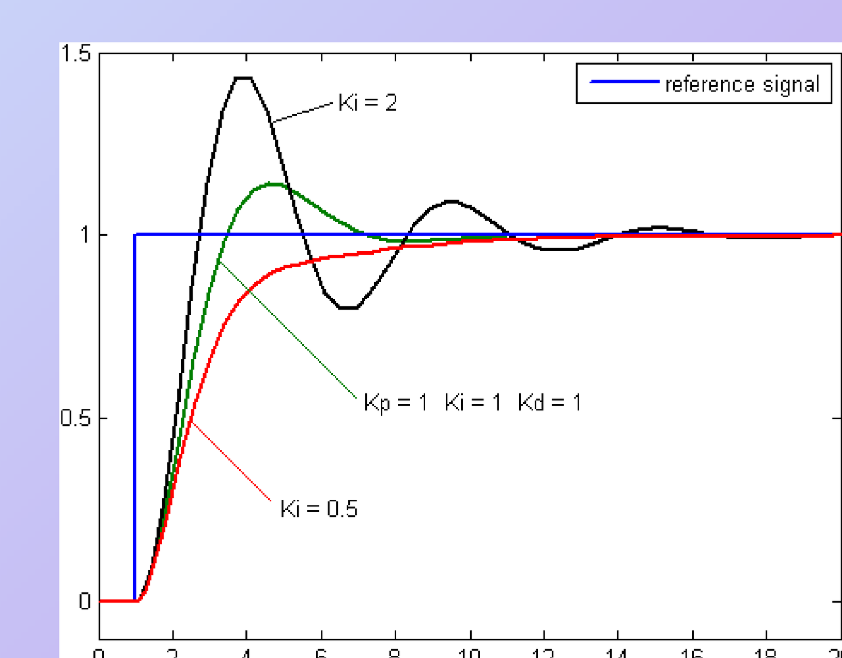


The D* search algorithm will find the optimal path, with respect to terrain difficulty, that our robot should travel.

Actuator Control

Proportional Integral Derivative (PID) controllers are feedback loops used to smooth real-time device control. We use PID controllers to ensure that steering, brake, and throttle control behave efficiently and without overcompensation.





Onward

- Threat Detection
  - People
  - Nuclear Material
  - Distinguish
- Threat Tracking/Follow
- Anomaly Detection
  - “That wasn’t there before…”

- Work Together
  - Swarm Behavior
  - Cooperative Search
  - Intelligent Coverage
- Base Station
- Security

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