

CS/EE/ME 75(a)

Oct. 9, 2019

Today:

- SubT Review
- Systems Architecture: Physical, Software
- Strategy/"ConOps"
- First Look at Projects
- Teaming
- Tentative Schedule:

The DARPA challenges

DARPA = Defense Advanced Research Project Agency

- Setting ambitious goals, making way for novel approaches that might otherwise seem too risky to pursue. [from DARPA website]
 - Realize advanced cutting-edge technologies
 - Address systems-level integration problems
- Have catalyzed advances in autonomy and changed the course of U.S. research/funding (for driving, robotics, manipulation).

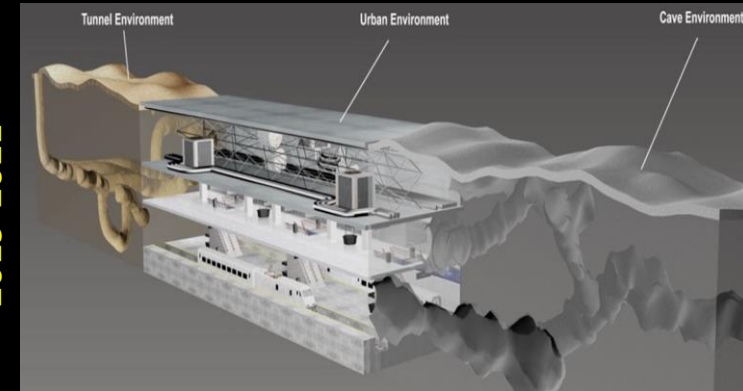
2003-2007

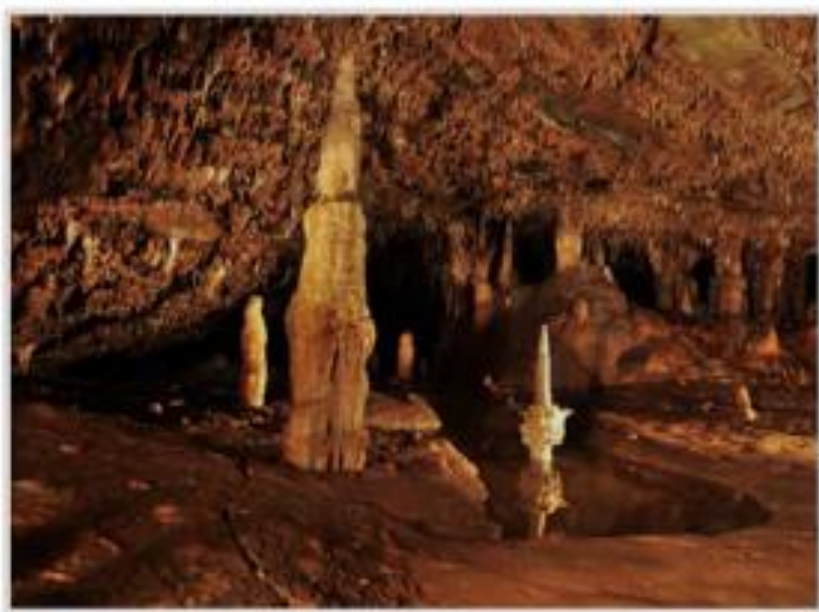


2012-2015



2019-2021





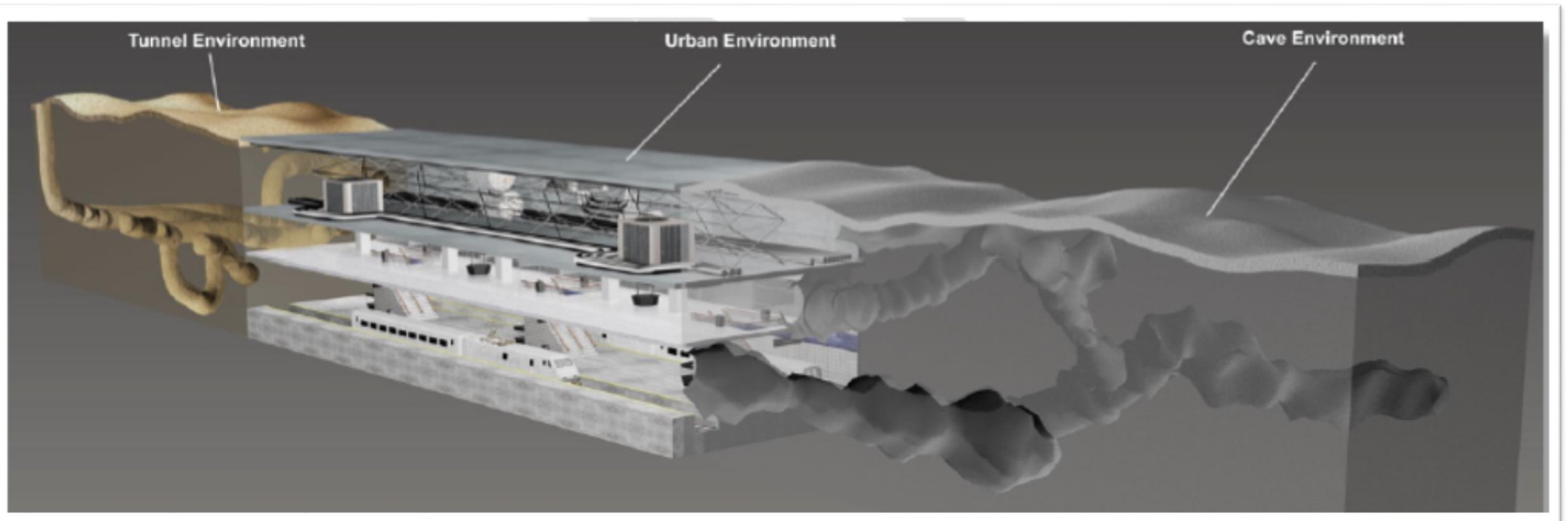
The DARPA Subterranean Challenge

(www.Subtchallenge.com)

Objective: Revolutionize autonomy/technologies needed for exploring extreme environments (tunnel, cave, lava tubes, pit craters, etc.) using robot teams.

Scope: 6 teams selected worldwide (DARPA awarded each ~\$4.5M/3yrs).

Duration: 3 years with 4 competitions and practice events.



Scoring/metrics

Goals:

- Find and identify ~30 objects
- Geo-locate objects (1m error in 1Km)
- Time to detection is scored
- Map the environment (10cm resolution)
- Endurance (eventually up to 5 hours)

Constraints

- One Human operator (high autonomy)
- No power, lighting, communications provided
- No prior map

Rules/details

- Entrance/exit is known
- No humans can enter the tunnel
- One human operator.
- The size of the underground space, size and types of obstacles will be announced ahead of the competition.
- Narrow passages: different sizes – minimum human crawlable
 - Hvac vents
 - Storm drain
 - Sewer system
 - Water tunnels

CoSTAR-bots: Collaborative SubTerranean Autonomous Resilient Robots to Explore Subterranean Environments



NASA's JPL
POC: Dr. Ali Agha (PI)



California Institute of Technology
POC: Dr. Joel Burdick



Massachusetts Institute of Technology
POC: Dr. Luca Carlone

General Challenges in SubT Environments

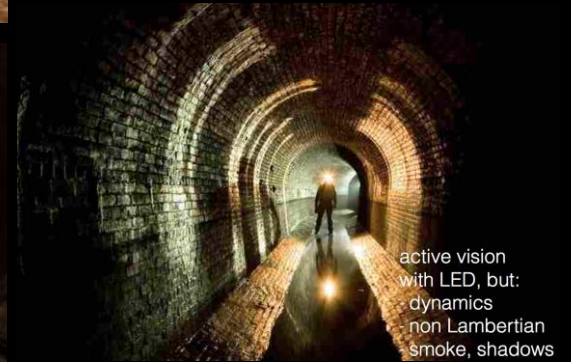
- Mobility

- Narrow passages
- Climbs and drops
- Unpredictable terrain
- Dust, debris



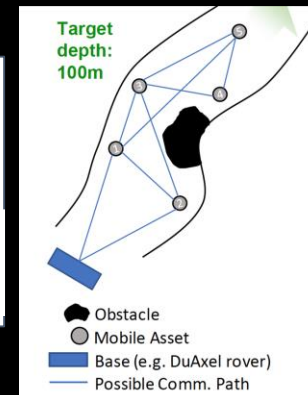
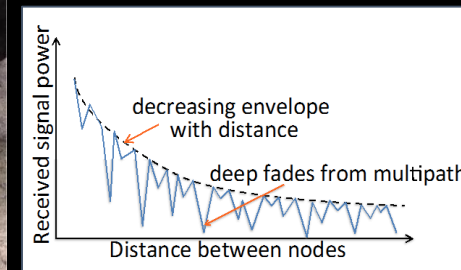
- Perception

- Bandwidth constraints
- Darkness/energy constraints
- Dust/debris
- Perceptual aliasing and high outlier rate
- Automated or human-guided recognition?



- Localization

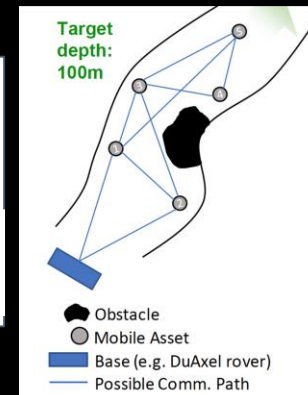
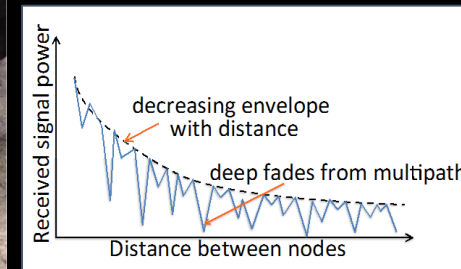
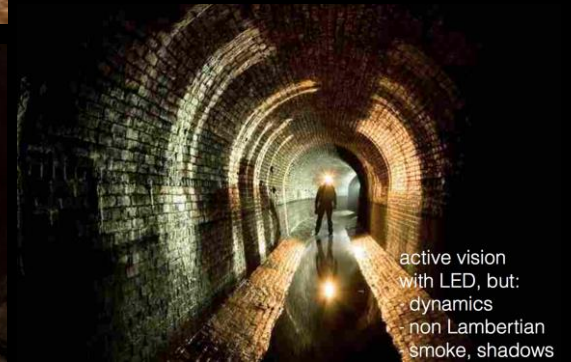
- No GPS underground
- Limited communication between vehicles
- Multi-vehicle aspect.



General Challenges in SubT Environments

- Communication

- Latency constraints
- Requires daisy-chain operation
- Multipath environment can generate unpredictable link qualities
- Rock/soil is poor transmission medium
- Need to model, validate, and mitigate uncertainties in data links between nodes in SubT environment
- Data drop out



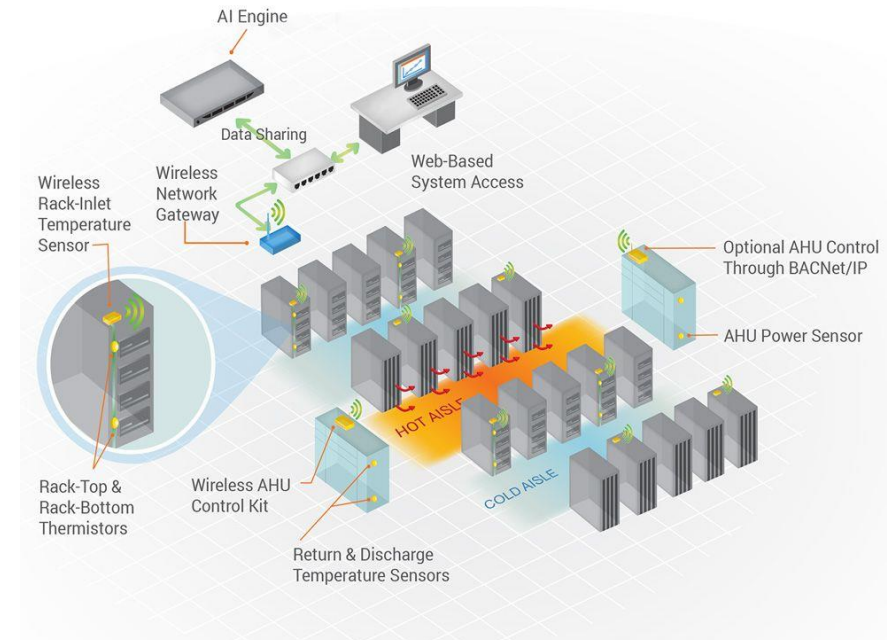
System Architecture

Some Definitions:

- A representation of an existing or future system that describes (at a “high level” of organization) the functional organization of the system components and their interactions. The architecture can be progressively refined to more detailed and concrete descriptions.
- The fundamental organization of a system, embodied in its components, their relationships to each other and to the environment, and the principles governing its design and evolution.
- A formal description of a system, or a detailed plan of the system at component level to guide its implementation.

Characteristics

- A system architecture should display the internal [interfaces](#) among the system’s components or subsystems, as well as the interface(s) between the systems and its environment and users.
- Usually represented as a diagram



CoSTAR-bots

Collaborative
SubT
Terranean
Autonomous
Resilient robots

Mobility

Long-endurance all-terrain mobility platform.



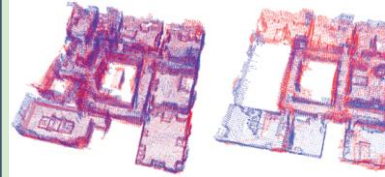
Localization

Onboard localization + Magneto-quasi-static-based resilient localization system.



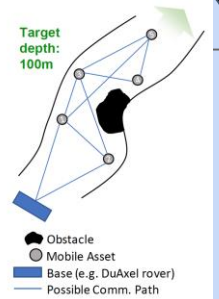
Distributed Perception

Robust distributed perception under uncertainty using DGPO.



Communication

Disruption-Tolerant Networking.



CoSTAR Robots



Autonomy

Risk-aware belief space autonomy using feedback-based information roadmaps.



Mapping

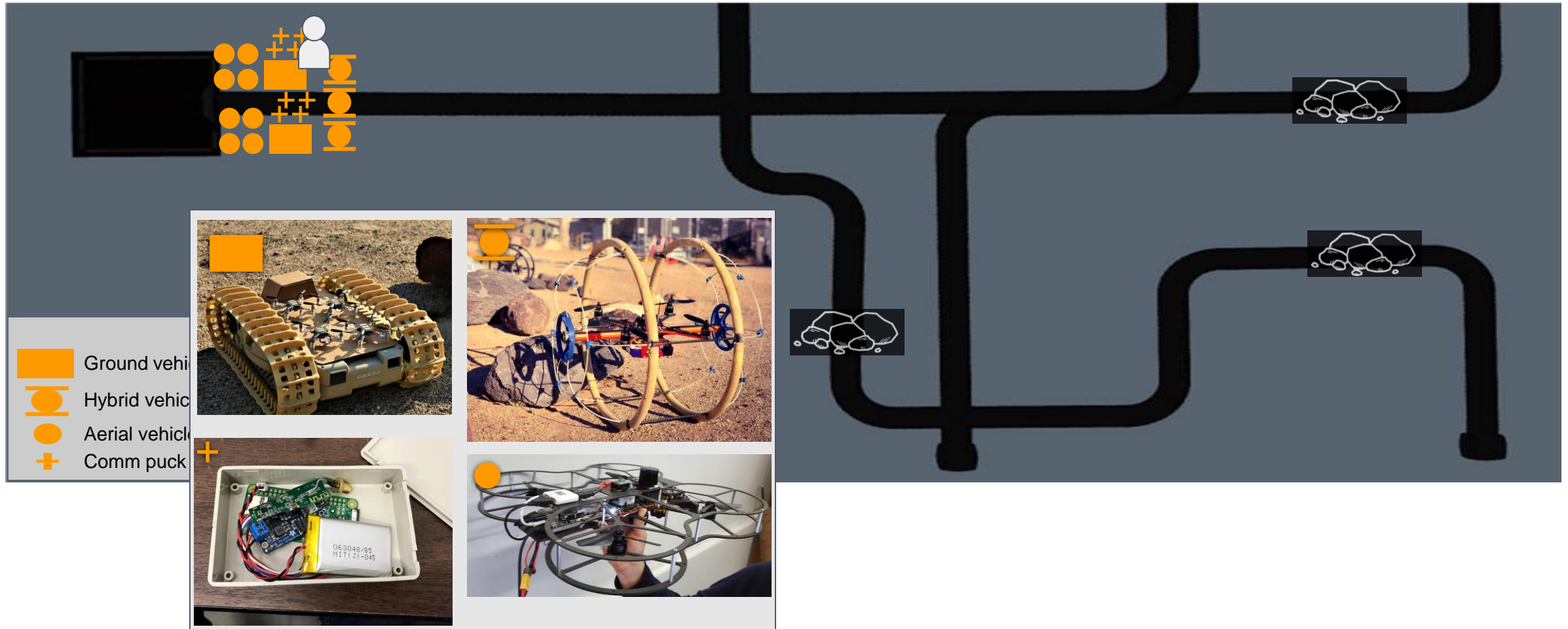
High-resolution and consistent representation using Confidence-rich grid mapping.



Testing facility: Caltech's center for Autonomous Systems and Technologies (CAST), JPL's large Mars Yard, Mueller Tunnel, Bronson/Pisgah/Big-Skylight caves, Galvez tunnel, and potentially abandoned LA

System Design Overview

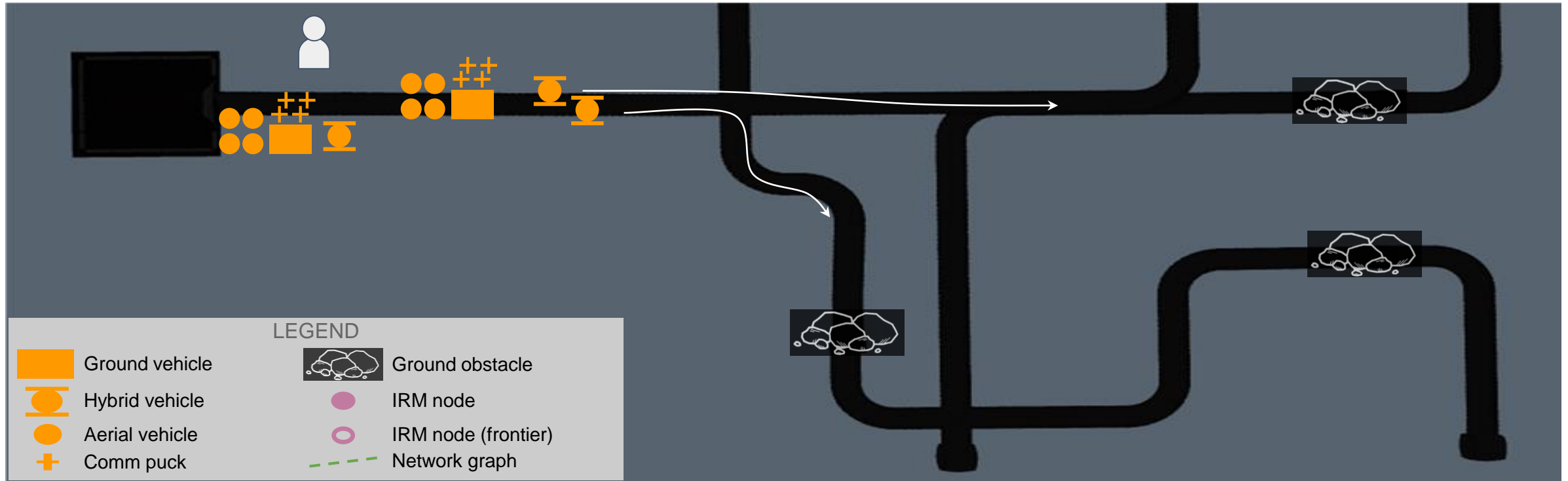
Simplified CONOPS (Concept of Operations)



Begin with a heterogeneous set of platforms at the base station

System Design Overview

Simplified CONOPS

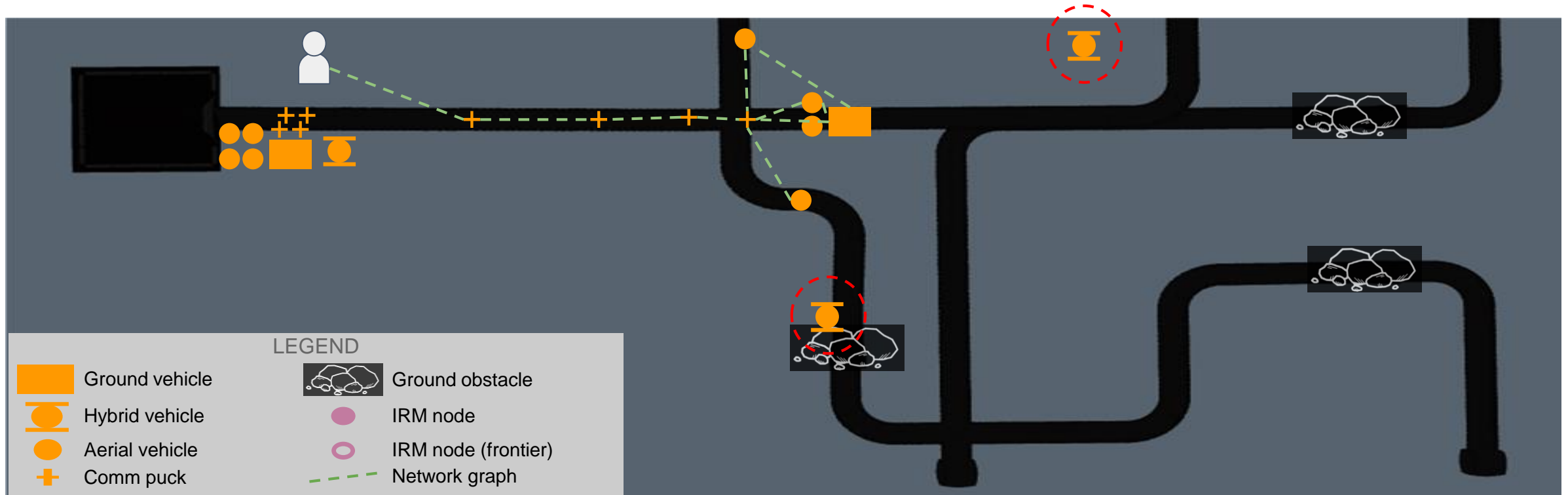


Thrust 1: *Explore the frontier* with a **vanguard** of hybrid ground/air vehicles with highly capable sensing for mapping and artifact detection.

Also: Ground vehicle carries in smaller platforms for future use.

System Design Overview

Simplified CONOPS

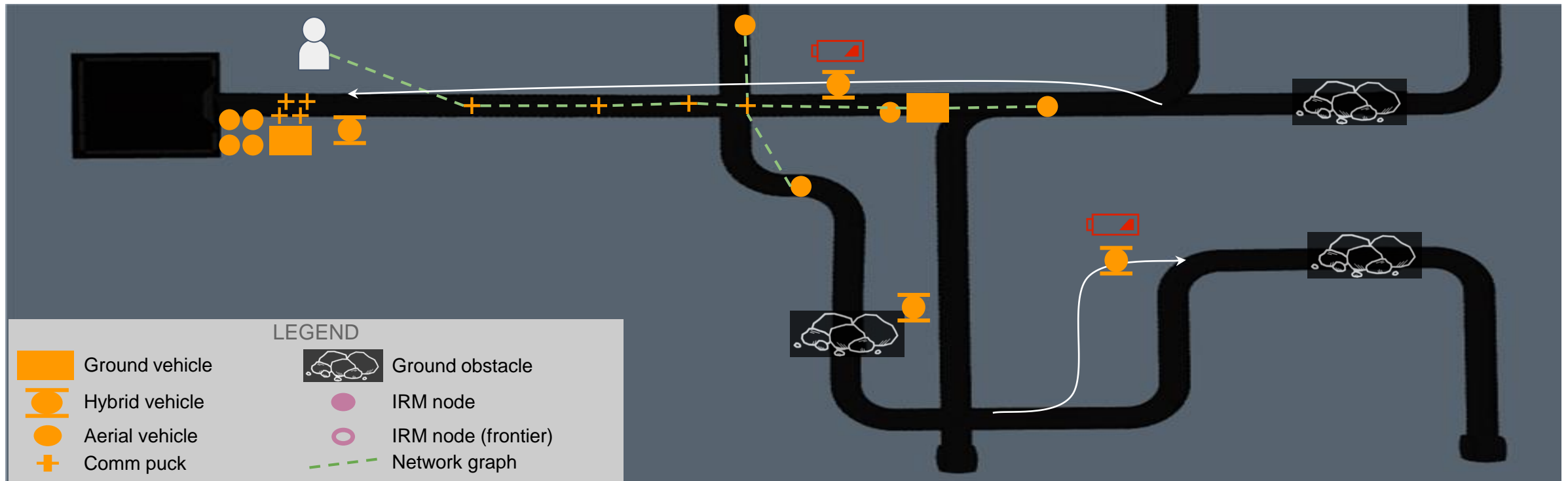


Thrust 2: *Extend the reach of the human supervisor* by tasking robots to create and propagate a **mesh** network for communications.

Ground robot deploys communication pucks, and aerial scouts can self-deploy for either comms relays or added sensing—as directed by either Supervisor or Autonomy.

System Design Overview

Simplified CONOPS

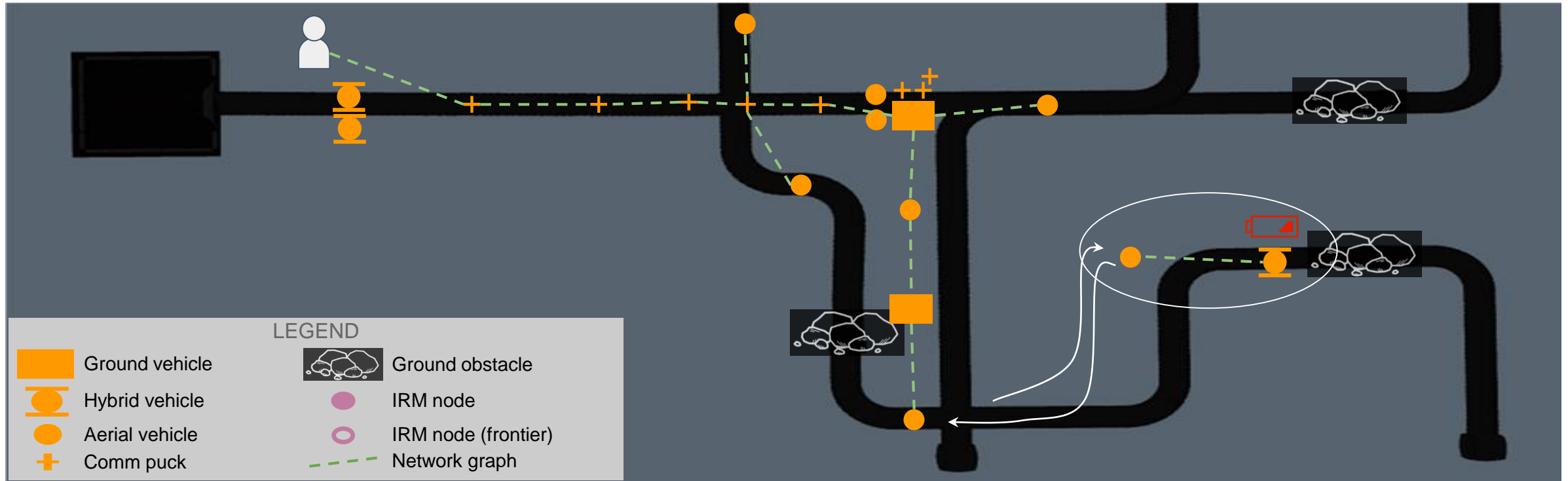


Vehicles can be configured (by Supervisor or Autonomy) for one of the following behaviors near battery depletion:

1. Return to Base—battery swap possible at base
2. Return to Mesh—ensure the data are exfiltrated, then continue
3. Explore Frontier—continue as is, aggressively prioritizing coverage

System Design Overview

Simplified CONOPS

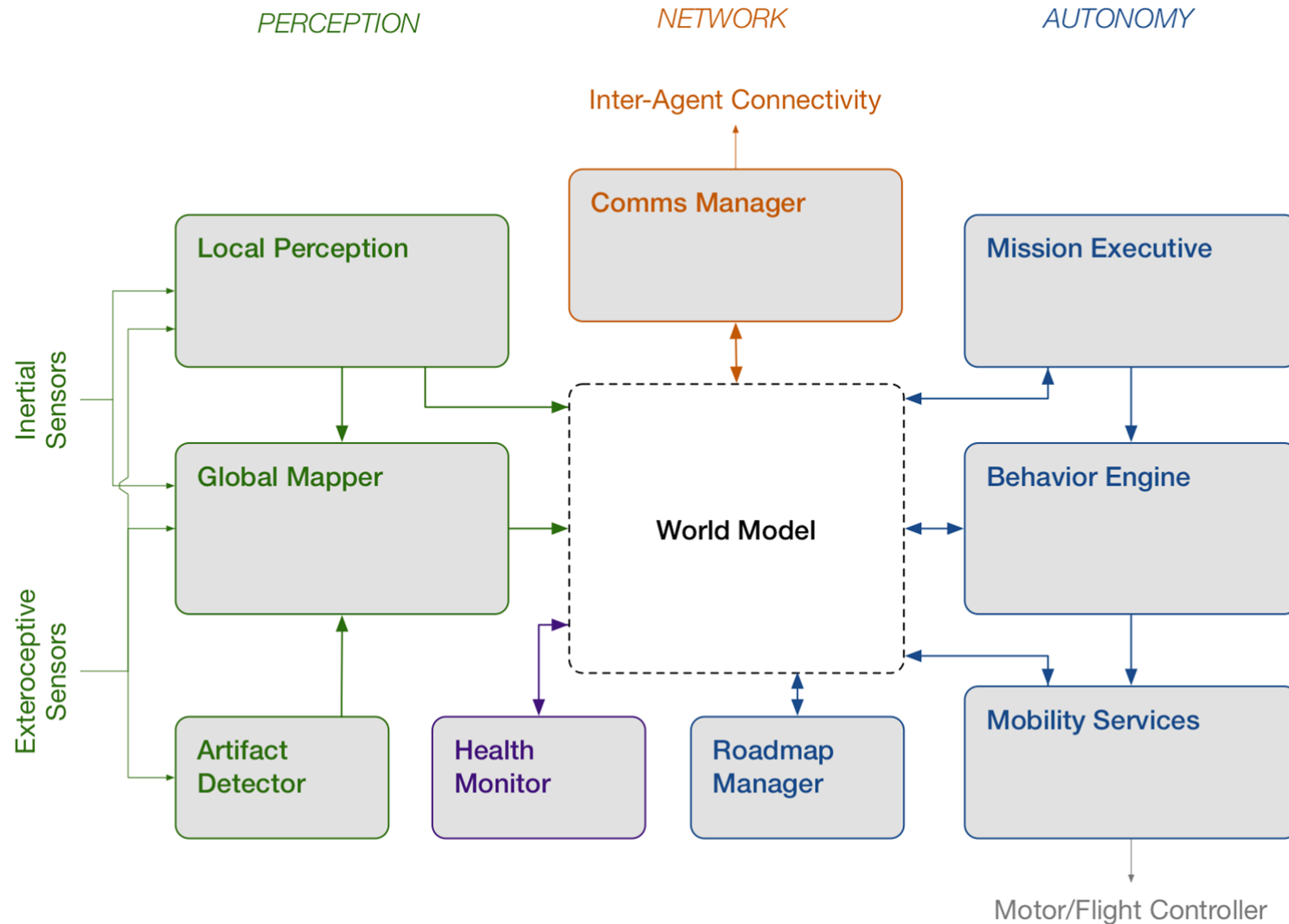


To enable vehicles to continue exploration beyond communication range, agents may be assigned to serve as **data mules**.

These behaviors continue until the entire course is explored.

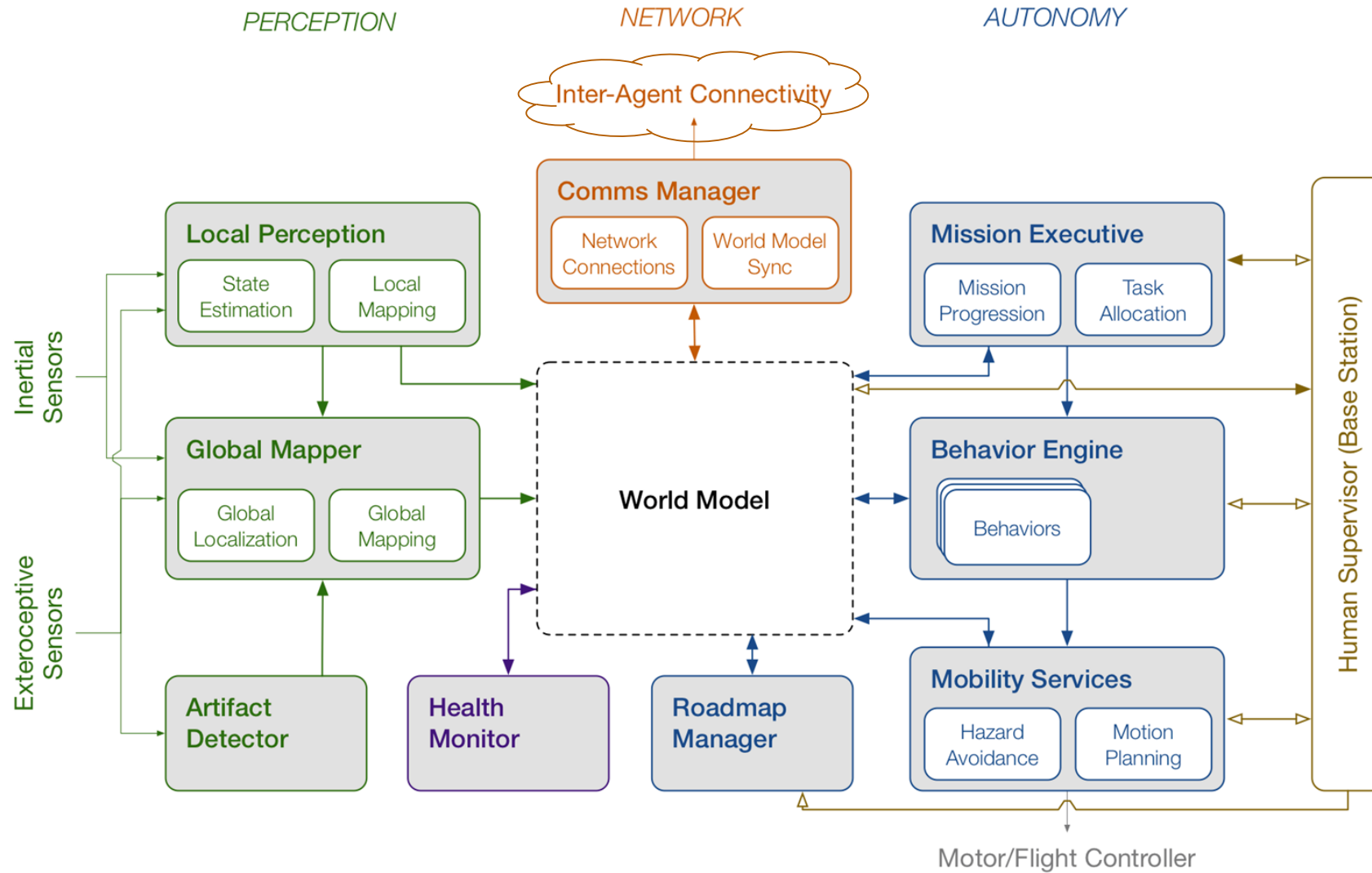
System Design Overview

Software: Functional Architecture (single agent)

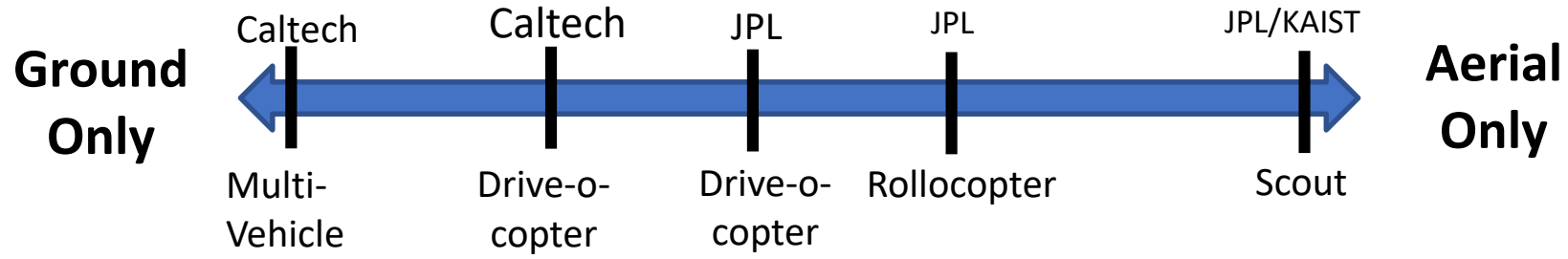


System Design Overview

Software: Functional Architecture



Cross-Domain Mobility



Mobility: 4-wheel Skid Steer

- Not good in sandy terrains
- Poor on stairs

Roles:

- Towing vehicle
- compute node
- MQS/IMU node

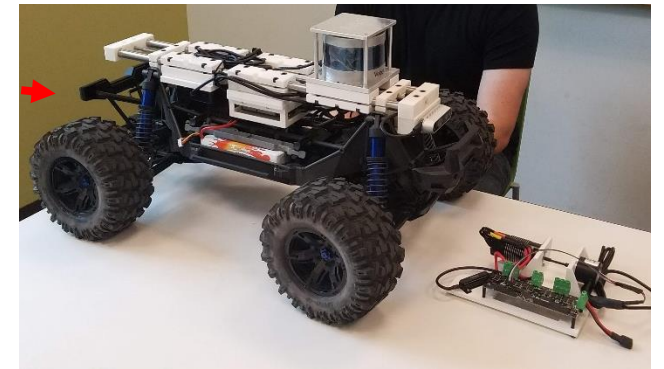
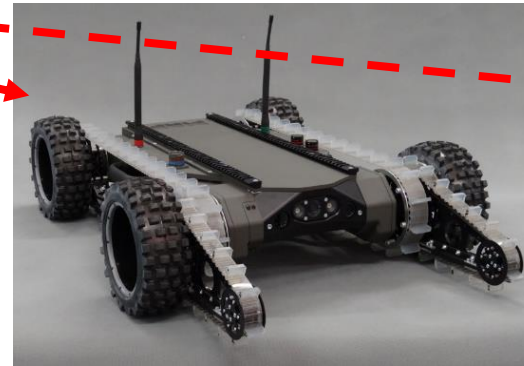


Mobility: Tracks

- Stairs
- Handles poor terrain

Roles:

- Light towing vehicle
- Mapper
- Stair Access



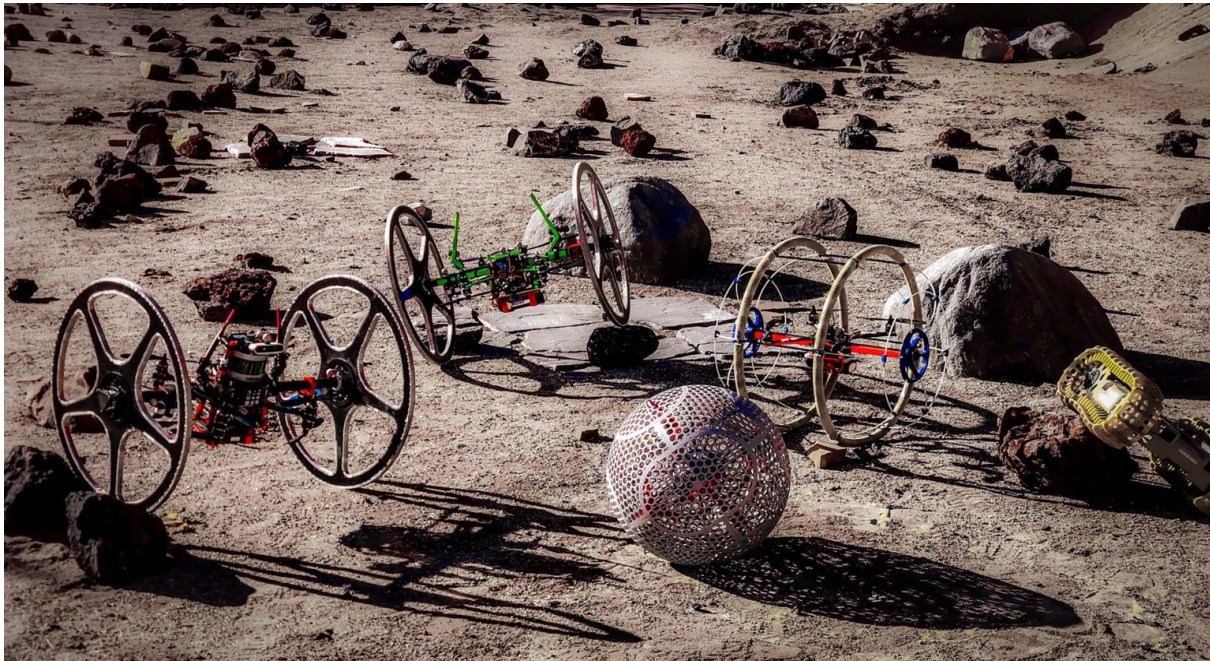
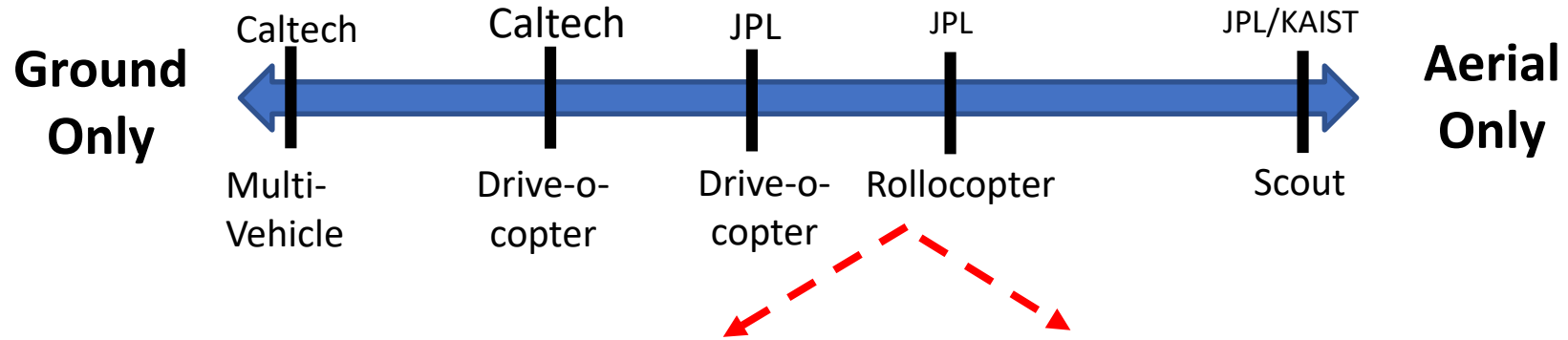
Mobility: Ackerman 4WD

- tunnels, urban circuit

Roles:

- “Scout-like” exploring vehicle
- Mapping/Detection
- Fast vehicle on moderate terrain

Cross-Domain Mobility



Approach

Rollocopter Spec.s

Flight system

- Coax Quadcopter, 9.5"x4.7" propellers

Physical properties:

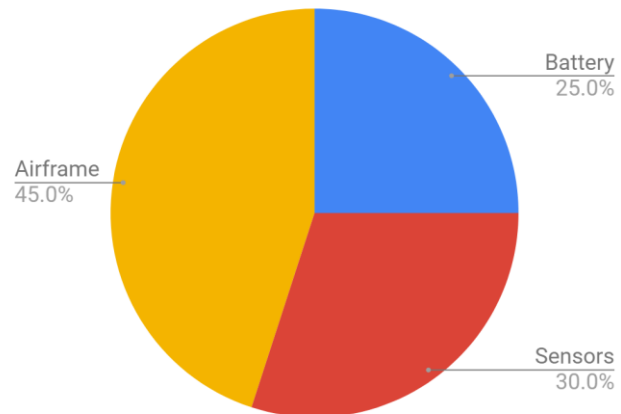
- Total weight: 4 kg

Battery

- 10Ah 4S Lipo

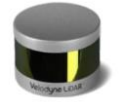
Endurance:

- Rolling: ~40min
- Hopping, bouncing, and flying: ~8 min



Sensors

3D Lidar: (VLP-16 Lite)



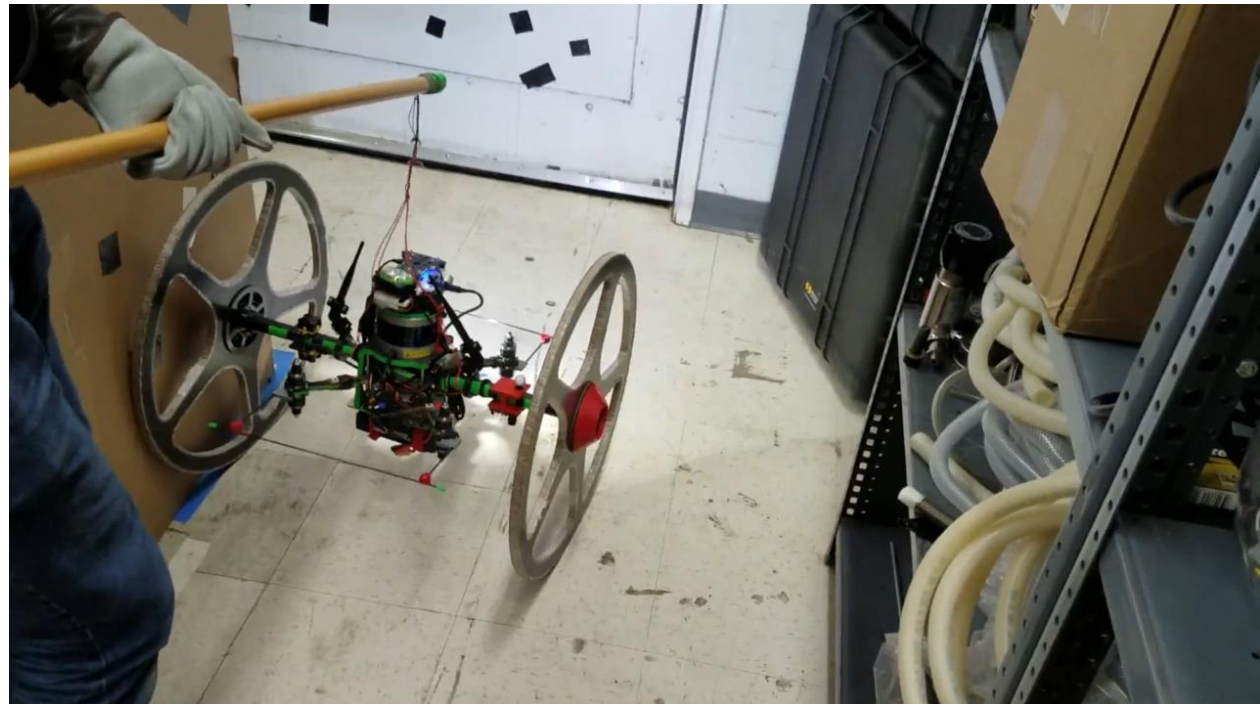
RGB-D Camera: (Intel Realsense)



IMU: (VectorNav VN100)



1D Lidar: (Garmin)



What Actually Got Deployed?



Videos from “Tunnel Circuit”

Videos of all scoring runs

<https://www.youtube.com/playlist?list=PL6wMum5UsYvYqHMxOkZuopRMqVxm9MtAJ>

Video of CoSTAR Final Run

<https://www.youtube.com/watch?v=QpkZlaLdrIk&list=PL6wMum5UsYvYqHMxOkZuopRMqVxm9MtAJ&index=27&t=0s>

Video “Fly-through” of Tunnel Circuit

<https://www.youtube.com/watch?v=-qqD243S6RM>

What will get deployed in Tunnel Circuit?



Two Huskies
(for ground floor)



Two Stair-Climbers
(for upper floors)



Baseline System

Stretch Options

Project Ideas

Well-defined Near Term & Long Term Projects

- Automated RC Car
 - Improved Mechanical Design
 - Added sensors, Improved State Estimation
 - Improved Steering Control
- Drive-o-copter
 - New Mechanical Design
 - Ground-up implementation of Autonomy, Hybrid mobility planning
 - Improved Sensor Suite

Less well-defined, but important Near Term Projects

- Tracked Vehicle Stair Climbing

Important Long Term Projects

- Long Flying Duration (diesel or electric) drone

Blue Sky, but very important Projects

- Deployable, robotic Total Station

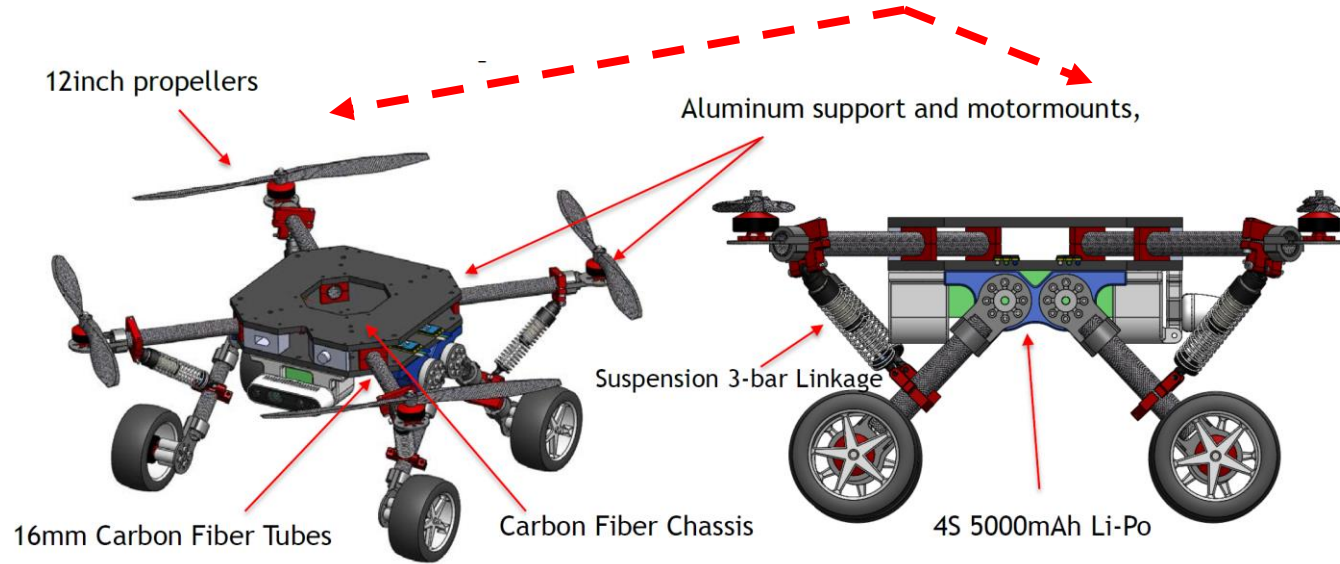
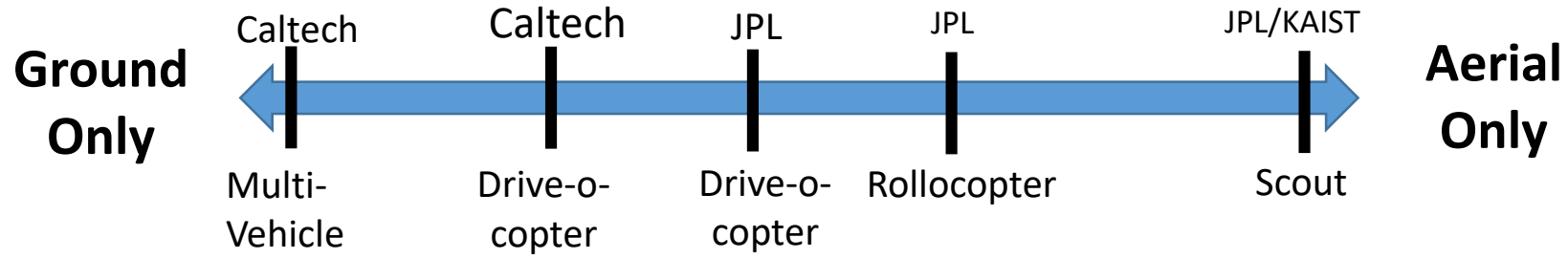


Automated RC Car Project Goals

1. Redesign Super-structure so that it is less top heavy
2. Add Sensors to wheels for “odometry”
3. Build 2nd car copy)
4. Develop odometry estimate using the wheel sensors
5. Improve steering control at high speeds and during backup
6. Stretch goals
 - Add sensor to suspension
 - Develop whole body estimator
 - Develop high speed navigation based on “perception aware” planning principles

Resources: Jake Ketchum (jketchum@caltech.edu) , Anushri Dixit (adixit@Caltech.edu), Nikhilesh Alatur (nikhilesh.alatur@jpl.nasa.gov)

Cross-Domain Mobility



Principle: primarily a driving machine which can “hop” or fly up stairs as needed.

- Multiple drive configurations
- “Easy-Swap” chasses



DRIVOCOPTER

Efficient Hybrid Platform for Flying and Driving

Caltech mce

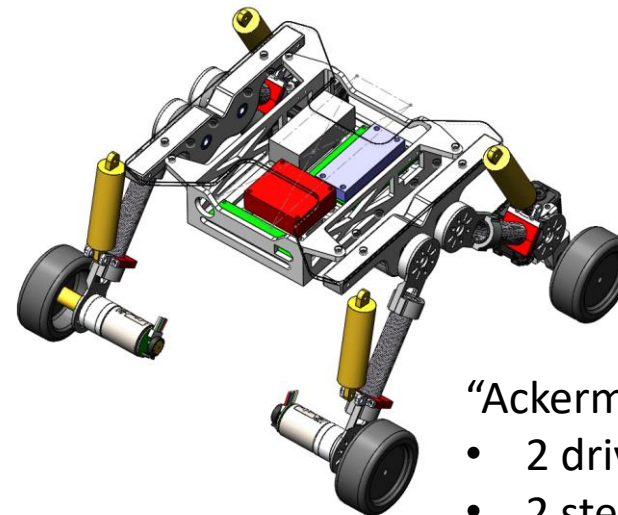


Driving Performance:

1. 65kJ spent for 951m of driving
2. 21% battery spent
3. Expected Driving Range: ~ 4.5km
4. COT of 2.0, close to humans
5. Average Speed: ~1m/s

“Swerve Steer”

- 4 drive motors
- 4 steer motors



Driving Performance:

1. Expected Driving Range: ~ 35 km
2. COT of 0.4, better than humans
3. Average Speed: ~1.5 m/s

DRIVOCOPTER

Ackermann Steer Platform
Off-Road Capabilities Demo

“Ackerman Steer”

- 2 drive motors
- 2 steer motors

Drive-o-Copter Project Goals

1. Design/Build specialized Urban Circuit Design
2. Finalize Sensor Suite
3. Bring up JPL autonomy package on Drive-o-Copter
4. Take-off and landing control
5. Test Extensively
6. Stretch goals
 - Hybrid Locomotion Planning



Resources: Arnon Lowenstein (lewinstein@gmail.com), Drew Singletary (asinglet@caltech.edu), Anushri Dixit (adixit@caltech.edu) , Amanda Bouman (abouman@caltech.edu)



Rover Robotics “Flipper”



Rover Robotics “Flipper”



Spin-off of RoboteX
“Emergency Response” Rovers

Stair Climbing Project Goals

1. “Centering control” while stair climbing
2. How to use autonomously use “arms” to facilitate climbs on complex stairs
 - Disaster recovery?
3. Estimate “Slip” during motion, particularly on stairs.
4. Stretch goals
 - Develop perception for stair climbing

Long Flight Duration Drone

(mainly for cave circuit & beyond)

1. Investigate at least 2 strategies
 - diesel power (no gasoline allowed) & collective pitch
 - Battery Power
2. Design/build prototype
3. Demonstrate autonomy



Resources: Luis Pabon (lpabonma@caltech.edu), Malcom Tisdale (mtisdale@caltech.edu) , Drew Singletary (asinglet@caltech.edu)

Blue Sky: robotic, multi-leg Total Station

1. Investigate:

- Can we make a multi-leg total station
- How accurate
- How to automate
- How to deliver

2. If feasible, Design/build prototype

3. Demonstrate

Resources: Joel



Homework

- Build a team of 3-6 people
- Select a project
- Prepare a “GoTChA” chart