Heterogeneous Multi-Robot Sampling

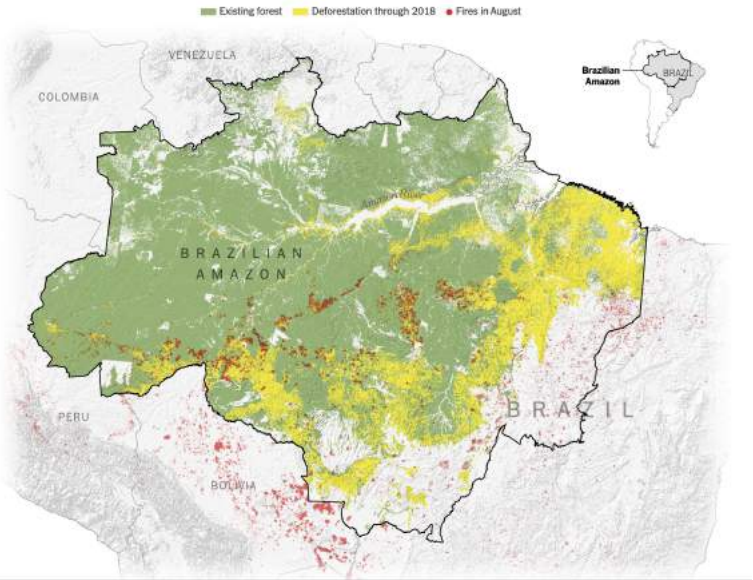
System Development Review

Team G: SAMP

Environmental Modeling

https://sea.mashable.com/culture/5813/the-amazon-forest-is-burning-to-the-ground-heres-how-it-happened-and-what-you-can-do-to-help

Temperature modeling

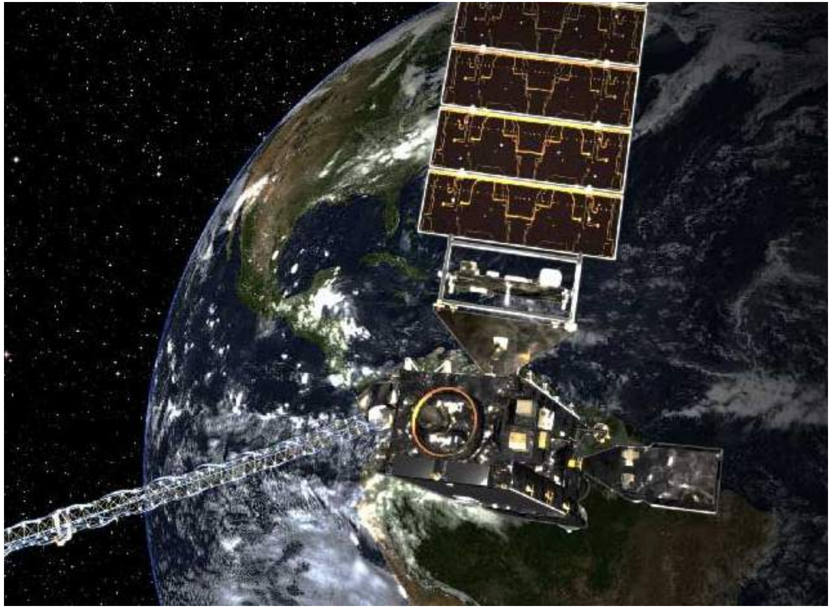


https://www.nytimes.com/interactive/2019/08/24/world/americas/amazon-rain-forest-fire-maps.html

Conventional Environmental Modeling

Satellite:

- Limited resolution
- Limited accuracy
- Huge cost



https://www.carbonbrief.org/explainer-how-surface-and-satellite-temperature-records-compare

Conventional Environmental Modeling

Manual modeling:

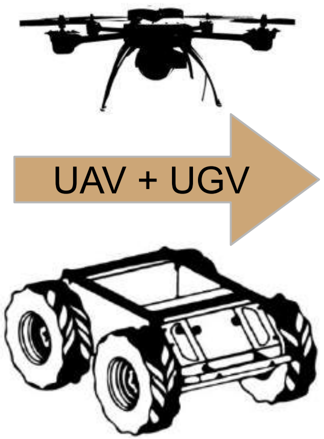
- Discretized and limited coverage
- Tremendous manpower
- Inefficient update

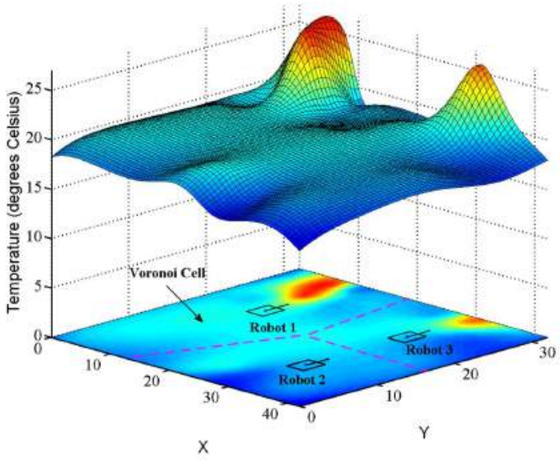
http://www.ecofishresearch.com/our-services/nvironmental-compliance-effects-monitoring

Project Description:

We aim to deliver a UAV-UGV team that performs online environmental sampling and modeling collaboratively given an outdoor area with different terrains.

https://secondnexus.com/environment/yellowstone-caldera-nasa-supervolcano/





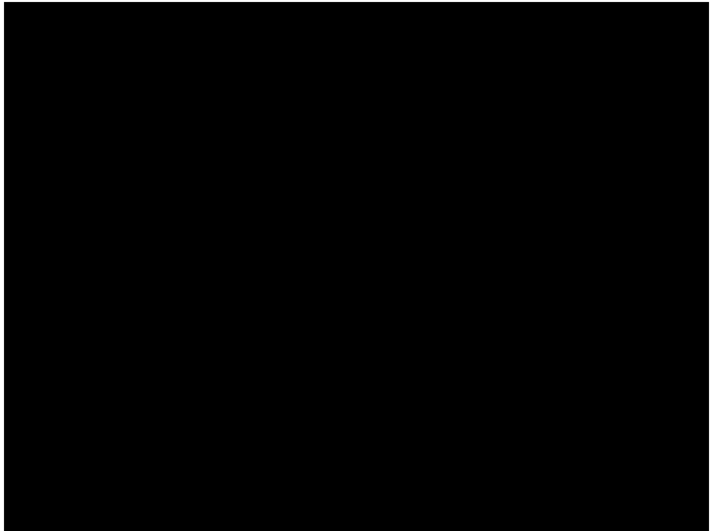
Wenhao and Katia, ICRA, 2018

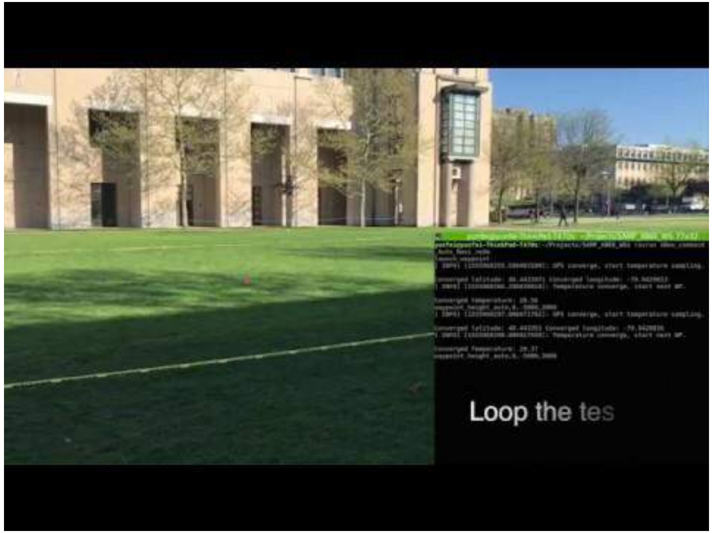
Use Case: Scientific Monitoring

- We want to monitor temperature on CMU campus.
- Team SAMP launched Pelican and Jackal to help building temperature distribution over CMU campus.

Use Case: Scientific Monitoring

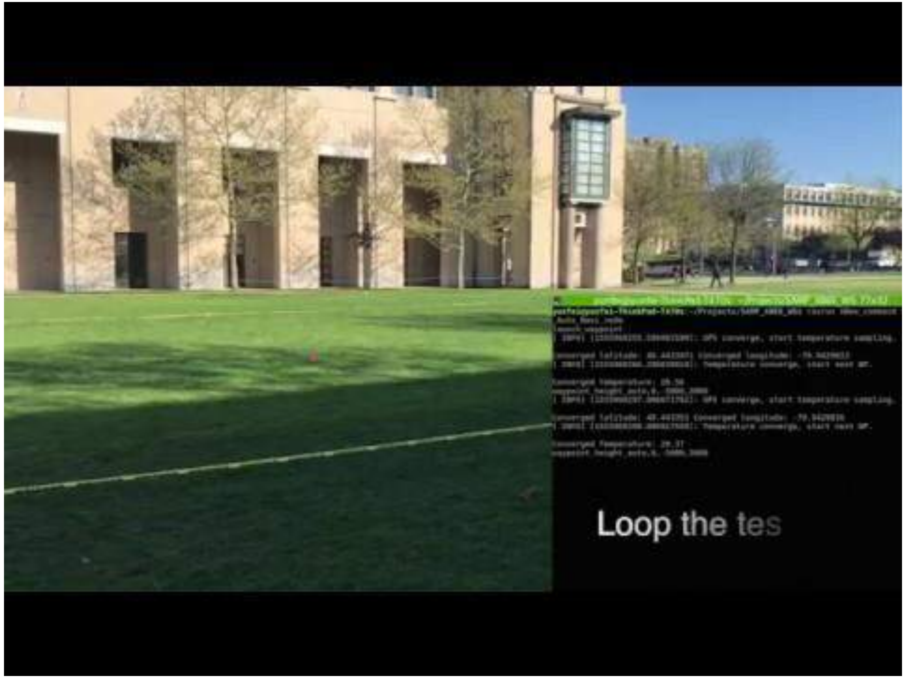
- Jackal and Pelican autonomously navigate around CMU campus to efficiently take temperature samples.
- Team SAMP gives an accurate temperature distribution for CMU campus within limited time.





Use Case: Scientific Monitoring

- Team SAMP gives an accurate temperature distribution for CMU campus within limited time.



Requirement Modification

- Test field ~~20m x 20m x 5m~~ 10m x 10m x 5m
- UAV ~~autonomously avoids obstacles~~ hovers over obstacles.

Current System Status

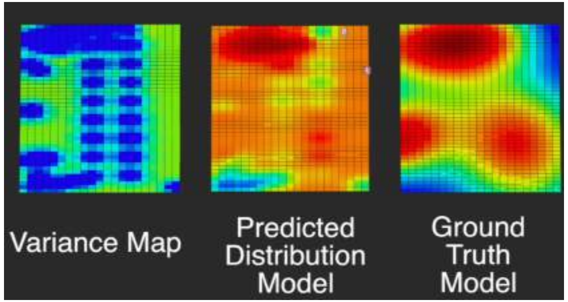
Current system status: Overall System Depiction

UAV Subsystem

Interest Point Locations

Temperature Samples

Update Temperature Model



Master Computer Subsystem

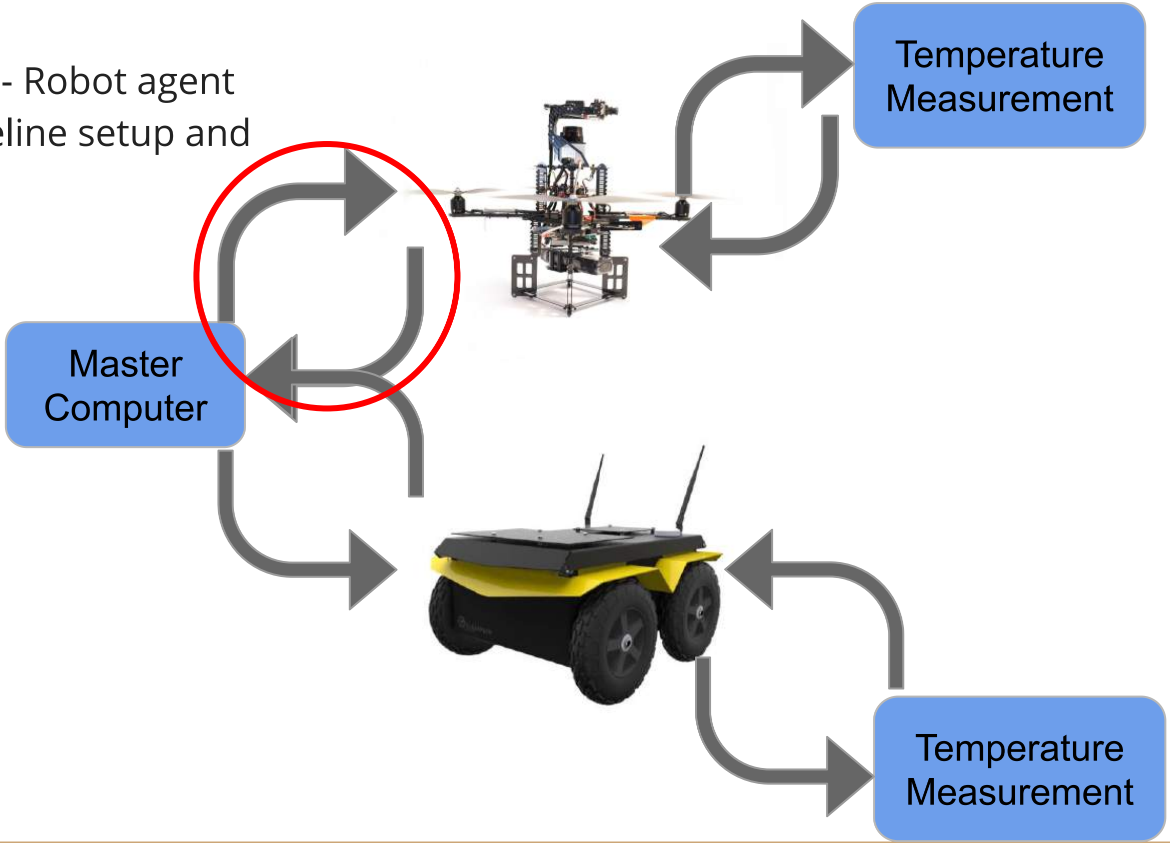
UGV Subsystem

Interest Point Locations

Temperature Samples

Current system status: Overall System Depiction

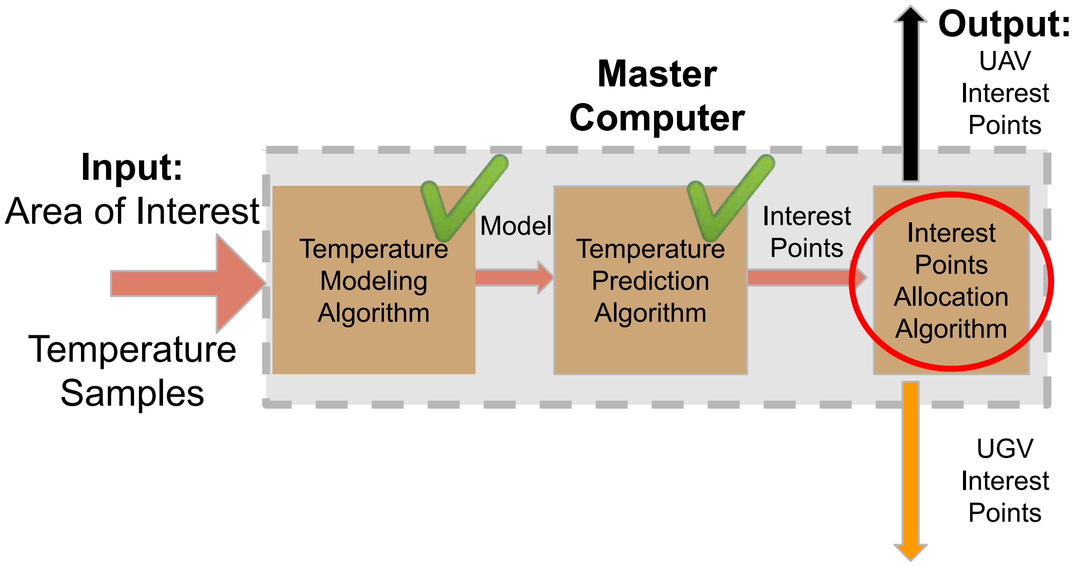
- Master computer - Robot agent collaboration pipeline setup and test



Master Computer : Functional Description

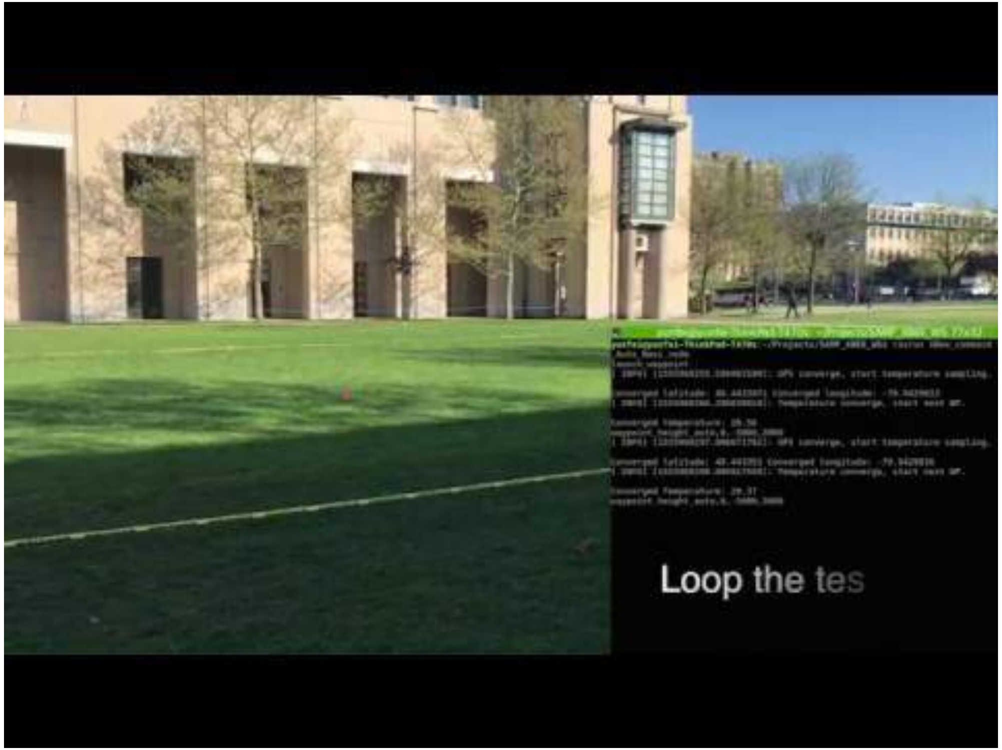
Procedure:

1. Mixture of Gaussian Process Models for temperature modeling.
2. Expectation and Maximization for temperature prediction.
3. Interest point allocation
   a. UAV/UGV Mobility
   b. Utility
      i. Prediction Accuracy

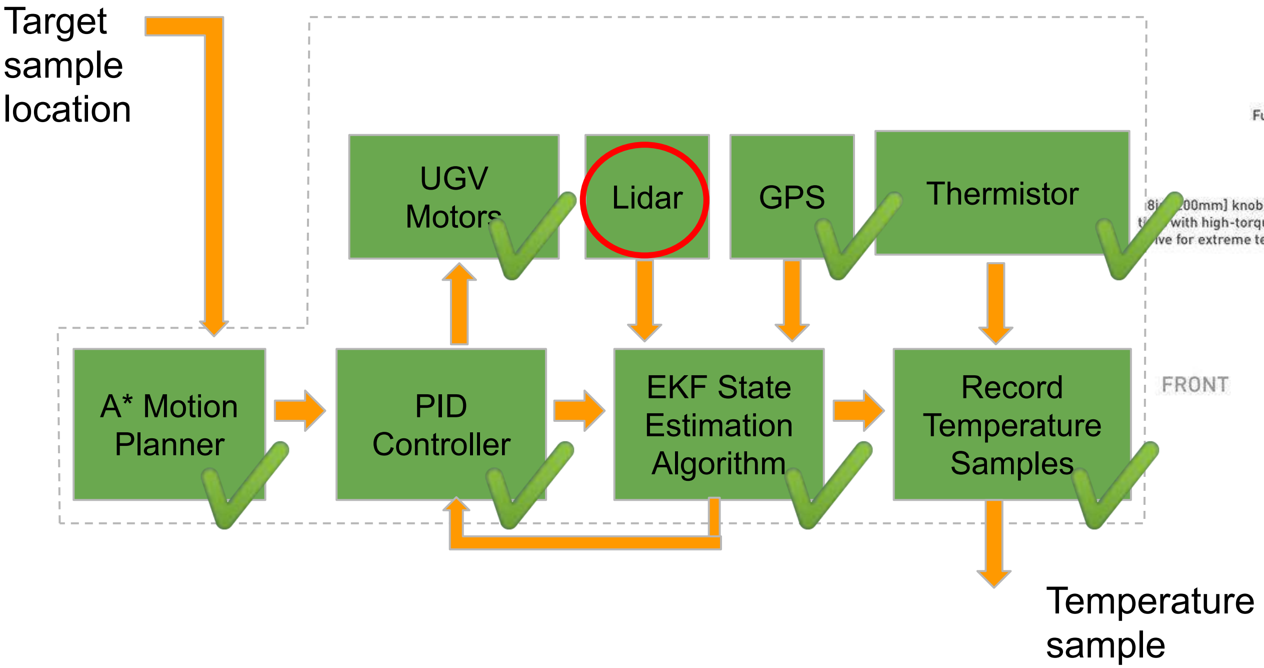


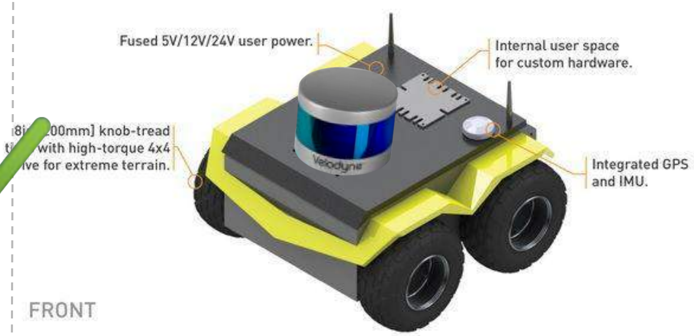
Master Computer : Current Stage of Development

- Sampling simulation



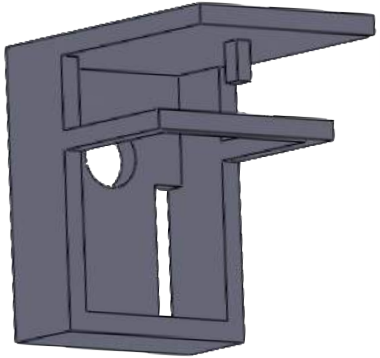
UGV Subsystem : Functional Description



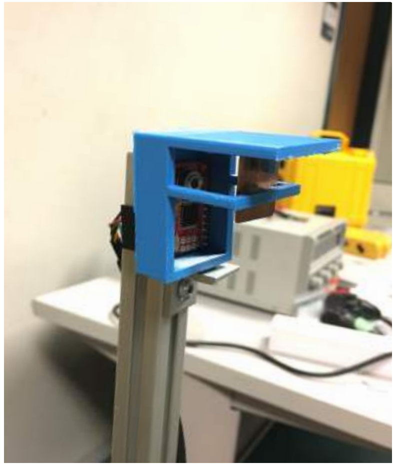


UGV Subsystem : Current Stage of Development

- Updated Temperature Measurement
  - 0.107ºC rms error
  - Converge time < 5s (from 23ºC to 14ºC)

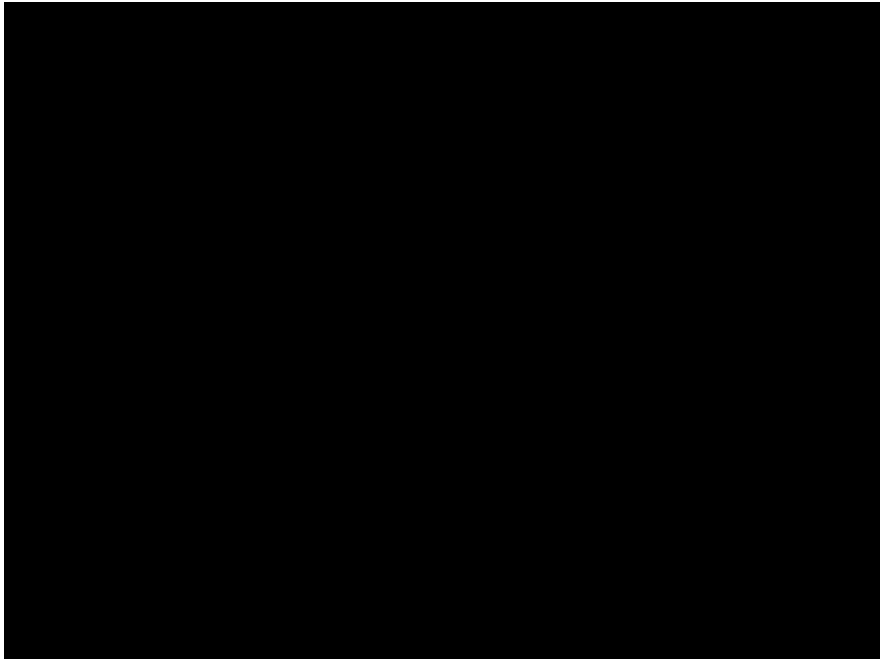




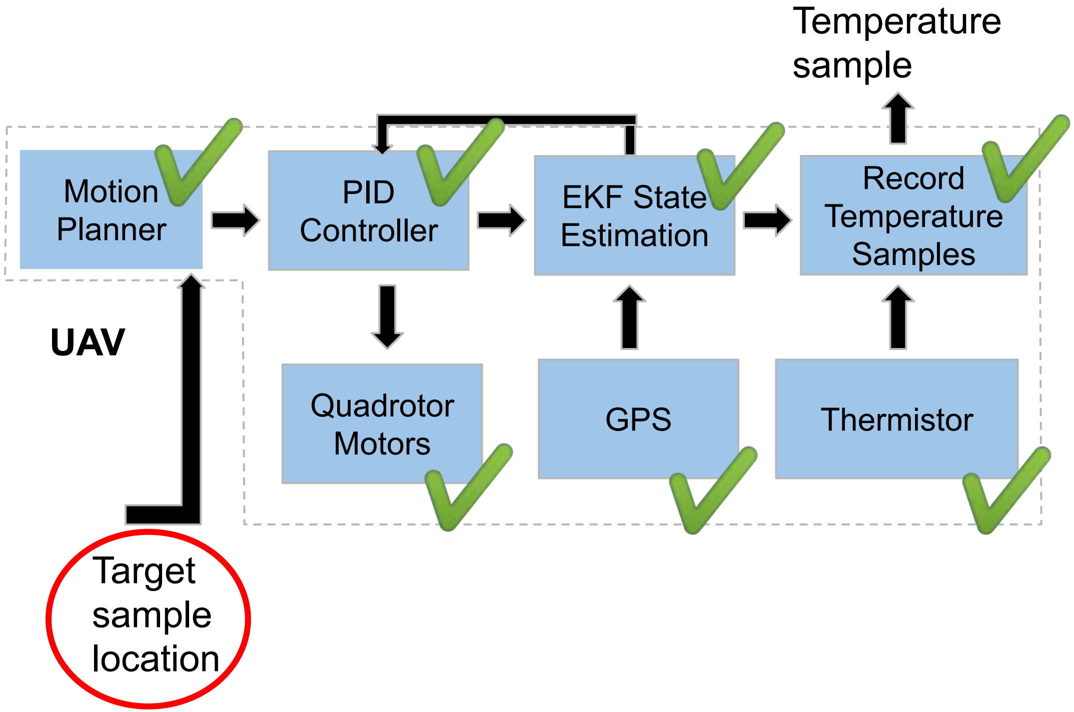


UGV Subsystem : Current Stage of Development

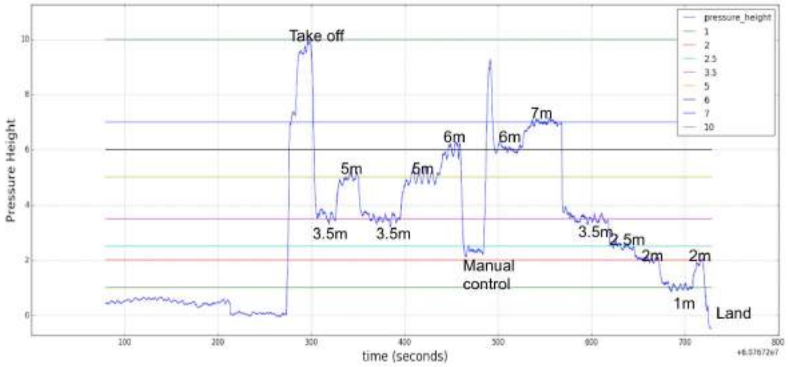
- Localization performance improvement using RTK GPS:
  - Test result: accuracy ~0.2m
- Integration with Master Computer
  - Verified master computer-robot working pipeline.

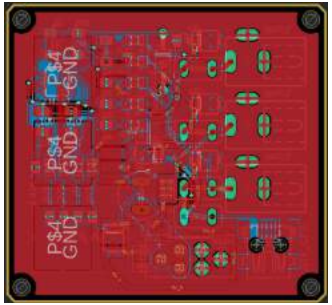


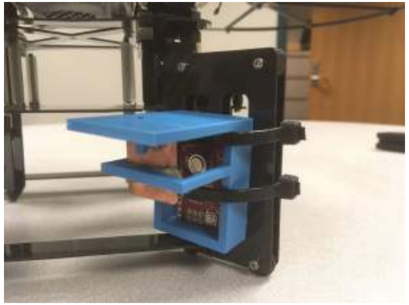
UAV Subsystem : Functional Description

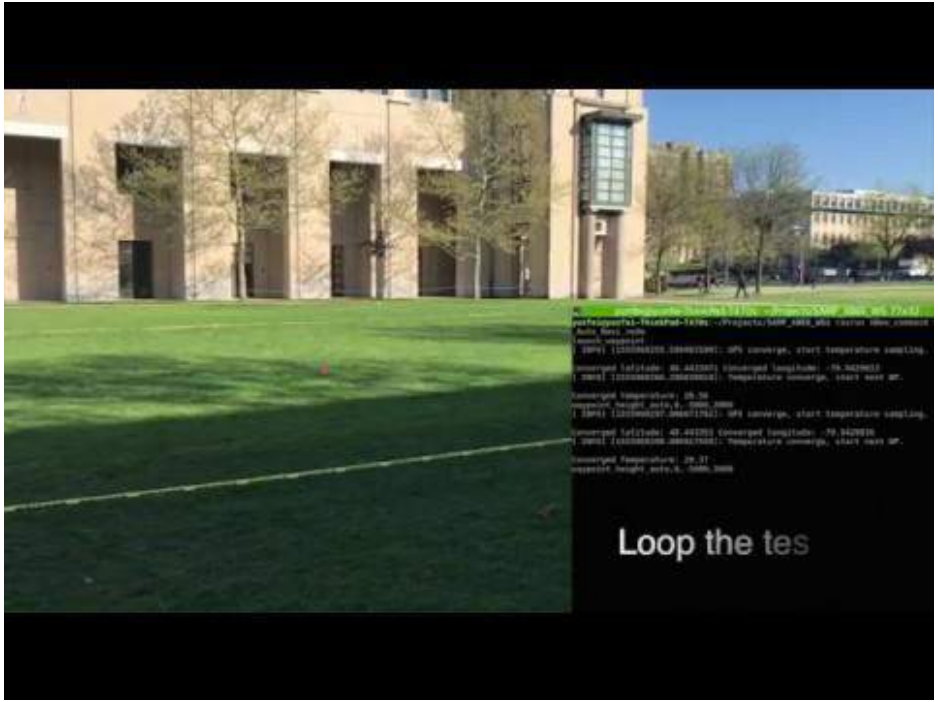


UAV Subsystem : Depictions







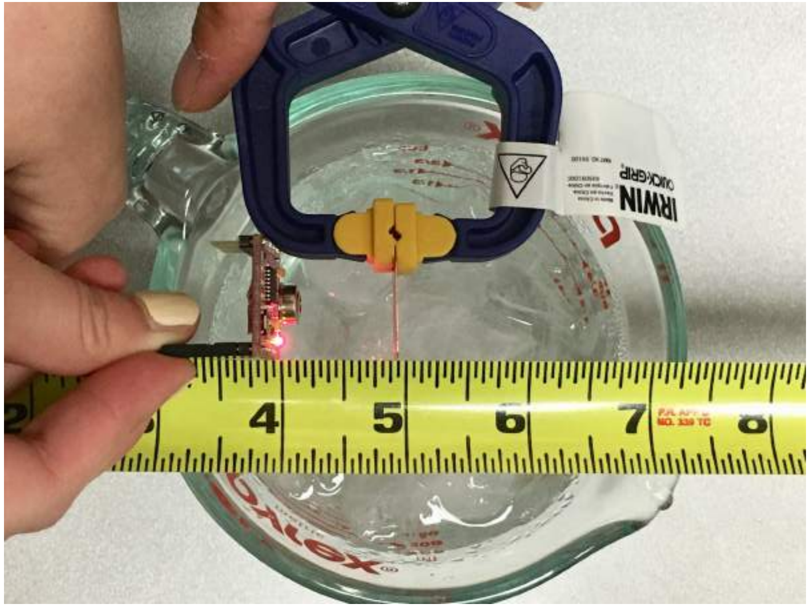


Modeling, Analysis, Results

Temperature Measurement Convergence Test

Challenges faced:

- Temperature measurement system refinement.
    - Problem : Low convergence rate.
    - Solution: Infrared sensor + Copper Pad.
    - Test results:
        - 0.107ºC rms error
        - Converge time < 5s (from 23ºC to 14ºC)



Challenges remaining:

- Obstacle avoidance
- Communication latency

Temperature Measurement Convergence Test

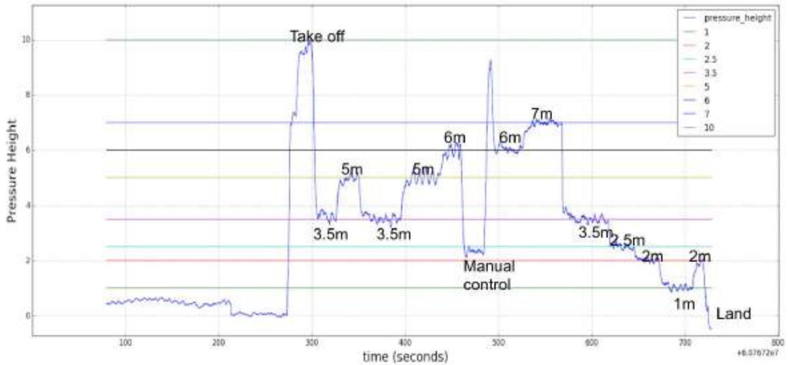
- Convergence Speed Test (Ice Water Experiment)

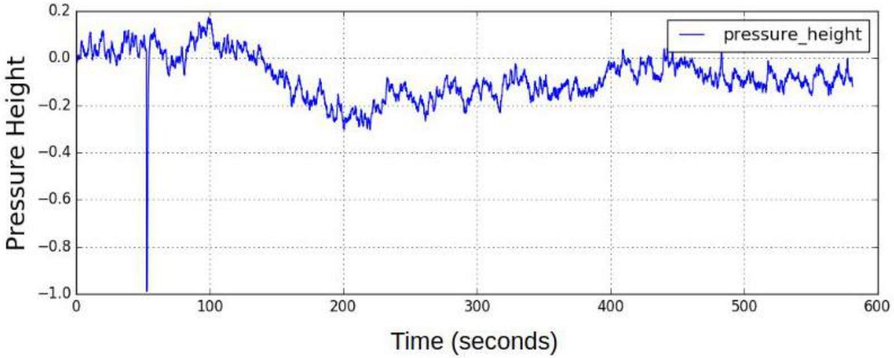
  - Converge time < 5s (from 23ºC to 14ºC)
- Measurement Accuracy Test
  - 0.107ºC rms error

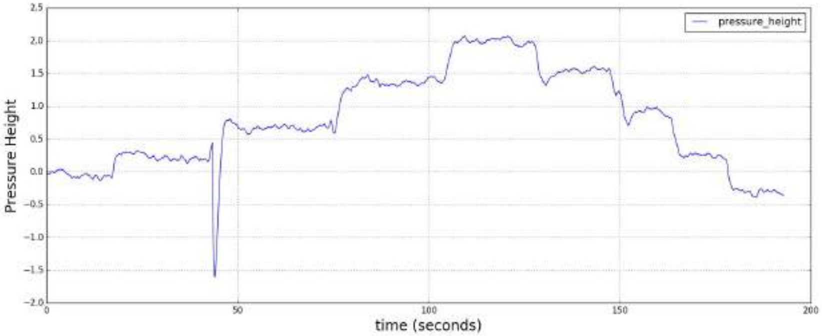
UAV Altitude Control Analysis

Hypothesis of Inaccurate Hovering:

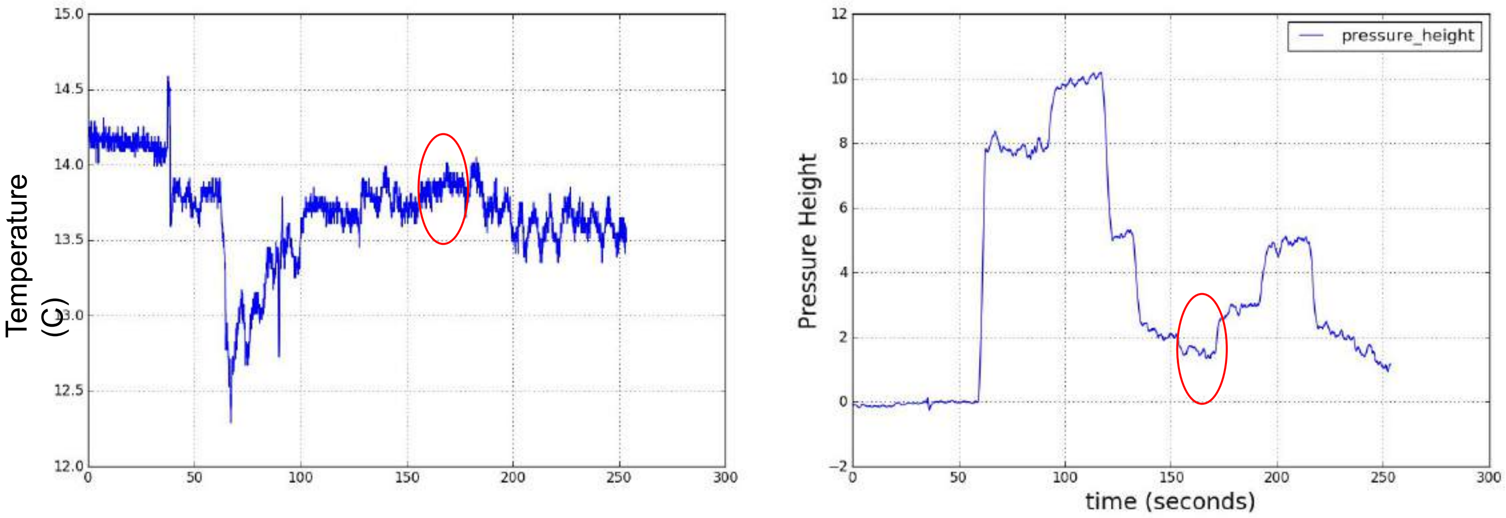
1. ~~Poor altitude controller~~
2. ~~Height measurement sensor not working properly.~~
3. ~~Noisy height measurement sensor source.~~
4. **Mismatch between sensor reading and actual height.**







UAV Temperature Measurement Analysis



- Temperature Measurement Test: keep collecting temperature while commanding different height
  - Measurement : 13.8
  - Ground truth : 14.8

Challenges

UGV Subsystem :

Challenges faced:

- Temperature measurement system refinement.
  - Problem : Low convergence rate.
  - Solution: Infrared sensor + Copper Pad.
  - Test results:
    - 0.107ºC rms error
    - Converge time < 5s (from 23ºC to 14ºC)

Challenges remaining:

- Obstacle avoidance
- Communication latency

UAV Subsystem :

Challenges faced:

- Temperature measurement system refinement.
- UAV Altitude Control Improvement
  - Problem: Inaccurate hovering position
  - Solution: calibrate before demo

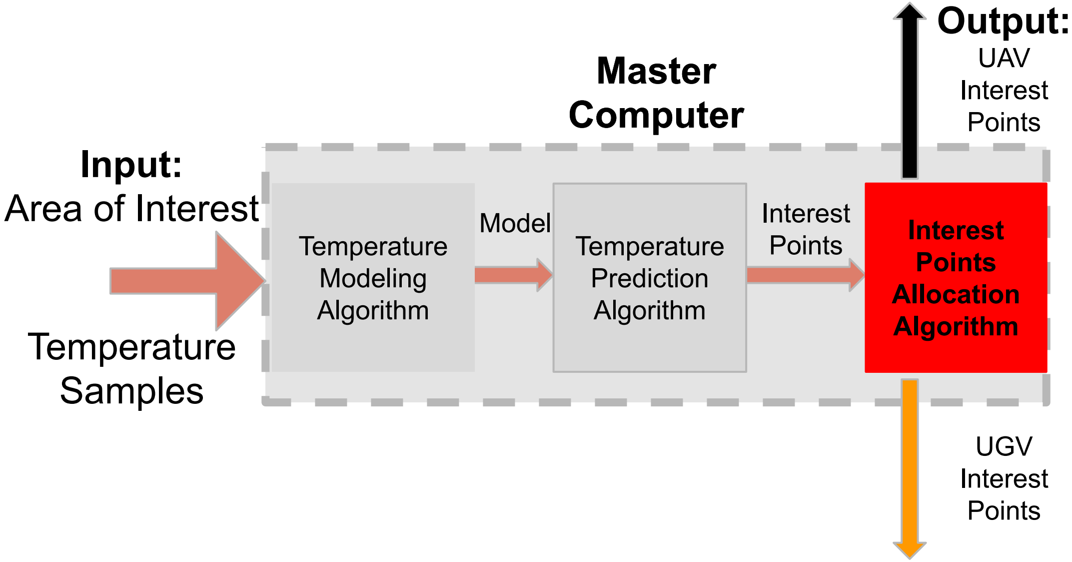
Challenges remaining:

- Temperature measurement with airflow
- Trade-off between safety and measurement accuracy
- Communication latency

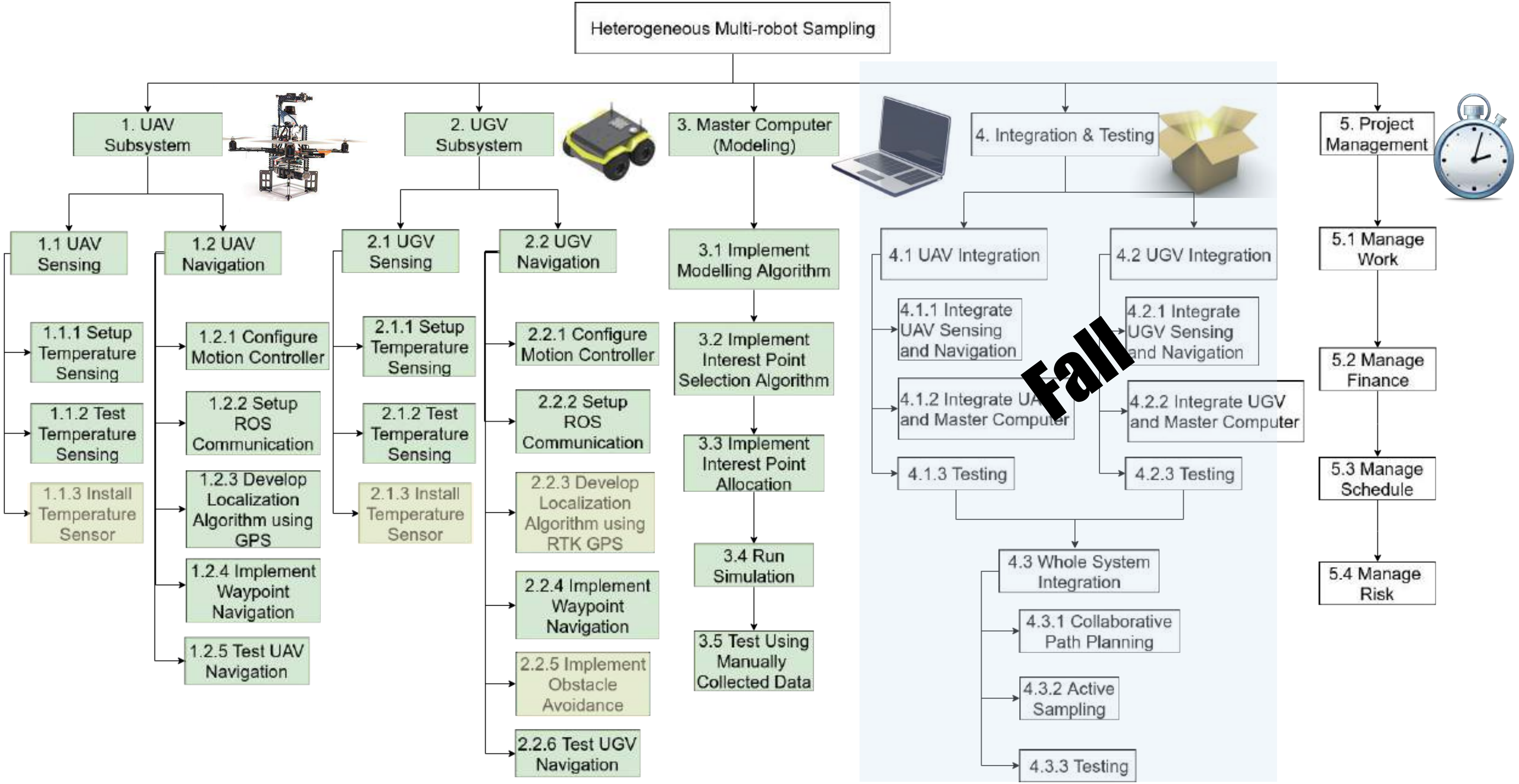
Master Computer :

Challenges remaining:

- Heterogeneous sampling
  - Consider UGV/UAV difference in mobility, battery life etc.
  - Consider UAV's disability in obstacle avoidance while assigning interest points

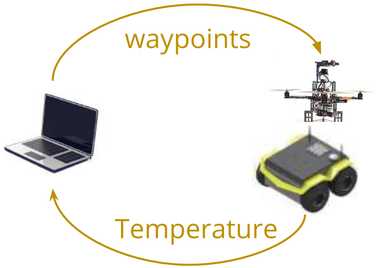


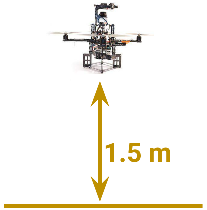
Schedule


Heterogeneous Multi-robot Sampling
1. UAV Subsystem
1.1 UAV Sensing
1.1.1 Setup Temperature Sensing
1.1.2 Test Temperature Sensing
1.1.3 Install Temperature Sensor
1.2 UAV Navigation
1.2.1 Configure Motion Controller
1.2.2 Setup ROS Communication
1.2.3 Develop Localization Algorithm using GPS
1.2.4 Implement Waypoint Navigation
1.2.5 Test UAV Navigation
2. UGV Subsystem
2.1 UGV Sensing
2.1.1 Setup Temperature Sensing
2.1.2 Test Temperature Sensing
2.1.3 Install Temperature Sensor
2.2 UGV Navigation
2.2.1 Configure Motion Controller
2.2.2 Setup ROS Communication
2.2.3 Develop Localization Algorithm using RTK GPS
2.2.4 Implement Waypoint Navigation
2.2.5 Implement Obstacle Avoidance
2.2.6 Test UGV Navigation
3. Master Computer (Modeling)
3.1 Implement Modelling Algorithm
3.2 Implement Interest Point Selection Algorithm
3.3 Implement Interest Point Allocation
3.4 Run Simulation
3.5 Test Using Manually Collected Data
4. Integration & Testing
4.1 UAV Integration
4.1.1 Integrate UAV Sensing and Navigation
4.1.2 Integrate UAV and Master Computer
4.1.3 Testing
4.2 UGV Integration
4.2.1 Integrate UGV Sensing and Navigation
4.2.2 Integrate UGV and Master Computer
4.2.3 Testing
4.3 Whole System Integration
4.3.1 Collaborative Path Planning
4.3.2 Active Sampling
4.3.3 Testing
Fall
5. Project Management
5.1 Manage Work
5.2 Manage Finance
5.3 Manage Schedule
5.4 Manage Risk

Fall Milestones

PR 7	PR 8	PR 9	PR 10	PR 11	PR 12
11 Sep	23 Sep	09 Oct	23 Oct	06 Nov	18 Nov
Setup UAV, UGV, Master Computer integration pipeline	Finish temperature sensor update with high accuracy and convergence rate.	Finish sampling using UGV in an obstacle-free region.	Finish sampling using UAV in an obstacle-free region.	Finish heterogeneous sampling in an obstacle-free region	Finish heterogeneous sampling in the required region with obstacles





Fall Milestones

Match the Schedule!

PR 7 — PR 8 — PR 9 — PR 10 — PR 11 — PR 12

PR 7 — 11 Sep

Setup UAV, UGV, Master Computer integration pipeline

PR 8 — 23 Sep

Finish temperature sensor update with high accuracy and convergence rate.

PR 9 — 09 Oct

Finish sampling using UGV in an obstacle-free region.

PR 10 — 23 Oct

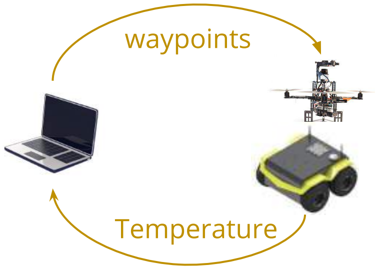
Finish sampling using UAV in an obstacle-free region.

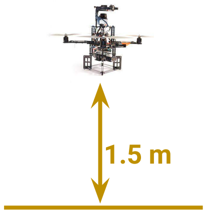
PR 11 — 06 Nov

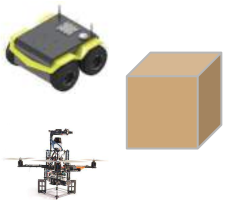
Finish heterogeneous sampling in an obstacle-free region

PR 12 — 18 Nov

Finish heterogeneous sampling in the required region with obstacles







Fall Valid Demonstration

Location: The cut.

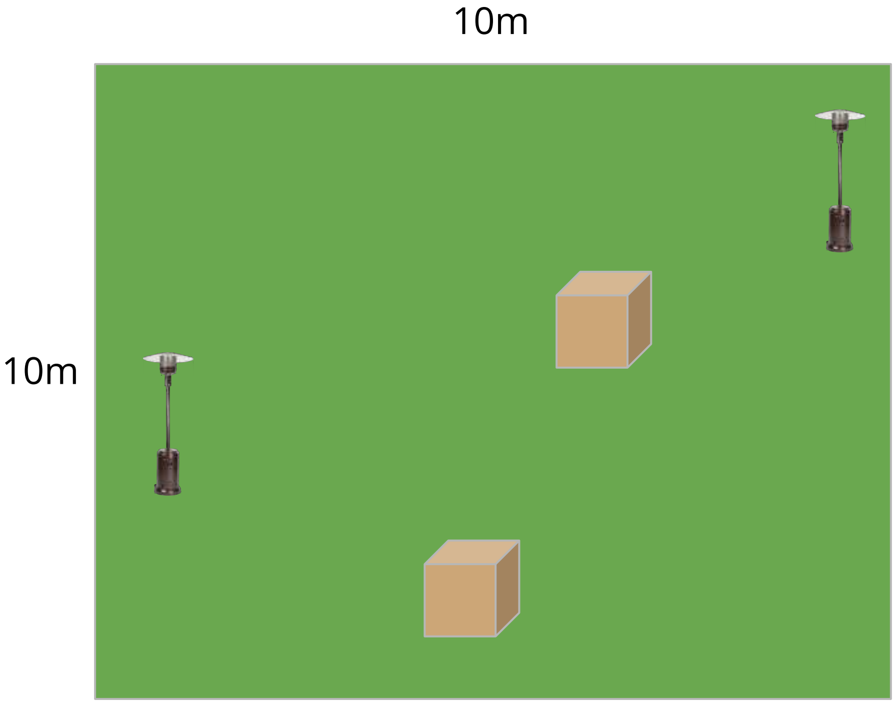
Equipment:

- Master Computer system
- UGV subsystem:
  - RTK GPS, Temperature measurement system (IR + Copper pad)
- UAV subsystem:
  - RTK GPS, Temperature measurement system (IR + Copper pad)
- Test facilities:
  - Ground truth temperature sensor, heat sources, Obstacles

Fall Valid Demonstration

Sequence of event

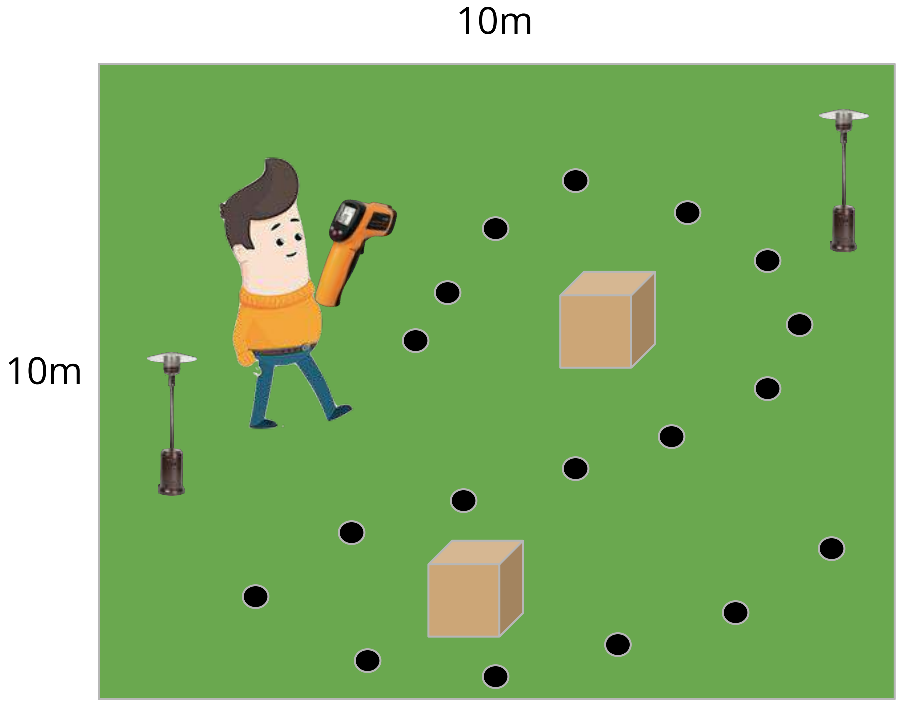
1. **Randomly place heat sources and obstacles in the 10m x 10m x 5m test field.**



Fall Valid Demonstration

Sequence of event

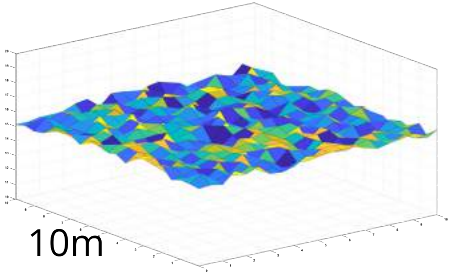
1. Randomly place heat sources and obstacles in the 10m x 10m x 5m test field.
2. **Manually collected ~20 temperature samples.**



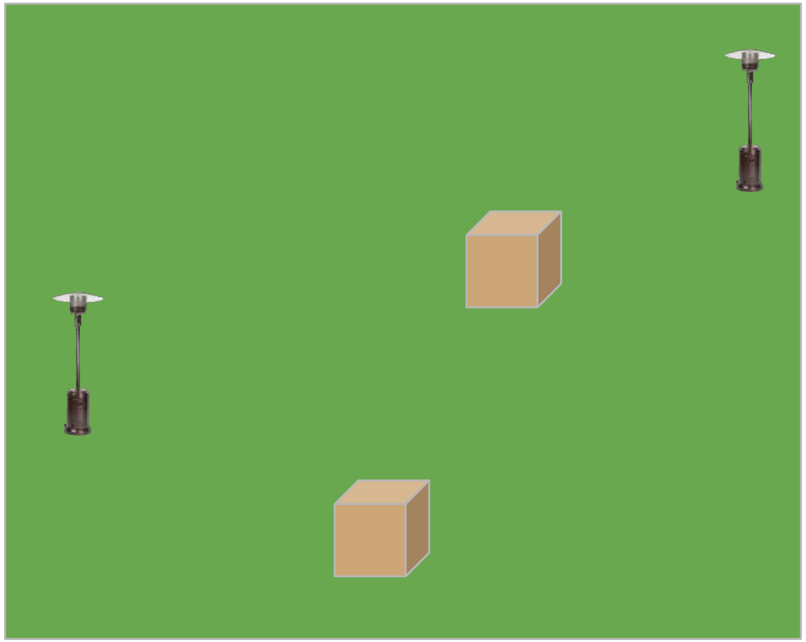
Fall Valid Demonstration

Sequence of event

1. Randomly place heat sources and obstacles in the 10m x 10m x 5m test field.
2. Manually collected ~20 temperature samples.
3. **Master computer updates temperature model.**



10m



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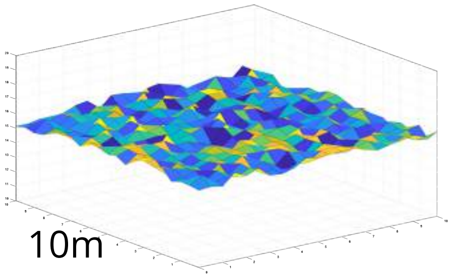
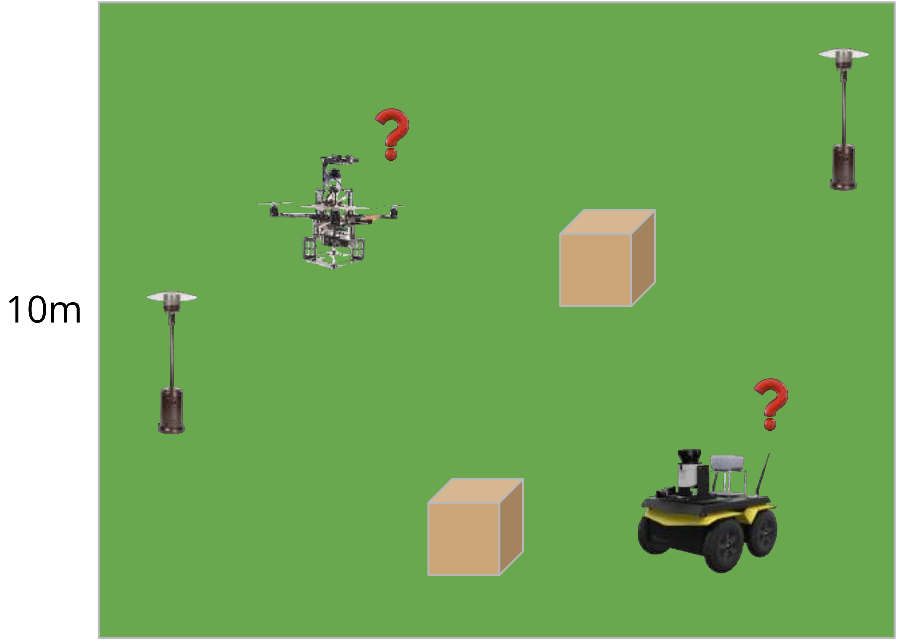


Sequence of event

1. Randomly place heat sources and obstacles in the 10m x 10m x 5m test field.
2. Manually collected ~20 temperature samples.
3. Master computer updates temperature model.
4. **Jackal/Pelican asks master computer for the next location to measure temperature.**



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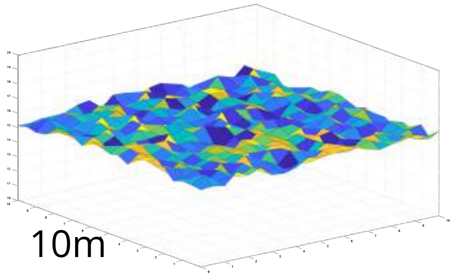

Sequence of event

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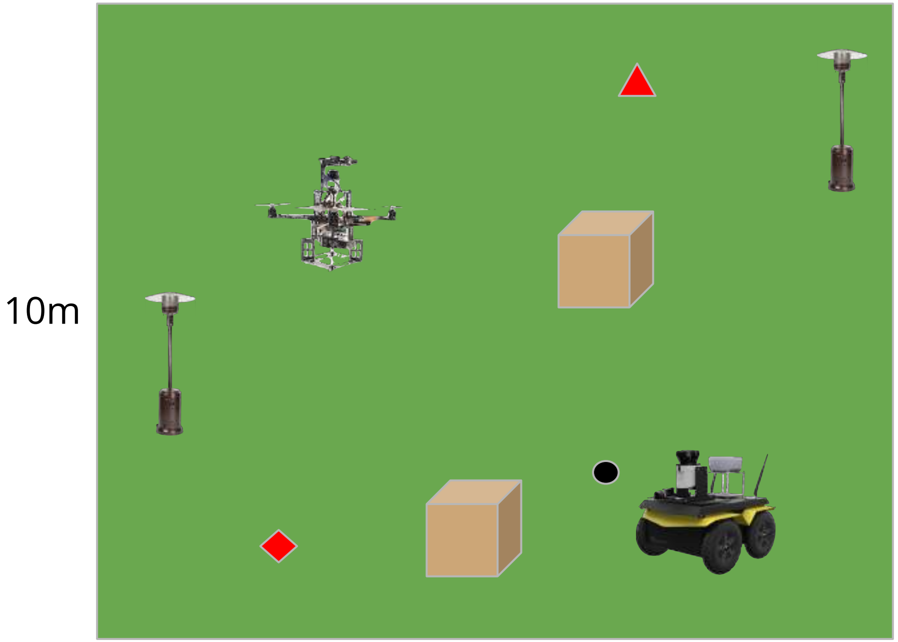
2. Manually collected ~20 temperature samples.
3. Master computer updates temperature model.
4. Jackal/Pelican asks master computer for the next location to measure temperature.
5. **Master computer selects the next interest points for Jackal/Pelican.**



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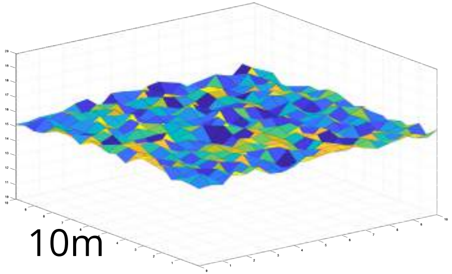

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3. Master computer updates temperature model.
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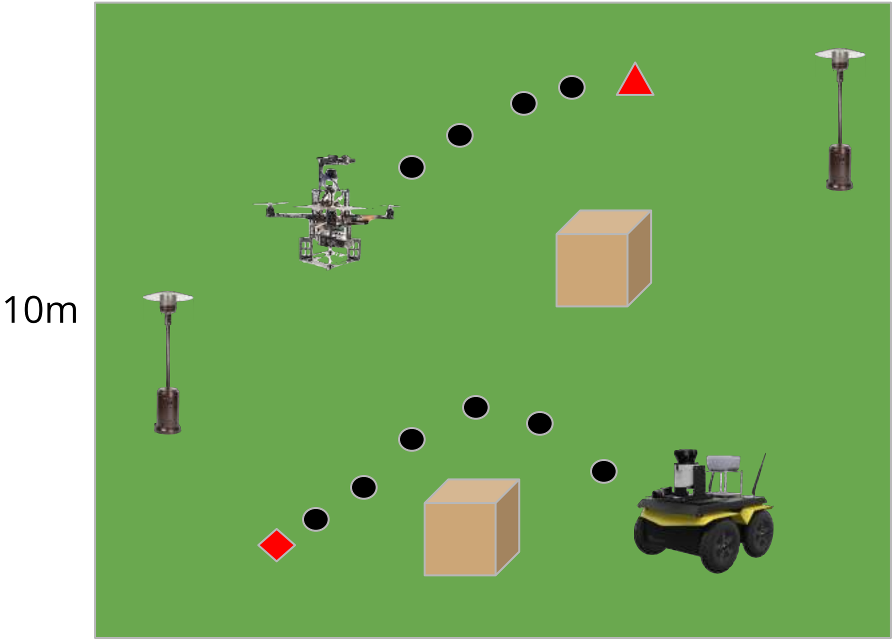
5. Master computer selects the next interest points for Jackal/Pelican.
6. **Jackal/Pelican navigates to the target position.**



Fall Valid Demonstration

Sequence of event

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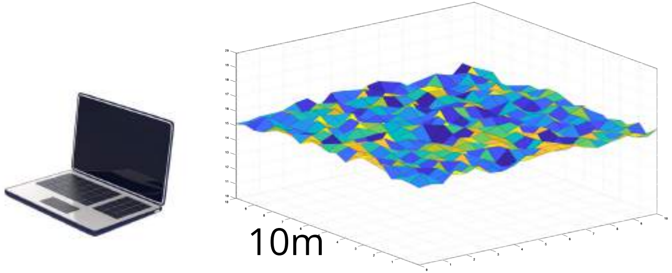
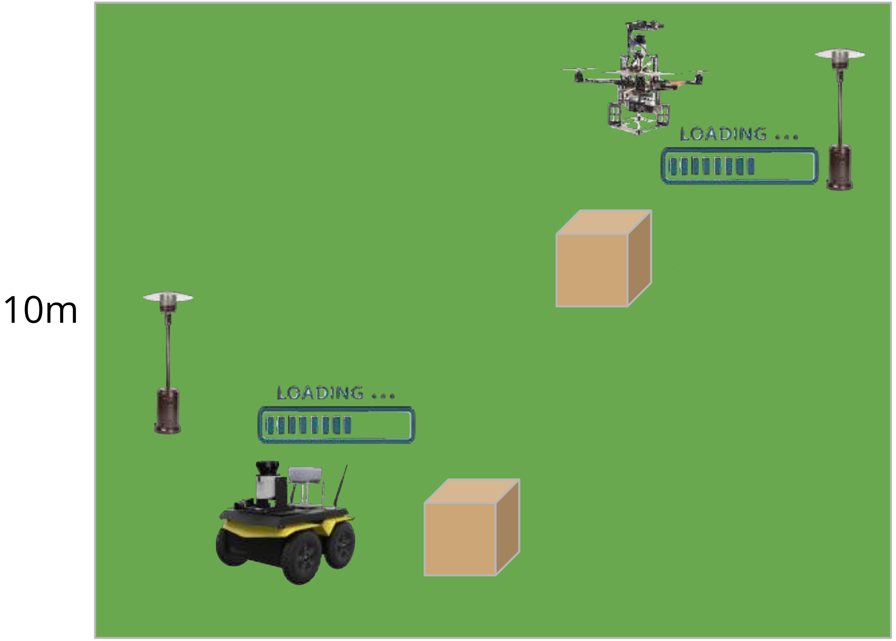
3. Master computer updates temperature model.
4. Jackal/Pelican asks master computer for the next location to measure temperature.
5. Master computer selects the next interest points for Jackal/Pelican.
6. Jackal/Pelican navigates to the target position.
7. **Jackal/Pelican collects temperature measurements.**





Fall Valid Demonstration

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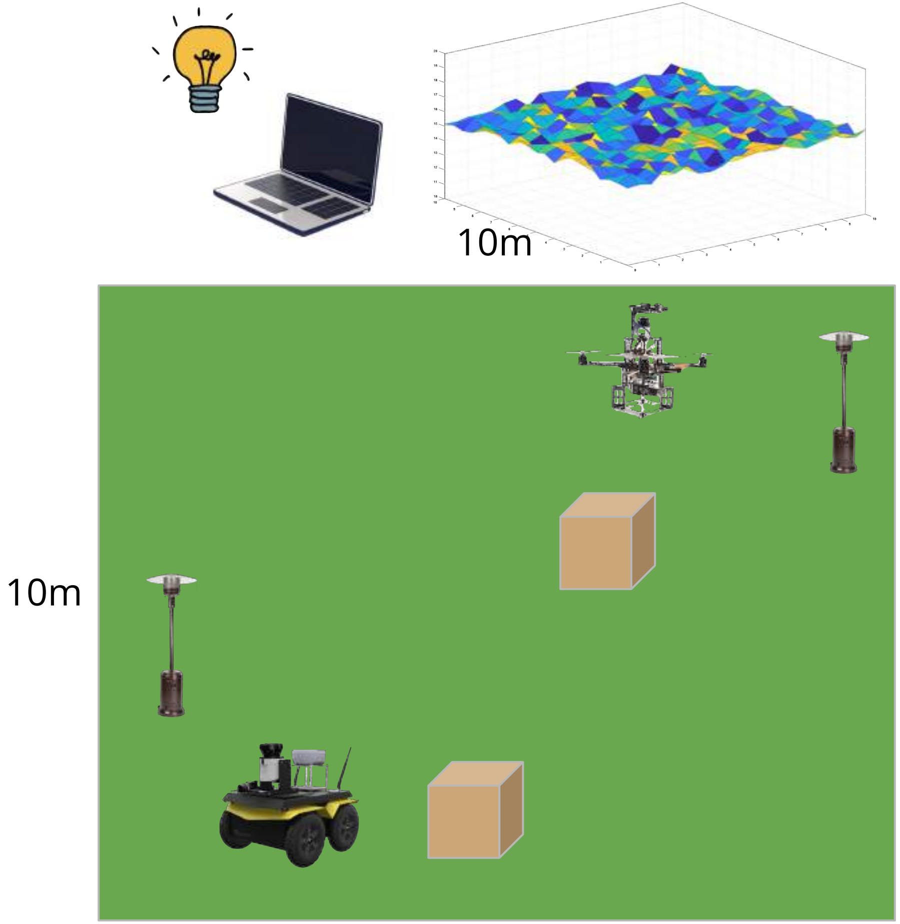
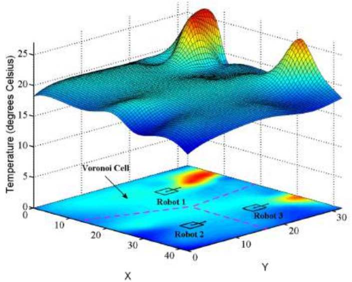
3. Master computer updates temperature model.
4. Jackal/Pelican asks master computer for the next location to measure temperature.
5. Master computer selects the next interest points for Jackal/Pelican.
6. Jackal/Pelican navigates to the target position.
7. Jackal/Pelican collects temperature measurements.
8. **Jackal/Pelican sends measurements back to Master computer.**



Fall Valid Demonstration

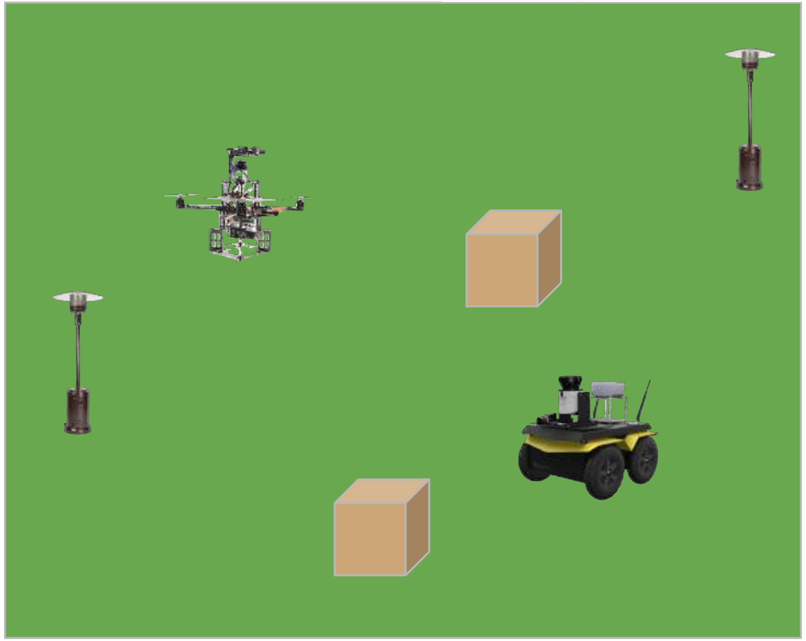


10m

Sequence of event

1. Randomly place heat sources and obstacles in the 10m x 10m x 5m test field.
2. Manually collected ~20 temperature samples.
3. Master computer updates temperature model.
4. Jackal/Pelican asks master computer for the next location to measure temperature.
5. Master computer selects the next interest points for Jackal/Pelican.
6. Jackal/Pelican navigates to the target position.
7. Jackal/Pelican collects temperature measurements.
8. Jackal/Pelican sends measurements back to Master computer.
9. Loop through step 3 - 8 until reaching time limit or temperature model converges.

10m



Fall Valid Demonstration

Performance matrix:

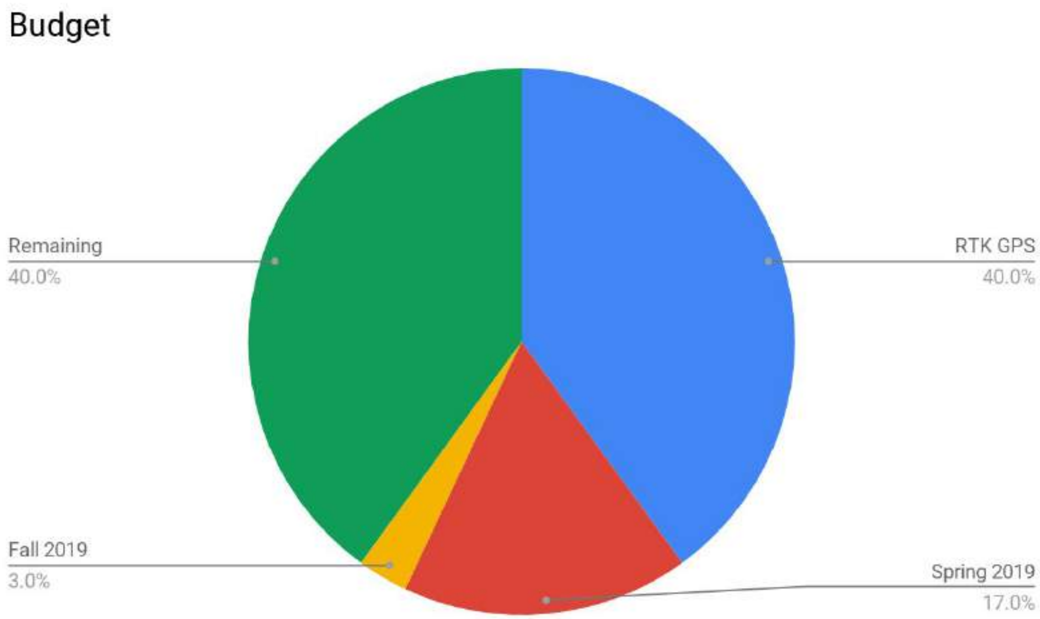
1. Robots should never hit obstacles.
2. The mean difference between 20 randomly-picked ground truth temperature measurement and model predictions should be less than or equal to 2 degrees.

Budge Status

Total Budget: $5,000

Spent: $3,025 (60%)

Budget Left: $1,975 (40%)



Budge Status /todo update

Part Name	Quantity	Unit Price	Total Price
Ground Truth Temperature Sensor	12	$49.99	$599.88
Ground Truth Temperature Sensor WiFi Gateway	1	$99.95	$99.95
Heat Source	2	$16	$32
Battery Monitor	1	$9.89	$9.89
On-board Temperature Sensor	4	$13.99	$55.96
Temperature Sensor Extension Cable	4	$6.99	$27.96
RTK-GPS Set (2 Rovers and 1 base)	1	$2,000	$2,000
		Total:	**$2,865.64**

Risk Management

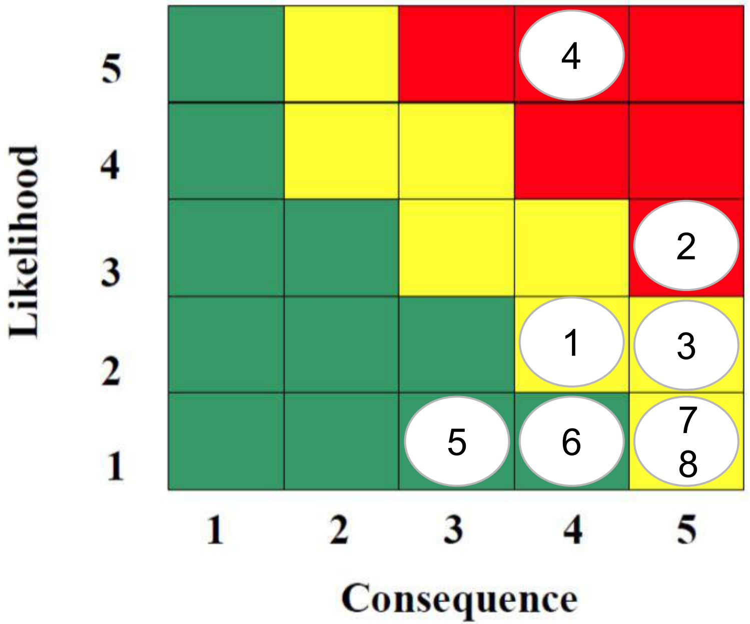
ID	Risk	Type	Description	Likelihood	Consequence	Risk Reduction Plan
1	Electric System Failure	Technical	The battery or electric system fails due to incorrect operation.	2	4	• Add reverse voltage and overvoltage protection. • Document and regulate operation.
2	Work Delay	Schedule	Heavy workload puts the team behind the schedule	3 (-1)	5	• Optimize the WBS to break down the workload into manageable pieces.
3	Run Out of Budget	Financial	Run out of funds purchasing parts and repairing robots.	2	5	• Make purchasing decision carefully after trade study.
4	Latency for Real-time Operation	Technical	Communication latency between master computer and UGV fails real-time operation.	5 (+1)	4	• Use a higher speed router.
5	Poor Weather for Validation Tests	Schedule	Poor weather prevents/delays the system from outdoor experiments.	1	3	• Monitor upcoming weather. • Schedule tests beforehand.

Risk Management

ID	Risk	Type	Description	Likelihood	Consequence	Risk Reduction Plan
6	Even Temperature Distribution	Technical	Temperate difference in the test field is close to or smaller than sensor noise.	1	4	• Use sensors with higher sensitivities based on previous experiment results. • Add heat sources to the test field to increase temperature variance.
7	Poor Localization Accuracy	Technical	Localization accuracy is not high enough considering the size of the test field.	1	5	• Use RTK GPS instead of built-in GPS.
8	Slow Temperature Convergence	Technical	Temperature converges too slow for ground truth and onboard sensors to meet the time requirement.	1 (-3)	5	• Use temperature sensors with faster response time.

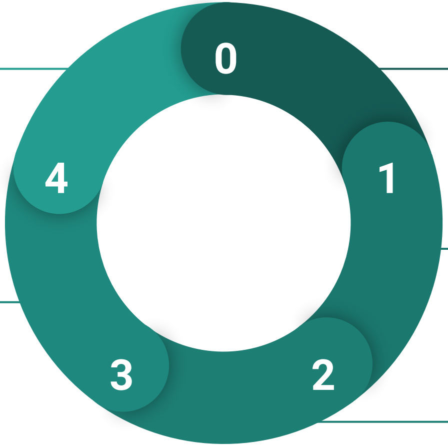
Updated Risk Management

1. Electric System Failure
2. Work Delay
3. Run Out of Budget
4. Latency for Real-time Operation
5. Poor Weather for Validation Tests
6. Even Temperature Distribution
7. Poor Localization Accuracy
8. Slow Temperature Convergence



Most Involved Portions

- System Integration
    - Start integration process early



Plan
Risk, Budget, Schedule

Implement/add Features
Implement features to the system

Test
Perform unit test to the added feature and then do field test

Analyze Problems
Collect problems from the system testing and find the root cause of the problems

Estimate Risk & Update Plan
Based on the problems re-estimate the risks and update plan.

Most Involved Portions

- Testing
    - Plan ahead
        - At least 3 days ahead the testing
    - Monitor Weather
        - Keep monitoring weather forecast
    - Start system integration test early
        - Starting from PR7
    - Unit tests
        - Test each small features/functions independently

Other Aspects

- Testing Facilities
  - Concerns:
    - Setting up Time
    - Safety
    - Providing temperature difference
  - Plans:
    - Test all the possible facilities early
    - Find the most suitable
- Course Load
  - Allocate heavier load to the beginning of the semester.
  - Set up milestones together and consider major homework/project deadlines

Q&A