Heterogeneous Multi-Robot Sampling
Test Plan

Team G: SAMP

Team Member:
Ning Wang
Yunfei Shi
Yang Zhang
Jianmin Zheng

Sponsor:
Katia Sycara

Advisor:
Dimi Apostolopoulos
John M. Dolan

Mentor:
Wenhao Luo
Sha Yi

Contents

1. Introduction

This test plan outlines the requirements and goals to be achieved by the SAMP Team (Team G) by the Fall Validation Demo. It describes general logistics, capability milestones, schedule of tests and specific details of each test. It also shows how these tests will lead us to achieve a fully functional multi-robot sampling system.

Each milestone is designed to let the system meets a specific functional requirement. Our final validation demo will be a fully functional demonstration of the multi-robot sampling system at CMU the cut. Detail testing procedures and the related requirements are presented in Section 4.3.

2. Logistics

2.1 Personnel

All team personnel will be present for each test. For subsystem tests, there will be two principal personnel who are more familiar with function unit to be tested to lead the test and perform task management. For the integration test which requires more effort in setting up and testing, each team personnel will be responsible for a part of the system to ensure the testing efficiency.

2.2 Location

Temperature measuring subsystem tests will be conducted at CMU RI 1st floor (Advanced Agent Lab). All the mobility tests will be performed at CMU the cut.

2.3 Equipment

Geral testing equipment includes:

- 20mm*20mm*0.3mm copper pad
- handheld infrared temperature thermometer
- SensorPush temperature sensor
- plastic clip
- Jackal UGV (with temperature sensing system integrated).
- Heat source
- Timer
- Pelican UAV (with temperature sensing system integrated).
- SensorPush temperature sensor

3. Schedule

PR	Date	Capability Milestone	Associated Test	Associated Requirement
7	11 Sept.	Integrate master computer with UAV and UGV subsystems	● 1.1 ● 1.2	● M.N. 6
8	25 Sept.	Finish temperature sensor update with high accuracy and convergence rate.	● 1.3 ● 1.4	● M.P. 4
9	09 Oct.	Finish UAV temperature measurement while hovering over the intended position.	● 3.1 ● 3.2	● M.P. 6
10	23 Oct.	Finish heterogeneous sampling in an obstacle-free region	● 2.1 ● 2.2 ● 4.1 ● 4.2	● M.P. 7 ● M.P. 9
11	06 Nov.	Finish obstacle avoidance motion planning for UGV	● 2.3	● M.P. 8
12	18 Nov.	Finish heterogeneous sampling in the required region with obstacles (FVD rehearsal)	● 4.3	● M.P. 1 ● M.P. 2 ● M.P. 3 ● D.P. 1
FVD	25 Nov.	Finish heterogeneous sampling in the required region with obstacles	● FVD	● M.P. 1 ● M.P. 2 ● M.P. 3 ● D.P. 1

4. Tests

4.1 Temperature Measurement System Tests

4.1.1 Test 1.1

<table>
<tr><td colspan="2">Objective</td></tr>
<tr><td colspan="2">To verify the surface temperature of the copper pad is equivalent to the ambient air temperature</td></tr>
<tr><td>Elements</td><td>Location</td></tr>
<tr><td>Temperature Measurement System</td><td>Advanced Agent Lab located at RI 1st floor</td></tr>
<tr><td>Equipment</td><td>Personnel</td></tr>
<tr><td>● 20mm*20mm*0.3mm copper pad
● handheld infrared temperature thermometer
● SensorPush temperature sensor
● plastic clip</td><td>● Paul Zheng
● Ning Wang</td></tr>
<tr><td colspan="2">Procedure</td></tr>
<tr><td colspan="2">1. Place the SensorPush temperature sensor on the table, record the reading T1 after converged
2. Hold the copper pad using a plastic clip in the air.
3. Use the handheld infrared temperature thermometer to measure the surface temperature of the copper pad, and record the reading T2 after converged</td></tr>
<tr><td colspan="2">Validation Criteria</td></tr>
<tr><td colspan="2">Difference between T1 and T2 shall be less than 2 ºC</td></tr>
</table>

4.1.2 Test 1.2

<table>
<tr><td colspan="2">Objective</td></tr>
<tr><td colspan="2">To demonstrate the temperature converge speed of the selected copper pad can meet the time requirement.</td></tr>
<tr><td>Elements</td><td>Location</td></tr>
<tr><td>Temperature Measurement System</td><td>Advanced Agent Lab located at RI 1st floor</td></tr>
<tr><td>Equipment</td><td>Personnel</td></tr>
<tr><td>● 20mm*20mm*0.3mm copper pad
● handheld infrared temperature thermometer
● A cup of ice water
● plastic clip
● timer</td><td>● Paul Zheng
● Ning Wang</td></tr>
<tr><td colspan="2">Procedure</td></tr>
<tr><td colspan="2">1. Hold the copper pad using a plastic clip in the air.
2. Use the handheld infrared temperature thermometer to measure the surface temperature of the copper pad.
3. With the sensor triggered on, move the copper pad and the handheld infrared temperature thermometer over the ice water
4. Use the timer to record the time for the measurement reading to converge</td></tr>
<tr><td colspan="2">Validation Criteria</td></tr>
<tr><td colspan="2">Converge time shall be less than 10s</td></tr>
</table>

4.1.3 Test 1.3

<table>
<tr><td colspan="2">Objective</td></tr>
<tr><td colspan="2">To verify the temperature measurement system on the robots can obtain accurate reading that meets the temperature accuracy requirement</td></tr>
<tr><td>Elements</td><td>Location</td></tr>
<tr><td>Temperature Measurement System</td><td>The Cut</td></tr>
<tr><td>Equipment</td><td>Personnel</td></tr>
<tr><td>Jackal UGV (with temperature sensing system integrated).
Pelican UAV (with temperature sensing system integrated).
SensorPush temperature sensor</td><td>Paul Zheng
Ning Wang</td></tr>
<tr><td colspan="2">Procedure</td></tr>
<tr><td colspan="2">Random select 10 locations and manually command Jackal UGV to collect temperature measurements at these locations with a height at 1m.
Manually control Pelican UAV to hover at these locations with a height at 1m and collect temperature measurements.
Use the SensorPush temperature sensor to measure the temperature at the same locations with a height at 1m.</td></tr>
<tr><td colspan="2">Validation Criteria</td></tr>
<tr><td colspan="2">Average difference between the readings by the robots and the readings by the SensorPush temperature sensor at same locations shall be less than 2 ºC</td></tr>
</table>

4.1.4 Test 1.4

<table>
<tr><td colspan="2">Objective</td></tr>
<tr><td colspan="2">To verify the converge time for the temperature measurement system on the robots can meet the time requirement.</td></tr>
<tr><td>Elements</td><td>Location</td></tr>
<tr><td>Temperature Measurement System</td><td>The Cut</td></tr>
<tr><td>Equipment</td><td>Personnel</td></tr>
<tr><td>Jackal UGV (with temperature sensing system integrated).
Pelican UAV (with temperature sensing system integrated).
Heat source
timer</td><td>Paul Zheng
Ning Wang</td></tr>
<tr><td colspan="2">Procedure</td></tr>
<tr><td colspan="2">Deploy heat source in the test area
Select one random location far from the heat source and manually command Jackal UGV to collect temperature measurement at that location with a height at 1m.
Manually command Jackal to a location near the heat source. Record the time for the measurement to converge.
Manually control Pelican UAV to hover at the starting location with a height at 1m and collect temperature measurement.
Manually command Pelican UAV to hover at the location near the heat source with a height at 1m. Record the time for the measurement to converge.
Repeat the experiment 5 times</td></tr>
<tr><td colspan="2">Validation Criteria</td></tr>
<tr><td colspan="2">The average converge time for UAV and UGV shall both be less than 10s.</td></tr>
</table>

4.2 UGV Subsystem Tests

4.2.1 Test 2.1

<table>
<tr><td colspan="2">Objective</td></tr>
<tr><td colspan="2">To verify the localization accuracy of Jackal UGV meets the performance requirement.</td></tr>
<tr><td>Elements</td><td>Location</td></tr>
<tr><td>Localization</td><td>The cut</td></tr>
<tr><td>Equipment</td><td>Personnel</td></tr>
<tr><td>● Jackal UGV
● Manual Controller
● RTK GPS
● IMU
● Wheel encoder system
● Land markers</td><td>● Yang Zhang
● Yunfei Shi</td></tr>
<tr><td colspan="2">Procedure</td></tr>
<tr><td colspan="2">1. RandomlyPut two land markers 10 meter away from each other, of which one as the start position and the other one as the goal position.
2. Record the GPS positions for two land markers.
3. Place a paper
4. Manually drive Jackal back on the land marker.
5. Record Jackal’s final position provided by its localization node.
6. Loop step 1 - 5 at 10 different locations.</td></tr>
<tr><td colspan="2">Validation Criteria</td></tr>
<tr><td colspan="2">The mean difference between the final locations and the initial locations should be less than 0.5m.</td></tr>
</table>

4.2.2 Test 2.2

<table>
<tr><td colspan="2">Objective</td></tr>
<tr><td colspan="2">To verify that Jackal’s GPS waypoint navigation meets accuracy and time requirements.</td></tr>
<tr><td>Elements</td><td>Location</td></tr>
<tr><td>Waypoint Navigation
Localization
Control</td><td>The cut</td></tr>
<tr><td>Equipment</td><td>Personnel</td></tr>
<tr><td>● Jackal UGV
● RTK GPS
● IMU
● Wheel encoder system</td><td>● Yang Zhang
● Yunfei Shi</td></tr>
<tr><td colspan="2">Procedure</td></tr>
<tr><td colspan="2">1. Randomly launch Jackal in the 10m x 10m test field.
2. Randomly pick a target location in the test field which is at least 3 meter away from Jackal.
3. Record the GPS position of the target location.
4. Send the GPS waypoint to Jackal and let it navigate to the target position.
5. Record the time Jackal needed to finish navigation and the difference between its final position and target position.
6. Loop step 1 to 5 for 5 times.</td></tr>
<tr><td colspan="2">Validation Criteria</td></tr>
<tr><td colspan="2">● The mean difference between the Jackal’s final positions and target goal positions should be less than 0.5m.
● The mean time for each navigation task should be less than 20 seconds.</td></tr>
</table>

4.2.3 Test 2.3

<table>
<tr><td colspan="2">Objective</td></tr>
<tr><td colspan="2">To verify the Jackal’s navigation ability among obstacles.</td></tr>
<tr><td>Elements</td><td>Location</td></tr>
<tr><td>Waypoint Navigation
Motion Planning
Localization</td><td>The cut</td></tr>
<tr><td>Equipment</td><td>Personnel</td></tr>
<tr><td>● Jackal UGV
● RTK GPS
● IMU
● Wheel encoder system
● Land markers
● Paper Boxes</td><td>● Yang Zhang
● Yunfei Shi</td></tr>
<tr><td colspan="2">Procedure</td></tr>
<tr><td colspan="2">1. Randomly put two land markers 10 meter away from each other, of which one as the start position and the other one as the goal position.
2. Record the GPS positions for two land markers.
3. Place a paper box as an obstacle between two land markers.
4. Command Jackal to navigate autonomously from the start position to the goal position.
5. Record Jackal’s final position and whether it hits the obstacle.
6. Loop step 1 - 5 for 5 times.</td></tr>
<tr><td colspan="2">Validation Criteria</td></tr>
<tr><td colspan="2">● The mean difference between the Jackal’s final positions and target goal positions should be less than 0.5m.
● Jackal should never hit the obstacle.</td></tr>
</table>

4.3 UAV Subsystem Tests

4.3.1 Test 3.1

<table>
<tr><td colspan="2">Objective</td></tr>
<tr><td colspan="2">To test the height control accuracy of AscTec Pelican UAV.</td></tr>
<tr><td>Elements</td><td>Location</td></tr>
<tr><td>Height</td><td>The cut</td></tr>
<tr><td>Equipment</td><td>Personnel</td></tr>
<tr><td>AscTec Pelican UAV
Manual Controller
RTK GPS
IMU</td><td>Paul Zheng
Yunfei Shi</td></tr>
<tr><td colspan="2">Procedure</td></tr>
<tr><td colspan="2">Setup RTK GPS.
Launch AscTec Pelican UAV.
Finish the safety check of the UAV.
Manually take off.
Send 5 different height commands to the UAV via ROS.
Measure the actual height of UAV using RTK GPS.</td></tr>
<tr><td colspan="2">Validation Criteria</td></tr>
<tr><td colspan="2">The mean difference between the hovering height and the command height should be less than 0.2m.</td></tr>
</table>

4.3.2 Test 3.2

<table>
<tr><td colspan="2">Objective</td></tr>
<tr><td colspan="2">To test the temperature measurement of AscTec Pelican UAV.</td></tr>
<tr><td>Elements</td><td>Location</td></tr>
<tr><td>Temperature Measurement on UAV</td><td>The cut</td></tr>
<tr><td>Equipment</td><td>Personnel</td></tr>
<tr><td>AscTec Pelican UAV(with temperature sensing system integrated)
Manual Controller
RTK GPS
IMU</td><td>Paul Zheng
Yunfei Shi</td></tr>
<tr><td colspan="2">Procedure</td></tr>
<tr><td colspan="2">Setup RTK GPS.
Launch AscTec Pelican UAV.
Finish the safety check of the UAV.
Manually take off.
Send a random waypoint commands with the height of 1m to the UAV.
Let the UAV to collect temperature measurements while hovering.
Use the SensorPush temperature sensor to measure the temperature at the same location.
Repeat step 5-7 5 times.</td></tr>
<tr><td colspan="2">Validation Criteria</td></tr>
<tr><td colspan="2">The mean difference of the two readings at same locations shall be less than 2 ºC</td></tr>
</table>

4.4 System Integration Tests

4.4.1 Test 4.1

<table>
<tr><td colspan="2">Objective</td></tr>
<tr><td colspan="2">To verify the integration between Jackal UGV and master computer.</td></tr>
<tr><td>Elements</td><td>Location</td></tr>
<tr><td>● Master Computer
● Jackal UGV
● Temperature measurement system</td><td>The cut</td></tr>
<tr><td>Equipment</td><td>Personnel</td></tr>
<tr><td>● Jackal UGV
● Master Computer
● Temperature sensor
● Heat source
● Obstacles</td><td>● Jianmin Zheng
● Ning Wang
● Yang Zhang
● Yunfei Shi</td></tr>
<tr><td colspan="2">Procedure</td></tr>
<tr><td colspan="2">1. Randomly place heat sources and obstacles in the 10m x 10m x 5m test field.
2. Initialize the temperature model with 20 manually-collected temperature samples.
3. Master compute updates temperature model and assign next interest point to Jackal.
4. Jackal navigates to the target position.
5. Jackal collects temperature measurements and send it back to master computer.
6. Loop through step 3 to 5 until it reaches the 25-minute time limit.
7. Randomly pick 10 positions in the test field to collect ground truth temperature measurements.
8. Compare the ground truth measurements and predictions.
9. Loop through step 1 to 8 for 3 times in total.</td></tr>
<tr><td colspan="2">Validation Criteria</td></tr>
<tr><td colspan="2">● Jackal should never hit the obstacle.
● The mean difference between ground truth measurements and predictions should never exceed 2 °C.</td></tr>
</table>

4.4.2 Test 4.2

<table>
<tr><td colspan="2">Objective</td></tr>
<tr><td colspan="2">To verify the integration between Pelican UAV and master computer.</td></tr>
<tr><td>Elements</td><td>Location</td></tr>
<tr><td>● Master Computer
● Pelican UAV
● Temperature measurement system</td><td>The cut</td></tr>
<tr><td>Equipment</td><td>Personnel</td></tr>
<tr><td>● Pelican UAV
● Master Computer
● Temperature sensor
● Heat source
● Obstacles</td><td>● Jianmin Zheng
● Ning Wang
● Yang Zhang
● Yunfei Shi</td></tr>
<tr><td colspan="2">Procedure</td></tr>
<tr><td colspan="2">1. Randomly place heat sources and obstacles in the 10m x 10m x 5m test field.
2. Initialize the temperature model with 20 manually-collected temperature samples.
3. Master compute updates temperature model and assign next interest point to Pelican.
4. Pelican navigates to the target position.
5. Pelican collects temperature measurements and send it back to master computer.
6. Loop through step 3 to 5 until it reaches the 25-minute time limit.
7. Randomly pick 10 positions in the test field to collect ground truth temperature measurements.
8. Compare the ground truth measurements and predictions.
9. Loop through step 1 to 8 for 3 times in total.</td></tr>
<tr><td colspan="2">Validation Criteria</td></tr>
<tr><td colspan="2">● Pelican UAV should never hit the obstacles.
● The mean difference between ground truth measurements and predictions should never exceed 2 °C.</td></tr>
</table>

Fall Validation Demo (FVD)

<table>
<tr><td colspan="2">Objective</td></tr>
<tr><td colspan="2">To verify the system integration between Jackal UGV, Pelican UAV and master computer.</td></tr>
<tr><td>Elements</td><td>Location</td></tr>
<tr><td>● Master Computer
● Jackal UGV
● Pelican UAV
● Temperature measurement system</td><td>The cut</td></tr>
<tr><td>Equipment</td><td>Personnel</td></tr>
<tr><td>● Jackal UGV
● Pelican UAV
● Master Computer
● Temperature sensor
● Heat source
● Obstacles</td><td>● Jianmin Zheng
● Ning Wang
● Yang Zhang
● Yunfei Shi</td></tr>
<tr><td colspan="2">Procedure</td></tr>
<tr><td colspan="2">
1. Randomly place heat sources and obstacles in the 10m x 10m x 5m test field.
2. Initialize the temperature model with 20 manually-collected temperature samples.
3. Master compute updates build temperature model.
4.
<table>
<tr><td>Jackal asks master computer for the next location to measure temperature.</td><td>Pelican asks master computer for the next location to measure temperature.</td></tr>
</table>
5.
<table>
<tr><td>Master computer selects the next interest point for Jackal.</td><td>Master computer selects the next interest point for Jackal.</td></tr>
</table>
6.
<table>
<tr><td>Jackal navigates to the target position.</td><td>Pelican navigates to the target position.</td></tr>
</table>
7.
<table>
<tr><td>Jackal collects temperature measurements and send it back to master computer.</td><td>Pelican collects temperature measurements and send it back to master computer.</td></tr>
</table>
8. Loop through step 3 to 7 until it reaches the 25-minute time limit. To be noted, the processes for Jackal and Pelican are done in parallel.
9. Randomly pick 10 positions in the test field to collect ground truth temperature
</td></tr>
</table>

measurements. 10. Compare the ground truth measurements and predictions. 11. Loop through step 1 to 8 for 3 times in total.
Validation Criteria
● Jackal and Pelican should never hit the obstacle. ● The mean difference between ground truth measurements and predictions should never exceed 2 °C.