Contents

Introduction

This document describes the system tests along with a schedule that we would be following for the spring semester. The tests are laid out to match our schedule for our external and internal milestones. The purpose of these tests is to verify the performance and system requirements we have promised to achieve by our spring demonstration.

Logistics

The equipment and test sites required for the project are enumerated below:

1. **Fully Integrated Aerial Platform:** Drone platform developed by using AirLab inventory. Other accessories such as multiple battery packs, toolkits, and Ground Control Station (GCS).
2. **MRSD Lab:** Site for development and unit-testing of some subsystems.
3. **Airlab Indoor Cage:** The AirLab's Indoor flight testing cage will be used for initial unit-testing for fire segmentation, localization, and state estimation subsystems. The OptiTrack MoCap System will be used for localization for stationary testings.
4. **Hawkins Test-site:** The parking lot of the Hawkins will be used for our internal dry-runs, final subsystem testing, and SVD demo.

Our primary working space is the CMU's AirLab (also our sponsor) in Squirrel Hill. The hardware system is housed there, and preliminary flight tests are performed in the cage at AirLab. The primary off-site testing and data collection location for us is Hawkins. For software system, we would be using the compute available to us in the MRSD lab and a common Wildfire workstation at AirLab.

Personnel

The Wildfire project consists of members from AirLab along with us where our focus is on the system integration, autonomy stack, and integration with hardware while pursuing a set use case. For the tests, in addition to the team members, currently, the POC Andrew Jong would be required for off-site testing as he has the pilot license. We aim for at least 2 of the five members to get a flying license shortly to aid in continuous testing.

Schedule

PR #	Date	Capability Milestone	Test	Requirements
PR1	2/16	• Electrical subsystem completed • Fabricated prototype mounts for Jetson Orin, thermal cameras, and RGB camera	1,2	MF1 MF2 MNF1 MNF2 MNF3
PR2	3/1	• Cameras calibration completed • Fire segmentation pipeline tested on prescribed fire data	3,4	MF3 MF4 MNF4
PR3	3/22	• Fire segmentation pipeline deployed on the aerial platform • Fire localization pipeline testing completed for static platform • Visual-inertial odometry pipeline deployed on aerial platform	5,6,7	MF3 MF4 MF6 MNF4
PR4	4/5	• Fire localization pipeline integrated for in-flight operation • Global fire map generation completed using VIO • Ground Control Station and GUI setup completed	8,9	MF2 MF3 MF5 MNF4 MNF5
PR5 (SVD)	4/18	• Finetuned operation of system	10	

Tests

Test 1: Electrical and Power Delivery System Test

<table>
<tr><td colspan="2">Objective</td></tr>
<tr><td colspan="2">To bench-test the electrical components and power delivery system for the platform.</td></tr>
<tr><td>Elements</td><td>Hardware/Aerial Robotic Platform Subsystem</td></tr>
<tr><td>Equipment</td><td>Fully-integrated Aerial Robotic Platform
Portable Power Bank, HDMI cable, HDMI-DP Adapter, Portable Display, Keyboard, and Mouse
Multi-meter</td></tr>
<tr><td>Location</td><td>AirLab Work Bench, RI SQH</td></tr>
<tr><td>Personnel</td><td>Kavin Kailash Ravie, Ishir Roongta</td></tr>
<tr><td colspan="2">Procedure</td></tr>
<tr><td colspan="2">Manually inspect the connections for the sensors and check the shorting of wirings.
Make sure the kill switch is engaged on the controller for the bench test to avoid unforeseen accidents.
Connect the portable display setup to the onboard computer.
Connect the battery to turn on the entire electrical system.
Check the supplied voltage for the FCU, ESC, and on-board computer. [V1] [V2] [V3]
Check for sensor feeds using the portable display, after running the live-visualization script on the mission computer. [V4]</td></tr>
<tr><td colspan="2">Verification Criteria</td></tr>
<tr><td colspan="2">V1: Appropriate and stable regulated voltage is supplied to the FCU [5V].
V2: Appropriate and stable voltage is supplied to the propulsion system [14.80-16.80V].
V3: Enough voltage is supplied to the on-board compute Nvidia AGX Orin [12V].
V4: Stable sensor feeds streaming to verify proper wiring connections to AGX Orin.</td></tr>
</table>

Test 2: Robotic Platform Structural Integrity Test

<table>
<tr><td colspan="2">Objective</td></tr>
<tr><td colspan="2">To test the airframe structure and rigidity of mounts for the sensor suite onboard the airframe.</td></tr>
<tr><td>Elements</td><td>Hardware/Aerial Robotic Platform Subsystem</td></tr>
<tr><td>Equipment</td><td>Fully-integrated Aerial Robotic Platform
Portable Power Bank, HDMI cable, HDMI-DP Adapter, Portable Display, Keyboard, and Mouse
Stable Internet Connection (for accessing the online flight-log analysis tool)
RC Transmitter
USB Thumb-drive
Ground station Laptop with QGC
Telemetry Link to download the flight Logs
Allen Keys and Screwdrivers</td></tr>
<tr><td>Location</td><td>AirLab Flight Cage, RI SQH</td></tr>
<tr><td>Personnel</td><td>Kavin Kailash Ravie, Ishir Roongta</td></tr>
<tr><td colspan="2">Procedure</td></tr>
<tr><td colspan="2">Manual physical inspection of screws for mounts, propellers, sensor attachments, landing gear, and wires(not hanging out). [V1] [V2]
Power on the RC Transmitter; make sure the kill switch is engaged on the RC transmitter during the on-ground setup phase to avoid unforeseen accidents.
Place the drone in the cage, connect the batteries, and establish a wireless telemetry link b/w FCU and GCS.
Connect the portable display, keyboard, and mouse; start the sensor script on the mission computer to collect a ROSBag with thermal and RGB feeds.
Once the script is online, disconnect all the I/O accessories from the Mission computer
Perform a flight test of at least 2 minutes with minimal aggressive movements.
Land the drone, and disarm the FCU.
Make sure the kill switch is engaged on the RC transmitter.
Reconnect I/O accessories.
Download the sensor ROSBag and the flight log from the drone.
Upload the flight log to the online log analysis tool to analyze vibration metrics. [V3]
Visualize ROSBag data using RViz to visually inspect the quality of the sensor feeds. [V4]
After all the tests are concluded power off the drone and disconnect all accessories.</td></tr>
<tr><td colspan="2">Verification Criteria</td></tr>
<tr><td colspan="2">V1: Motor mounts rigidly affixed to the main airframe structure (no relative motion).
V2: Sensor mounts (IMU, Thermal, and RGB Cameras) rigidly mounted to the airframe.
V3: In-flight IMU vibration metrics should be lower than the prescribed limits (5 m/s/s).
V4: No motion blur should be visible on all the camera image feeds.</td></tr>
</table>

Test 3: Camera Calibrations

Objective	
Ensure accuracy of intrinsic and extrinsic calibration of fisheye and thermal cameras	
Elements	Hardware Subsystem, Perception Subsystem
Equipment	● Jetson Orin ● Portable Display, Mouse and Keyboard ● FLIR Boson+ Cameras ● RGB Fisheye Cameras ● Heated/Non-Heated Calibration Checkerboard
Location	AirLab, SQH
Personnel	Jaskaran Singh Sodhi, Gangadhar Nageswar
Procedure	
1. Power on Jetson Orin. 2. Connect portable display, mouse, and keyboard to Jetson Orin. 3. Start the sensor time-sync script 4. Record diverse motions from all 6 cameras for fisheye calibration. 5. Record diverse orientations and distances with heated checkerboard. 6. Get intrinsic and extrinsic parameters from calibration software. 7. Get RMS reprojection error from calibration software. **[V2]** 8. Run latency analysis script to get the relative latency from the recorded sensor feeds **[V1]**	
Verification Criteria	
● **V1:** The sensors should have maximum relative latency of 100ms. ● **V2:** Calibration RMS reprojection error less than 2.5 pixels.	

Test 4: Fire Segmentation on Dataset

<table>
<tr><td colspan="2">Objective</td></tr>
<tr><td colspan="2">To effectively segment and differentiate fires on prescribed fire thermal data using the developed fire segmentation pipeline</td></tr>
<tr><td>Elements</td><td>Perception Subsystem, Fire segmentation model</td></tr>
<tr><td>Equipment</td><td>Diverse heat sources
Local computer
Fire segmentation model
Hand-held IR thermometer</td></tr>
<tr><td>Location</td><td>AirLab, SQH</td></tr>
<tr><td>Personnel</td><td>Jaskaran Singh Sodhi, Gangadhar Nageswar, Shashwat Chawla</td></tr>
<tr><td colspan="2">Procedure</td></tr>
<tr><td colspan="2">Spread out heat sources of different temperature ranges at different distances.
Place the platform such that maximum heat sources are in field-of-view.
Map raw thermal feed using radiometric-to-temperature mapping. [V2]
Use temperature feed to segment for primary and secondary hotspots.
Verify accuracy of the segmented masks. [V1]</td></tr>
<tr><td colspan="2">Verification Criteria</td></tr>
<tr><td colspan="2">V1: Detect fires with 70% accuracy.
V2: The frames per second (fps) achieved from the segmentation model should be a minimum of 10 FPS.</td></tr>
</table>

Test 5: Fire Segmentation on Real-time Feed

<table>
<tr><th colspan="2">Objective</th></tr>
<tr><td colspan="2">Detect and segment fire from the thermal feed in real-time during system flight</td></tr>
<tr><td>Elements</td><td>Thermal Perception, Drone System</td></tr>
<tr><td>Equipment</td><td>Fully-integrated Aerial Robotic Platform
Heated/Non-Heated Calibration Checkerboard
Space heaters
Soldering rod</td></tr>
<tr><td>Location</td><td>AirLab, SQH & Hawkins</td></tr>
<tr><td>Personnel</td><td>Jaskaran Singh Sodhi, Gangadhar Nageswar, Shashwat Chawla</td></tr>
<tr><th colspan="2">Procedure</th></tr>
<tr><td colspan="2">Create a test scene consisting of diverse heat sources.
Power on the RC Transmitter; make sure the kill switch is engaged on the RC transmitter during the on-ground setup phase to avoid unforeseen accidents.
Place the drone in the cage, connect the batteries, and establish a wireless telemetry link b/w FCU and GCS.
Connect the portable display, keyboard, and mouse; start the sensor script on the mission computer to collect a ROSBag with thermal and RGB feeds.
Once the script is online, disconnect all the I/O accessories from the Mission computer.
Arm and take-off the UAS.
Verify thermal feed on Rviz and overall system latency.
Launch the thermal segmentation script. [V2]
Land the drone, and disarm the FCU.
Make sure the kill switch is engaged on the RC transmitter.
Reconnect I/O accessories to visualize and evaluate the segmented fire. [V1]</td></tr>
<tr><th colspan="2">Verification Criteria</th></tr>
<tr><td colspan="2">V1: Detect fires with at least 70% accuracy.
V2: The frames per second (FPS) achieved from the segmentation model should be a minimum of 10FPS.</td></tr>
</table>

Test 6: Localize Fire on Static Aerial Platform

<table>
<tr><td colspan="2">Objective</td></tr>
<tr><td colspan="2">Ensure in-flight fire localization accuracy of segmented fires</td></tr>
<tr><td>Elements</td><td>Perception Subsystem, Drone Hardware, State Estimation</td></tr>
<tr><td>Equipment</td><td>Fully-integrated Aerial Robotic Platform
Diverse heat sources
Fire segmentation model
Fire localization model</td></tr>
<tr><td>Location</td><td>AirLab, SQH & Hawkins</td></tr>
<tr><td>Personnel</td><td>Jaskaran Singh Sodhi, Gangadhar Nageswar, Shashwat Chawla</td></tr>
<tr><td colspan="2">Procedure</td></tr>
<tr><td colspan="2">Create a test scene consisting of diverse heat sources.
Move the heat sources while keeping the aerial platform static.
Verify thermal feed on Rviz and overall system latency.
Launch the thermal segmentation script.
Launch the thermal localization script.
Visualize and evaluate the fire map in the world frame. [V1]</td></tr>
<tr><td colspan="2">Verification Criteria</td></tr>
<tr><td colspan="2">V1: Accurately localize fire positions up to 5 m of distance in front of the drone.</td></tr>
</table>

Test 7: Visual-Inertial State Estimation Test

<table>
<tr><td colspan="2">Objective</td></tr>
<tr><td colspan="2">To test the robustness and stability of GPS-denied localisation using the developed Visual-Inertial Odometry state estimator</td></tr>
<tr><td>Elements</td><td>Hardware/ Aerial Robotic Platform Subsystem, State Estimation</td></tr>
<tr><td>Equipment</td><td>Fully-integrated Aerial Robotic Platform
Portable Power Bank, HDMI cable, HDMI-DP Adapter, Portable Display, Keyboard, and Mouse
USB Thumb-drive
RC Transmitter
Ground Station Laptop with QGC
Telemetry Link to download the flight Logs
Allen Keys and Screwdrivers</td></tr>
<tr><td>Location</td><td>AirLab Flight Test Cage, RI SQH</td></tr>
<tr><td>Personnel</td><td>Kavin Kailash Ravie, Ishir Roongta</td></tr>
<tr><td colspan="2">Procedure</td></tr>
<tr><td colspan="2">Power on the RC Transmitter; make sure the kill-switch is engaged on the RC transmitter during the on-ground setup phase to avoid unforeseen accidents.
Place the drone in the cage, connect the batteries, and establish a wireless telemetry link b/w FCU and GCS.
Connect the portable display, keyboard, and mouse; start the required scripts to start the VIO on the mission computer, AruCo-based pose estimation and log these data to ROSBag.
Once the script is online, disconnect all the I/O accessories from the Mission computer
Perform a hovering flight test; takeoff to 1.50m above the fiducial marker and let it hover without any movement inputs for at least 2 minutes.
Land the drone, and disarm the FCU.
Make sure the kill-switch is re-engaged on the RC transmitter.
Reconnect I/O accessories.
Download the ROSBag from the drone.
Run drift analysis script locally to analyze the VIO drift metrics. [V1] [V2]
After all the tests are concluded power off the drone and disconnect all accessories.</td></tr>
<tr><td colspan="2">Verification Criteria</td></tr>
<tr><td colspan="2">V1: Stable VIO estimates at the required update rate of 10Hz
V2: Hovering positional RMSE of < 0.20 m w.r.t ground-fixed fiducial marker pose as ground-truth</td></tr>
</table>

Test 8: In-flight Fire Localisation

Objective	
Ensure in-flight fire localization accuracy of segmented fires	
Elements	Perception Subsystem, Aerial Robotic Platform, State Estimation
Equipment	• Fully-integrated Aerial Robotic Platform • Diverse heat sources • Fire segmentation model • Fire localization model
Location	AirLab, SQH & Hawkins
Personnel	Jaskaran Singh Sodhi, Gangadhar Nageswar, Shashwat Chawla
Procedure	
1. Create a test scene consisting of diverse heat sources. 2. Power on the RC Transmitter; make sure the kill switch is engaged on the RC transmitter during the on-ground setup phase to avoid unforeseen accidents. 3. Place the drone in the cage, connect the batteries, and establish a wireless telemetry link b/w FCU and GCS. 4. Connect the portable display, keyboard, and mouse; start the sensor script on the mission computer to collect a ROSBag with thermal and RGB feeds. 5. Once the script is online, disconnect all the I/O accessories from the Mission computer. 6. Arm and take-off the UAS with state estimation (MoCap or on-board). 7. Verify thermal feed on Rviz and overall system latency. 8. Launch the thermal segmentation script. 9. Launch the thermal localization script. 10. Land the drone, and disarm the FCU. 11. Make sure the kill switch is engaged on the RC transmitter. 12. Reconnect I/O accessories to visualize and evaluate the fire map in world frame. **[V1]**	
Verification Criteria	
V1: Localize the fire **within 2.5 m** of the ground truth fire location.	

Test 9: Ground Control Station Communications Test

Objective	
To test the integration of the GCS unit with our Aerial Platform and visualize the sensor data through custom UI.	
Elements	Hardware/ Aerial Robotic Platform Subsystem and GCS Unit
Equipment	• Fully-integrated Aerial Robotic Platform • Portable Power Bank, HDMI cable, HDMI-DP Adapter, Portable Display, Keyboard and Mouse • GCS Unit • Open-reel Tape Measure
Location	Hawkins/Football field CMU
Personnel	Kavin Kailash Ravie, Ishir Roongta
Procedure	
1. Place the drone starting at 50 meters from the GCS station, subsequently increasing the distance. 2. Setup the GCS Unit and attempt connection with the drone. **[V1] [V3]** 3. Start the scripts to capture sensor data and telemetry data. **[V2]** 4. Check the FPS of the processed sensor data visualization. **[V4]** 5. Disconnect the GCS unit. 6. Disconnect the battery and document the pocket loss and FPS with reference to the distance between GCS and drone.	
Verification Criteria	
V1: GCS unit connects to the Aerial Platform. **V2:** Able to configure drone mission parameters from the GCS unit. **V3:** Stable link connection with a communication range of **at least 150 meters**. **V4:** Stream processed visualization data at a **minimum of 5 FPS**.	

Test 10: Spring Validation Demo

Objective	
System Integration and Validation for SVD	
Elements	Aerial Robotic Platform, State Estimation, Thermal Perception, GCS
Equipment	● Fully-integrated Aerial Robotic Platform with State Estimation, Fire Perception and GCS Subsystems ● Portable Power Bank, HDMI cable, HDMI-DP Adapter, Portable Display, Keyboard, and Mouse ● Router; Stable Internet Connection (for accessing the online flight-log analysis tool) ● RC Transmitter, Ground station Laptop with QGC ● Telemetry Link to download the flight Logs ● Diverse Fire Sources ● Fire Extinguishers, Water Jug, Ash Bucket
Location	Hawkins
Personnel	Whole Team
Procedure	
1. Spread out and place the heat sources in the parking lot of Hawkins. 2. Measure and record the location of the fire pits from take-off (global origin). 3. Switch on all heat sources and input fire pit locations into ground station laptop. 4. Power on the RC Transmitter; make sure the kill switch is engaged on the RC transmitter during the on-ground setup phase to avoid unforeseen accidents. 5. Place the drone in the cage, connect the batteries, and establish a wireless telemetry link between FCU and GCS. 6. Connect the portable display, keyboard, and mouse; start the sensor script on the mission computer to collect a ROSBag with thermal and RGB feeds. 7. Once the script is online, disconnect all the I/O accessories from the Mission computer 8. Begin timer, arm, and take-off the UAS with state estimation (MoCap or on-board). 9. Launch the master script for fire segmentation, localization, and state estimation. **[V1][V2]** 10. Teleoperate UAS to desired locations, and return to home and land. **[V3][V4]** 11. Make sure the kill switch is engaged on the RC transmitter and turn down heat sources. 12. Reconnect I/O accessories to visualize and evaluate the fire map in world frame. 13. Analyze accuracy of hotspots displayed in UI compared to measured ground truth.	
Verification Criteria	
V1: Detect all hotspots with **at least 70%** accuracy. **V2:** Hotspots localized within **2.5 m** of accuracy. **V3:** Communicate with drone up to **150 meters**. **V4:** UI displays updated fire map **throughout** duration of flight.	

Appendix

A. Mandatory Functional Requirements

ID	Requirement	Performance Metric
MF1	Be Teleoperable	Able to receive and execute movement commands from the user.
MF2	Communicate with User	Have a communications range upto 150m
MF3	Sense Environment	Fisheye and Thermal Camera can detect obstacles.
MF4	Detect Fire	Detect Fire with more than 70% accuracy.
MF5	Localize Fire	Accurately localize fire positions up to 5 m of distance.
MF6	Localize Itself	Hovering positional RMSE of < 0.20 m w.r.t ground-fixed fiducial marker pose as ground-truth. Localize itself at 10Hz.

B. Mandatory Non-Functional Requirements

ID	Requirement	Performance Metric
MNF 1	Have appropriate Dimensions/Size	Have a flight time of 5min.
MNF 2	Have Fail-safes	Indicate low battery.
MNF 3	Be of rugged design	Rigidity of mounts after Aerial platform flight.
MNF 4	Rely on passive sensors only	Sense environment using Thermal and fisheye cameras.
MNF 5	Be easy to use	Interactive GUI and GCS System.