Contents

Introduction

This document describes the system tests along with a schedule that we would be following for the Fall 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. **NREC Dome:** The NREC Dome (outdoor drone cage) 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 NREC. 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, only the MRSD team would primarily visit the test site as the requirement of obtaining the pilot license is currently underway by 2 team members.

Schedule

PR #	Date	Capability Milestone	Test	Requirements
PR7	9/11	● Classical Thermal Stereo (CTS) performance diagnostics. ● Fix Testing Site. ● Setup SITL Pipeline.	1	MNF1 MNF3 MNF4
PR8	9/25	● Thermal calibration completed. ● CTS Pipeline evaluated on live feed. ● Point-to-Point autonomy pipeline validated in simulation ● FAA Part 107 certification requirements satisfied.	2,3,4	MNF2
PR9	10/9	● Hardware revamp completed. ● MSO performance validated in NREC. ● Fire localization tested with improved calibration. ● Point-to-point and exploration pipelines validated in simulation. ● Verify planning stack compatibility with on-board compute.	5,6,7, 8	MF1 MF4 MF5 MF6 MF10
PR10	10/30	● SVD encore capabilities validated in NREC. ● End-to-end system integrated and tested.	9	MF2 MF3 MF7 MF8
PR11	11/13	● Reliability and stress testing completed.	10	MF9
FVD	11/18	● Full system capabilities demonstrated.		MNF5

Tests

Test 1: Classical Thermal Stereo Pipeline Test on Dataset

Objective	
To test and diagnose classical thermal stereo performance using the pre-rectified stereo thermal image dataset.	
Elements	Fire Perception Subsystem
Equipment	• Development PC
Location	Remote
Personnel	Kavin Kailash Ravie, Jaskaran Singh Sodhi
Procedure	
1. Obtain access to the KAIST Multi-Spectral Stereo (MS2) AV Dataset. 2. Download the dataset locally. 3. Run the developed CTS node on this data and collect results. 4. Perform qualitative evaluation of results **[V1].** 5. Perform quantitative evaluation **[V2].** 6. Evaluate the compute performance of the node **[V3].**	
Verification Criteria	
V1: Qualitatively (visually) reasonable depth estimation results. **V2:** 99%-ile depth errors within **0.5m** for maximum scene depth of **10m**. **V3:** Minimum 3D Pointcloud output rate of **15Hz**.	

Test 2: Thermal Calibration Test

Objective	
To test the intrinsic and extrinsic calibration performance for thermal camera distortion and stereo rectification.	
Elements	Hardware/Aerial Robotic Platform Subsystem
Equipment	• Aerial Platform • Portable Display, Mouse and Keyboard • Thermal Checkerboard
Location	AirLab Work Bench, SQH
Personnel	Gangadhar Nageswar, Shashwat Chawla, Jaskaran Singh Sodhi
Procedure	
1. Physically calibrate Thermal camera focus by visualizing feed in Boson GUI. 2. Power on Jetson Orin. 3. Connect portable display, mouse, and keyboard to Jetson Orin. 4. Setup and power-on heated checkerboard. 5. Place heated checkerboard in one of cameras fov and record diverse movements. 6. Perform Step 5 for the other camera. 7. Place heated checkerboard in both of the cameras fov and record diverse movements. 8. Develop preprocessing pipeline for improving calibration stability. 9. Get intrinsic and extrinsic parameters from calibration softwares (Kalibr & Matlab Toolbox). 10. Get RMS reprojection error from calibration softwares. **[V1] [V2]** 11. Input Camera processing and visualize epipolar lines. **[V3]**	
Verification Criteria	
V1: Achieve subpixel (<1) reprojection error for intrinsic calibration of cameras. **V2:** Achieve subpixel (<1) reprojection error for joint extrinsic calibration of the camera pair. **V3:** Validate camera rectification by visualizing the geometry of epipolar lines.	

Test 3: Classical Thermal Stereo Pipeline Test using Live Data

<table>
<tr><td colspan="2">Objective</td></tr>
<tr><td colspan="2">To test the performance of classical thermal stereo dense-reconstruction based on the new calibration.</td></tr>
<tr><td>Elements</td><td>Hardware/Aerial Robotic Platform Subsystem, Thermal Perception</td></tr>
<tr><td>Equipment</td><td>Aerial Platform
Portable Display, Mouse and Keyboard
Heated Calibration Checkerboard</td></tr>
<tr><td>Location</td><td>AirLab, SQH</td></tr>
<tr><td>Personnel</td><td>Gangadhar Nageswar, Shashwat Chawla</td></tr>
<tr><td colspan="2">Procedure</td></tr>
<tr><td colspan="2">Power on Jetson Orin
Connect portable display, mouse, and keyboard to Jetson Orin
Setup and power-on heated checkerboard
Measure the distance of the checkerboard from the drone and estimate its location
Check live thermal feed in Rviz
Run thermal stereo depth estimation script; followed by evaluation script [V1]
Visualize the 3D Pointcloud in Rviz, and obtain the estimated location of checkerboard [V2]
Run latency analysis script to get the inference rate of CTS [V3]</td></tr>
<tr><td colspan="2">Verification Criteria</td></tr>
<tr><td colspan="2">V1: Qualitatively (visually) reasonable depth estimation results.
V2: Depth error of checkerboard within 0.5m for maximum scene depth of 10m.
V3: Minimum 3D Pointcloud output rate of 15Hz.</td></tr>
</table>

Test 4: P2P Autonomous Navigation SITL Test

<table>
<tr><td colspan="2">Objective</td></tr>
<tr><td colspan="2">Test out P2P Planners in Simulation with HW-motivated constraints.</td></tr>
<tr><td>Elements</td><td>Simulation, Autonomy subsystem</td></tr>
<tr><td>Equipment</td><td>Development PC
HW Platform</td></tr>
<tr><td>Location</td><td>Simulation</td></tr>
<tr><td>Personnel</td><td>Ishir Roongta, Kavin Kailash Ravie</td></tr>
<tr><td colspan="2">Procedure</td></tr>
<tr><td colspan="2">Setup PX4 Gazebo SITL framework
Setup open source point-to-point autonomous navigation planner
Perform initial test runs with the default configuration
Extract kino-dynamic and sensing constraints from our drone platform and enforce these in SITL
Test the planner with above constraints and log run time for an estimated path length. [V1]
Modify the control interfaces to adapt them for our aerial system.</td></tr>
<tr><td colspan="2">Verification Criteria</td></tr>
<tr><td colspan="2">V1: The planner can reach the user-specified goal safely while satisfying the enforced realistic constraints</td></tr>
</table>

Test 5: Verification Tests for Modified Hardware

<table>
<tr><td colspan="2">Objective</td></tr>
<tr><td colspan="2">To perform preliminary hardware tests after modifications and possible reductions on the platform.</td></tr>
<tr><td>Elements</td><td>Hardware Subsystem</td></tr>
<tr><td>Equipment</td><td>FCU
Realsense
Fisheye Camera
ORDv1 Frame
Development PC</td></tr>
<tr><td>Location</td><td>AirLab, 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">Procure new components: FCU, RealSense D456 depth camera
Systematically disassemble the drone from top-plate and disconnect sensors and component wirings.
Completely disconnect the older FCU and replace it with new one.
Preliminary test of the new FCU by connecting to QGC and check supplied voltage.[V1]
Remove 5 of 6 the fisheye cameras and their mounts and switch the master camera to front-down position.
Assemble the drone as required and check if MSO initializes successfully [V2]
Integrate the D456 camera with the airframe and verify rigidity
Perform electrical integration for D456 while making sure that it operates in USB3.2 mode by verifying the feeds in RealSense Viewer GUI [V3]
Assemble the rest of the drone.
Perform calibration of the entire platform on QGC and perform hover test.
Check log usage for FCU and proper voltage supply to platform components.[V4] [V5] [V6] [V7]
Verify RealSense feed for motion blur and feed stability.[V8]</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: Handheld test by running MSO with expected odometry rate of ~ 200Hz and no latency.
V3: Stable RealSense feeds streaming to verify proper wiring connections to AGX Orin
V4: Appropriate and stable voltage is supplied to the propulsion system [14.80-16.80V].
V5: Enough voltage is supplied to the on-board compute Nvidia AGX Orin [12V].
V6: In-flight IMU vibration metrics should be lower than the prescribed limits (5 m/s/s).
V7: FCU log should indicate a nominally safe level of system resource utilization
V8: RealSense camera mount rigidly mounted to the airframe and motion blur</td></tr>
</table>

Test 6: Visual Inertial State Estimation Test

<table>
<tr><td colspan="2">Objective</td></tr>
<tr><td colspan="2">To test the robustness and stability of the MSO state estimator following hardware platform revamps.</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, NREC Dome (Outdoor)</td></tr>
<tr><td>Personnel</td><td>Jaskaran Singh Sodhi, Kavin Kailash Ravie</td></tr>
<tr><td colspan="2">Procedure</td></tr>
<tr><td colspan="2">1. Transport the required equipment to NREC outdoor flight test site.
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 on level surface, connect the batteries, and establish a wireless link b/w FCU and GCS.
4. Start the state-estimator node on the on-board computer, and verify that visual pose estimates are received by the FCU at the required update rate [V1]
5. Start logging data for post-flight evaluation
6. Perform a hovering flight test; takeoff to 2.50m AGL and maintain a uninterrupted hover for atleast 2 mins while visually evaluating the drift characteristics.
7. Land the drone, and disarm the FCU, stop data logging.
8. Make sure the kill-switch is re-engaged on the RC transmitter.
9. Power off the drone and swap the batteries if required.
10. Now perform steps 3 to 5 before performing takeoff and flying multiple laps achieving a total track length of >100m.
11. Download the recorded data from the drone.
12. Run drift analysis script locally to analyze the VIO drift metrics. [V2] [V3]
13. After all the tests are concluded power off the drone.</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 about the nominal hover position setpoint.
V3: Have a drift of < 4% over a track length of 100m</td></tr>
</table>

Test 7: Test Fire Localization with Improved Calibration

<table>
<tr><td colspan="2">Objective</td></tr>
<tr><td colspan="2">Validate localization accuracy of segmented fires using the improved camera intrinsics/extrinsics.</td></tr>
<tr><td>Elements</td><td>Perception Subsystem, Aerial Robotic Platform, State Estimation</td></tr>
<tr><td>Equipment</td><td>Aerial Robotic Platform
Diverse heat sources
Fire segmentation model
Fire localization model</td></tr>
<tr><td>Location</td><td>AirLab, SQH</td></tr>
<tr><td>Personnel</td><td>Gangadhar Nageswar, Shashwat Chawla</td></tr>
<tr><td colspan="2">Procedure</td></tr>
<tr><td colspan="2">Power on Aerial Robotic Platform and verify thermal feed on Rviz .
Create a test scene consisting of diverse heat sources with their ground-truth locations.
Launch the thermal segmentation and localization script.
Record estimated heated sources locations.
Calculate L2 euclidean distance between estimated and ground-truth locations [V1]</td></tr>
<tr><td colspan="2">Verification Criteria</td></tr>
<tr><td colspan="2">V1: Localize the fire within 2.5 m of the ground truth fire location.</td></tr>
</table>

Test 8: Point-to-point and exploration pipelines validated in simulation

<table>
<tr><td colspan="2">Objective</td></tr>
<tr><td colspan="2">Validate P2P and exploration pipelines with, if necessary, modifications in simulation and verify compatibility with our platform’s compute and environment.</td></tr>
<tr><td>Elements</td><td>Autonomy Subsystem, Aerial Robotic Platform Subsystem</td></tr>
<tr><td>Equipment</td><td>● Development PC
● Fully integrated aerial platform</td></tr>
<tr><td>Location</td><td>Simulation, Airlab RI SQH</td></tr>
<tr><td>Personnel</td><td>Ishir Roongta, Shashwat Chawla, Kavin Kailash Ravie</td></tr>
<tr><td colspan="2">Procedure</td></tr>
<tr><td colspan="2">1. Run P2P planner and exploration pipeline on simulation.
2. Log run-times for a simulated path length. [V1]
3. Once satisfied with the above, build the planner stack in our Docker environment and on AGX Orin.
4. Verify all package dependencies are met. [V2]
5. Launch the planner stack on ORDv1 without starting the mission.
6. Ensure i/o interfaces are proper.
7. Launch the planner stack with other modules in the software stack. [V3]</td></tr>
<tr><td colspan="2">Verification Criteria</td></tr>
<tr><td colspan="2">V1: P2P Planner and Exploration mission runs under 3 minutes for a similar to FVD setting in simulation.
V2: Successful build
V3: Successful bring-up without conflicts.</td></tr>
</table>

Test 9: End-to-end system integrated and tested

Objective	
Test subsystems and the entire system at NREC Dome (Outdoor)	
Elements	Aerial Robotic Platform, State Estimation, Thermal Perception, Autonomy, GCS
Equipment	• Fully-integrated Aerial Robotic Platform with State Estimation, Fire Perception, and GCS and Autonomy 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	NREC Dome (Outdoor)
Personnel	Whole Team
Procedure	
1. Spread out and place the heat sources in the NREC Outdoor Flight-Test area. 2. Measure and record the ground location of the heat sources from take-off (global origin). 3. Switch on all heat sources and input source locations into fire map. 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. Input goal location and the mission starts and UAS lands on desired location successfully.**[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 the accuracy of hotspots displayed in UI compared to measured ground truth.**[V5]**	
Verification Criteria	
V1: Detect all hotspots with **at least 70%** accuracy. **V2:** Hotspots localized within **2.5 m** of accuracy. **V3:** Navigate between obstacles greater than equal to **5m** separation. **V4**: Communicate with drone up to **150 meters**. **V5:** UI displays updated fire map **throughout** duration of flight.	

Test 10: Perform Stress Testing and Reliability of the entire system

Objective	
Test the entire system end-to-end in various configurations and edge cases at NREC, to identify the limits and capabilities of each subsystem	
Elements	Aerial Robotic Platform, State Estimation, Thermal Perception, Autonomy, 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 • RC Transmitter, Ground station Laptop with QGC • Telemetry Link to download the flight Logs • Diverse Fire Sources • Fire Extinguishers, Water Jug, Ash Bucket
Location	NREC Dome (Outdoor)
Personnel	Whole Team
Procedure	
1. Spread out and place the heat sources in the NREC Outdoor Flight-Test area. 2. Measure and record the ground location of the heat sources from take-off (global origin). 3. Switch on all heat sources and input source locations into fire map. 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. Input goal location, the mission starts, and UAS lands on the desired location. **[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 the accuracy of hotspots displayed in UI compared to measured ground truth.**[V5]**	
Verification Criteria	
V1: Detect all hotspots with **at least 70%** accuracy. **V2:** Hotspots localized within **2.5 m** of accuracy. **V3:** Navigate between obstacles greater than equal to **5m** separation. **V4**: Communicate with drone up to **150 meters**. **V5:** UI displays updated fire map **throughout** duration of flight.	

Fall Validation Demo

<table>
<tr><td colspan="2">Objective</td></tr>
<tr><td colspan="2">System Integration and Validation for FVD</td></tr>
<tr><td>Elements</td><td>Aerial Robotic Platform, All Subsystems</td></tr>
<tr><td>Equipment</td><td>● Fully integrated Aerial Robotic Platform
● Fire Sources and Obstacles
● Fire Extinguishers, Water Jug, Ash Bucket</td></tr>
<tr><td>Location</td><td>NREC Dome (Outdoor)</td></tr>
<tr><td>Personnel</td><td>Whole Team</td></tr>
<tr><td colspan="2">Procedure</td></tr>
<tr><td colspan="2">1. Spread out and place the heat sources in the NREC Dome.
2. Measure and record the ground location of the heat sources from take-off (global origin).
3. Switch on all heat sources and input source locations into fire map.
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. Arm the drone and take off with state estimation enabled (on-board).
8. Launch the master script for fire perception, state estimation, and navigation. [V1][V2]
9. (a) UAS navigates autonomously to the desired goal, and lands safely. [V3][V4][Go to 1]
(b) UAS autonomously explores the desired region and lands when finished. [V3][V4]
10. Visualize and evaluate the fire map in real-time, for both runs.</td></tr>
<tr><td colspan="2">Verification Criteria</td></tr>
<tr><td colspan="2">V1: Detect all fires with at least 70% accuracy.
V2: Fire localized within 2.5 m of accuracy.
V3: UI displays incremental fire map in real-time.
V4: Navigate autonomously between obstacles with a minimum separation of 5m.</td></tr>
</table>

Appendix

A. Mandatory Functional Requirements

ID	Requirement	Performance Metric
MF1	Be Teleoperable	Receive & execute movement commands from user.
MF2	Communicate with User	Have a communications range up to 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.
MF7	Map Environment	Navigate obstacles with separation > 5m.
MF8	Plan Safe Trajectory Toward Goal	Able to plan obstacle-free trajectory on-board.
MF9	Be Capable of Completing Mission	Have a flight time of 5min.
MF10	Operate in GPS degraded Forest Environment	Able to navigate in completely GPS-denied environment.

B. Mandatory Non-Functional Requirements

ID	Requirement	Performance Metric
MNF1	Have appropriate Dimensions/Size	Have a flight time of 5min.
MNF2	Have Fail-safes	Indicate low battery.
MNF3	Be of rugged design	Rigidity of mounts after Aerial platform flight.
MNF4	Rely on passive sensors only	Sense environment using Thermal and fisheye cameras.
MNF5	Be easy to use	Interactive GUI and GCS System.