
Spring Project Test Plan

FireSense

Collaborative SLAM in Fire Scenes

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1 Introduction

This document outlines the test schedule of the FireSense MRSD Capstone project. The tests are organized by Project Review (PR), leading up to the Spring Validation Demo (SVD), with each PR serving as a major milestone in our development cycle. The details of each test will be used to confirm fulfillment of the requirements.

2 Logistics

2.1 Personnel

Personnel allocation scales with test complexity. Small-scale validation is conducted by the respective subsystem leads, while full-scale system integration involves the entire team. For environmental validation, like cold-smoke trials, the team will coordinate with Allegheny County Fire Academy (ACFA) administrators. Future hot-smoke testing will necessitate collaboration with active ACFA firefighters.

2.2 Equipment

Equipment requirements scale with the fidelity of the test environment. Small-scale component validation utilizes standard laboratory workstations and diagnostic tools. For system-level environmental testing, artificial smoke generators and grenades are required to simulate visual occlusion (Cold Smoke). High-fidelity Hot Smoke validation will further require integrating the payload with active firefighter gear during live training exercises.

2.3 Location

Testing will be conducted at two primary locations depending on the scale and environmental requirements:

Development Site (NSH B512):

Located on the B-level of Newell Simon Hall. This site is used for component-level testing, subsystem integration, and minor validation tasks.

Field Test Site (ACFA, *W Ridge Dr, Allison Park, PA 15101*):

Serves as the primary location for system-level validation:

- **Cold Smoke:** Conducted in Buildings A, B, or C using artificial smoke.
- **Hot Smoke:** Restricted to Building B only, requiring for scheduled burns.

3 Schedule

Date	Event	Capability Milestones	Tests	Reqs.
12 Feb.	Progress Review 1	Hardware: - Boson & Sensor functionality test - Thermal, IMU installation - BOM check (sensors, power) - Hardware interface design Software: - SLAM frontend deployment - Loop closure detection method identified Environment: - No smoke, slow motion, single floor	Test 1.	M.F.2
26 Feb.	Progress Review 2	Hardware: - Payload v1.0: Handheld design & assembly - Power: Use Orin pinouts - Boson: Wired connection (thermal image on command station) - Sensors: Time sync & calibration - PCB: Designed, checked, and ordered Software: - Reliable MACVO - Test MACVO accuracy Environment: - No smoke, Fast motion, Single-floor	Test 2. Test 3. Test 4.	M.F.1 M.F.3 M.N.3 M.N.4
19 Mar.	Progress Review 3	Hardware: - Payload v1.1: Modular design, Quick-connect wiring - Boson+: Heat dissipation - Modularization check - Fast Firefighter Motion stress test Software: - SLAM (frontend + backend) working - Depth estimation through cold smoke - Global map accuracy test - Foxglove Interface Environment: - Cold Smoke, Fast motion, Single-floor	Test 5. Test 6.	M.F.1 M.F.2 M.F.3 M.F.4 M.F.5 M.F.8 M.N.3 M.N.4

Date	Event	Capability Milestones	Tests	Reqs.
02 Apr.	Progress Review 4	Hardware: - PCB Soldering & Assembly - PCB Integration (power & debug) - Wireless: Heltec 915 MHz radios - Heat Resistance Material - Payload V1.1: Deployable - Boson+ Integration Software: - SLAM with Multi-floor mapping - GUI integration Environment: - Cold smoke, Multi-floor - Fast Firefighter Motion	Test 7. Test 8. Test 9. Test 10.	M.F.6 M.F.7 M.N.1 M.N.3 M.N.4 M.N.5
16 Apr.	Spring Validation Demo (SVD)	Milestone: - Fully working Payload v1.1 - Full System Validation - Final Adjustments	Test 11.	M.F.1 M.F.2 M.F.3 M.F.4 M.F.5 M.F.6 M.F.7 M.F.8 M.N.3 M.N.4 M.N.5
23 Apr.	Spring Validation Demo Encore	Milestone: - Fully working Payload v1.1 - Final Demonstration	Test 11.	M.F.1 M.F.2 M.F.3 M.F.4 M.F.5 M.F.6 M.F.7 M.F.8 M.N.3 M.N.4 M.N.5

4 Tests

4.1 Test 1: Sensor Functionality Test

Test 1: Sensor Functionality Test	
Objective	Verify that the Boson Thermal camera and ZedX (IMU) are transmitting data to the computer, and that the Boson can be successfully configured
Element	Perception subsystem
Location	MRSD lab
Equipment	1. Boson thermal camera 2. ZedX (IMU) 3. Laptop
Personnel	Joy Yang, Tina Hsu
Procedure	
1. Connect the sensors to the onboard computer and power up the system. 2. Open a terminal to ensure both sensors are recognized by the OS. 3. Initialize the ROS drivers for both sensors to establish the software-to-hardware link. 4. Launch camera software to verify the Boson thermal feed is visible, and the Zed X IMU topics are publishing data. 5. Send a basic command via the computer (e.g."Trigger FFC" or "Change to slave mode") to the Boson to confirm bidirectional serial/SDK communication. 6. Verify sensing range.	
Verification Criteria	
1. Both the Boson thermal camera and ZedX are correctly identified as active devices. 2. The thermal video feed is visible, and the IMU inertial data is being published continuously on the ROS network. 3. The Boson camera successfully executes and acknowledges configuration commands. 4. Verify the sensing range of the sensor covers 0.8 to 12 m.	

4.2 Test 2: Wired connection test

Test 2: Wired connection test	
Objective	Verify the reliability of the wired data transmission between the Payload v1.0 and the Command Station, specifically validating the visualization of the Boson thermal camera
Element	Hardware Subsystem (Payload v1.0)
Location	NSH B Floor
Equipment	1. Payload v1.0 2. Boson thermal camera 3. ZedX 4. Command Station (Laptop)
Personnel	Joy Yang, Tina Hsu, Robert Kerwin
Procedure	
1. Connect the Payload v1.0 to the Command Station using the wired tether. 2. Power on the computing unit (Orin) and ensure sensors (Boson, ZedX) are active. 3. Establish an SSH connection from Command Station to Payload to verify network connectivity. 4. Launch sensor driver nodes and data visualization software (e.g., Foxglove/Rviz). 5. Physically manipulate (shake/bend) the cable connection to simulate handheld usage stress. 6. Observe the data stream for interruption or artifacts.	
1. SSH connection remains stable with low latency ($< 1\text{ms}$) during operation. 2. Thermal image stream is successfully displayed on the Command Station. 3. No visual artifacts (tearing/freezing) or frame drops observed during cable manipulation. 4. Frame rate remains consistent (target: $\geq 30\text{ Hz}$ for Boson).	

4.3 Test 3: Time Sync and Calibration Test

Test 3: Time Sync and Calibration Test	
Objective	Ensure the Boson thermal camera and ZedX sensors are temporally aligned and spatially calibrated.
Element	Perception subsystem
Location	NSH B Floor
Equipment	1. Boson thermal camera 2. ZedX (IMU) 3. NVIDIA Jetson AGX Orin
Personnel	Joy Yang, Jerry Hou
Procedure	
1. Trigger the Time-synchronization protocol to align the ZedX IMU packets with the Boson thermal frames. 2. Check recorded logs to ensure the timestamp offset between sensors is within tolerance. 3. Perform Intrinsic Calibration for the Boson to correct for lens distortion. 4. Perform Extrinsic Calibration to define the physical coordinate relationship between the ZedX and the Boson. 5. Move the payload to verify the thermal feed and IMU data respond simultaneously on the Orin without drift.	
Verification Criteria	
1. Maximum Timestamp Offset: ≤ 10 ms. 2. Intrinsic Reprojection Error: ≤ 1.5 pixels. 3. Extrinsic Rotational Error: ≤ 0.1 degrees. 4. Extrinsic Translational Error: ≤ 5 mm.	

4.4 Test 4: MAC-VO Accuracy Test

Test 4: MAC-VO Accuracy Test	
Objective	Test the accuracy and frame rate of the SLAM frontend (MAC-VO).
Element	SLAM Subsystem
Location	AirLab Office
Equipment	1. TartanRGBT 2. NVIDIA Jetson AGX Orin
Personnel	Jerry Hou, Prakhar Mishra
Procedure	
1. Recalibrate TartanRGBT sensors. 2. Record data with TartanRGBT in the AirLab office. 3. Verify data integrity. 4. Run MAC-VO with recorded thermal image data. 5. Run MAC-VO with recorded RGB image data as benchmarking result.	
Verification Criteria	
1. Relative translation error ≤ 0.01 m per 1 m traveled compared to RGB benchmarking result. 2. Relative orientation error $\leq 0.45^\circ$ per 1 m traveled compared to RGB benchmarking result. 3. Successfully estimate pose for a complete data sequence. 4. Frame rate ≥ 0.2 Hz on AGX Orin.	

4.5 Test 5: Hardware function stress test

Test 5: Hardware function stress test	
Objective	Validate the mechanical stability, thermal management efficiency, and electrical reliability of Payload v1.1 under sustained operation and dynamic "Fast Firefighter Motion" conditions.
Element	Hardware Subsystem (Payload v1.1)
Location	MRSD Lab / Hallway (for motion)
Equipment	1. Payload v1.1 (Modular design) 2. Boson+ thermal camera 3. External Temperature Gun / Probe 4. Mobile Power Supply (Battery) 5. Command Station (Laptop for monitoring)
Personnel	Tina Hsu, Joy Yang, Robert Kerwin
Procedure	
1. Modular Check: Assemble Payload v1.1 using the quick-connect wiring interfaces and verify connection security. 2. Thermal Stress: Power on all sensors (Boson+) and computing units. Run the system at full load for 20 minutes. 3. Measure and record temperatures of key components (Compute, Camera housing) every 5 minutes. 4. Motion Stress: While the system is running, simulate "Fast Firefighter Motion" (jogging 10m, rapid 90-degree turns, and sudden stops). 5. Inspect internal wiring and mechanical fasteners for any loosening after motion.	
Verification Criteria	
1. Heat Dissipation: Component temperatures stabilize within safe operating limits (e.g., CPU < 80°C, Camera < 60°C) without thermal throttling. 2. Mechanical Stability: No rattling, loose screws, or disconnected wires (Quick-connects remain secure) after motion test. 3. Data Integrity: Sensor data stream (Boson+) remains continuous with no dropouts during rapid motion.	

4.6 Test 6: Full SLAM Test

Test 6: Full SLAM Test	
Objective	Test SLAM subsystem with odometry frontend and optimization backend integrated.
Element	SLAM Subsystem
Location	AirLab Office
Equipment	1. FireSense Payload 2. Command Station (Laptop)
Personnel	Jerry Hou, Prakhar Mishra
Procedure	
1. Set up FireSense Payload v1.1 - verify sensor feeds, and payload battery level. 2. Set up command station. 3. Establish wired Ethernet connection between payload and command station. 4. Move payload around. Ensure there are loops in the trajectory. 5. Record sensor data and SLAM result. 6. Record RGB data as benchmarking result.	
Verification Criteria	
1. Absolute translation error ≤ 1 m traveled compared to RGB benchmarking result. 2. Absolute orientation error $\leq 45^\circ$ compared to RGB benchmarking result. 3. Successfully estimate pose for a complete data sequence. 4. No gaps in trajectory or map. 5. Loop closure detection works correctly.	

4.7 Test 7: PCB Integration Test

Test 7: PCB Integration Test	
Objective	Test assembled PCB with payload components
Element	System - FireSense Payload v1.1
Location	NSH B Floor
Equipment	1. FireSense Payload v1.1
Personnel	Robert Kerwin
Procedure	
The PCB is expected to have passed Electrical Rules Check (ERC) and Manufacturing Rules Check (MRC) prior to board order and assembly. 1. Solder components onto PCB. 2. Visual inspection of solder joints for cold solder/bridge defects. 3. Validate all circuits with oscilloscope and power supply. 4. Connect and test voltage supplies up to expected current draw. 5. Connect payload components and perform dry-run of system. 6. Confirm functionality of debug features.	
Verification Criteria	
1. Visual inspection reveals no imperfections. 2. Oscilloscope and power supply inspection reveals no unexpected voltage/current draw. 3. Successfully supplies power to payload components, enabling operation. 4. Debug features are accessible after assembly and provide readings.	

4.8 Test 8: Wireless Connection Test

Test 8: Wireless Connection Test	
Objective	Establish wireless connection between payload and command station.
Element	System - FireSense Payload v1.1 with Command Station
Location	Allegheny County Fire Academy
Equipment	1. Communication Radios (for team personnel communication) 2. FireSense Payload v1.1 3. Command Station
Personnel	Robert Kerwin, Joy Yang
Procedure	
1. Ensure power supplied to payload network bridge. 2. Ensure power supplied to command station router. 3. Configure Router & bridge. 4. Send data packet from payload to command station in open air environment. 5. Send data packet from payload to command station from building A, B, and C.	
Verification Criteria	
1. Network equipment turns on and connects to each other. 2. Data is successfully transmitted from payload to command station at a transmission rate of at least 2 Mbps.	

4.9 Test 9: Foxglove GUI Interface Test

Test 9: Foxglove GUI Interface Test	
Objective	To verify that all ROS topics are visualized correctly at Command Station.
Element	Unit - Foxglove Studio
Location	NSH B Floor
Equipment	1. FireSense Payload v1.1 2. Command Station (Laptop) 3. Recorded ROS bag of FireSense Payload in operation
Personnel	Prakhar
Procedure	
1. Launch foxglove_bridge ROS node on payload. 2. Open Foxglove Studio on command station. Load FireSense UI layout. 3. Play recorded ROS bags for payload and command station.	
Verification Criteria	
1. "Problems" Tab in Foxglove Studio shows no problems. 2. Each UI panel visualizes data correctly.	

4.10 Test 10: System Validation Test: SVD Dress Rehearsal

Test 10: System Validation Test: SVD Dress Rehearsal	
Objective	To discover system-level improvements/bugs in preparation for SVD
Element	System - FireSense Payload v1.1 with Command Station
Location	Allegheny County Fire Academy (ACFA)
Equipment	1. Smoke Machine 2. Face Masks 3. Miscellaneous Home Furniture 4. Communication Radios (for team personnel communication) 5. Extension cord 6. Floor guiding lights 7. Payload v1.1 8. Command Station (Laptop)
Personnel	Jerry Hou, Tina Hsu, Robert Kerwin, Joy Yang, Prakhar Mishra
Procedure	
1. Set up FireSense Payload v1.1 - verify sensor feeds, and payload battery level. 2. Set up command station. 3. Verify communication link between the payload and command station exists. 4. Fill in metal building at ACFA with smoke machine. Place miscellaneous home furniture at various places in the building. 5. Place the device at the marked starting point. Wait for 10 seconds without moving for initialization. 6. One team personnel wear masks, and enters the smoke-filled area carrying the payload. 7. The person first moves slowly for some time, covering multiple rooms. Then, proceed to move with the payload in fast motion. 8. Go back to previously visited locations. 9. End operation after 15 minutes at the marked starting point. 10. Use recorded ROS bag to benchmark SLAM performance against ground truth.	
Verification Criteria	
1. Loop closure detection works correctly. 2. No gaps in trajectory or map. 3. Continuous data link between payload and command station. 4. Absolute translation error ≤ 1 m, using starting point as reference. 5. Absolute orientation error $\leq 45^\circ$, using starting point as reference.	

4.11 Test 11: Spring Validation Demo

Test 11: System Validation Demo	
Objective	System functionality demonstration
Element	System - FireSense Payload v1.1 with Command Station
Location	Allegheny County Fire Academy
Equipment	1. Smoke Machine 2. Face Masks 3. Miscellaneous Home Furniture 4. Communication Radios (for team personnel communication) 5. Extension cord 6. Floor guiding lights 7. Payload v1.1 8. Command Station (Laptop)
Personnel	Jerry Hou, Tina Hsu, Robert Kerwin, Joy Yang, Prakhar Mishra
Procedure	
1. Set up FireSense Payload v1.1 - verify sensor feeds, and payload battery level. 2. Set up command station. 3. Verify communication link between the payload and command station exists. 4. Verify Record Button is working to record ROS topics. 5. Fill in metal building at ACFA with smoke machine. Place miscellaneous home furniture at various places in the building. 6. Present the system to the audience. 7. One team personnel wear masks, and enters the smoke-filled area carrying the payload. Another explains live GUI to the audience. 8. The person first moves to different rooms in the building. 9. If the SLAM performance is satisfactory in slow movement, proceed to move with the payload in fast motion. Move to a different floor and observe multi-floor SLAM performance. 10. End operation after 15 minutes at the marked starting point. 11. Use recorded ROS bag to benchmark SLAM performance against ground truth.	
Verification Criteria	
1. Loop closure detection works correctly. 2. No gaps in trajectory or map. 3. Continuous data link between payload and command station. 4. Absolute translation error ≤ 1 m, using starting point as reference. 5. Absolute orientation error $\leq 45^\circ$, using starting point as reference.	

5 Appendix

5.1 Mandatory Functional & Performance Requirements

Table 1: Mandatory Functional and Performance Requirements

F.ID	Functional Requirement	P.ID	Performance Requirement
System-Level			
M.F.1	Map the interior of a residential building	M.P.1.1	Accuracy of 5 m Chamfer Distance
		M.P.1.2	Update frequency of 0.2 Hz
M.F.2	Sense physical barriers	M.P.2.1	Sensing distance between 0.8 to 12 m
M.F.3	Localize the position of all active payloads	M.P.3.1	1 m absolute translation error (ATE)
		M.P.4.1	
M.F.4	Create accurate global map	M.P.3.2	45° absolute orientation error (AOE)
		M.P.4.2	
Subsystem-Level (Command Station)			
M.F.5	Interface with Fire Chief	M.P.5.1	Satisfactory approval rate 80%
Subsystem-Level (Payload)			
M.F.6	Communicate with command station	M.P.6.1	Bandwidth at 2 mbps
M.F.7	Communicate through physical barriers	M.P.7.1	Tolerate packet error rate of 30%
M.F.8	Sense through fire and smoke	M.P.8.1	Distance at least 2 m

5.2 Mandatory Non-Functional

Table 2: Mandatory Non-Functional Requirements

System		Payload	
ID	Requirement	ID	Requirement
M.N.1	Be deployable	M.N.3	Be modular
M.N.2	Have two payloads	M.N.4	Be carriable by the firefighter
		M.N.5	Have a simple power supply
		M.N.6	Connect to mountable feature

5.3 Desired requirements

Table 3: Desirable Functional and Performance Requirements

F.ID	Functional Requirement	P.ID	Performance Requirement
System-Level			
D.F.1	Identify Points of Interest (POI) such as victims or exits	D.P.1.1	Position accuracy 3 m
		D.P.1.2	Mean Average Precision (mAP) of 0.4
Subsystem-Level (Command Station)			
D.F.2	Generate paths for navigation guidance	D.P.2.1	Generate within 3 s.

Table 4: Desirable Non-Functional Requirements

System	
ID	Non-Functional Requirement
D.N.1	Be robust to aggressive motion
D.N.2	Use the same terminology used by Fire Department professionals
D.N.3	Have a communications array that comply to FCC rules and regulations