
Fall Project Test Plan

FireSense

Collaborative SLAM in Fire Scenes

Team: F

Author: Jerry Hou

Andrew ID: jerryhou

E-mail:

jerryhou@andrew.cmu.edu

Author: TzuYi Yang

Andrew ID: tzuyiy

E-mail:

tzuyiy@andrew.cmu.edu

Author: Ya-Ting Hsu

Andrew ID: yatinghs

E-mail:

yatinghs@andrew.cmu.edu

Author: Robert Kerwin

Andrew ID: rkerwin

E-mail: rkerwin@andrew.cmu.edu

Author: Prakhar Mishra

Andrew ID: pmishra3

E-mail: pmishra3@andrew.cmu.edu

Mentor: Andrew Jong (AirLab)

E-mail: ajong@andrew.cmu.edu

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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 Fall Validation Demo (FVD), 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. Subsystem leads conduct small-scale validation, while the full team handles full-scale system integration. For environmental validation, like hot-smoke trials, the team will coordinate with Allegheny County Fire Academy (ACFA) administrators will collaborate 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.

System-level environmental testing, particularly high-fidelity hot-smoke validation, will require a heat-resistant payload and firefighters equipped with full protective gear to replicate realistic operating conditions.

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:

- **Clear Air:** Conducted in Building A.
- **Hot Smoke:** Conducted in Building A, requiring for scheduled hay or pallet burns.

3 Schedule

Date	Identifier	Capability Milestone(s)	Tests	Req.
25-Aug–9-Sep	Sprint 1	- Assess feasibility and effort for new features. - Finalize key technical decisions.	–	–
9–22-Sep	Sprint 2	- Complete Payload 2 and PCB designs. - Implement radar signal processing. - Complete CSLAM design.	T04, T06, T09	M.F.1-4,8, M.N.2-6
23-Sep–6-Oct	Sprint 3	- Demonstrate offline radar SLAM on collected data. - Assemble Payload 2.	T04, T06, T08	M.F.1-4, M.N.3-6,
7–18-Oct	Sprint 4	- Establish stable hardware for repeatable data collection. - Demonstrate the SLAM frontend and CSLAM independently offline.	T01, T05, T06, T08, T09	M.F.1-4, M.N.1,2
19–27-Oct	Sprint 5	- Refine payload hardware with the PCB. - Integrate SLAM frontend and backend. - Design the command GUI.	T02, T06, T08, T09	M.F.3-4, M.N.5, D.N.2
28-Oct–10-Nov	Sprint 6	- Complete system integration and testing. - Verify two-payload operation through an integrated rehearsal.	T01–T10	all
16-Nov	FVD	- Demonstrate collaborative SLAM in hot smoke. - Display shared maps and temperature trends at the command station.	T11	all
23-Nov	FVD Encore	- Repeat the integrated demonstration after correcting FVD issues. - Verify improvements in collaborative SLAM and temperature display.	T12	all

4 Tests

4.1 Test 1: Recording and Synchronization

Test 1: Recording and Synchronization	
Objective	Establish reproducible, time-aligned data for both payloads without recording-induced frame loss.
Element	Sensor interfaces, trigger/time synchronization, ROS 2 recorder, and storage.
Location	MRSD lab and Allegheny County Fire Academy (ACFA).
Equipment	Payload 1 and Payload 2.
Personnel	Jerry and Joy
Procedure	
1. Load the payload-specific YAML configuration. Record hardware, clock, trigger, topic, and calibration settings. Verify that insufficient storage prevents recording from starting. 2. Measure sensor time offsets using optical flow from thermal and RGB cameras and acceleration measurements from the IMU. 3. Perform three 15-minute recordings per available payload with full processing and communication enabled. Repeat once without recording to compare topic rates. 4. Replay each bag, count missing frames and timestamp reversals, and verify that another team member can reproduce the workflow.	
Verification Criteria	
1. At least 99% of expected messages are retained on every required topic in each run, with no timestamp reversals or corrupted bags. 2. Cross-sensor timestamp residual is at most 5 ms; tighter algorithm-specific limits take precedence. 3. Storage checks reject insufficient-space starts, and run naming, metadata recording, and replay succeed for all runs.	

4.2 Test 2: Temperature Mapping and Display

Test 2: Temperature Mapping and Display	
Objective	Verify repeatable apparent surface temperature measurements at ceiling, mid-level, and floor regions, enabling the incident commander to assess thermal conditions, monitor trends, and identify room-level changes that may indicate developing flashover conditions.
Element	Payload1.
Location	NSH B506.
Equipment	Mapping-curve tool, laptop, recording software, thermal camera, toaster oven, heat gun, thermocouple, and GUI.
Personnel	Tina and Robert
Procedure	
1. Collect raw 16-bit data at stable setpoints spanning approximately 25–350 °C. Record raw frames, reference temperatures, gain states, and camera metadata. 2. Fit a raw16-to-temperature mapping that accounts for transitions between high and low gain. 3. Validate at held-out temperatures and report bias, absolute error, RMSE, repeatability, gain-switch behavior, and saturation. 4. Apply controlled rising and falling target temperatures. Compare trend direction and magnitude with the reference and verify ceiling-facing and head-height target labels. 5. Transmit measurements while moving between rooms and verify that the command GUI displays the corresponding room and temperature information.	
Verification Criteria	
1. Median absolute temperature error is at most 5 °C and the 95th percentile is at most 10 °C within the declared calibrated range. Reference uncertainty is reported. 2. Invalid or saturated measurements are flagged, and data older than 30 seconds is marked stale. 3. Measurements from a previous room are not displayed as current-room data.	

4.3 Test 3: Enclosure and Thermal Endurance

Test 3: Enclosure and Thermal Endurance	
Objective	Verify that internal thermal control prevents thermal throttling under full compute load.
Element	Payload 1 enclosure, insulation, thermal batteries, computer, and battery arrangement.
Location	NSH for internal thermal testing; ACFA for controlled heat exposure with facility staff.
Equipment	Payload 1, command station, and monitor.
Personnel	Robert and ACFA staff.
Procedure	
1. Seal the enclosure and operate all compute and radio loads at ambient conditions. Log CPU/GPU and enclosure temperatures at least once per second for 15 minutes. 2. Compare the final insulation and phase-change configuration with a safe baseline under identical initial conditions. Record throttling, temperature slopes, and power. 3. After passing the bench test, expose instrumented hardware to facility-approved staged heat. Measure temperatures at the payload, lens, and protected electronics. 4. Target a measured payload exposure of 300 °F for 10 minutes, extending only within approved limits. After cooling, inspect the payload and repeat sensing, power, and communication checks.	
Verification Criteria	
1. M: At least 15 minutes of sealed full-compute operation with CPU/GPU temperatures below 90 °C and no throttling. Lower component limits take precedence. 2. M: Design target is survivability at 300 °F for approximately 10–20 minutes. P: Initial qualification requires at least 10 minutes at the measured target exposure. 3. P: No functional loss, enclosure breach, or unsafe deformation; all post-exposure checks pass.	

4.4 Test 4: Radar Processing and Odometry

Test 4: Radar Processing and Odometry	
Objective	Select a radar configuration that supports useful processing rates on Orin Nano and produces measurable odometry quality during motion.
Element	Radar, IMU, payload, and Orin Nano.
Location	NSH, MRSD lab, and ACFA clear-air route.
Equipment	Radar payload with Orin Nano.
Personnel	Jerry.
Procedure	
1. Record three runs at each nominal speed of 0.5, 1.0, 2.0, 3.0, 4.0, and 5.0 m/s, including turns and a return to the start. Measure actual speed. 2. Sweep range/Doppler and angle FFT settings using fixed recorded inputs. Measure processing time, point-cloud rate, resource use, and data volume on Orin Nano. 3. Run the selected settings live. Compute absolute trajectory error (ATE) and relative pose error (RPE) after a fixed rigid alignment. 4. Repeat in clear air at ACFA. If a valid continuous reference is unavailable, report surveyed checkpoint and end-to-start errors separately.	
Verification Criteria	
1. Radar and odometry outputs sustain at least 15 Hz for 15 minutes without growing queues or crashes. 2. ATE RMSE is at most 1 m, translational RPE RMSE is at most 25%, and endpoint error is at most 2% of traversed distance in every reference-valid run.	

4.5 Test 5: Thermal-Inertial Odometry

Test 5: Thermal-Inertial Odometry	
Objective	Evaluate thermal-inertial frontend candidates and select an option robust to realistic walking and turning motions.
Element	Thermal camera, IMU, and payload.
Location	NSH, MRSD lab, and ACFA clear-air dataset.
Equipment	Payload 1 stereo thermal system and Payload 2 mono setup, if available.
Personnel	Jerry and Prakhar.
Procedure	
1. Compare candidates using the same held-out route and reference. Include nominal speeds of 0.5 and 1.0 m/s and a 90° turn within two seconds; measure actual motion. 2. Run three repetitions per motion profile. Evaluate cuVSLAM and MacVIO only in supported configurations, documenting 16-bit-to-8-bit preprocessing and calibration. 3. Compute ATE, one-second translational RPE, lost-tracking intervals, and output latency on the intended computer. Use the same alignment and scoring as T04. 4. Run the selected candidate alongside recording and communication. Document unsupported Payload 2 sensor modes and validate the selected alternative.	
Verification Criteria	
1. ATE RMSE is at most 1 m and translational RPE RMSE is at most 25% for every reference-valid route. 2. Tracking availability is at least 99%, with no unreported pose gap longer than 1 second in each run. 3. Pose output rate is at least 5 Hz.	

4.6 Test 6: Payload 2 Assembly and PCB Test

Test 6: Payload 2 Assembly and PCB Test	
Objective	Verify that the assembled wearable payload, PCB, power distribution, and connectors support repeatable field data collection.
Element	Payload 2 assembly, PCB, compute, and sensor interfaces.
Location	NSH.
Equipment	Payload 2, final PCB, current-limited supply, multimeter, oscilloscope, power logger, scale, battery monitor, and strain-relief inspection checklist.
Personnel	Robert.
Procedure	
1. Inspect continuity, polarity, mounting, and connector retention. Energize rails with a current-limited supply and measure voltage, ripple, and current at idle and full load. 2. Confirm that every sensor is detected and recording starts using the standard workflow. 3. Operate the complete sensing, compute, and radio load from the intended battery for 30 minutes. Log rail voltages, current, temperatures, and brownout events. 4. Perform a 15-minute wear and movement trial with turns, crouching, and doorway passage. Inspect wiring and mounts for separation and repeat T01 after assembly changes.	
Verification Criteria	
1. P: All rails and temperatures remain within component specifications, with zero resets or sensor disconnects during endurance and mobility trials. 2. P: Ten of ten power cycles and service cycles succeed, with no exposed conductors, loose mounting, or damaged insulation. 3. P: Full-load battery endurance is at least 30 minutes, and T01 passes on the final wiring. Heat suitability is verified separately through T03.	

4.7 Test 7: Communications under field conditions

Test 7: Communications under field conditions	
Objective	Verify that required sensor data from both payloads can be reliably transmitted to the command station simultaneously throughout the intended ACFA route.
Element	Communication system, two payloads with thermal cameras, radar, and IMU data streams, and command station receiver.
Location	ACFA
Equipment	Two FireSense payloads, 915 MHz HaLow bridges and router, antennas, and command station laptop.
Personnel	Joy, Jerry and Prakhar
Procedure	
1. Set up the command station and HaLow communication system at the test location. 2. Verify the connection between each payload and the command station. 3. Measure the sustainable communication bandwidth along the ACFA test route. 4. Stream the required sensor data from one payload to the command station, including thermal camera, radar point cloud, and IMU data. 5. Repeat the test with both payloads transmitting simultaneously. 6. Test different thermal camera compression settings to evaluate different image qualities and data sizes. 7. Record the transmitted and received data rates and check for dropped or corrupted sensor data. 8. Select the highest-quality thermal compression setting that can be reliably transmitted throughout the required test area.	
Verification Criteria	
1. At least 99% of thermal camera, radar point cloud, and IMU data are received without corruption. 2. The received sensor data remains usable by the downstream processing pipeline.	

4.8 Test 8: Single-Payload Live SLAM with World-Frame Init

Test 8: Single-Payload Live SLAM with World-Frame Init	
Objective	Live single-payload SLAM on both payloads (radar-VIO, intra-payload LCs, command backend). One payload also detects the thermal AprilTag, registers, and maps in that world frame. Not a two-payload collaborative test.
Element	Radar-VIO frontend, intra-payload LC, tag world-frame init (one payload), factor-graph backend.
Location	NSH B512 and NSH B-level hallway / nearby rooms.
Equipment	Payload 1 and Payload 2 (Boson+, 4D radar), command desktop, thermal AprilTag, wireless link, Foxglove.
Personnel	Prakhar and Jerry; one additional operator per payload.
Procedure	
1. Place the thermal AprilTag at the marked entrance. Launch the command-station SLAM pipeline and Foxglove with inter-payload loop closure disabled. Power Payload 1 and confirm that thermal, IMU, radar, keyframe, and wireless streams are live. 2. Hold Payload 1 on the tag until detection and relative-pose estimation succeed, then register so the backend initializes <code>world</code> from the tag. Walk a single-floor loop that revisits at least one corridor. Payload 2 does not participate in this session. 3. Save the map, unregister Payload 1, and retain the ROS bag, backend log, trajectory file, and point cloud (.pcd). 4. Repeat the mapping session independently on Payload 2. Tag-based registration is not required for Payload 2; an IMU-gravity world frame is acceptable.	
Verification Criteria	
1. Each payload completes one live mapping session with a continuous trajectory and no backend crash. 2. Payload 1 detects the tag and finishes registration before mapping keyframes are processed. At the tag, <code>world→odom</code> is consistent with the known tag pose. 3. On corridor revisit, intra-payload loop closures are accepted with a measured non-identity relative pose rather than an assumed identity transform. 4. Return-to-start translation error is at most 1 m and orientation error is at most 45°. Foxglove shows live pose, sparse map, and thermal image for the active payload.	

4.9 Test 9: Collaborative SLAM with Inter-Payload Loop Closures

Test 9: Collaborative SLAM with Inter-Payload Loop Closures	
Objective	Two payloads map online in one world frame with inter-payload LC on , so overlap fuses the maps. World origin comes from the thermal tag. This is the toggle-on case.
Element	Shared backend, <code>world→odom1 / odom2</code> , tag start, inter-payload LC relative pose.
Location	NSH B512 and B-level corridors with a shared tag start and overlapping routes.
Equipment	Both payloads (Boson+, 4D radar), command desktop, same AprilTag as Test 8, two wireless links, Foxglove.
Personnel	Prakhar, Jerry, one operator per payload, and a note-taker.
Procedure	
1. Place the same thermal AprilTag used in Test 8. Launch the command backend with two sessions and <code>enable_inter_payload_lc:=true</code>. Power both payloads and confirm independent thermal, IMU, radar, and keyframe streams. 2. Each payload views the same tag and registers into the shared world frame. Do not begin overlapping motion until both payloads are in the mapping state. 3. Walk overlapping routes through a shared corridor or room. Watch both optimized paths, the shared sparse map, and loop-closure markers. If the factor graph diverges, disable inter-payload loop closure and stop the run. 4. End at known poses, preferably the tag. Save the shared map, unregister both payloads, and retain synchronized bags, backend logs, both trajectories, and the point cloud. Record the loop-closure toggle value in the session metadata.	
Verification Criteria	
1. Both payloads remain in a single world frame for the full run. <code>world→odom1</code> and <code>world→odom2</code> stay valid, and payload identities do not swap. 2. At least one inter-payload loop closure is accepted, appears in the log and as a Foxglove marker, and reports a non-identity relative pose with finite covariance. The run finishes with the inter-payload toggle still enabled. 3. In the overlap region, the two maps and trajectories agree more closely than in the prior toggle-off run, without split walls or doubled trajectories. Foxglove shows both live poses and one shared sparse map.	

4.10 Test 10: System Integration Test

Test 10: System Integration Test	
Objective	Verify that all FireSense subsystems are correctly integrated and can operate together as a complete two-payload system.
Element	Complete system: two payloads, communication system, collaborative SLAM, and command station.
Location	ACFA front room and adjacent rooms, with the command station outside at a pretested position.
Equipment	Two FireSense payloads, command station laptop, HaLow communication system, and thermal AprilTag.
Personnel	Jerry, Prakhar, Tina, Robert and Joy
Procedure	
1. Set up the command station and both FireSense payloads. 2. Cold-start both payloads and verify all sensors and software components are running correctly. 3. Establish communication between both payloads and the command station and verify that all required sensor data is received. 4. Carry both payloads through multiple rooms and overlapping areas along the ACFA test route. 5. Verify that localization outputs from both payloads are correctly integrated into the collaborative map and continuously updated at the command station. 6. Verify that thermal information from both payloads is correctly transmitted, associated with the corresponding payload, and displayed at the command station. 7. Review the recorded data and identify any failures between sensing, communication, localization, collaborative mapping, and command-station visualization.	
Verification Criteria	
1. Sensor data from both payloads is correctly received with the corresponding payload. 2. Localization outputs from both payloads are correctly integrated into the shared map. 3. Collaborative map and thermal information from both payloads are correctly displayed at the command station. 4. All subsystems operate together for the 15-minute test without critical integration failures.	

4.11 Test 11: Fall Validation Demonstration

Test 11: Fall Validation Demonstration	
Objective	Demonstrate collaborative SLAM of two heat-resistant payloads, and temperature display on GUI in a realistic smoke and heat scenario.
Element	Complete system: one handheld payload, one wearable payload, and command station.
Location	ACFA Building A, with the command station outside at the pavilion.
Equipment	Thermal AprilTag, thermal resistant payloads, radios, command station, tested spare components, and ACFA-controlled heating and smoke equipment.
Personnel	Whole Team and firefighters
Procedure	
1. Position the thermal AprilTag to establish a common global frame for both payloads. 2. Set up the command station. 3. Cold-start both payloads, run health checks, initialize the common frame, and start synchronized payload, screen, and temperature logging. 4. Have ACFA firefighters establish the planned heat and smoke conditions. 5. Firefighters carry both payloads through the building for a 15-minute collaborative SLAM demonstration, provided conditions remain within approved limits. Display shared maps and layered temperature information at the command station. 6. Review recorded ROS bags and benchmark against valid reference measurements.	
Verification Criteria	
1. Collaborative SLAM operates successfully, with shared maps visible at the command station. 2. Generate clear floor plan. 3. Both payloads remain safe during heat exposure. 4. GUI correctly displays environment information, including rising and falling temperature trends. 5. No gaps occur in the trajectories or map.	

4.12 Test 12: FVD Encore

Test 12: FVD Encore	
Objective	Repeat FVD and demonstrate improvements after FVD failures.
Element	Complete system: one handheld payload, one wearable payload, and command station.
Location	ACFA Building A, with the command station outside at the pavilion.
Equipment	Thermal AprilTag, thermal resistant payloads, radios, command station, tested spare components, and ACFA-controlled heating and smoke equipment.
Personnel	Whole Team and firefighters
Procedure	
1. Position the thermal AprilTag to establish a common global frame for both payloads. 2. Set up the command station. 3. Cold-start both payloads, run health checks, initialize the common frame, and start synchronized payload, screen, and temperature logging. 4. Have ACFA firefighters establish the planned heat and smoke conditions. 5. Firefighters carry both payloads through the building for a 15-minute collaborative SLAM demonstration, provided conditions remain within approved limits. Display shared maps and layered temperature information at the command station. 6. Review recorded ROS bags, benchmark SLAM against valid reference measurements, and assess improvements over the FVD.	
Verification Criteria	
1. Collaborative SLAM operates successfully, with shared maps visible at the command station. 2. Generate clear floor plan. 3. Both payloads remain safe during heat exposure. 4. GUI correctly displays environment information, including rising and falling temperature trends. 5. No gaps occur in the trajectories or map.	