Team Arcus
Autonomous Multimodal Aerial Mapping Vehicle

Test Plan

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MRSD Team B

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I. Introduction

This document details the exhaustive list of tests leading up to and including the Spring Validation Experiment. Logistics of each test and test execution steps are all outlined. Each test plan serves to verify and validate a subsystem of the UAV and will be completed for a progress review or the final evaluation of the UAV system. The order of tests is shown in the schedule.

II. Logistics

Location
Unless otherwise stated, testing will take place at the Planetary Robotics Laboratory at Carnegie Mellon University.

Personnel
All tests will be conducted by the team members listed below. Any special participating personnel will mentioned on a case-by-case basis for each test plan.

- Clare Cui
- Maitreya Naik
- Angad Sidhu
- Logan Wan

III. Schedule

Date	PR#	Capability Milestones	Test	System Requirements
2/15	**8**	Mapping	8.1 Demonstrate PixRacer/ MAVROS functionality 8.2 RGB Camera Calibration Test	
3/1	**9**	Mapping Localization Hardware Verification	9.1 Demonstrate RGB color mapping 9.2 Electrical Verification Test 9.3 Localization Drift Test	MPR2, MPR3, MPR5
3/22	**10**	Localization	10.1 Loop Closure Test	
4/5	**11**	Autonomy	11.1 Demonstrate UAV waypoint navigation in simulation	
4/17	**12**	Autonomy	12.1 Demonstrate UAV waypoint navigation with vehicle	MPR1, MPR4, MPR6, MPR7
4/26	**SVE**	Full functionality	SVE1, SVE2	MPR8, MPR9, MPR10

IV. Tests

8.1 Demonstrate PixRacer/ MAVROS functionality

Objective	Demonstrate successful integration of PixRacer/MAVROS
Elements to be Tested	● PixRacer ● Mavros
Equipment	● PixRacer ● Laptop ● Power cable ● USB-TTL-Pixracer Telem interface cable
Procedure	1. Ensure that 3DR Radio is connected on PixRacer. 2. Connect PixRacer with power cable to Laptop. 3. Connect interface cable between PixRacer and Laptop. 4. Bring up QGroundControl (QGC) and connect to the ACM comm link 5. Go to QGC=> <Cogs symbol> => Radio 6. Make sure moving the RC sticks reflects movement in QGC. 7. Use control change switch on RC controller to change to “Offboard Control” mode. 8. In QGC -> Widgets -> Analyze, scroll down to TARGET parameter. 9. On the computer, run demo node to set target poses 10. Track actuation commands in Analyze widget. 11. Use control change switch on RC controller to change to “Stabilize” mode.
Verification Criteria	● The TARGET values in the QGC Analyze widget reflect the demo program’s commands in “Offboard Control” mode. ● We can also check QGC-> <Megaphone/Warning symbol> for MAVLink messages sent or received by PixHawk

8.2 RGB Camera Calibration Test

Objective	Show that the RGB camera is calibrated
Elements to be Tested	● RGB Camera ● Laptop
Equipment	● UAV ● Laptop ● April Tag Calibration Board
Procedure	1. Connect RGB camera to laptop. 2. Start up camera node and image viewer node. 3. Run Kalibr camera validator with intrinsic calibration yaml file and target (apriltag) yaml file. 4. Move April Tag Board around the front of the camera, stepping from side to side and getting closer and farther away. Record at least six different positions.
Verification Criteria	Intrinsics Verification ● The reprojection error for each configuration of the Apriltag board is within 0.5px ● Lines on April Tag Board are straightened through visual inspection as displayed on monitor

9.1 Occupancy Grid Mapping Test

Objective	Demonstrate online mapping with colorized voxel occupancy grid map
Elements to be Tested	● Localization ● Mapping
Equipment	● UAV ● RC controller ● Laptop ● GPS antenna ● Telemetry modules ● Cable extender ● External power source for Modem/Laptop ● April Tag Calibration Board

Procedure	1. Setup ground control station 2. Setup UAV for tele-operated flight 3. Fly UAV for 5 minutes around MoCap Arena 4. View map in real time on ground control station screen 5. Land UAV on landing pad
Verification Criteria	● Visually verify that dense voxel grid map is created and is colorized ● Verification of online mapping will be completed visually during flight time

9.2 Electrical Verification Test

Objective	Ensure that the Electrical system is functional
Elements to be Tested	● PDB ● 3DR Power Module ● ESC ● Monitor, Mouse, and Keyboard
Equipment	● UAV ● Multimeter
Procedure	1. Check if the voltage at the input of the PDB is between 15-16.8V 2. Check if the voltage on the output from the PDB to the LiDAR is 12V 3. Check if the voltage on the output from the PDB to the Brix is 19V 4. Check if the voltage at the input of the 3DR Power Module is between 15-16.8V 5. Check if the voltage at the output of the 3DR Power Module to ESCs is between 15-16.8V
Verification Criteria	● Brix turns on (Power button lights up) ● Bring up rviz and velodyne node on an SSH connection or through monitor-keyboard connection on the Brix and verify point cloud is being generated from Velodyne. ● On the ground control computer, connect to the drone in QGroundControl and verify battery voltage reading being displayed.

9.3 Localization Drift Test

Objective	Ensure drift in localization is below threshold
Elements to be Tested	● Localization and State estimation algorithms
Equipment	● UAV ● Monitor, mouse, & keyboard (connected to onboard computer) ● Piksi RTK GPS
Procedure	1. Power up Piksi RTK GPS base unit 2. Power up UAV. 3. Connect to UAV from base station. 4. Ensure RTK Fix is available. 5. Start SLAM software stack and visualize data. 6. Start bag recording software. 7. Walk 50 meters in a non-looping path with drone. 8. Power down drone.
Verification Criteria	● Drift in drone's position is less than a meter after 50 meters travelled.

10.1 Loop Closure Test

Objective	Demonstrate ability to detect and close loop in SLAM
Elements to be Tested	● Localization and State estimation algorithms
Equipment	● UAV ● Monitor, mouse, & keyboard (connected to onboard computer) ● Piksi RTK GPS

Procedure	1. Power up Piksi RTK GPS base unit 2. Power up UAV. 3. Connect to UAV from base station. 4. Ensure RTK Fix is available. 5. Start SLAM software stack and visualize data. 6. Start bag recording software. 7. Walk in predetermined, marked, and measured path around a building. 8. Power down drone.
Verification Criteria	● Loop detected ● Trajectory path and state estimate updated

11.1 Waypoint Navigation in Simulation

Objective	Demonstrate ability to navigate via waypoints through a simulation environment
Elements to be Tested	● Simulation Sandbox ● Navigation algorithms ● Localization and State Estimation Algorithms
Equipment	● Computer
Procedure	1. Start up simulation environment with all hexrotor packages running 2. Manually input navigation goal using RViz 3. Command vehicle to return to takeoff position 4. Measure landing error distance away from takeoff position
Verification Criteria	● Viable trajectory is planned ● Simulation navigation goal is achieved ● Autonomously navigate to goal destination with maximum 3m error

12.1 Waypoint Navigation with Vehicle

Objective	Demonstrate ability to navigate via waypoints through the LaFarge quarry
Location	LaFarge Duquesne Quarry
Elements to be Tested	● Fully integrated hardware system ● Localization and state estimation algorithms ● Mapping algorithms ● Navigation algorithms
Equipment	● UAV ● Spare set of batteries ● RC Controller ● Laptop ● GPS Antenna ● Telemetry Antenna ● Fold Out Table ● External Power Source ● Surge Protector ● Extension Cable ● Wifi Router
Procedure	1. Follow preflight checklist (appendix) 2. Power on ground control station 3. Power on vehicle 4. Remotely arm vehicle 5. Use ground control station to choose a distant navigation waypoint 6. After hovering for 5 seconds, command vehicle to return to landing pad
Verification Criteria	● Vehicle completely executes flight plan successfully ● Autonomously navigate to goal destination with maximum 3m error ● Detects and avoids walls with minimum height of 2m by giving a minimum 3m berth

13.1 Spring Validation Experiment: SLAM and Teleoperation

Objective	Demonstrate the UAV is capable of online localization and mapping and providing a map back to the user in real time.
Elements to be Tested	● Localization and state estimation ● Online mapping ● Communication with ground control station ● Teleoperation
Equipment	● UAV ● Spare set of batteries ● RC Controller ● Laptop ● GPS Antenna ● Telemetry Antenna ● Fold Out Table ● External Power Source ● Surge Protector ● Extension Cable ● Wifi Router ● Brightly Colored Tape ● Camera and tripod ● Waypoint Pad and Wooden Beacon
Location	Lafarge Duquesne Quarry
Procedure	1. Follow preflight checklist (appendix) 2. Set up UAV on landing pad 3. Set up the ground control station 4. Set up camera, waypoint pad, and wooden beacon at chosen waypoint location that is partially obstructed by a quarry wall from UAV landing pad location. (relevant for 13.2 SVE) 5. Tele-operate vehicle and map for 5 minutes, visualize real-time map on base station monitor 6. Visualize real-time mapping error on base station 7. Land UAV on landing pad 8. Replace batteries if batteries have less than 15 V 9. Show video of previous map with comparison to ground truth FARO scan
Verification Criteria	● Compare with GPS to determine that localization drift is less than 0.1 m/m travelled

	● Map sent to ground control refreshes at minimum rate of 0.5 Hz ● Visually inspect a generated colorized dense voxel grid map ● Visually inspect loop closure occurring ● Visually check that teleoperation distance is greater than 20 m

13.2 Spring Validation Experiment: Autonomous Navigation

Objective	Demonstrate the UAV is capable of autonomous navigation, including trajectory planning and obstacle detection and avoidance.
Elements to be Tested	● Localization ● Planning algorithm ● Object detection/avoidance ● Communication with ground control station
Equipment	● UAV ● Spare set of batteries ● RC Controller ● Laptop ● GPS Antenna ● Telemetry Antenna ● Fold Out Table ● External Power Source ● Surge Protector ● Extension Cable ● Wifi Router ● Brightly Colored Tape ● Camera and Tripod ● Waypoint Pad and Wooden Beacon
Location	Lafarge Duquesne Quarry

Procedure	1. Follow preflight checklist (appendix) 2. Place bright tape 3 m away from wall along planned trajectory path 3. Set up UAV on landing pad 4. Set up the ground control station 5. Command UAV to distant waypoint location previously set up in 13.1 SVE, using the map formed in 13.1 SVE 6. Command UAV to lower itself and hover such that it is within camera frame 7. Command vehicle to return back to base 8. Visualize voxel grid map on base station
Verification Criteria	● Visually check to make sure UAV avoids wall (minimum size of 2 x 1 m^2) with a minimum of 3 m distance from center axis by looking at position relative to tape ● Visually check from camera footage that UAV navigated to waypoint with less than 3 m of error based on location of center axis

V. Appendix

Preflight Checklist

Objective	Ensure that the drone is safe for take off
Elements to be Tested	● Drone Hardware components ● Drone software bring-up
Equipment	● UAV ● Monitor, mouse, & keyboard (connected to onboard computer) ● April Tag Calibration Board
Procedure	**Electrical** 1. Battery Voltage above 16V for proper functioning 2. Battery connected to PDB and 3DR Power Module 3. 3DR Power Module connected to PixRacer and ESCs 4. Verify 19V DC step-up connected into PDB 5. Connect LiDAR and BRIX to PDB **Mechanical** 1. LiDAR securely in place. 2. Propellers properly screwed in 3. PixRacer, safety switch, buzzer, telemetry radio, and RC radio secured. 4. BRIX, and PDB secured. 5. Battery inserted in compartment and secured (does not fall out when drone is pitched up by 90 degrees) 6. 3DR uBlox GPS stable and glued in on top facing front. 7. Piksi GPS and Antenna secured. **Software** 1. Check PixHawk SD card for “etc\extras.txt”. It should contain a. “gps stop b. mc_att_control stop c. mc_quat_control start” 2. Re-insert SD Card into PixHawk 3. Pull-up QGroundControl and connect to drone using USB Cable 4. Verify all sensors calibrated and verify battery voltage reading. 5. If sensors are uncalibrated, unmount LiDAR and propellers, and run calibration using QGroundControl.

	6. Connect to PixHawk after calibration to verify. 7. Disconnect USB Cable. 8. Power on RC controller. 9. Connect battery terminal to 3DR Power Module. 10. Start Logging PixHawk Data using QGroundControl 11. Try SSH into BRIX 12. Start roscore 13. Launch sensor, GPS, and BLAM nodes 14. Verify ros network on Ground Control PC in the same network by running “rostopic list” 15. Verify LiDAR running by “rostopic echo /velodyne_points”
Verification Criteria	● Tele-operate flight for at least 30 seconds