MOOS-DAWG 2026

Deploying a Fixed-Wing UAV Swarm for Wildfire Detection Using MOOS-IvP

Integration, Communication, and Field Results

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Why UAV Swarms for Wildfire Detection?

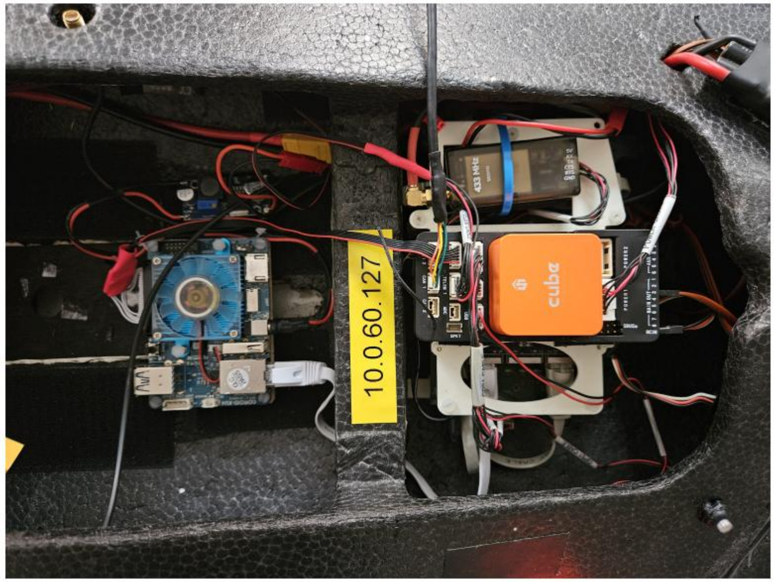
- **Wildfires are growing in frequency and scale**:
  Early detection is the highest-leverage intervention
- **Goal:**
  a scalable network of autonomous fixed-wing UAVs that cooperatively search an area and detect fires fast
- **Approach in two phases**
  (1) prove MOOS-IvP can fly a single UAV: navigation, comms, mission execution
  (2) extend to a coordinated multi-UAV fleet with cooperative coverage algorithms
- **Context:**
  developed with the NTNU RAINDROPS team toward the XPRIZE Wildfire Challenge (1000 km² in 10 min)

Skywalker X8 ready for launch

The Platform

Skywalker X8 · Cube Orange · Odroid XU4

- **Airframe:**
  Skywalker X8 tailless fixed-wing, elevon-controlled, bungee-launched
- **Autopilot**:
  Cube Orange running ArduPilot / ArduPlane 4.5.7, low-level control, takeoff and landing, RTL failsafes
- **Payload computer**:
  Odroid XU4 (octa-core ARM)
  Runs the full MOOS-IvP community
  All trajectory decisions made onboard
- **Sensors**:
  GNSS, triple-redundant IMUs, magnetometer, barometer, pitot airspeed
- **GCS:**
  Ubuntu laptop with pMarineViewer
  Redundant Mission Planner PC



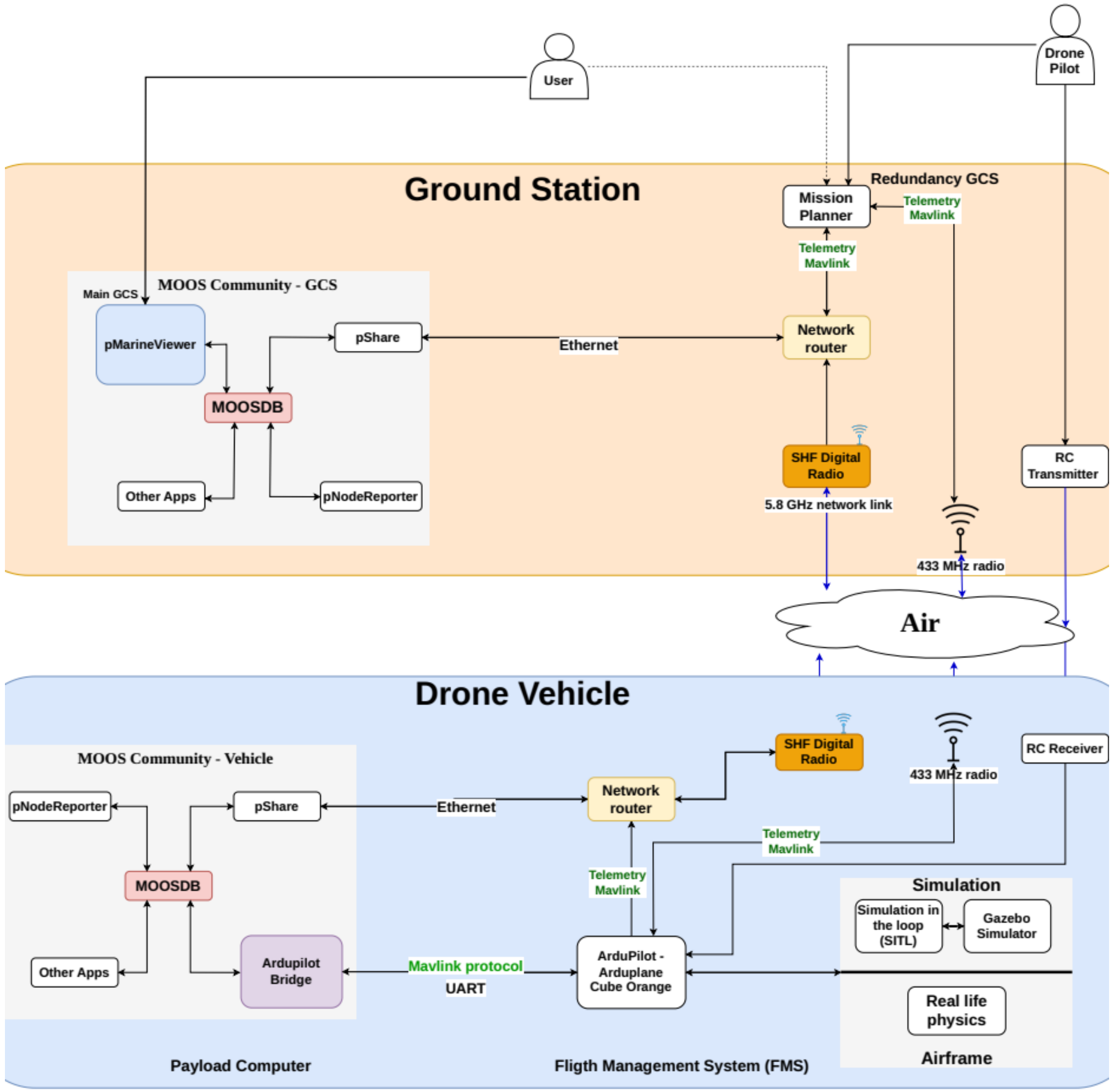
Cube Orange + SBC inside the X8

GCS antennas

Bungee launcher and the X8 rigged on the catapult

Autonomy: The Backseat Driver on a Fixed-Wing UAV

- **IvP Helm runs entirely on the payload computer**
  behavior-based autonomy, multi-objective optimization
- **Helm issues high-level course, speed and altitude decisions**
  ArduPilot keeps authority over low-level flight control
- **Clean separation:**
  Autonomy stays vehicle-agnostic
  The same helm concepts carry from marine vehicles to UAVs
- **New UAV behaviors:**
  BHV_ConstantAltitude and BHV_Voronoi_uav added to the helm
- **MAVLink over UART**:
  links payload computer and autopilot



Full UAS architecture — ground station and drone vehicle

pArduBridge: MOOS ↔ ArduPilot

Custom MOOS app — the MAVLink interface

- **Maintains the UAV state:**
  polls the autopilot and publishes position, speed, altitude, heading to the MOOSDB (NAV_*)
- **Sends commands to the autopilot:**
  Helm's DESIRED_* variables become GUIDED-mode targets over MAVLink
- **Mode management:**
  MANUAL / AUTO / RTL / GUIDED
  Helm active only in GUIDED
- **Failsafe:**
  If the MOOS GCS connection is lost ->
  pArduBridge commands Return-to-Launch
- **Built on MAVSDK (C++):**
  modified to work with ArduPilot rather than PX4-based systems

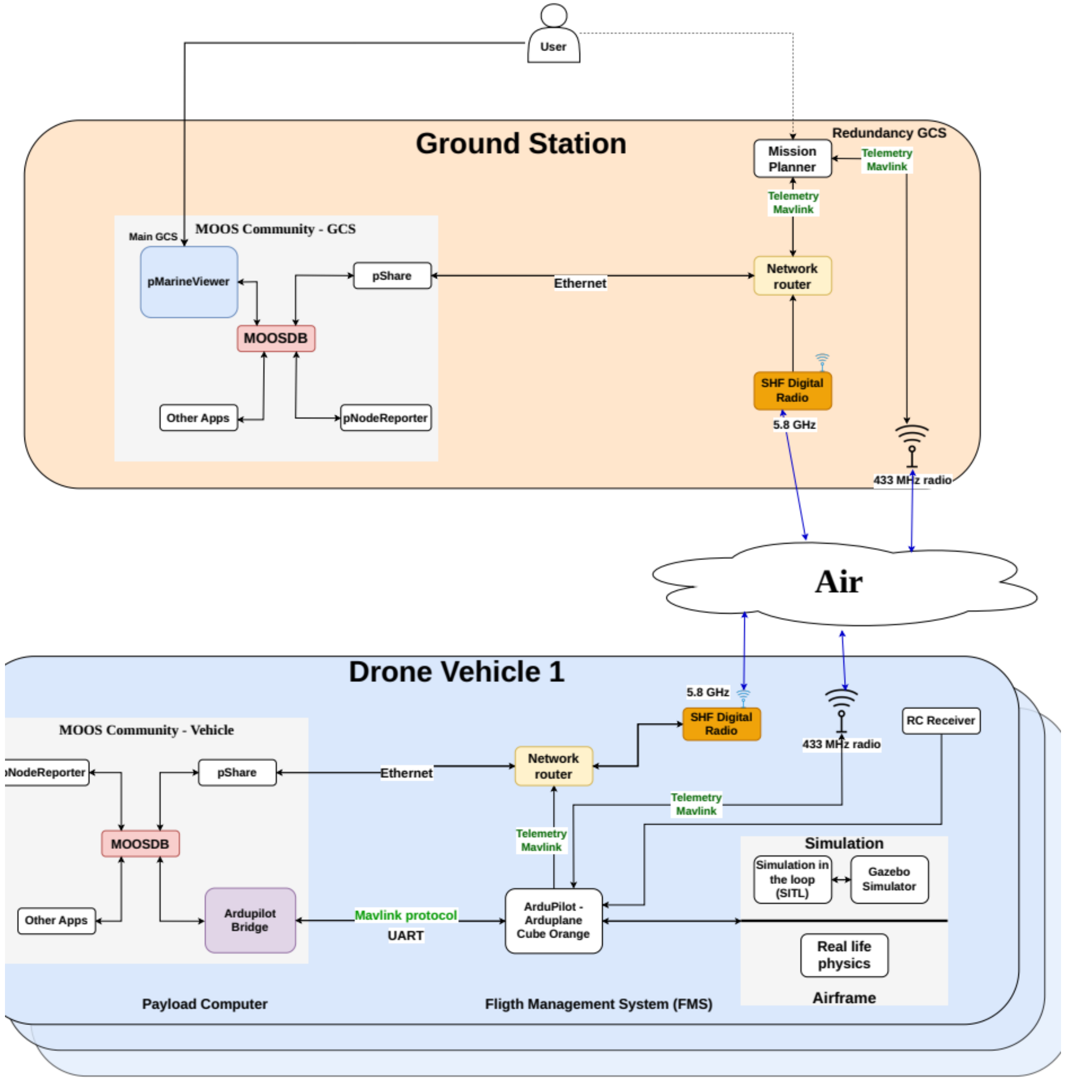
```
==============================================================
pArduBridge skytrailer                                0/0(637)
==============================================================
============================================
File: pArduBridge
============================================
 -------- Configuration Settings ----------
ArduPilot URL: 0.0.0.0
ArduPilot Port: 14570
ArduPilot Protocol: Udp
Simulation Mode: SITL
-------------------------------------------
UAV States:
------------------
           Is Armed: false
         Is Healthy: true
             In Air: false
        Flight Mode: Manual
    Helm On BUSY: false
   Helm GUIDED HOLD: false

UAV Parameters:
------------------
       Min AirSpeed: 11 m/s
       Max AirSpeed: 19 m/s
State Information:
------------------
       Helm Autonomy Mode: HELM_ACTIVE
  (Latitude , Longditute): 63.3974 , 10.1455
                  (X , Y): 99.7283 , -10.003
           Altitude (MSL): 106.21 m
                  Heading: 56.9453 deg
-------------------------------------------
States     Measurments  Helm  Targets
---------  -----------  ----  -------
Speed:     0            0     15
COG:       214.46       0     0
Altitude:  -0.05        0     100
-------------------------------------------
Waypoint                Lat        Lon
-----------------       ---------  ---------
Home Coord:             63.397427  10.145538
Next Wypt Coord:        0          0
Course Wypt Coord:      0          0
-------------------------------------------
Debug                     Value
--------------------      -----
Do set fly waypoint:      false
Do takeoff:               false
command groundSpeed:      false
=================================================================
Most Recent Events (1):
=================================================================
[0.00]: Set marker at home location: x=99.72,y=-10,width=10,type=gateway,
label=Home_skytrailer,color=purple,scale=10.00000
```

pArduBridge live status output

Communication Architecture

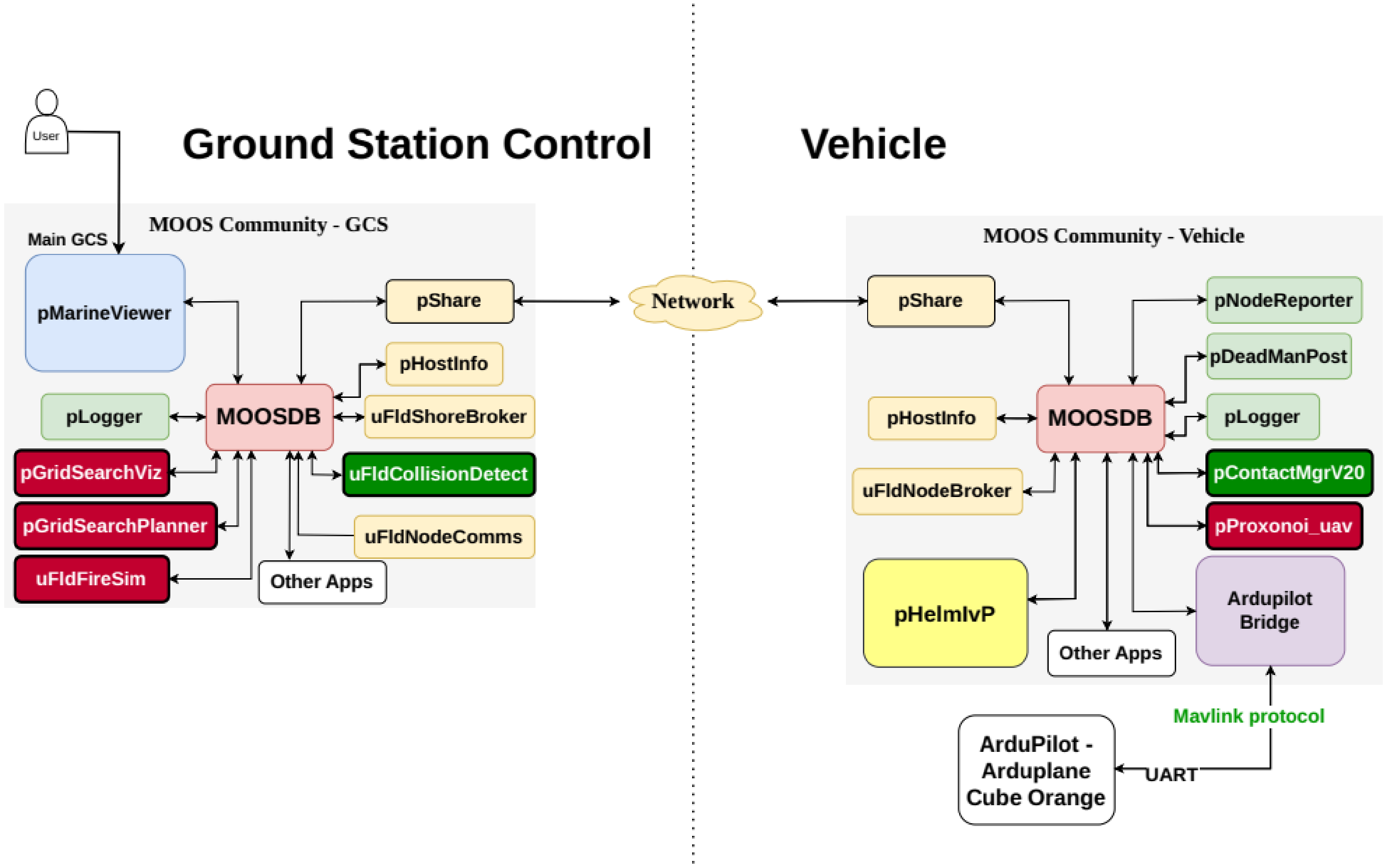
- **5.8 GHz Ubiquiti Rocket M5 mesh**:
    Primary LAN linking all UAVs and the GCS
    Effective range up to 10 km
- **433 MHz SiK telemetry**:
    Redundant MAVLink link
    Prioritized if the UAV leaves SHF range
- **MAVProxy:**
    Multiplexes the two radio links for the redundancy GCS (Mission Planner)
- **Every vehicle gets a unique IP on the network router**:
    Adding a UAV to the fleet is plug-and-play
- **RC transmitter**:
    Direct pilot override for safety at all times



Multi-vehicle UAS network

One MOOS Community per Vehicle

Swarm Toolbox handles fleet-wide state sharing

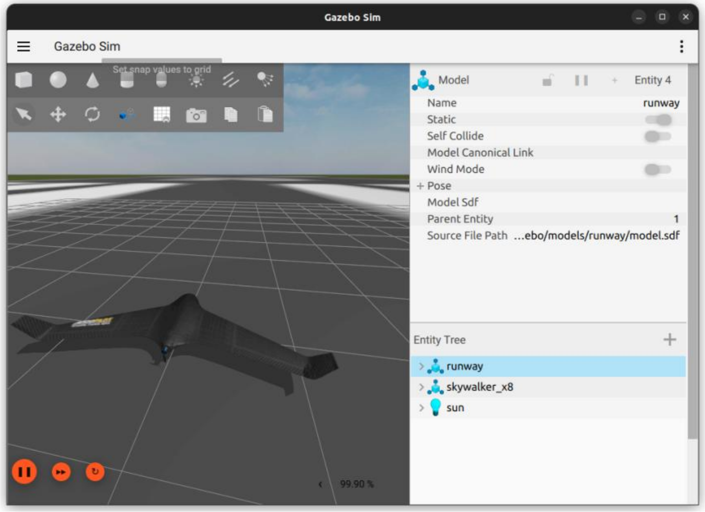


GCS and vehicle communities — dark red apps are custom-made

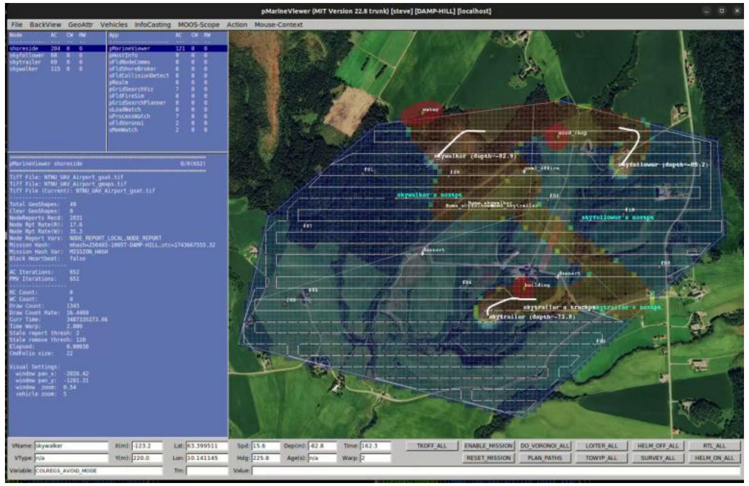
- **pShare + pNodeReporter**:
  Real-time state sharing across the fleet over the LAN
- **uFldNodeBroker / uFldShoreBroker**:
  Automatic discovery and variable bridging
  DHCP-safe
- **uFldNodeComms**
  Mediates all inter-vehicle messages
- **pMarineViewer**:
  Mission monitoring and high-level commanding from one laptop
- **pDeadManPost:**
  15 s of GCS silence → RTL

Test Pipeline: SITL → Lab → Field

- **ArduPilot SITL + Gazebo:**
  Same MOOS community, simulated physics
  Nothing changes but the autopilot endpoint
- **uFldFireSim**:
  Custom app spawning fires and adjudicating detections (GCS-side)
- **pGridSearchViz:**
  Live coverage grid, decay of stale cells, altitude-dependent sensor footprint
- **pGridSearchPlanner**
  Generates the TMSTC* coverage paths
- **Mission score:**
  Completeness (50%) + time efficiency (50%),
  plus detection-time and coverage statistics



Gazebo + ArduPilot SITL with the X8 model



Video — TMSTC mission run in simulation (with point filtering)*

Two Cooperative Search Strategies

TMSTC*

Turn-minimizing Multirobot Spanning Tree Coverage

- **Centralized**:
  GCS plans complete lawnmower-style paths up front
- **Minimizes turns**:
  Cost function adapted to fixed-wing turn dynamics
- **Systematic:**
  Guaranteed full coverage → best latest-detection time
- **Replanning**:
  Full recomputation when the region changes

Voronoi Search

Lloyd's-algorithm dynamic partitioning (BHV_Voronoi_uav)

- **Decentralized:**
  each UAV moves toward the centroid of its own Voronoi cell
- **Emergent trajectories**:
  No predefined paths, rapid early exploration
- **Fast on average**:
  Lowest average / median fire-detection times
- **Robust to change:**
  Ignored regions handled with no replanning at all

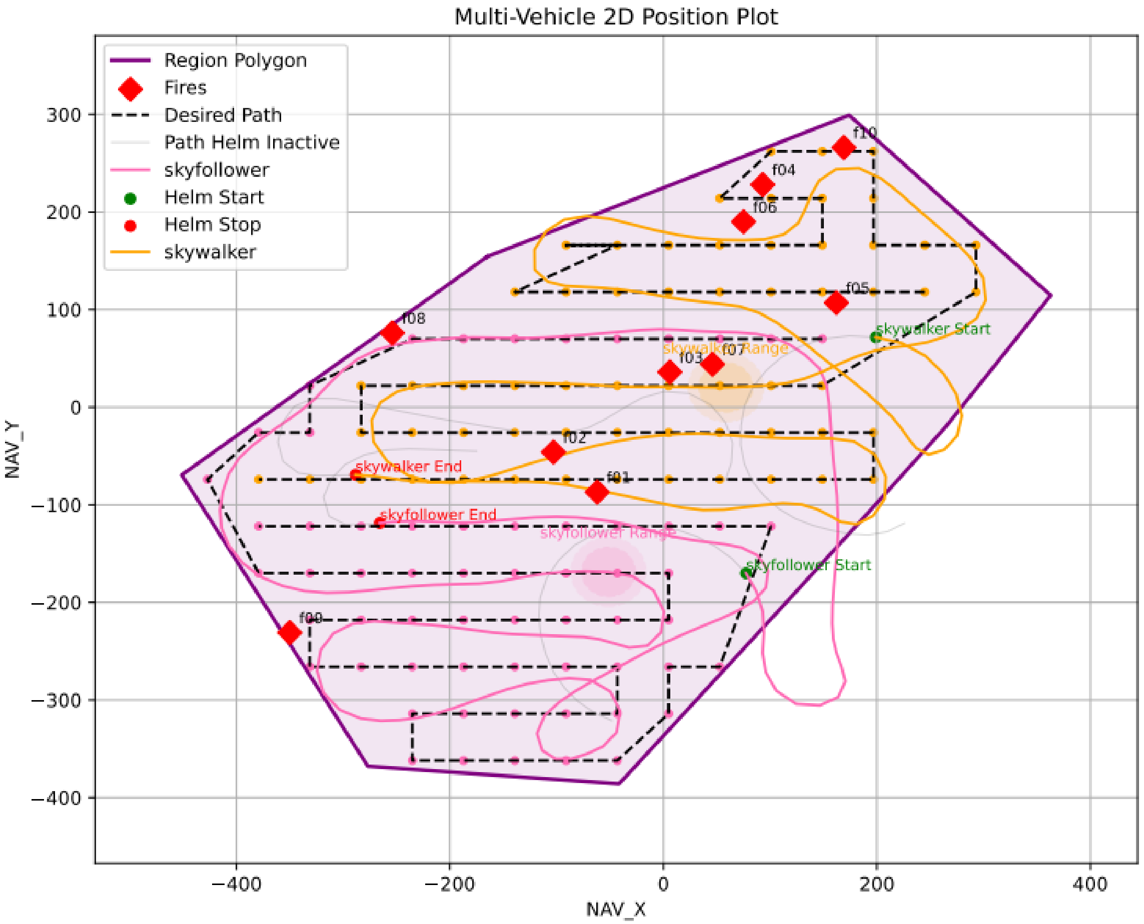
Field Campaign — NTNU UAV Lab

- **Two Skywalker X8s**: flying simultaneously
- **Vertical separation 90 m / 120 m**:
  Plus lateral collision monitoring (uFldCollisionDetect)
- **Mission:**
  cooperative search of a VLOS region with 10 simulated fire targets (uFldFireSim adjudicates detections)
- **Four starting configurations:**
  Different launch positions to test robustness
- **TMSTC* flown in the field**:
  Voronoi Search evaluated in simulation with identical parameters

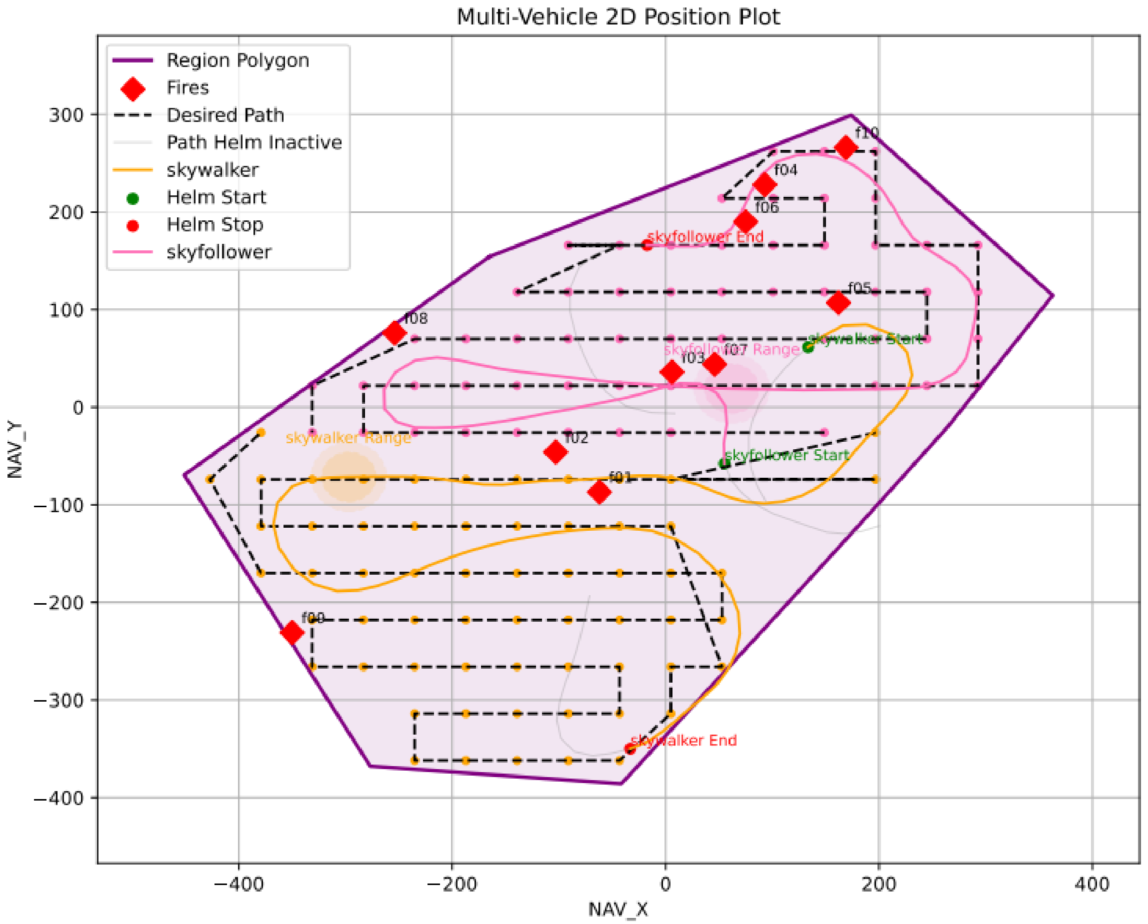
Rigging the two X8s

Video — bungee launch

Field Results: All Fires Found Every Scenario



Scenario 3 — start SE + NE

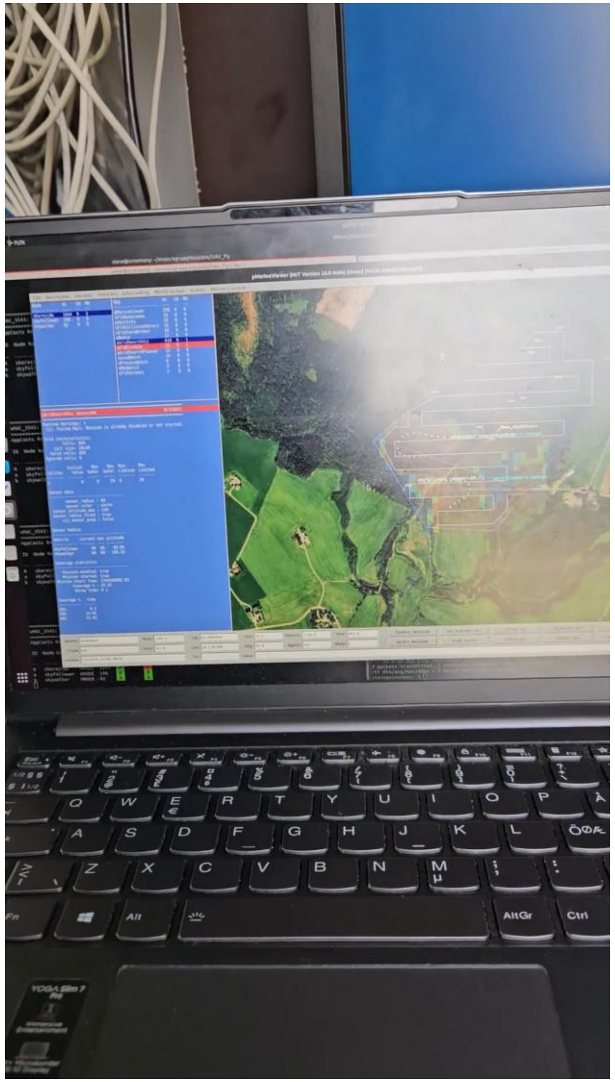


Scenario 4 — start S + N

All 10 fires detected before mission end in all four field scenarios; both UAVs returned home.

In the Air — TMSTC* Fire Mission

Pre-flight rigging

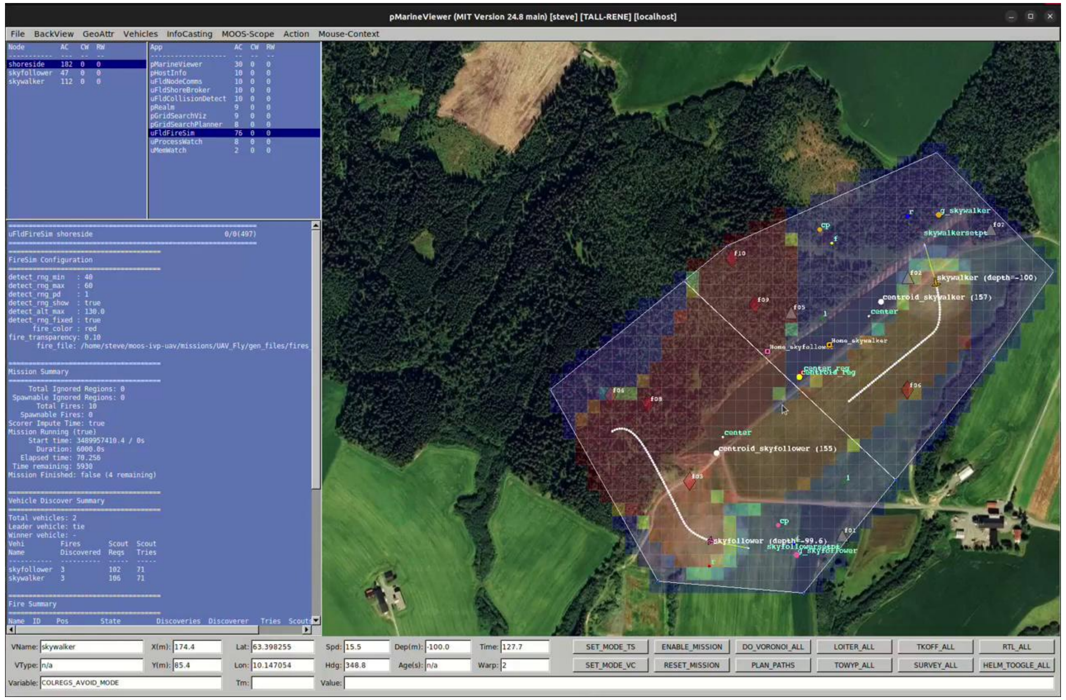


Video — from the GCS screen to both X8s overhead

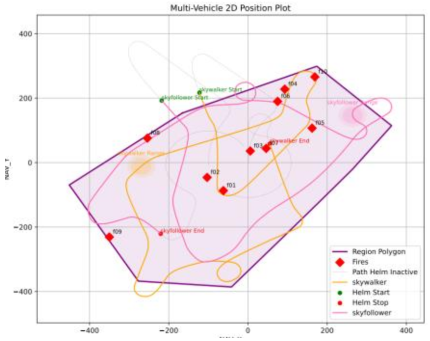
Altitude-separated, on station

Voronoi Search — Simulation with Field Parameters

- **Same setup as the field**:
  Two UAVs, same VLOS region, 10 fires, 10 min deadline
- **All four scenarios:**
  Full score - every fire detected, high coverage
- **Lower average detection times than TMSTC*:**
  Rapid, dynamic early exploration
- **Trajectories are emergent:**
  No preplanned paths
  Motion falls out of the Voronoi partitioning
- **Caveat:**
  Needs ≥ 2 vehicles
  A single UAV orbits the region centroid and never completes

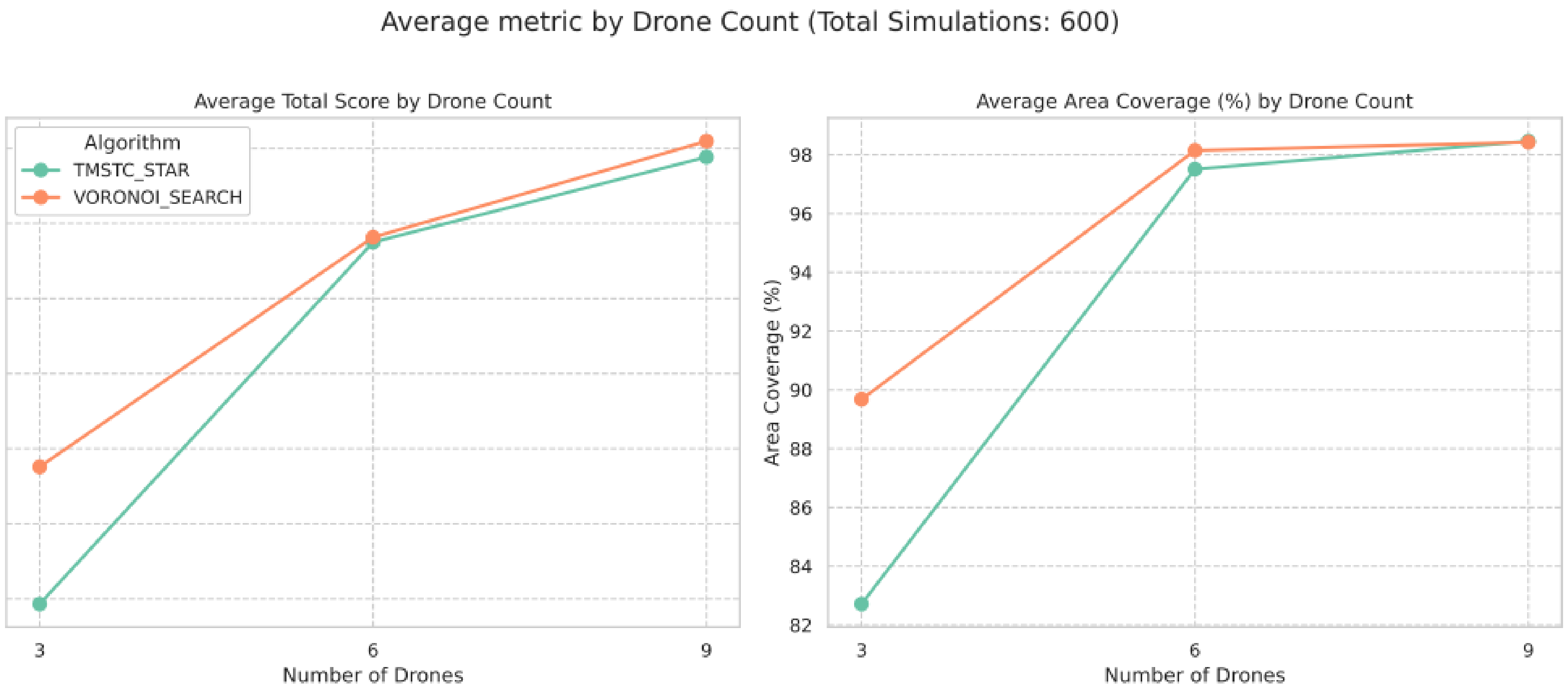


Video — two-UAV Voronoi Search over the field area



Scaling the Fleet: 3, 6 and 9 UAVs

600 simulated missions · 2 km² region · 10 min deadline · 40 random fire layouts



Average total score and area coverage vs. fleet size

- **3 drones:**
  Voronoi 68.8 VS.
  TMSTC* 59.7 average total score
- **6–9 drones:**
  Gap narrows; both > 90% completeness
- **Trade-off holds:**
  Voronoi: best average detection
  TMSTC*: best worst-case

More drones → faster coverage and earlier detections for both algorithms.

Lessons from Flying Fixed-Wing Swarms

- **Fixed-wing logistics dominate field time:**
  bungee launches, rigging and recovery are serial, per-aircraft work
- **Altitude separation is cheap insurance**:
  lateral-only collision logic + 30 m vertical offset kept operations safe
- **Failsafes first:**
  layered RTL (RC loss, GCS loss, pDeadManPost) made testing stress-free
- **Sim-to-field transfer was clean**:
  Identical MOOS communities in SITL and flight
  Surprises stayed small

Lab testing — both X8s on the bench

Takeaways

MOOS-IvP flies fixed-wing UAVs:

backseat driver over ArduPilot, validated in SITL and in the field

Pick your algorithm by the mission:

Voronoi for fast average detection, TMSTC* for guaranteed worst-case coverage

Scales with the fleet:

3 → 9 drones: faster coverage, earlier detection, narrowing algorithm gap

Future work

Terrain-aware planning and detection models · onboard fire sensors (detection on the vehicle, not the GCS) · TMSTC* replanning under non-convex constraints · larger-scale field trials

Thank you — questions?

Code: github.com/scarter668/moos-ivp-uav

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