Quad-X Swarm

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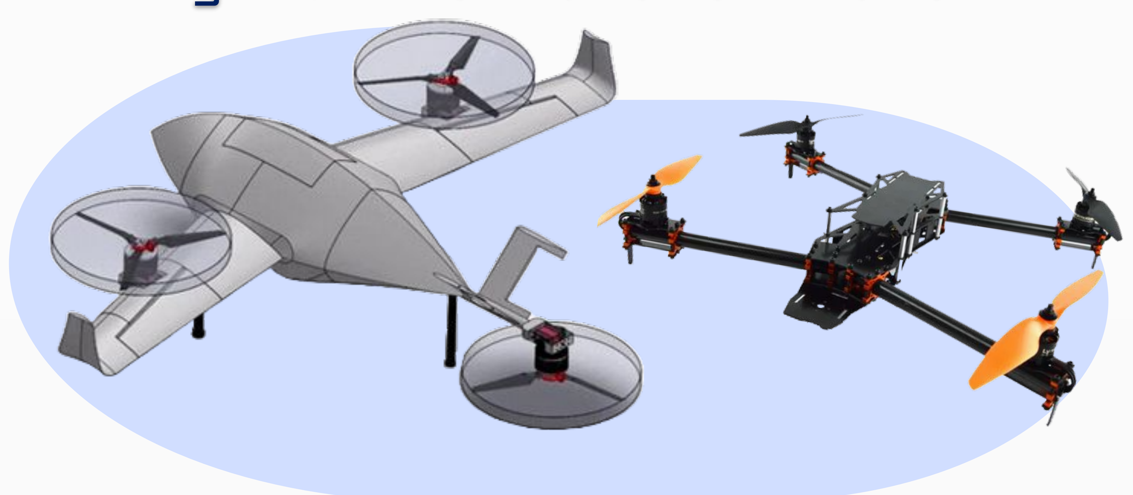
Introduction

The goal of **Quad-X Swarm** is to develop the underlying swarm mechanics and expandable mission framework for autonomous unmanned aerial vehicles (UAVs) to complete complex multi-step missions. In this case we focused on thermal-imaging based search and rescue.

Fig 1. VTOL and Child UAV



The UAVs will be controlled autonomously by a central 'parent' UAV. This unique **centralized swarm mechanic** is structured so that under ideal conditions collision avoidance is intrinsic to our grid-based approach.

- All search areas & the area around the parent are divided into **cells of 2.5 x 2.5 meters**.
- This grid enables the **thermal imaging of individual cells** used by the thermal detection algorithm for SAR operations.

Requirements

- **Functional Requirements:**
  - The parent **must control** all children's *take off, flight and landing.*
  - The parent **must avoid collisions** with children and prevent collisions between children.
  - Thermal processing must be done over the **entirety of the search area**.
  - Thermal Processing must be **lightweight** and not overwhelm the parent's processor.
  - The system must **accurately simulate latency** for UAV communications.
  - Simulated **physics must be realistic**.
  - Simulator must produce **relevant metrics**.
- **Non-Functional Requirements:**
  - An **easy to use** interface for mission management and parent control.
  - Physics and rendering must not impact **performance** of the simulation.

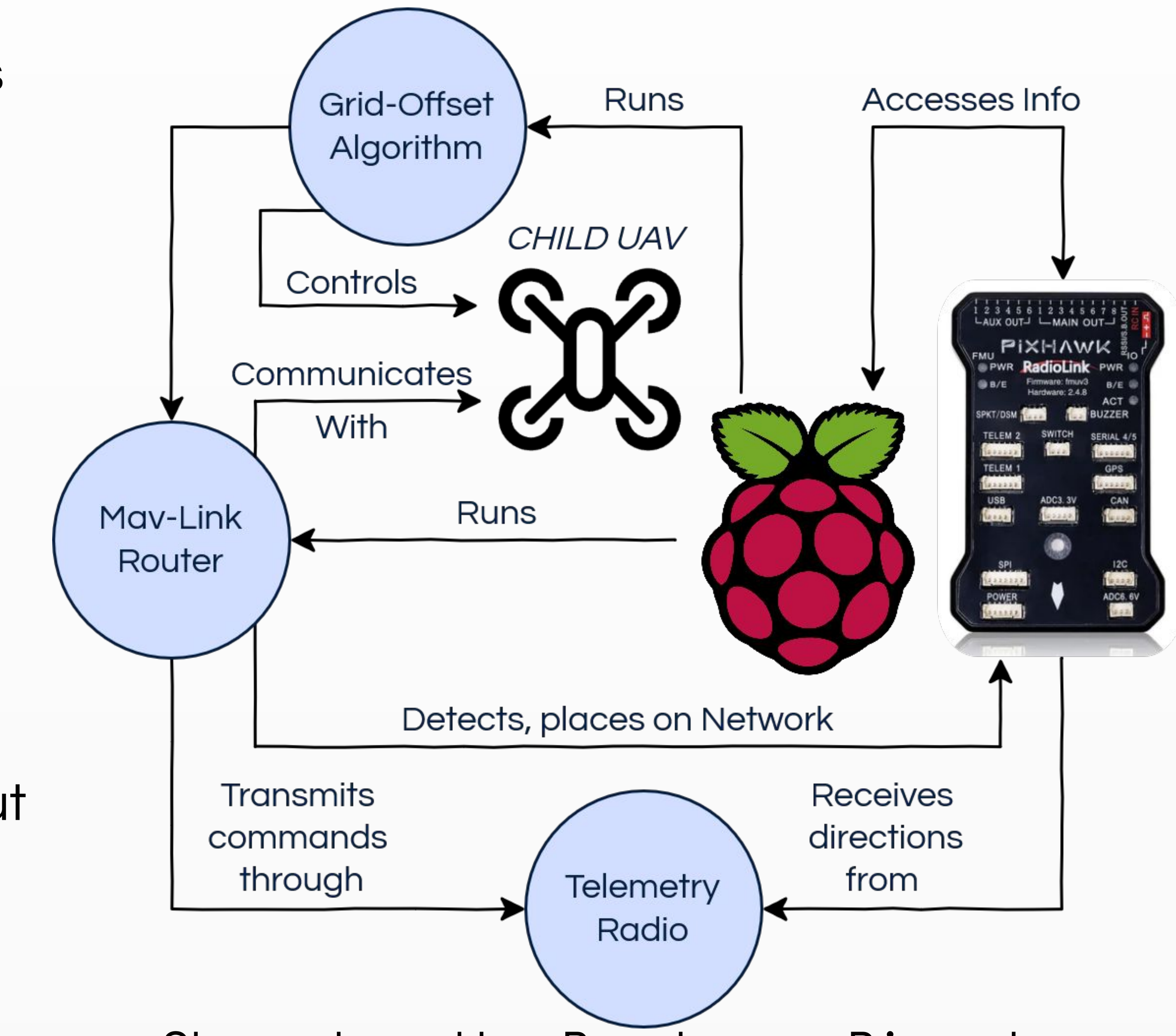
Project Design

Key: Black Box = Pixhawk, Raspberry = Pi

Fig 2. (right) shows how the parent-child setup is configured.

- On startup the **Grid-Offset Algorithm** boots up and initiates the **MAVLink network**.
- The **Pixhawk flight controller** receives directions over the **telemetry radio** on its **MAVLink** network.
- The Pixhawk sends the current **GPS and Inertial Measurement Unit (IMU)** data to the **Raspberry Pi**.
- The Raspberry Pi utilizes the IMU data as input to the perpetual **Grid-Offset algorithm**.
- The **Grid-Offset algorithm** communicates relevant instruction data to the children to both maintain **swarm structure** and avoid **collisions**.

Fig 2. System Design



Shows how the Raspberry Pi and Pixhawk Flight controller work with our algorithm to enable our design

Implementation and Testing

Fig 3. Marked Thermal Image

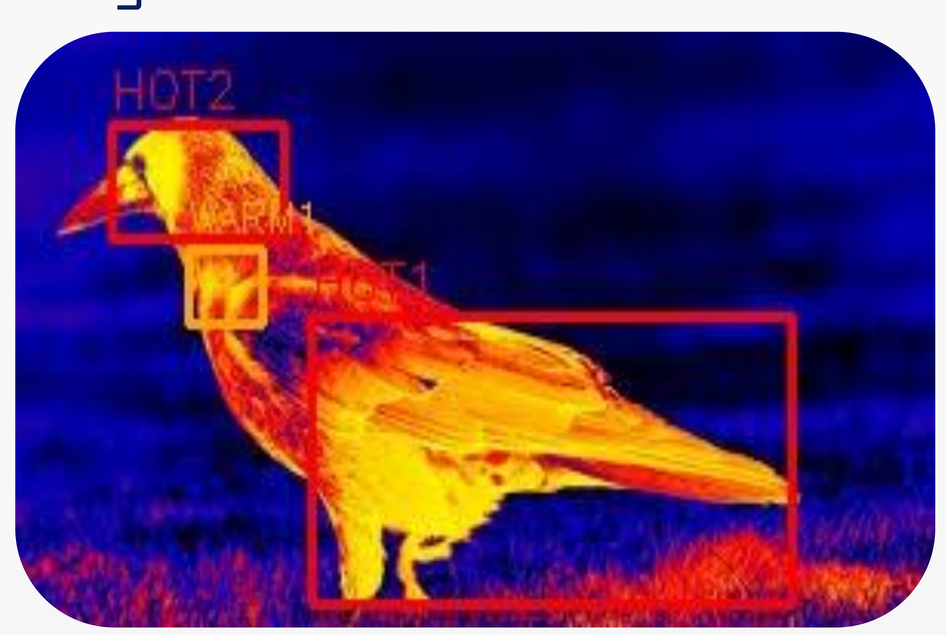


Fig. 3: Output from thermal detection algorithm with multiple hotspots identified.

Fig 4. Simulation

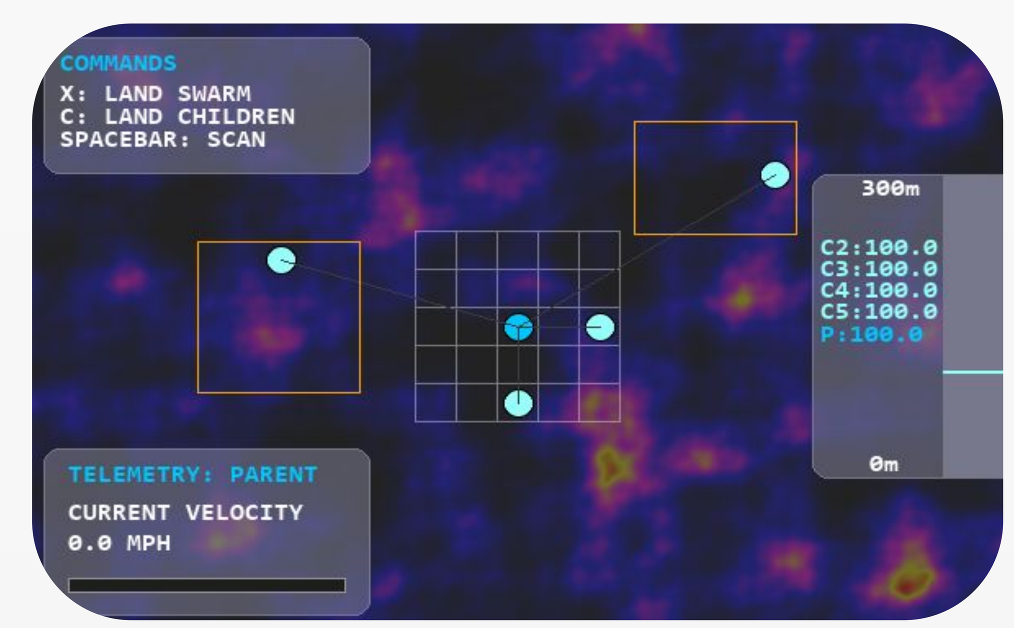


Fig. 4: Simulation used for testing algorithm correctness

- **Parent-Child Swarm Hierarchy Implementation**
  - Communication between the parent and children uses the **pymavlink library** for real world uses while supporting direct simulated communication for our testing and demonstration.
  - Data involving the parent velocity and all UAVs' altitude are **displayed and recorded**.
  - Location, velocity, and acceleration data of the UAVs are generated to **simulate real movements and reactions** to movement commands over MAVLink during testing.
  - Resilience testing was done to **ensure safe distances** between UAVs to **avoid collisions**.
- **Thermal Detection Algorithm**
  - Separate algorithm developed for individual **image analysis and marking**.
  - Runs independently once thermal image of cell is taken by child UAV
  - Analyzed images are **marked with coordinates of hotspots** noted in output file.
  - Manual testing used to **ensure accuracy in identification of hotspots** as seen in figure 3. In addition, automated testing of missions in simulator was done to **ensure consistent results**.

Evaluation

In addition to our listed requirements, we have also completed several target metrics to ensure safety and efficiency in our system framework.

- Missions operate successfully and are completed under **up to 5% MAVLink communication packet loss**
- Our UAVs maintain an average distance of **2.5 meters during 99% of flight**, and collisions are **minimized to near-zero probability**.
- Children land within *5 meters* of the parent.
- **Missions are divided between children** when a singular mission contains more than 36 cells.
- SAR algorithm identifies & prioritizes all hotspots within a given search area.

Conclusions

The Quad-X Swarm project as it stands offers a new method for UAV swarms to perform SAR operations.

- Algorithm supports up to 8 child UAVs seamlessly
- Current framework allows for expansion to other areas such as autonomous navigation or delivery.

Next steps:

- Algorithm needs to undergo more rigorous unit testing in order to scope out any edge cases.
- Integrating the system with physical UAVs and VTOL X.
- Safety Features such as calculated positions and object avoidance.

Overall, **we succeeded** in setting up a modular swarm & mission framework from which SAR operations can be fine tuned, and missions such as delivery and civil engineering surveillance implemented with ease. Quad-X is ready for **deployment and testing in the real world**.

Acknowledgements

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