Flying a UAS Using an Auto Pilot in GPS-Denied Environments

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WSMR – White Sands Missile Range

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Mission/SOW

Mission Statement:

- We enhanced the versatility of UAS operations by creating an alternative navigation system for use in GPS-denied environments.

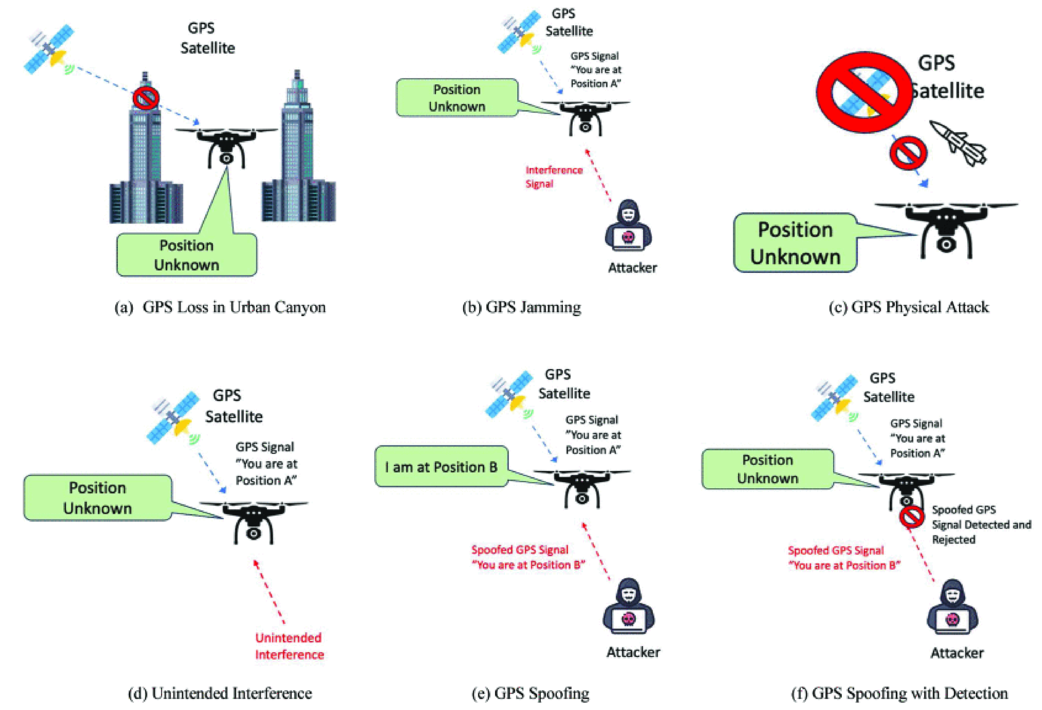
Statement of Work (SOW):

- Researched alternative navigation methods
- Designed a sensor fusion system
    - IMU (Inertial Measurement Unit)
    - LiDAR (Light Detection and Ranging)
    - Depth Camera
- Identified hardware and software components
- Tested system for 10-meter accuracy
- Optimized performance based on test analysis
- Documented system setup for client's use

Through our research, testing, and iterative process, our capstone team worked diligently to develop a reliable navigation solution that enhanced UAS operations in GPS-denied environments for WSMR**.**

Research

- UASs rely on GNSS, such as GPS, but signals can be blocked or disrupted by obstacles, spoofing, or jamming.
- UAS swarm navigation utilizes Kalman filters, leader-follower control, and AI-driven sensor fusion, with CNN-based distance estimation outperforming other methods, though challenges in accuracy and real-time adaptation remain.
- Research integrates IMUs, cameras, and alternative methods like UWB and radar inertial odometry with Pixhawk to counter GNSS disruptions and improve autonomy.

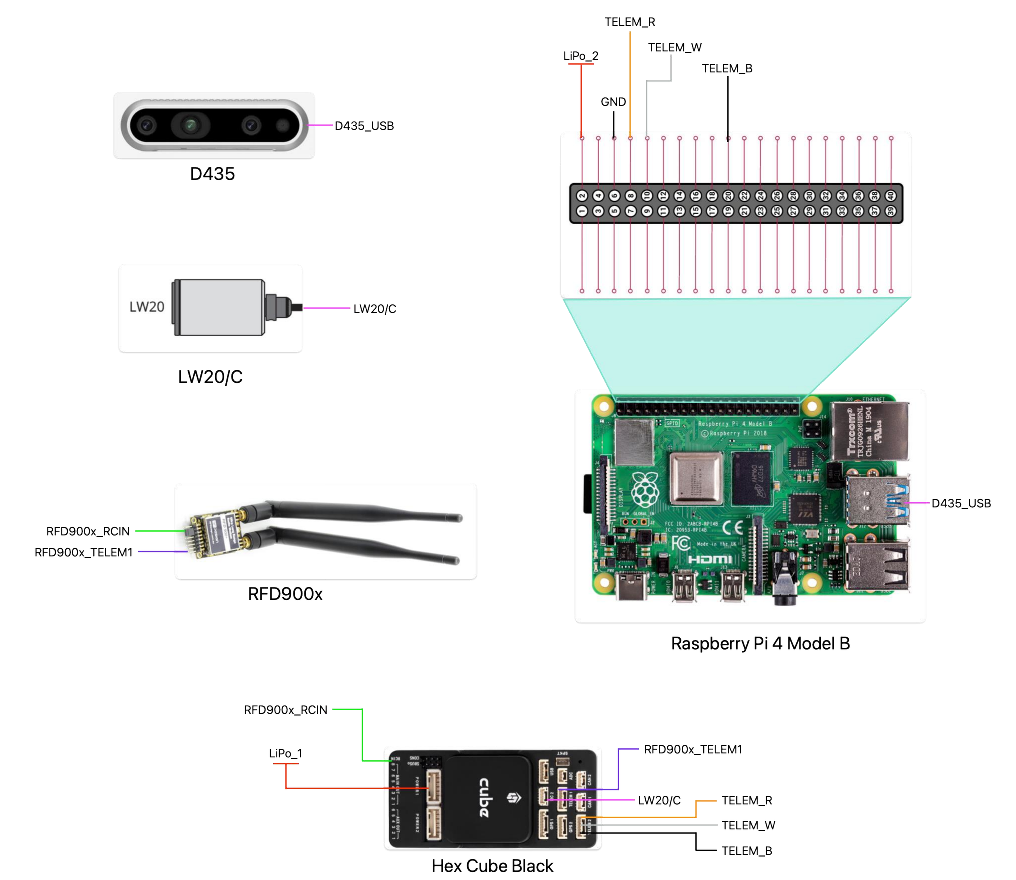


Different Types of GPS-Denied Scenarios
Picture from IEEE

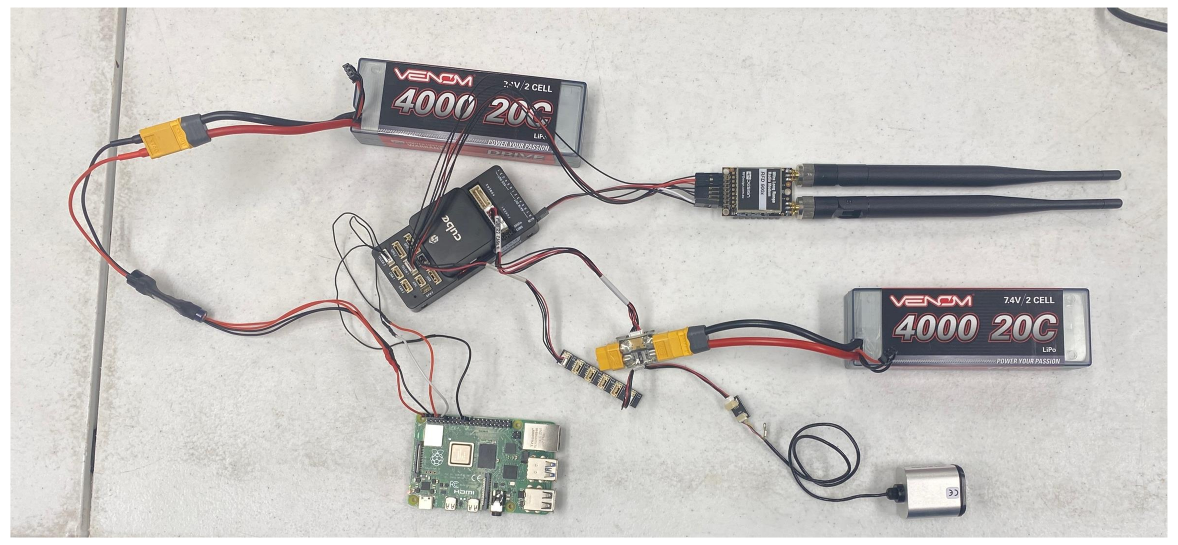
Final Design

Our design utilized LIO (LiDAR Inertial Odometry) for position calculation and a forward-facing depth camera for obstacle detection. Position computation occurs on a Raspberry Pi and coordinates are transmitted using a telemetry module to a base computer.

- **Raspberry Pi 4 Model B:** Served as the main processing unit for data processing from sensors and position calculation.
- **Intel RealSense Depth Camera D435:** Mounted forward-facing for obstacle detection using depth perception.
- **LightWare LW20/C LiDAR:** Provided precise distance measurements for altitude control and navigation.
- **Hex Cube Black:** Functioned as the flight controller, managing telemetry and sensor integration.
- **RFD900x Telemetry Module:** Enabled long-range communication between the UAS and the ground station.
- **Wiring and Connectivity:** The system was integrated using USB and telemetry ports, with power supplied by LiPo batteries.



System Wiring Connection
Picture by Capstone Team



LIO System Setup
Picture by Capstone Team

Test Results

Our tests focused on 3 areas of our system: overall power usage, sensor accuracy, and position calculation from code. Major results from our tests included:

1. Our system could be **powered for at least 20 minutes**, meeting power consumption goals for flights.
2. All **sensors collected data as expected**: IMU collected 3-axis accelerometer, gyroscope, and magnetometer data; LiDAR recorded accurate distance measurements; depth camera provided stereoscopic images, one lens recording visible light and the other recording depth images.
3. The telemetry modules used **allowed data from our system to be transmitted and received** by a base computer.
4. Our code could **calculate a position** based on data provided by our sensors.

Optimization of System

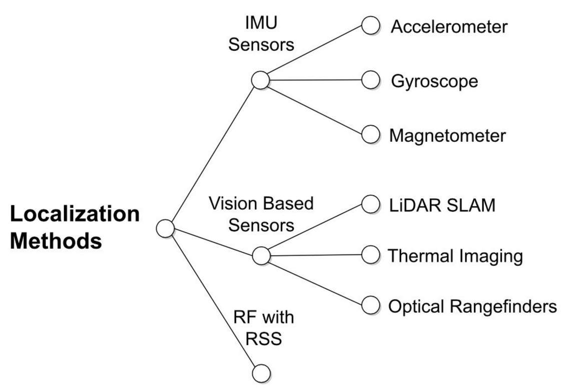
- Low-level communication with the flight controller was established through **pymavlink**, enabling real-time telemetry access and precise control of vehicle parameters for testing and tuning.
- **DroneKit** was used to automate flight missions, collect sensor data, and efficiently test. autonomous behaviors using Python scripts.
- **LIO (LiDAR-Inertial Odometry)** integration enabled accurate localization in GPS-denied environments; tuning parameters and sensor alignment were refined based on real-time feedback from flight data.
- The combination of these tools reduced the overall testing cycle, allowing faster iteration and validation of the navigation system.
- After initial tests, we refined our system by filtering data to account for IMU sensor drift.

Concept Development

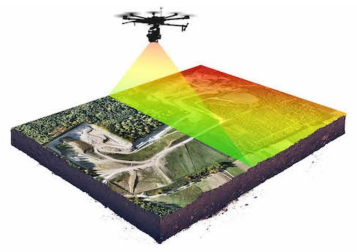
We considered technologies and localization methods which had already been researched, including:

- **Ground nodes** communicating via UWB
- **LiDAR SLAM** for simultaneous localization and mapping
- **Cellular RF from received signal strength** from existing cellular infrastructure
- **Optical rangefinders** which combine camera-based systems and algorithms to compute relative movement
- **Thermal imaging** tuned to specific temperature ranges for vision-based positioning in the darkness
- **IMUs** with algorithms to calculate position changes
- **Sensor fusion using Kalman filtering** or other methods to integrate data from multiple sensors

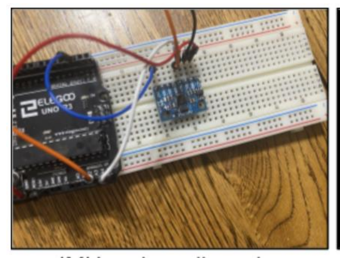
The insights gained from evaluating these technologies and localization methods guided the development of our final concept which fuses IMU data with LiDAR measurements.



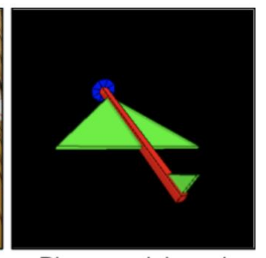
Concept Development
Picture by Capstone Team



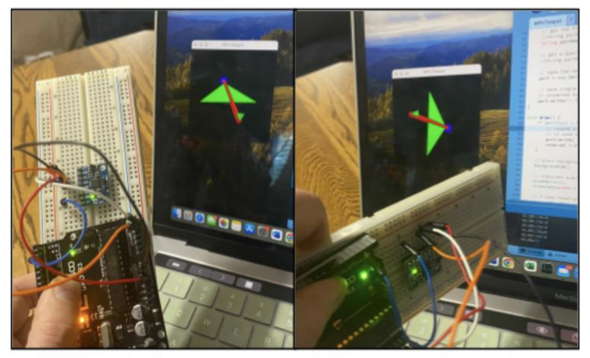
LiDAR Imaging
Picture from Wingtra



IMU on breadboard connected to UNO board



Plane model used for demonstration



IMU capturing gyroscope data to transfer to plane model

IMU Gyroscope Demonstration
Picture by Capstone Team

References

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