Project Overview

This project involved the development of the hardware and software to enable multi-environmental localization, mapping, and navigation on a Micro Aerial Vehicle (MAV). In essence, the primary goal was the creation of an MAV that can handle indoor and outdoor environments while carrying a payload.

The MAV uses a multi-sensor stack to achieve robust localization, mapping, and navigation in both indoor and outdoor environments. The main sensors used are various Inertial Measurement Units (IMUs), GPS, various cameras, ultrasonic sensors, and LIDAR. Different sensors work well in different environments and lighting conditions, so the data from all of these sensors is intelligently combined to allow for highly robust onboard SLAM. 2D localization and 3D mapping occurs in real-time. In addition, the system is tolerant of disturbances and obstacles.

With the addition of remote guidance and telemetry, the MAV is able to navigate to an arbitrary georeferenced location, then navigate inside the building to a target waypoint to deliver cargo. Alternatively, it could retrieve cargo from inside a building and deliver it elsewhere. Potential applications of this project include search and rescue, surveillance, warehouse management, package delivery, and more.

Objectives

The main objectives of this project can be broken down into several categories.

- Base Platform
  - Development of GPS-enabled MAV base platform.
  - Integration of Optical Flow hardware and software.
  - Addition of LIDAR-based SLAM and obstacle avoidance.
  - Extension of IMU odometry to use visual-inertial fusion.
  - Fusion of the four sensor methods above.
- Testing and Optimization
  - Testing of the system indoors and outdoors.
  - Optimization of navigation to use waypoint guidance.
  - Detection of current environment.
  - Switching of sensor gains in different environments.
- Optional Features
  - Addition of hardware for payload manipulation.
  - Creation of a user-friendly ground control station.

Of these, all but the last have been completed.

Constraints

This project was constrained primarily by the total cost. A generous limit of $1500 was set; however, the MAV itself had a cost of under $1000 due to various education discounts and grants. This "sticker price" could be reduced at scale.

The ability to effectively navigate an indoor environment is itself a constraint, as it limited the maximum size of the MAV. To preserve maneuverability indoors, the maximum size of the MAV was constrained to a 65 cm (26 in) cube. This was selected to provide clearance to pass through a standard 36 inch wide doorway.

With an MAV of this size, the maximum takeoff weight generally doesn't exceed 4 kg (9 lb). A conservative limit of 2.5 kg was set to improve battery life and agility once off the ground. The additional weight capacity allows for the MAV to carry a sizeable payload.

A bare minimum battery life constraint was set at of 10 minutes of airtime to provide enough time to cover long distances outdoors and navigate larger buildings.

Flight Testing

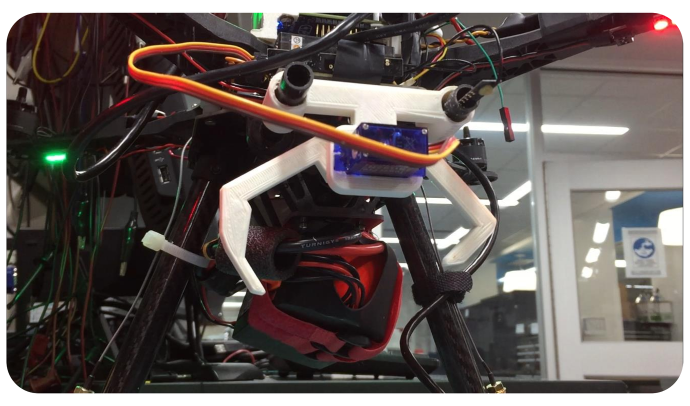
GPS and Optical Flow correction allow for the MAV to be very stable in indoor and outdoor environments. Outdoors, wind causes slight (~5cm) disturbances before the MAV detects enough movement to warrant a correction back to the desired position.

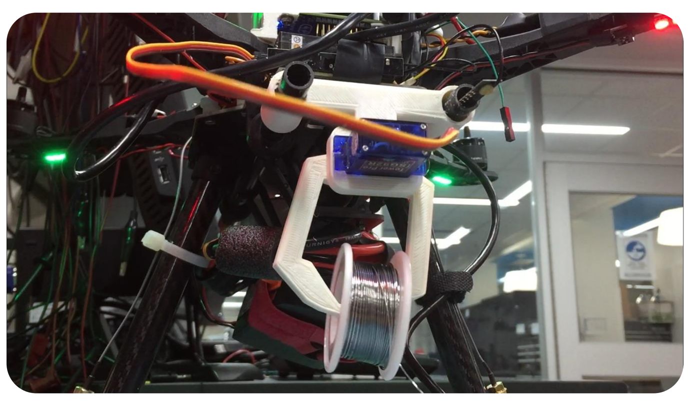
The MAV has the following flight modes. These modes are switched on-the-fly from the remote controller or through autonomous logic.

- <u>Takeoff</u> – climb to cruise altitude .
- <u>Land</u> – descend until ultrasonic sensor measures <3in of altitude (drone on ground).
- <u>Hover</u> – maintain heading and spatial location, and counteract any deviations from the originally set location and heading. GPS/OpticalFlow (outdoors) or LIDAR/OpticalFlow (indoors).
- <u>GPS Guidance</u> – Receive target GPS coordinates from Control Center. Climb to 50ft altitude and follow straight-line path to the desired location. Avoid potential obstacles with LIDAR.
- <u>Indoor Exploration</u> – Fly towards areas that have comparatively lower map density to make the map more complete. Avoid potential obstacles.
- <u>Indoor Navigation</u> – Receive target waypoints from the Control Center. Generate paths to navigate to the desired waypoints. Fly autonomously to the target waypoints while avoiding obstacles.
- <u>Manual</u> – Use remote controller input for horizontal movement as well as climb/descend and yaw (horizontal rotation). When the sticks are released and centered, maintain the current position, altitude, and heading using sensor data.
- <u>Assisted Manual</u> – Similar to Manual but ignore controller input if it would result in crashing into an obstacle detected by LIDAR or cameras.

Cargo

The MAV has the capacity to carry around 1kg (~2 lbs) of payload. To manipulate payloads, a general cargo claw was designed and 3D printed out of ABS plastic. If the MAV would repeatedly be carrying the same cargo, a more specialized claw/manipulator could be designed and mounted to handle it more effectively.





Future Study

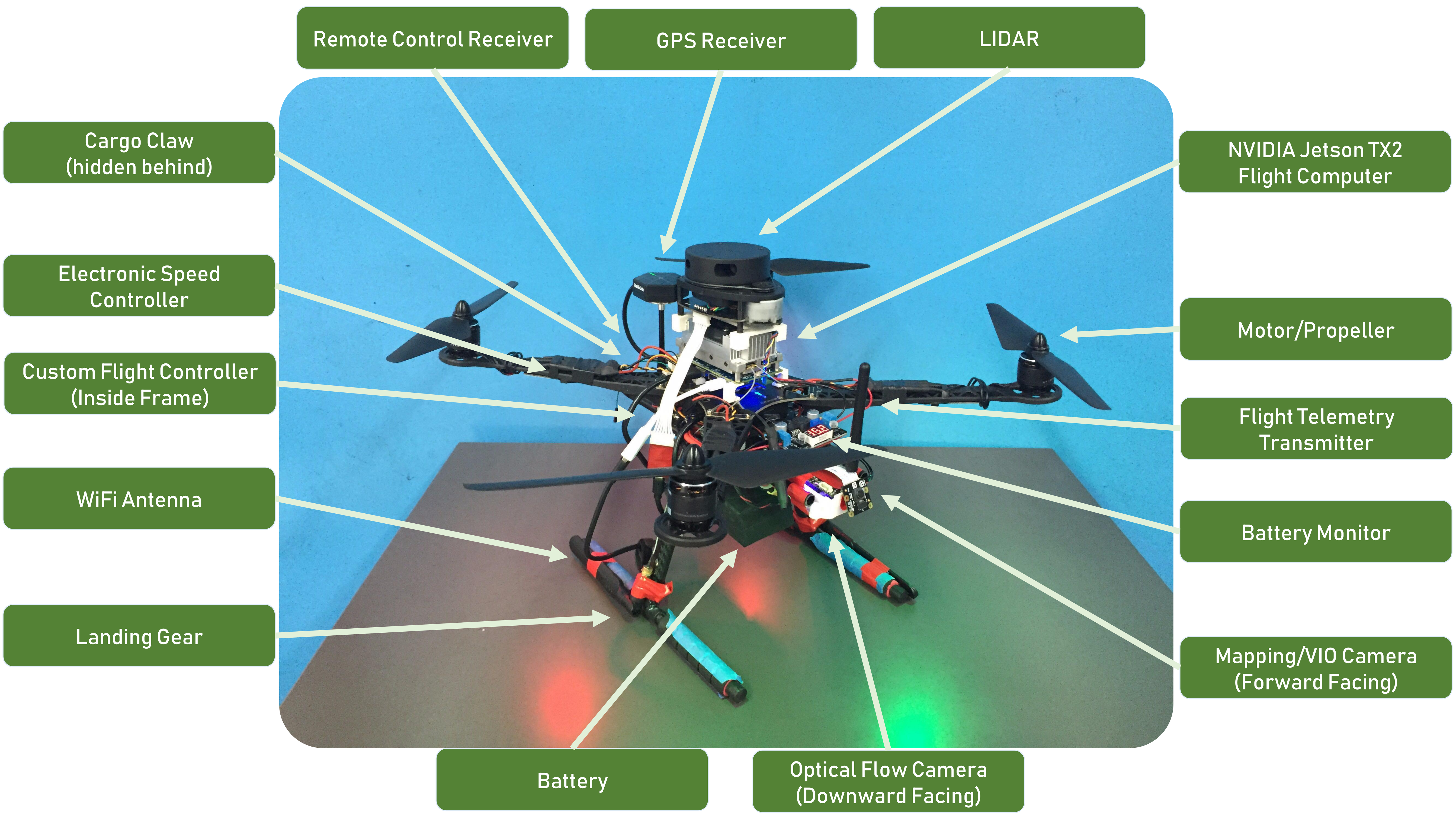
There are a few developments that would greatly increase the usability of this project in commercial applications or make it more effective in general.

The first would be to complete the final "Optional" objective - the creation of a user-friendly ground control station. Currently, the remote laptop runs several independent programs that each achieve a single goal. For development this works fine; however, it isn't an ideal solution for general use. As a result, the development of a single program that combines all of the other ones in an intuitive interface would increase usability.

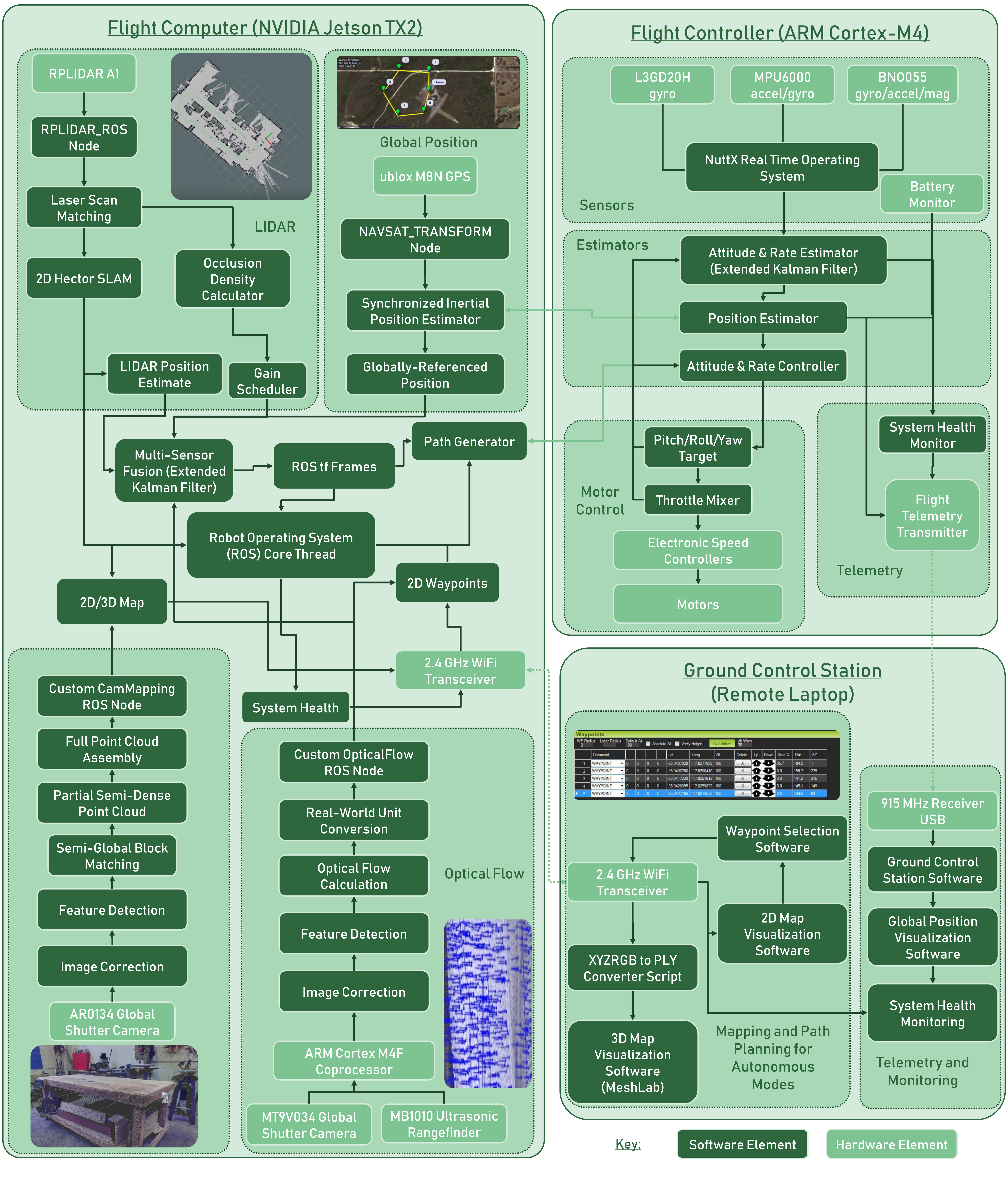
Another would be to improve the reliability of the automatic environment detection. Currently, environment switching happens primarily by analyzing the density of LIDAR data to detect the current environment (indoor or outdoor). By implementing a machine learning classifier, likely a Logistic Regression / Predictive Learning Model, data from multiple sensors could be interpreted to detect the current environment type more reliably.

System Overview

The Micro Aerial Vehicle (MAV) platform consists of the major components listed below, as well . Many of the components are commercially available products with modifications. Notable custom parts include the flight controller and battery monitor. In compliance with the design constraints, the entire UAS costs around $900 fully equipped, with around $200 in ground support hardware. It fits easily within the 26 inch cube size with approximate dimensions of 24" (L) x 24" (W) x 12" (H). In addition, the system weighs 2.05kg (4.5 lbs), and can fly for approximately 10 minutes before landing to recharge the battery. Overall, it met all of the main constraints. The top speed is approximately 12.5 m/s (28 mph) outdoors and 0.5-2 m/s (1-4 mph) indoors, depending on how dense the environment is (i.e. how many obstacles are in the way).



Software Overview



All images by Parthiv Krishna (Finalist)