Multimodal Mapping with Aerial Vehicles

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Background

Unmanned aerial vehicles are being used increasingly more in many industries, including agricultural data analysis and collection, infrastructure inspection, search and rescue, and space exploration. However, the utility of these platforms is limited by the information ground operators have in real-time, as well as limited-fidelity map information, which prevents more complex planning and autonomy.

This project seeks to improve the state-of-the art by developing a hardware and software platform that is capable of online multimodal map generation.

System Architecture

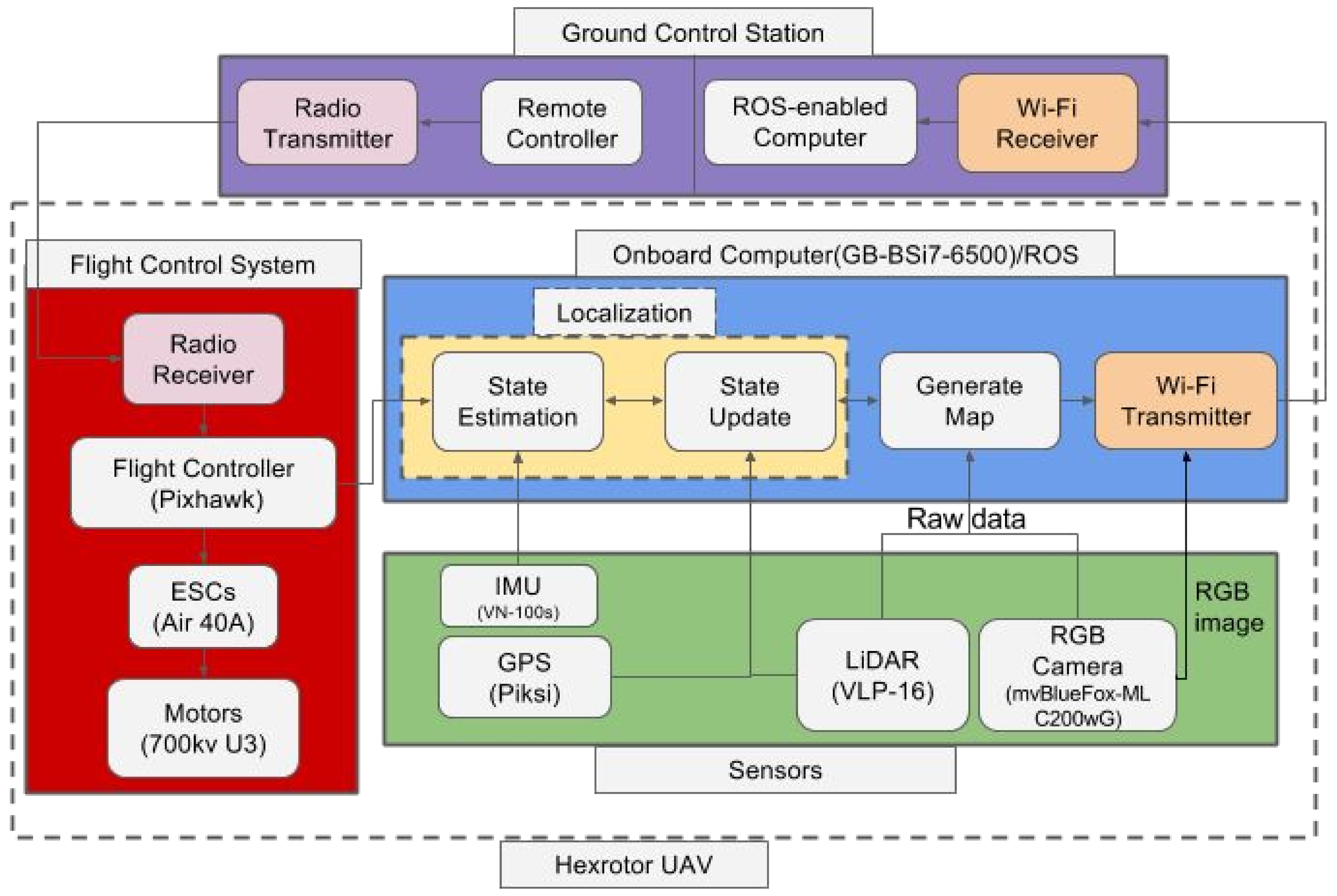

Figure 1: System architecture diagram depicting interconnected flight control, state estimation / mapping, sensing, and ground control subsystems.

Hardware Platform

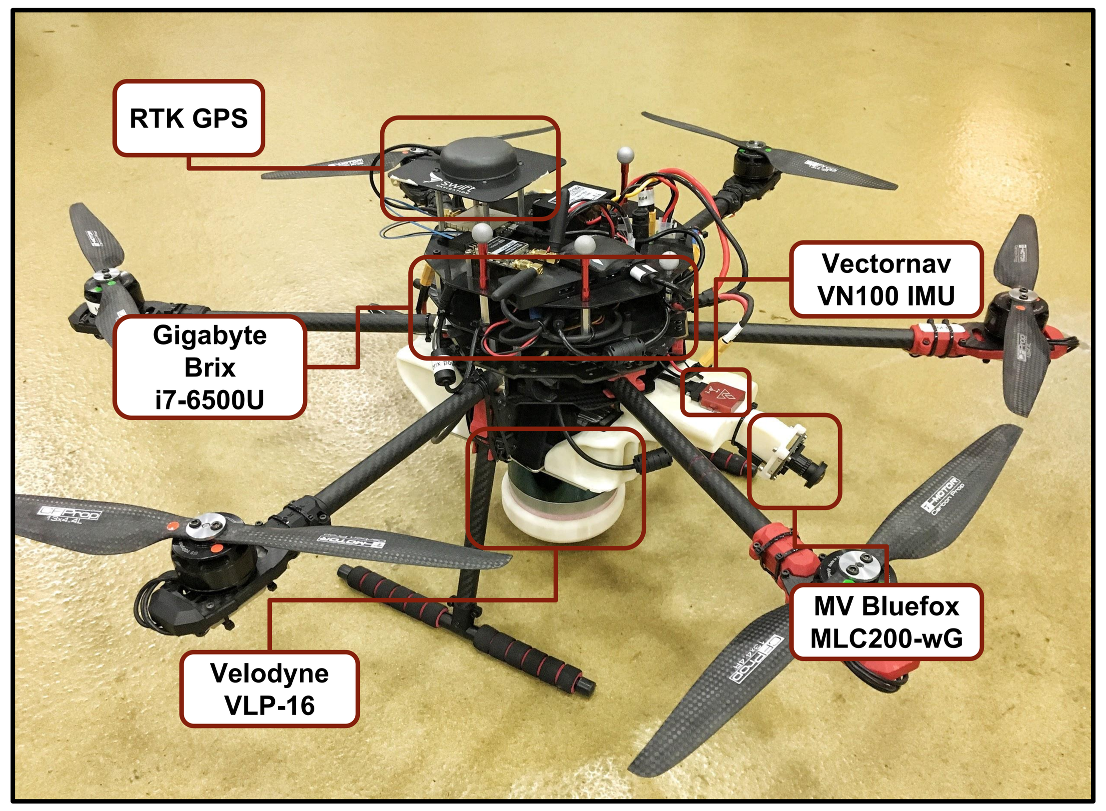

Figure 2: Velodyne LiDAR and MV Bluefox RGB camera provide imaging data, IMU provides more robust state estimation, and an RTK GPS was used for ground truth measurement

State Estimation

Our LiDAR-based SLAM state estimate algorithm is as follows:

- Calculate odometry transform via ICP with sequential laser scans.
- Calculate localized transform via ICP with laser scan to map.
- Feed IMU pre-integrated measurements and localized transform estimates into factor graph and optimize for final pose.
- Check nearby poses in factor graph and compare laser scans to detect loop closure.

This pointcloud-based state estimation was then compared to a state-of-the-art Vicon motion-capture state measurement for performance validation.

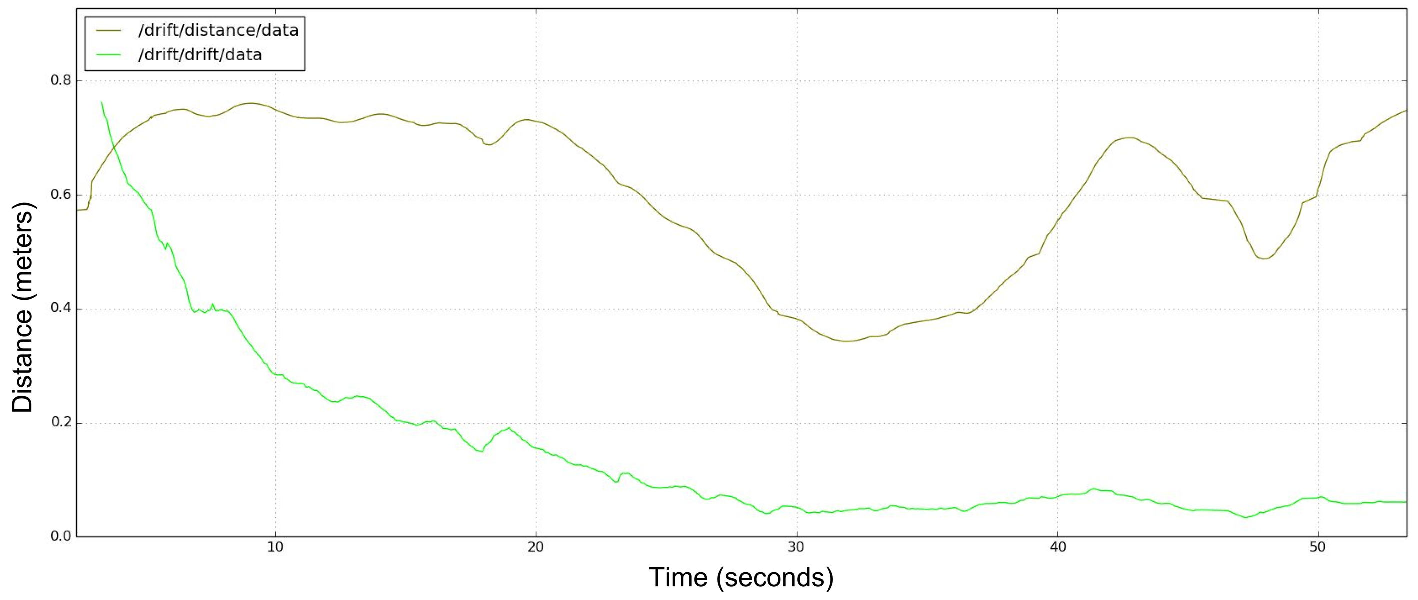

Figure 3: Drift from ground truth at the current time (brown curve) and the drift over the total distance traveled (green curve).

Mapping

Our colorized mapping subsystem operates as follows:

- Receive 3D distance information from LiDAR
- Calculate transformation, reprojection into camera frame
- Apply RGB color value in camera frame to 3D point
- Add point to occupancy grid map with color data

Other points not in the camera frame are added to a non-colorized occupancy grid map.

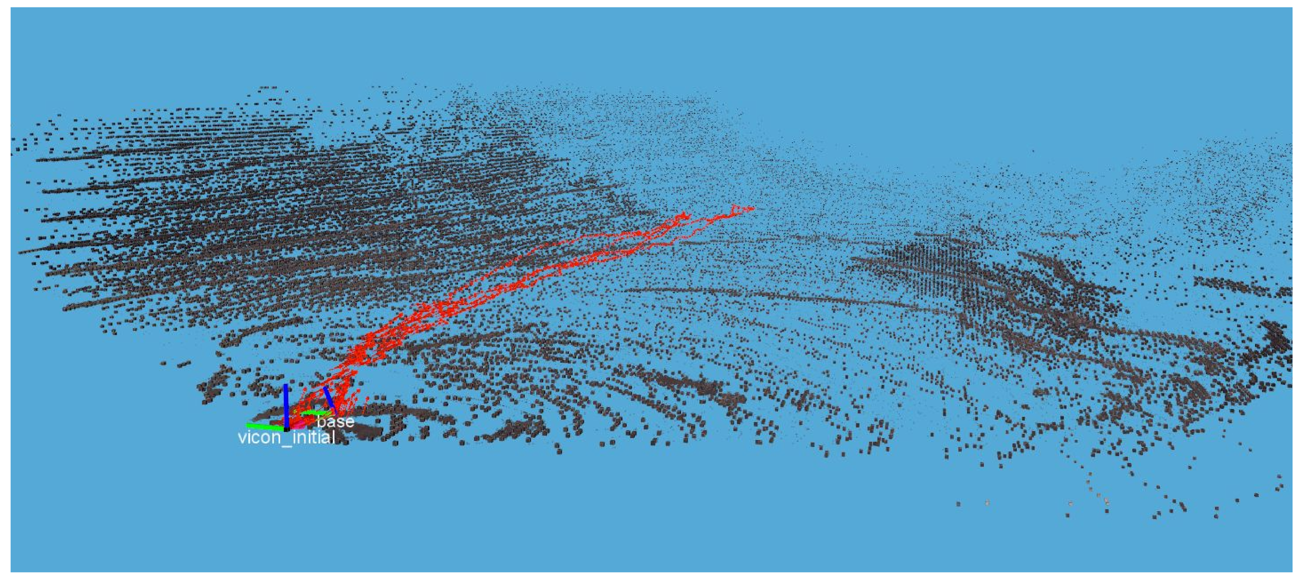

Figure 4: Colorized dense voxel grid map generated by the vehicle in real time with odometry visualization

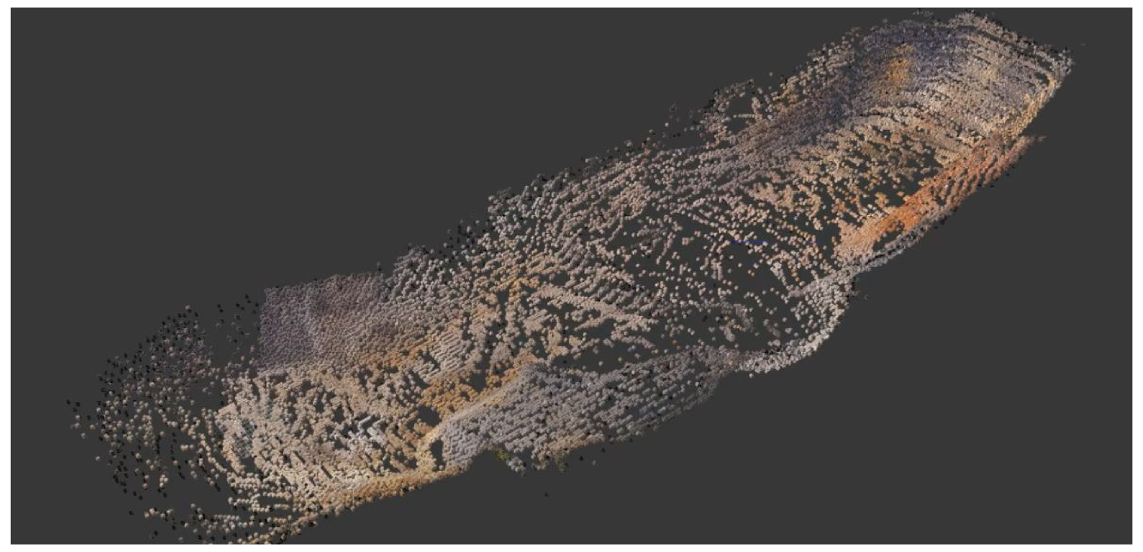

Figure 4: Reconstruction of virtual LaFarge quarry in simulation

Navigation Simulation

In order to demonstrate system performance in an expected use case scenario, a simulation environment was used. A mesh of the LaFarge Duquesne quarry was generated using photogrammetry, and imported into our environment. Simulated Velodyne and RGB camera sensors on a vehicle were used to mimic the actual sensors on the vehicle. Using a simple RRT planner, the vehicle was able to successfully navigate around simulated obstacles in the environment.

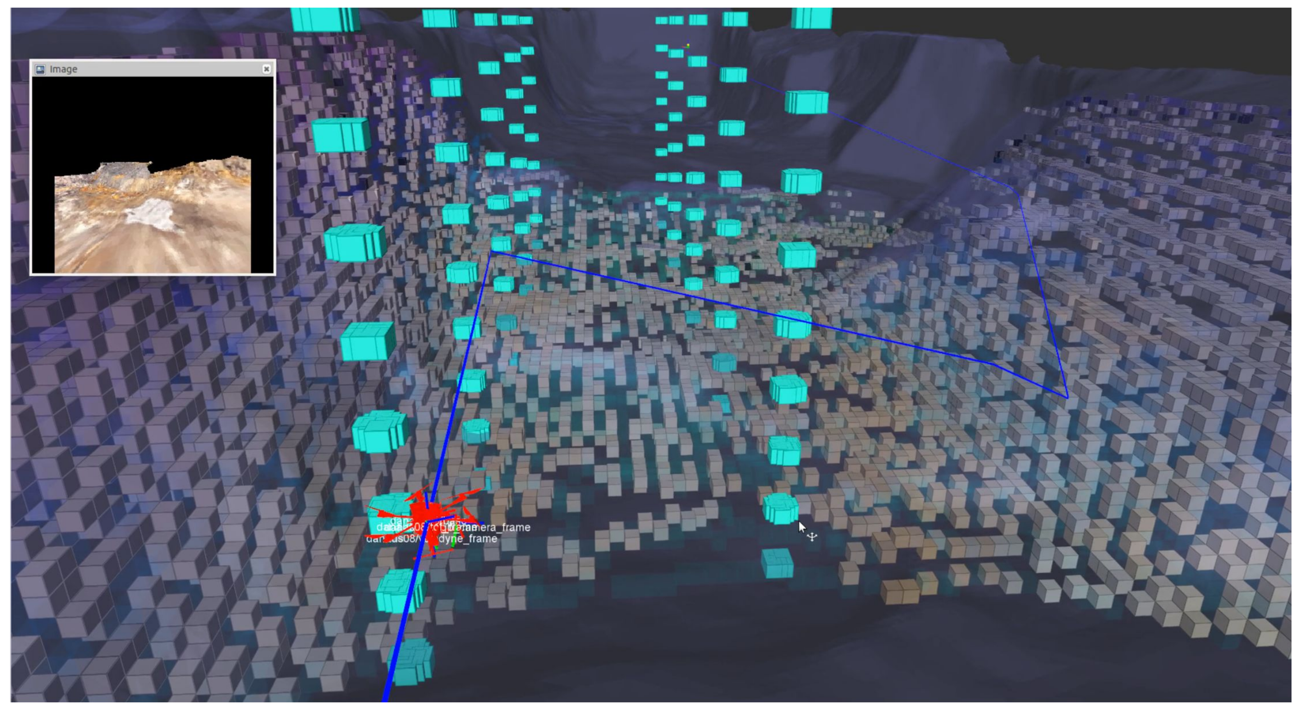

Figure 6: The simulated vehicle follows a path generated by its RRT planner. The obstacles are vertical pillars with a footprint size of 50 cm x 50 cm

Conclusion

Our results demonstrate the feasibility of online color mapping in an autonomous aerial vehicle. We are able to generate rich, multimodal maps which are extensible to multiple sensor modalities. We have also demonstrated accurate state estimation in a GPS-denied environment via LiDAR scan matching, and show how our mapping and state estimation pipelines can be extended to an autonomously exploring aerial vehicle.

Acknowledgements

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