National Aeronautics and Space Administration

Development of a Small Unmanned Aerial System for Automated Facility Inspection

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Abstract

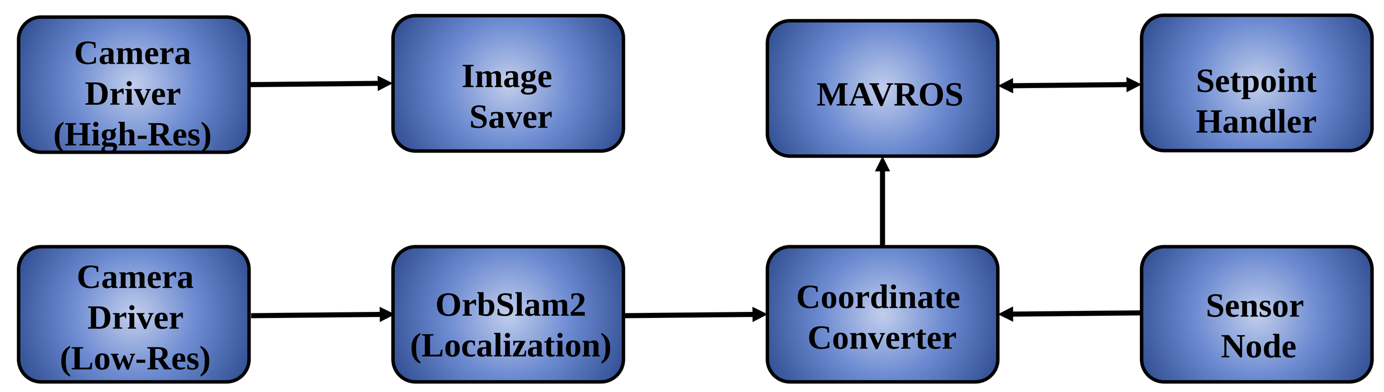
Critical NASA test facilities such as the National Full-Scale Aeronautics Center (NFAC) are large, aging, and difficult to inspect manually, requiring resources such as time, skilled personnel, scaffolding, and safety equipment. This IRAD-funded project explores the use of unmanned aerial systems for autonomously performing diagnostic imaging of the NFAC, while a separate portion uses machine learning to process images and catch defects such as loose/missing fasteners. Work completed during this project explores solutions for localizing in a dark GPS- and magnetometer-denied environment. Firstly, we have a software architecture using ROS, px4, and the ORB-SLAM2 algorithm to localize-and-map using visual techniques to provide positional feedback. Secondly, a hardware platform (drone and payload) has been developed, integrating cameras, lights, Pixhawk flight controller, and processing power into a lightweight system. Deliverables include demonstration of the system in NASA facilities and a sample dataset for processing. The project is also the basis for a Master's project emphasizing robotics and control; educational outcomes, therefore, include exploration and implementation of navigation, attitude estimation, localization, and control schemes in challenging environments.

Objective & Solution

The NFAC (below) presents an enormous warehouse-like environment, with wall sections reaching roughly 10 stories tall. The ultimate goal is to fly a UAV (i.e., a drone) equipped with onboard lighting and high-resolution camera to capture diagnostic images at evenly spaced grid points along these walls at a distance of 1 meter. These images are post-processed via deep learning in a separate leg of the project, explored by Nick Califano. This type of indoor flying requires control systems to localize without the use of GPS or magnetometer; one such solution is Simultaneous Localization and Mapping (SLAM) which can be realized, among other methods, using computer-vision techniques and a small onboard computer. Combining SLAM with an off-the-shelf flight controller forms a powerful and viable solution for these objectives.

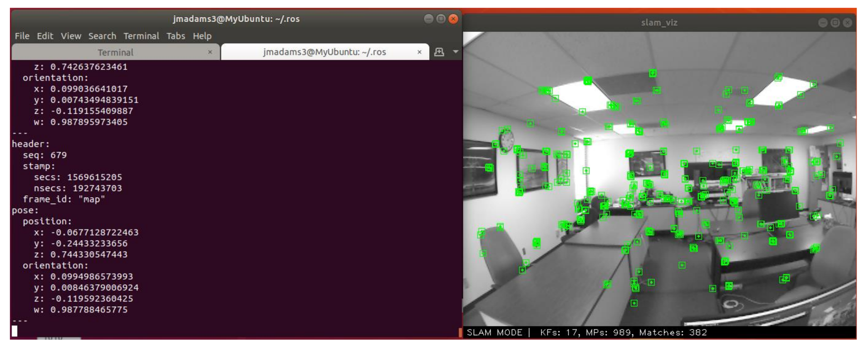
https://www.nasa.gov/centers/ames/images/content/109854main_AC84-0712-15.1.jpg

Software Architecture



Robot Operating System (ROS) is a message-based layer which allows interconnected drivers and other executable nodes to communicate in a highly modular fashion. ROS was used for the software running on the onboard PC (Intel NUC) with primary node information flow connected as above, and functioning as follows:

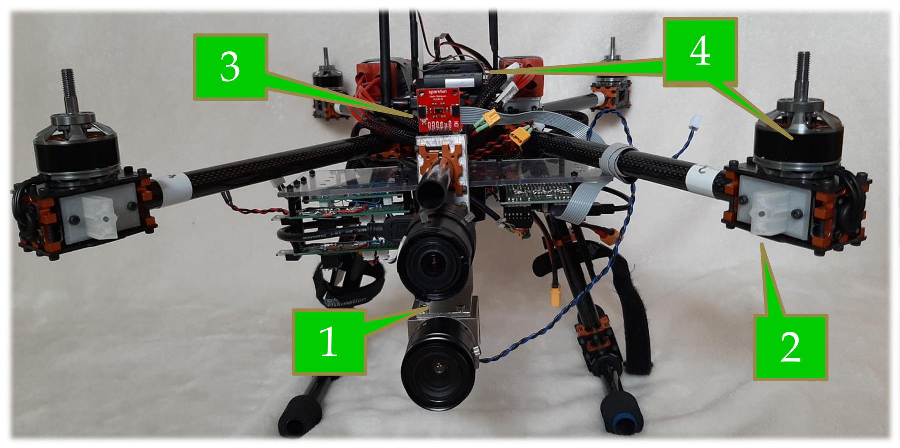
- **Camera drivers**: command cameras to take, save, and pass along images
- **Orb Slam 2**: performs monocular vision-based SLAM to provide position and attitude data, although scaled to arbitrary units and reference frame (example screenshot below)
- **Coordinate converter**: rotates and scales SLAM data into real-world axes using inertial and range sensor data, resulting in gravity-down readings given in meters
- **Setpoint Handler:** monitors position, snaps photos at gridpoints, and streams setpoints
- **MAVROS**: communicates with flight controller to exchange location data and setpoint commands with onboard computer



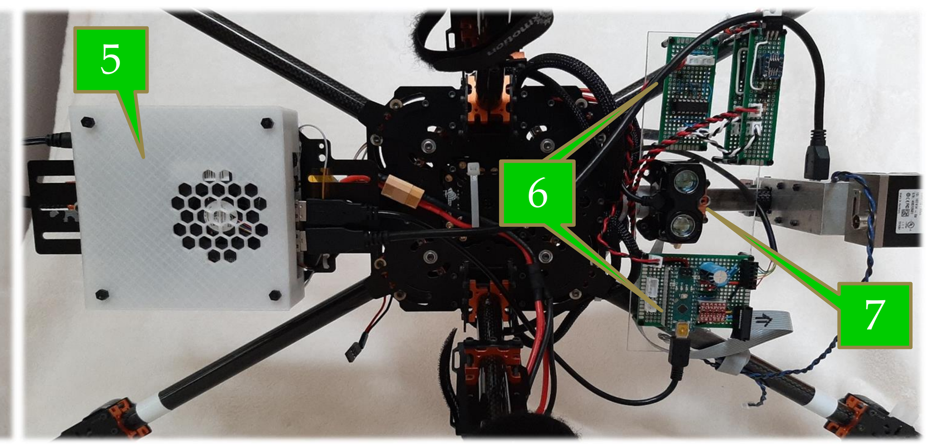
Left: Example OrbSlam 2 functionality localizing in office environment utilizing feature detection from the low-res camera stream, and outputting 6-dof pose data into the ROS ecosystem. [self-taken image]

The modular nature of ROS allows any localization option to be 'dropped in' without affecting any other node .

Hardware/Payload Architecture



Front View [Self Taken]

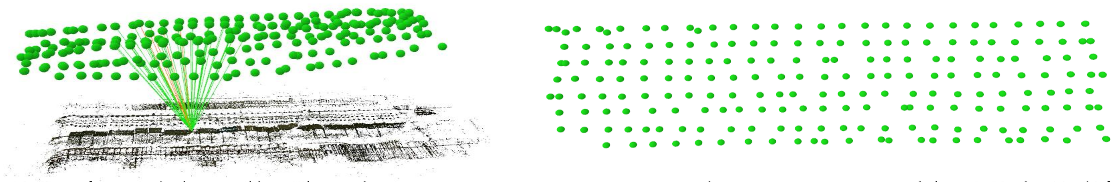


Underbelly View [Self Taken]

① 1MP localization and 12MP data collection cameras
② Mount points for articulated LED array providing onboard lighting (LEDs not pictured)
③ Forward-facing range sensor allows adjustments for constant distance to wall
④ Flight controller, ESCs, BLDC motors, radio links, etc (standard drone platform hardware)
⑤ Onboard computer in lightweight 3D-printed case (Intel NUC)
⑥ Driver circuitry for LEDs and ranging sensors. LEDs triggered directly by camera GPIO
⑦ Downward-facing range sensor used for measurement scaling and height data (optionally)

Results

- A payload prototype was developed, affectionately dubbed the "Drone on a Stick," which integrated the full hardware system into a handheld package. The prototype allowed testing and integration of the software system
- Cart-mounted testing successfully demonstrated the ability to localize in real-world coordinates using only the camera and ranging sensors. Work in the NFAC culminated in the collection of a new dataset for use with the deep learning portion
- The prototype was converted and optimized for integration onto a UAV platform as pictured under Hardware Architecture. Early flight testing is underway (protocol development, weight optimization, controller tuning, etc)



Data from lab wall, taken by cart-mount system and post-processed by Nick Califano via photogrammetry software. Demonstrates 3D camera poses and grid locations

Conclusion & Next Steps

This project served as a strong foundation and the culmination of my graduate career as a student of robotics and control. It explored a full range of topics relevant to the implementation of an autonomous system while helping to demonstrate the viability of UAVs for indoor inspection: ROS, OpenCV, controls, attitude estimation, and more. Furthermore, I learned a myriad of professional engineering skills including industry best practices, effective troubleshooting, navigating bureaucracy, and professional communication.

Future work for this project includes:

- Continuation of flight testing, including setpoint streaming and indoor missions following controller tuning
- Fine-tuning of the orb-slam conversion algorithms or exploring other localization solutions, as well as improving position filtering within px4
- Flight missions within the NFAC (long-term goal)

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