Autonomous Mapping of Factory Floors Using a Quadrotor MAV

William Vega-Brown, Jonathan Kelly, Abraham Bachrach, Adam Bry, Samuel Prentice, and Nicholas Roy

***Abstract*—We are developing a quadrotor-based system for autonomous mapping of factory floors. Information from a monocular camera, a laser rangefinder, and an IMU on-board the vehicle is fused to generate a 3D point cloud and a 2D image mosaic. These data products can then be used by the factory operators for logistics planning, equipment management, and related tasks.**

I. Introduction

Small quadrotor helicopters are particularly flexible and versatile micro air vehicle (MAV) platforms; their ability to move freely in 3D space and to hover makes them ideal for use in many environment-sensing applications. In this extended abstract, we consider the problem of autonomously mapping a factory floor using a quadrotor. Information for multiple sensors on-board the vehicle is fused to produce a detailed 3D point cloud and/or a 2D image mosaic. These data products can be used by the factory operators for various tasks, such as logistics planning and equipment management.

II. Motivation and Approach

Modern factories are large, dynamic and potentially hazardous environments. It can be very difficult to obtain a synoptic view of activity on the factory floor; while useful, ground robots typically are not able to provide the same coverage as an aerial platform. Environmental obstacles, such as wiring and supports, as well as cranes and other service equipment, preclude making the (common) assumption that the world is 2.5D and increase the complexity of the navigation problem. This motivates our work on developing a robust and efficient quadrotor system for perception and data acquisition in the factory domain.

Although quadrotors are stable and maneuverable, the versatility comes at a price: a quadrotor has limited payload capacity, as well as strong constraints on available battery power and, in turn, flight time. This means that a full sensor suite cannot be carried, necessitating careful design to maximize the observable range and capabilities while minimizing weight and power consumption. Furthermore, on-board computational resources are limited, and thus efficient planning algorithms are required to process available data and to enable safe movement through the cluttered environment.

Our experimental platform is a Pelican quadrotor, designed by Ascending Technologies. Able to carry roughly 500 g of payload, the Pelican has a tightly integrated control loop that runs at 1 kHz to stabilize the roll and pitch of the vehicle. Higher level modules then interface with this the lower-level control system. The vehicle carries a 2 GHz Intel Atom computer with 802.11n wireless network capability.

The authors are with the Robust Robotics Group, Computer Science and Artificial Intelligence Laboratory, Massachusetts Institute of Technology.

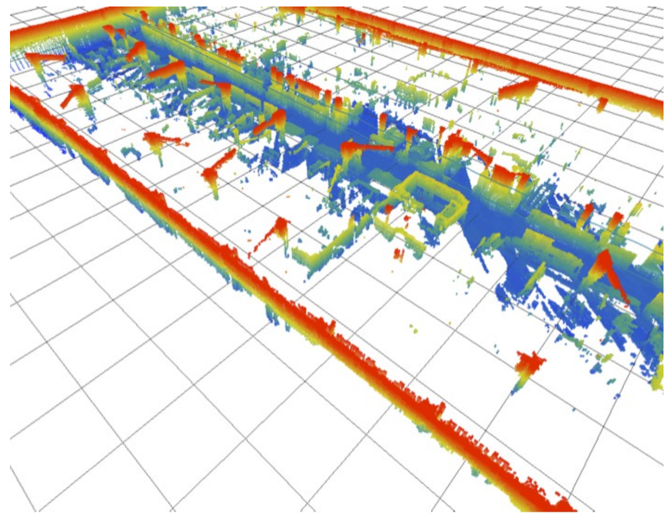

Fig. 1. Laser point cloud generated from scan data acquired by our quadrotor helicopter in a factory. The quadrotor carried two laser rangefinders in this case: one Hokuyo URG-30LX mounted horizontally and used for scan matching, and one Hokuyo URG-30LX mounted vertically to capture 'slices' of the environment.

For the factory mapping task, we add an additional Hokuyo URG-30LX laser rangefinder, a MicroStrain 3DM-GX3-25 IMU, and a μEye camera with a wide-angle lens. Several beams from the Hokuyo are redirected downwards by a small mirror to estimate the height of the vehicle above the ground surface. A more detailed description of the hardware and several of the sensing algorithms can be found in [1].

Our software suite is built using a component architecture, where each component runs as an independent process. Processes communicate with one another using the LCM communications middleware, which relies on the UDP broadcast protocol to maintain low latency [2]. The system is centered around an extended Kalman filter driven by the MicroStrain IMU; other software modules preprocess raw sensor data prior to filtering. These modules include a laser scan matcher, which computes position and yaw displacements from planar LIDAR data, as well as an image registration module that generates optical flow information continuously from an image stream. Additional modules use the EKF state estimate for navigation, control, and obstacle avoidance. The system is designed to be operated either entirely autonomously, or in a mixed mode where an (untrained) human operator is able to control motion using a simplified point-and-click interface. The on-board software ensures that the vehicle maintains stability and avoids collisions.

One of the chief problems is that, in the factory environment, we cannot make the assumption that the ground is planar. Clutter on the floor will typically cause significant jumps in the measured height of the vehicle when it flies over obstacles. We handle this primarily by leveraging optical flow and IMU measurements to reject spurious jumps. We employ a similar strategy to deal with another failure mode of the laser scan matcher: the presence of an overhang or ledge can cause the scan matcher to report a large horizontal displacement due to a small change in height or orientation. The scan matcher alone cannot discern whether the environment has changed or the quadrotor has moved. We rely on optic flow and inertial measurements to disambiguate these two situations.

Our optic flow algorithm employs the Fourier-Mellin transform to estimate the relative translation, rotation, and scale change from image frame to image frame [3]. These measured values are compared with predictions computed using the current state estimate, inside the Kalman filter. The failure modes of the optic flow algorithm tend to be different from those of the scan matcher, increasing the overall robustness of the system.

The Pelican has sufficient payload capacity to carry an additional high-resolution camera. This camera can be used to collect detailed images, which can then be stitched together to form a mosaic of the entire factory floor. Other sensor configurations are also possible, for example using multiple Hokuyo laser scanners or structured light scanners such as the Microsoft Kinect.

III. Experiments and Ongoing Work

To date, we have flown in one factory owned by Siemens Corporation and located in Sacramento, California (see Figure 1). Our early test flights indicated that there were instabilities in the height estimates generated by the laser, prompting us to explore optical flow and tighter IMU integration to counteract these instabilities. Recent tests of the modifications on the MIT campus have shown promise in mitigating laser failures; we expect to test in another factory in the near future.

Our current work focuses on three areas. First, we aim to enhance our sensing capabilities without a significant increase in weight by extending the visual navigation system with a forward-facing camera. Second, we plan to improve our state estimator by exploring probabilistic methods to learn mappings between measurement covariance and environment features (e.g., the brightness or contrast of an image, or the number of individual laser beams included in a matched scan). Third, we are currently building an updated controller which will permit more aggressive maneuvering and intelligent path planning. These changes should further simplify the operator task.

References

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