Aerial Point-Cloud Generation using the Microsoft Kinect on an Autonomous Quadrotor

Project Members: Jeff Cooper, Jitu Das, Priya Deo, Daniel Jacobs,
Mike Ornstein, Harrison Rose, Alex Zirbel.
Advisor: Sanjiv Singh

Abstract:

A robot is most useful when it not only understands and responds to its environment, but is able to convey its information to a human operator in a useful way. This research aims to tackle the simultaneous goals of navigation in a tightly constrained indoor area and the transfer of useful information in a format designed for human use. The quadrotor aerial platform provides an attractive solution to the navigation problem: being extremely maneuverable, powerful enough to carry high-performance sensing equipment, and compact enough to fit through small gaps such as a broken window, a quadrotor can gather data about a location before humans or other robots enter it. Microsoft's Kinect sensor provides both color and depth data at an extremely low cost, which the robot can gather and transfer to an off-board unit for processing. Once this data is available, point-clouds can be used to display each reading and corresponding color in a 3D map which a human operator could visually understand. The combination of autonomous exploration, 3D data collection, and useful display is the principal goal which this project will attempt to achieve.

Research Question and Significance:

Indoor aerial navigation is a challenge in robotics: space is limited and many obstacles could interfere with a robot accomplishing its goals. Nevertheless, a robot capable of investigating an indoor environment has numerous applications. Examples include search of dangerous environments, such as collapsed or contaminated buildings in the aftermath of natural disasters; exploration of structures difficult to enter, such as a high floor entered through an open window; and military operations where an aerial vehicle can enter and exit the surrounding area without detection.

Two critical elements are requirements for these goals: the aerial robot must be small and maneuverable, and must be able to relay data back in a format that is useful to humans. For this application, our team chose to use a quadrotor helicopter for its speed and flexibility. The second element of our research question is to collect and process the data provided by the onboard sensors in a useful way. Raw depth data, as captured directly from the sensor, might be useful for assisting other robots, but humans like to see a three-dimensional map of an area, including color, to get an intuitive sense of what the robot has seen.

We hope to collect and display data in a format geared toward humans by combining depth readings with a color image. By projecting each pair of color and depth readings into a global coordinate frame, we can display a cloud of points so that a viewer can explore the robot's generated map in 3D. To accomplish this we will use Microsoft's XBOX Kinect sensor, which provides both color and depth images at an extremely cheap price compared to other commercial sensors with comparable output.

Previous research includes the Carnegie Mellon Robotics Institute's work on autonomous quadrotors, the University of Pennsylvania's demonstrated aerial maneuvers, MIT's work towards autonomous aerial vehicles, and our own previous research on autonomous quadrotors in unstructured environments. Our new goals extend this prior work into a new area. The Robotics Institute's quadrotor robustly avoids obstacles while tracking moving objects, which we would like to emulate with a cheaper model and set of sensors. The University of Pennsylvania relied heavily on offboard processing and high-speed cameras, which we would like to replace with an on-board perception package. The MIT group has proven quadrotors to be an effective platform for autonomous indoor flight and we would like to achieve similar results with a more economical solution. This work complements our previous SURG grant, in which we demonstrated autonomous exploration using an autonomous quadrotor in an unstructured environment, usually outdoors. With this research we will use our same platform and algorithms, but introduce structure to the environment and add more human usable feedback.

Autonomous aerial mapping continues to be a hotbed of activity in robotics research, given the range of applications in unreachable and unsafe environments combined with the flexibility of an aerial platform. For example, the International Aerial Robotics Competition has offered $20,000 to the winner of a competition based on indoor navigation and exploration, and a reliable robot that can navigate itself indoors and in tight spaces would open the doors to higher-level concepts like group exploration or searching for objects in a large indoor space. The Quadrotor Project hopes to contribute to this field by developing a reliable platform to navigate indoor spaces and produce useful 3D maps.

Project Design and Feasibility:

The Quadrotor Project will combine existing proven aerial platforms in this next design for indoor flight. Previous research and algorithms for autonomous flying will be combined with the community-driven MikroKopter aerial platform. Since the MikroKopter is relatively simple to construct, the bulk of mechanical design work will comprise installation of the new Microsoft Kinect sensor and its corresponding processor, after construction of the MikroKopter.

The MikroKopter, like the previous AeroQuad-based design, provides a number of libraries for autonomous flight, stabilization, and some waypoint navigation. Our challenge will be to use this foundation to keep track of the robot's position at all times and generate accurate point-clouds using the Kinect sensor - an innovative use of the MikroKopter's groundwork. To accomplish these goals, the Quadrotor team will use the collective resources of the Robotics Club as well as collaboration with the Robotics Institute's Micro Air Vehicle Group.

The Quadrotor team itself is a dedicated, small team of students with a heavy background of robotics projects. Weekly status meetings keep the project moving in a timely and organized manner.

Background:

Our team comes from a background heavy in robotics research and includes majors in Computer Science, Electrical and Computer Engineering, and Mechanical Engineering. Most of our members work on other Robotics Club projects HyLo, Colony, and RobOrchestra. Three members of our team also built a robot which competed in the 2010 Mobot competition. Relevant coursework includes classes such as Robotic Manipulation (16-384), Mobile Robot Programming Lab (16-362), and Introduction to Feedback Control Systems (16-299), which provide experience in control systems, navigation, and planning. Four of our members have research experience with the Robotics Institute working in the humanoids, snake, and manipulation labs. Finally, our project team includes a certified pilot who is able to apply standard flight protocol to our autonomous platform.

Feedback and Evaluation:

The majority of feedback will come from our advisor, Sanjiv Singh, and from our collaboration with Benjamin Grocholsky and the Quadrotor projects in the Robotics Institute. During weekly meetings, the Quadrotor project evaluates itself compared to the proposed timeline and sets goals for the following week. The group has hashed out an initial timeline indicating the deadlines for key tasks.

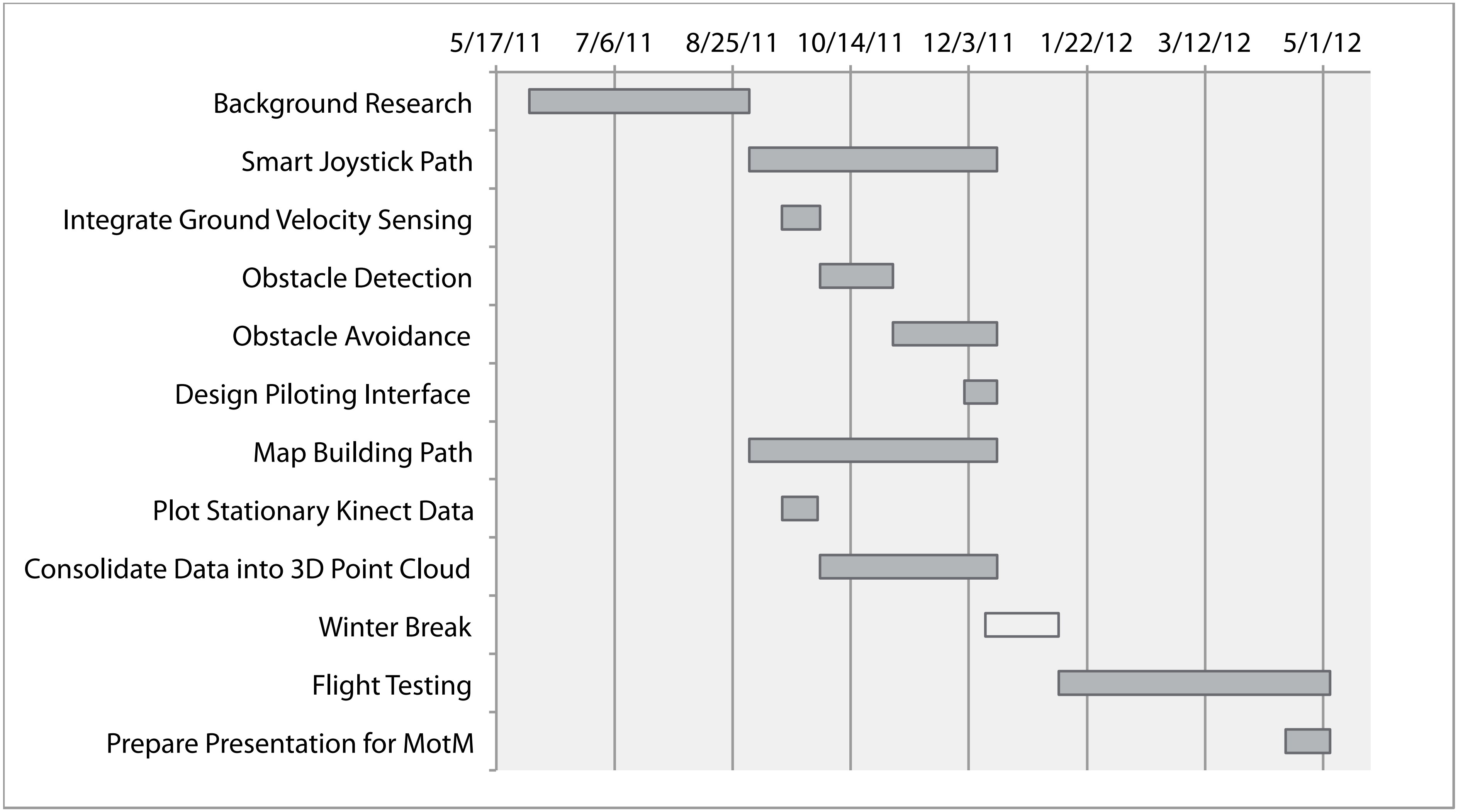
Other sources of evaluation include comparison to existing projects such as AeroQuad and the University of Pennsylvania's quadrotor research. Visiting motion capture labs will also be helpful in accurately testing the Quadrotor project.

Dissemination of Knowledge:

As we develop our project, the Quadrotor project will share its results and code base with the MikroKopter forums as well as with other open-source aerial robotics projects such as AeroQuad. Online documentation will facilitate replication of design and tests. The Meeting of the Minds provides an opportunity to present the final state of our work the the Carnegie Mellon community. The final presentation will include an oral presentation and a video or, space permitting, demonstration of our quadrotor in action.

Item	Description	Source	Cost
Kinect Sensor	Microsoft XBOX Kinect Sensor	http://www.amazon.com/Kinect-Sensor-Adventures-Xbox-360/dp/B002BSA298/ref=sr_1_1?ie=UTF8&qid=1300860236&sr=8-1	$139.98
Sensor Fixture	Parts to attach Kinect	http://www.mcmaster.com/	$45.96
PICO821LGA-530	Pico-ITX w/ Intel Atom Z530 1.6GHz	http://www.orbitmicro.com/global/pico821lga-530-p-13395.html	$533.25
KVR533D2S4/2G	Kingston 2GB DDR2 RAM	http://www.orbitmicro.com/global/kvr533d2s4-2g-p-6918.html	$41.20
DC1M-08GD31C2D-B	InnoDisk iCF4000 8GB CF Card	http://www.orbitmicro.com/global/dc1m-08gd31c2d-b-p-12966.html	$130.61
ArduEye Rox1 Shield	Centeye Optical Flow Sensor	http://centeye.com/products/purchas/	$109.00
		Total:	$1,000.00

Timeline:



5/17/11
7/6/11
8/25/11
10/14/11
12/3/11
1/22/12
3/12/12
5/1/12
Background Research
Smart Joystick Path
Integrate Ground Velocity Sensing
Obstacle Detection
Obstacle Avoidance
Design Piloting Interface
Map Building Path
Plot Stationary Kinect Data
Consolidate Data into 3D Point Cloud
Winter Break
Flight Testing
Prepare Presentation for MotM