Exploration and Mapping of Unstructured Environments using an Autonomous Quadrotor

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Abstract:

Robots are an increasingly common sight in all areas of daily life, and are increasingly useful to humans. As their capabilities expand, they are able to move from strictly controlled environments into an uncharted and potentially dangerous world, where they can accomplish tasks humans would rather avoid. Exploration of hazardous locations like collapsed buildings, mines, and other disaster areas is left largely to humans because few modern robots have the capabilities to reliably replace human explorers. The quadrotor aerial platform provides an attractive solution to this 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. Once this data is available and the terrain is mapped, robots and humans entering the environment can explore and travel much more efficiently. Applications for this information range from urban navigation to search and rescue maps that can help quickly develop paths to areas of interest. This research team aims to tackle the problem of exploring and mapping unstructured environments using an autonomous quadrotor.

Research Question and Significance:

Robot platforms capable of autonomous navigation are useful in a number of applications, including exploration of inaccessible environments and aerial-ground cooperation, in which a versatile scouting robot might relay position and direction information to a larger or less-mobile robot, or to a human crew. Applications for such a robot include search-and-rescue operations, military operations where use of GPS and land navigation is impossible, and safety evaluations of dangerous environments and disaster zones.

The Quadrotor project seeks to solve this problem by developing a robotic aerial platform capable of autonomously mapping environments with or without GPS, and navigating either autonomously or semi-autonomously. An aerial platform was chosen because it can access places where ground based robots simply could not reach. Quadrotors themselves are versatile, capable of hovering, fast, and scalable to multiple robots.

Previous research has attempted to solve these problems. The Carnegie Mellon Robotics Institute developed a completely autonomous helicopter that automatically searches for, locks onto, and follows a target. Using cameras and range sensors, this helicopter avoids obstacles in its path and can transmit images back to a ground station. The Quadrotor project seeks to accomplish these goals more cheaply and robustly using a quadrotor platform rather than a helicopter.

The University of Pennsylvania developed a control system for quadrotors capable of navigating them through small gaps, landing in inverted positions, and even lifting objects, but used high-speed off-board cameras, limiting them to use in a controlled environment. The open-source AeroQuad project develops the mechanical model for a quadrotor and provides a code base for remote-controlled flight, which we will expand by making our quadrotor autonomous.

As steps to reach full autonomous control, the Quadrotor Project plans to implement three types of control: remote control, a semi-autonomous control system, and a fully autonomous system. Remote control can be implemented from the ground in a third-person perspective, or from streaming video from the quadrotor to obtain a pilot's seat view. Adding obstacle detection and avoidance, as well as stabilization routines, transforms remote control into semi-autonomous navigation. Fully autonomous mode will also be implemented with and without GPS, in accordance with our goal of mapping GPS-denied environments.

Terrain mapping is one of the most actively researched areas in autonomous robotics. Robotic exploration of hazardous locations is incredibly useful - in military missions and disaster relief, for example. Using GPS maps, optical flow sensing, and computer vision, the Quadrotor project can be used to map terrain that would be difficult to explore otherwise.

Once terrain mapping and autonomous navigation is established, the quadrotor is also able to perform another suite of real-world tasks. Our team hopes to continue the project with aerial photography and videography - for example, the quadrotor could hover over a Carnegie Mellon sports game and broadcast video from inaccessible angles, or photograph a buggy race from the air.

Project Design and Feasibility:

The Quadrotor project uses a proven aerial platform (our custom working prototype) and pre-existing sample code base (derived from the open-source AeroQuad project, which is developing a stable robot for remote control flying) as starting points from which to research new methods and applications of autonomous navigation.

As previously mentioned, this research team has already developed a mechanically functional flying prototype. Though some mechanical work remains, the majority of our time will be spent addressing issues of autonomous control as commanded from an off-board vision processor and motion planner as well as integrating critical sensors to the flying platform. The real challenge will be implementing motion planning and autonomous mapping in the processing side of development.

This research will employ the equipment and collective knowledge of the Robotics Club and will be driven by the interest and motivation of its members. Additionally, group members have been in contact with the Micro Air Vehicle group (Robotics Institute).

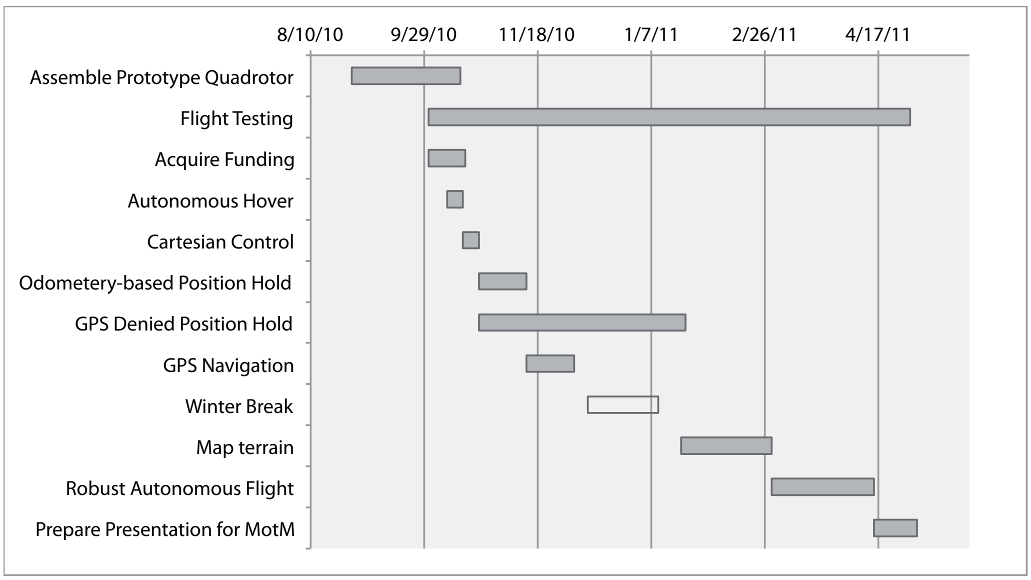
Our research team meets most days, and has developed the precedent of dedicating approximately 100 man-hours per week in the prototyping, testing, and configuration stage through weekly checkpoint meetings and afternoon work meetings which have kept the project moving forward in a timely and well-organized manner.

Background:

Our team comes from a background heavy in robotics research and includes majors in Computer Science, Electrical and Computer Engineering, Mechanical Engineering and Chemical 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. Two of our members have research experience with the Robotics Institute working in the humanoids 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 the Micro Air Vehicle Group 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. Finally, our team plans to compete in the 2011 International Aerial Robotics Competition, which will force us to create more ambitious goals and show how our progress compares with other research groups'.

Dissemination of Knowledge:

As we develop our project, the Quadrotor project will share its results and code base with the open-source AeroQuad research. 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, and competition in the 2011 International Aerial Robotics Competition will show the Quadrotor project's work to the larger research community. The final presentation will include an oral presentation and a video or, space permitting, demonstration of our quadrotor in action.

Budget:

See attached budget sheet.

Item	Vendor	Part Number	Cost	Purpose/Description
Arduino Mega	SparkFun	DEV-09152	$55.00	Onboard microcontroller; attitude and sensor processing
AeroQuad Shield	Carancho	v2.0	$32.95	Interfaces accel, gyro, mag, barom with Arduino
3 Axis Accelerometer	SparkFun	SEN-09723	$32.95	Gives acceleration feedback along x,y and z axis
3 Axis Gyroscope	SparkFun	SEN-09801	$54.95	Gives angular velocity feedback along x,y and z axis
3 Axis Magnetometer	SparkFun	SEN-09371	$54.95	Compass module
Barometer	SparkFun	SEN-09694	$21.95	Provides altitude feedback
GPS	SparkFun	GPS-09436	$98.95	Global reference and localization
Optical Flow Sensors	DigiKey	ADNS-3060-ND	$8.80	Provide velocity feedback based on computer vision
Optical Flow Sensor Boards	BatchPCB	N/A	$33.00	Breakout board to hold optical flow sensors and lenses
Optical Flow Sensor Lenses	optics-online	DSL851A	$41.80	Allows different focal lengths for each optical flow sensor
Lense Mounts	optics-online	CMT801	$26.40	Mounts lense for optical flow sensor to PCB
50mW Green Laser	Amazon	B003AY6MHS	$30.79	Generates lines for vision tracking
CCD Camera	RangeVideo	DX201	$165.00	Onboard camera for flight capturing and live feedback
Video Telemetry Hardware	RangeVideo	AVS-900-500-12V	$231.00	Transmits video from air to ground for vision processing
Pan Tilt Camera Mount	RobotShop	RB-Lyn-74	$39.59	Enables wide field of view and scanning capabilities
Wireless Telemetry Hardware	SparkFun	WRL-09085	$71.49	Transmits and recieves data from air and ground
Total			**$999.54**	