Research Statement: Intelligent Aerial Vehicles

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January 5, 2010

1 Overview

Currently unmanned aerial vehicles (UAVs) rely on preplanned missions at high altitude or teleoperation at low altitude and do not actively collect and reason about obstacles, landing sites, wind, position uncertainty, and other aerial vehicles. However, to enable autonomous missions in cluttered environments it is necessary to react to all available information during mission execution.

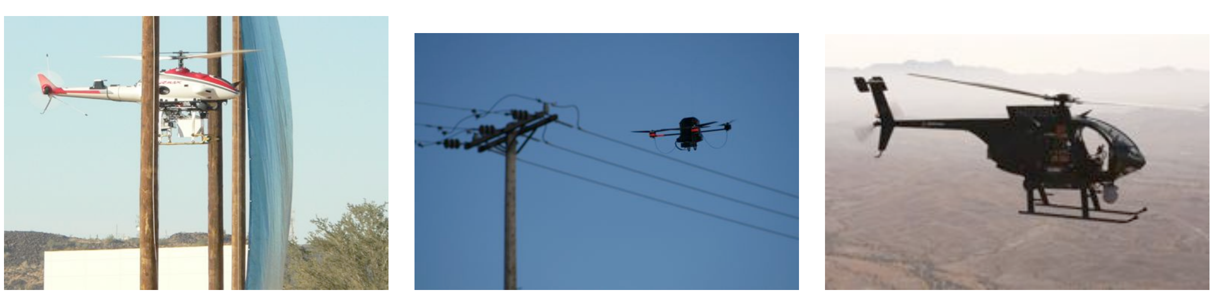
The ability to adapt to feedback from the environment in real-time during mission execution is highly sought since it enables operation in previously unaccessible environments such as tight canyons, urban environments, and under the tree canopy. In particular for rotary wing vehicles it is necessary to be aware of the environment since the operational advantage is in the ability to hover.

With the proposed research agenda the safety of manned as well as unmanned aerial vehicles will be increased. While cars today have intelligent cruise control, and automatic parking, helicopter pilots have no aids that allow them to find suitable landing sites and give them obstacle warnings at low altitude.

The problem of operating aerial vehicles close to obstacles requires advances in many different disciplines. However one area in particular that has not been considered carefully is flexible real-time motion planning that incorporates many of the constraints necessary in a real mission. While in principal many of the algorithms developed for ground robots apply to aerial robots the solutions in prior work tend to focus on the traversability of the environment. Aerial vehicles on the other hand have a larger set of possible actions available to perform exploration, stay controlled, and build globally consistent maps simultaneously.

2 Thesis Research

My prior research at Carnegie Mellon University has focussed on planning and perception algorithms for unmanned aerial vehicles of different sizes. In particular I have developed multiple algorithms to enable operation at low altitude in unstructured environments that learn how to avoid obstacles based on observing human operators and incorporate several constraints to search for landing sites for a helicopter.



(a) RMax Helicopter (b) Airrobot Quadrotor (c) Unmanned Little Bird Helicopter

Figure 1: Aerial vehicles who perform autonmous missions close to obstacles that I have automated with my colleagues.

2.1 Learning to Avoid Obstacles

Reactive obstacle avoidance control laws are appealing because they are fast to compute and can react immediately to previously unknown obstacles. However it is difficult to set the parameters that govern the response and in prior work typically parameters are tuned by hand. My colleagues and I developed a method to automatically learn the parameters based on observations of a human pilot. We combined the reactive and deliberative planning and tested high-speed (8 m/s) obstacle avoidance on the vehicle shown in Fig. 1a on more than 1000 flight segments with thin wires, vegeation, and buildings. This research gave insight into learning action based on a strong parametric control model.

2.2 Calculating the Obstacle Cost Function

A voxel evidence grid representation of obstacles is popular because it is fast to update and can filter noisy measurements. For planning purposes the obstacle map needs to be converted into a map that represents the cost of being in a particular location. The obstacle cost function is proportional to the distance to obstacles and can be calculated with the distance transform. Repeatedly calculating the full distance transform makes planning prohibitevly expensive. I therefore developed an efficient incremental algorithm based on D* Lite to calculate the distance transform in 3D. We compared the algorithm to state-of-the-art non-incremental and incremental algorithms and experienced a 10-times speed increase for realistic sensor measurements for the quadrotor vehicle shown in Fig. 1b.

2.3 Searching for Landing Sites

An essential capability for unmanned rotory-wing vehicles is to be able to land at and find unimproved landing zones (LZs). Currently, rotorcraft rely on well-chosen give GPS coordinates to land. I developed a multi-objective planner to search for landing sites that uses the feedback from obstacles, information gain based on collected landing sites, and dynamic constraints to search for landing sites. The optimization based search significantly (3x) outperforms a uniform probability search schedule and is also able to incorporate obstacle constraints. We will test the algorithm on a full-scale helicopter.

2.4 Evaluating Landing Sites

It is difficult to estimate if a landing site is suitable to land on, because a small slope and obstacles are already hazardous for helicopters. In prior work on LZ evaluation slope and roughness constraints were considered to estimate the availability of a site. In our work we combine the coarse evaluation based on slope and roughness with a fine evaluation that uses a 3D model of the helicopter and a trangulation of the range measurements to optimally position the vehicle. Since the contact of the landing gear with the ground is modelled, dangerous obstacles that might be ignored in the coarse evaluation can be incorporated. Furthermore, the approach, abort, and ground path are incorporated in the evaluation. Using our algorithm we are able to find safe and efficient landing zones for aerial vehicles.

3 Agenda

I plan to continue research in unmanned aerial vehicles by advancing the capabilities in autonomy to provide higher performance and safety. The major open questions I am planning to address in my research are

1. *Integrated Mission and Motion Planning:* How can we integrate higher level mission planning with planning the actual motion of the vehicle? My prior work has shown that using objective functions instead of a goal point leads to robust behavior and is more intuitively specified. How can the objective functions be sequenced intelligently? How can the feedback from the environment be integrated in a principled way?

2. *Combining Multiple Objectives:* How can multiple objectives be combined to lead to a global optimal behavior? To behave optimally multiple conflicting objectives have to be considerd whose priority will

change depending on the state of the mission, robot, and environment. What is a principled method to combine multiple objectives in planning?

3. *Integrating Discrete and Continuous Planning:* What are efficient methods to integrate continuous with discrete planning methods? State-of-the-art methods in kinodynamic motion-planning use either continuous optimization or discrete search. How can we use continuous optimization to minimize the discrete search graph necessary to quickly find all the different homotopic paths in an environment?

Since I believe that results on real UAVs have the largest impact there are many research opportunities for students of all levels. GPS-denied control, 3D SLAM, minature precise GPS/INS, light custom range sensors, and light computing are all challenges that need to be addressed before a low flying UAV is capable of operation. This requires innovative mechanical and electronic design as well as real-time algorithms and necessitates inter-disciplinary collaboration.

For students solving these problems provides a hand's on experience in systems engineering as well as in their respective specialty and the necessary collaboration prepares them well for academia and industry in a booming UAV market. To further foster the involvment I will lead a MAV team to participate in competitions such as MAV, IMAV, EMAV, and AUVSI IARC.

The interest in intelligent autonomous unmanned aerial vehicles is large because there are numerous applications. In the past I have helped to attract funding and write proposals for industrial partners and government agencies. I have worked with Honywell, EADS, Piasecki and executed contracts with the agencies such as Army TATRC and DARPA. My research program is relevant to commercial funding as well as government funded programs by agencies such as DARPA, DOD, NIST, and NASA. I am looking forward to lead and conduct the theoretical as well as applied research described above to advance the state of the art on unmanned aerial systems.