Formation Control for Cooperative Localization of MAV Swarms (Demonstration)

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ABSTRACT
Large UAVs depend on GPS technology to accurately describe their position, and navigate to their objectives successfully. However, Micro Air Vehicles (MAVS) cannot rely on GPS technology when navigating indoors. Much research has been conducted to develop robust control systems for MAV formations. Most of this research requires off-board sensing to provide formation control. In this work we demonstrate a formation control technique for MAVs, using on-board sensing and off-board processing. We demonstrate the usage of on-board vision and inertial sensors to localize two MAVs relative to each other. Our hardware platform is the Parrot AR Drone, which has a vast sensor suite including two on-board cameras, an inertial measurement unit, compass, and ultrasonic range-finder for altitude measurement. The drones are controlled using National Instrument's LabView 2011, and commands are issued wirelessly via a 802.11 WIFI network.

Categories and Subject Descriptors
I.2.11 [**Artificial Intelligence**]: Coherence and Coordination – *Intelligent Agents*

General Terms
Algorithms, Design, Experimentation

Keywords
Multi-agent coordination, GPS-denied environments, Formation Control

1. INTRODUCTION
As adoption of autonomous vehicles continues to grow, interest in micro-air-vehicles has led to exciting advances by many research institutions around the world. The sFly project [1], led by researchers at ETH Zurich, demonstrated the usage of cooperative MAVs for search and rescue in GPS-denied environments. The Robust Robotics Group at MIT has demonstrated a number of state estimation techniques using a single MAV and various sensors [2]. The GRASP Lab at the University of Pennsylvania has demonstrated complex formation control using off-board sensors [3]. This work demonstrates formation control using on-board sensors. The ultimate goal of this work is to develop a cooperative localization system, using low-cost hardware.

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2. EXPERIMENTAL PLATFORM
This work uses the Parrot AR Drone V.1, a low-cost commercial quadrotor helicopter featuring a diverse set of sensors. The drone has two cameras: a forward facing VGA camera and a ground-facing CMOS camera. A ground-facing ultrasonic sensor in the base of the drone is used to determine current altitude. An Inertial Measurement Unit, containing three gyroscopes and three accelerometers, is used to return angular position and in the plane of the MAV. The MAV communicates via an internal 802.11 WIFI router that can be connected to by a PC. On power-up, the drone establishes a WIFI Network with a configurable SSID, to which controllers connect.

In order to determine how to control the Drones, we had to reverse-engineer the characteristics of the existing onboard control system. Parrot provides SDK-level control of the AR Drone. The Drone's Pitch, Roll, and Yaw positions can all be controlled individually, and are sent to the drone through the SDK's Progressive Command Protocol (PCMD). The PCMD enforces a Max Pitch/Roll Angle, resembling the behavior of electromagnetic saturation. The user can issue floating point values from -1 to 1 for each of the positions to be controlled. This range represents a percentage of the Max Pitch/Roll Angle, a parameter defined in the initial configuration of the drone, meaning that the Drone uses an internal control loop to rotate the drone about a given axis and hold that angular position.

When hovering, the internal control loops attempt to keep the angular positions of the drone as close to zero as possible, while maintaining a constant altitude.

3. FORMATION CONTROL
The formation control system consists of two subsystems, which enable visual recognition and control over the position of a MAV.

3.1 Vision System
This system uses Labview's IMAQ libraries to find Parrot's orange drone tags, as seen in Figure 1. First we extract the red and green color planes from the video stream, and subtract green from red. This results in a grayscale image of the orange color plane. An image threshold is then applied to eliminate all pixels which are of magnitude less than 160. Next, IMAQ's "shape detect" is used to find potential rectangles in the image. The set of

rectangles is searched to find a pair of similar rectangles. Given the size of a rectangle, an expected position is calculated for a second rectangle. A rectangle exists at the expected position, the software returns the 3-D coordinates of the pair of blobs as a single MAV.

Figure 1 Parrot AR Drone v1.0 with Orange Tags

By placing the orange tags at known positions on the body of the drone, we can calculate the distance between drones.

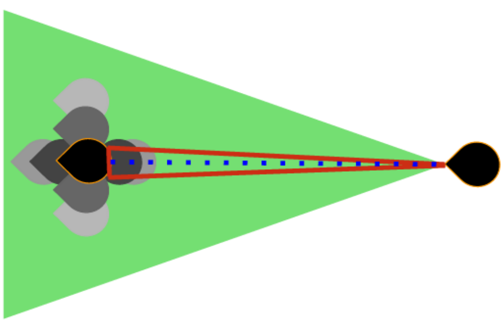

Figure 2 The distance between MAVs is calculated based on unique markings on each MAV

3.2 Control System

In order to control the position of each robot in the formation, we use visual feedback provided by our vision to issue angular position commands. The control system consists of a P-D controller for motion as a part of a formation, and an open-loop controller for hovering.

3.2.1 A_t - Translational Acceleration of a MAV

In its default behavior, each MAV uses its ultrasonic altimeter to maintain a height of 1 meter above a detected surface. In constructing our model, we assume that there is minimal change the MAV's altitude as it translates. Thus as the MAV moves, we can calculate the translational acceleration as a trigonometric component of the acceleration caused by gravity. We calculate this acceleration using the inter-drone distance determined by the vision system.

3.2.2 Initial Proportional Controller

Our basic command signal involves calculating a desired acceleration given the difference in current position and desired position, based on the visual feedback information. This command signal is converted into a desired angular position, given the relation described in the previous paragraph. Therefore, as the distance error decreases, the desired angular position decreases to zero.

3.2.3 Final P-D Controller

However, simply applying a force in a given direction will not result in the drone stopping at the desired position; an opposing force must be applied. Using A_t, as the drone's desired acceleration decreased, we measure the difference between the current acceleration and the desired acceleration, and compensate for this error.

3.2.4 Open Loop Hover Controller

In addition to visual feedback, we use the sensed angular velocities to create a small periodic control signal, which helps the drone resist translation caused by environmental disturbances. This involves modulating the frequency, amplitude, and duty cycle of a square wave, using the sensed angular velocities of the drone. As angular velocity increases, an opposing signal of a particular frequency, amplitude, and duty cycle, is applied in order to lower angular velocity, and so lower translational drift. This system is independent of the vision system, and helps the drone maintain its previous position when visual feedback was unavailable.

4. DEMONSTRATION

The demonstration will consist of one MAV following another; the presenters will control one of the two drones. A live feed of the follower drone's camera will be displayed on a laptop, along with calculated distance, velocity, and acceleration relative to the leader drone.

5. ACKNOWLEDGMENTS

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