Real Time, Onboard-only Landing Site Evaluation for Autonomous Drones

by

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Abstract

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Acknowledgements

I would like to thank the Flying Spaghetii Monster and his noodly appendage.

Contents

Chapter 1

Introduction

1.1 Problem Statement and Motivation

The goal of the proposed research is to explore the topic of autonomous, unstructured drone landing. Current autonomous landing methods have at least one of the following disadvantages: they are blind to obstacles, they require previously *known* landing sites, they depend on sophisticated ground control stations for offloading of expensive computation. This proposed research targets a gap in current autonomous landing methods. Specifically, we aim to develop a method for quickly analyzing terrain and identifying safe landing sites using only embedded computational hardware and a minimal set of sensors.

Landing is a particularly difficult aspect of drone flight, owing mainly to its risky nature and required precision. As a result, most drone landings are carried out by (or under the supervision of) a human operator, inherently limiting the applicability of autonomous drones. Some autopilot software includes an Application Programming Interface (API) for *precision landing*, which allows a drone to localize and direct itself with respect to a landing pad during an autonomous landing, according to data provided by external sensors and programs. However, there is no particular method of autonomous landing in widespread use. As autonomous and semi-autonomous drones are not able to reliably handle landings on rough terrain or in non-ideal conditions, human operators often disable autonomous control during landing (opting for full manual control), or abuse/hack the landing system by descending to a low altitude, grabbing hold of the drone, and disabling the motors, as shown in Figure 1.1. Aside from potentially exposing users to dangerous rotors, this landing technique showcases the limitations induced by a lack of autonomous landing method.

In sufficiently flat, large areas, fully autonomous drone missions can end with a GPS-based autonomous landing which is blind to obstacles in the environment. However, intuitively and demonstrably, this can lead to crash-landings at landing sites that have obstacles within the error radius of the GPS, which can be anywhere from a few centimeters to a few meters. In the available open source autopilot softwares, obstacles are simply not handled, and drones will continue their landing attempts even if fatally obstructed.

1.2 Background

1.2.1 Autopilot Software/Hardware

The most prominent, open source drone autopilot software packages are ArduPilot [1] and PX4 [4], which can integrate easily with many additional/custom software packages. DJI drones, while the most commonly used consumer-grade drones, use proprietary, closed source autopilot software that has a limited API for interacting with external software. Thus, ArduPilot and PX4 and custom drones are typically used for research on drones themselves, while DJI software

Figure 1.1: Non-ideal, human-assisted landing in the absence of an autonomous, safe landing method that considers the surrounding environment.

and drones are typically used for consumer/commercial tasks. ArduPilot and PX4 communicate using the same open source, customizable protocol - MAVLink [2] - which has APIs in many different programming languages as well as with Robot Operating System (ROS).

1.2.2 Simulation Software

1.2.3 Robotics Software

1.2.4 Fiducial Markers

1.3 Related Work

Chapter 2

Current Progress

2.1 Initial Hexacopters

After finishing a master thesis [5] wherein I developed an algorithm for autonomously landing a drone using fiducial markers in simulation, the next step was to test this method on physical platforms. The algorithm required identifying fiducial markers through image analysis, tracking the markers via a gimbal-mounted camera, calculating position targets in order to direct the drone towards the landing pad, and communicating those position targets to the flight control software. The base frame for the drones are the Tarot 680 hexacopter kit, which provides a good thrust-to-weight ratio, good flight stability, and space for mounting multiple computational components. A combination of Raspberry Pi and Navio2 [3] shield serve as a flight controller which can communicate with a companion board. The companion boards (a Google Coral Dev board and an NVIDIA Jetson Nano) communicate via a USB network to the flight controller and perform all heavy computations involving image analysis, coordinate system transforms, PID control, and position target generation.

An overview the components is as follows:

- **11.1 V LiPo Battery:** this battery provides power to a battery eliminator circuit (BEC) for isolation of the power system for the computational electronics (the flight controller and companion board).
- **BEC (Battery Eliminator Circuit):** the BEC transforms 11.1V power to 5V power for the flight controller and companion board. The flight controller and companion board each have their own 4A channel to meet their given power requirements.
- **Flight Controller:** this combination of a Raspberry Pi 3 B+ and Navio2 shield runs the ArduPilot software to control the drone, and communicates with the companion board to control the gimbal.
- **Telemetry Radio:** the telemetry radio provides two-way communication between the flight controller and a ground control station that is also fitted with its own telemetry radio. It is connected to the flight controller via USB. The software on the ground control station provides an interface for real-time status messages and sending high-level commands.
- **RC Receiver:** the RC receiver provides a one-way radio link between the pilot's transmitter and the flight controller, allowing the pilot to manually control the drone. It is connected to the flight controller via SBus which provides an 8-channel multiplexed PWM signal to reduce the needed wires and space. This provides an interface for control by a human pilot, which is often used in testing but will eventually be mostly unused.
- **22.2 V LiPo Battery:** this battery provides power to the speed controllers and gimbal.

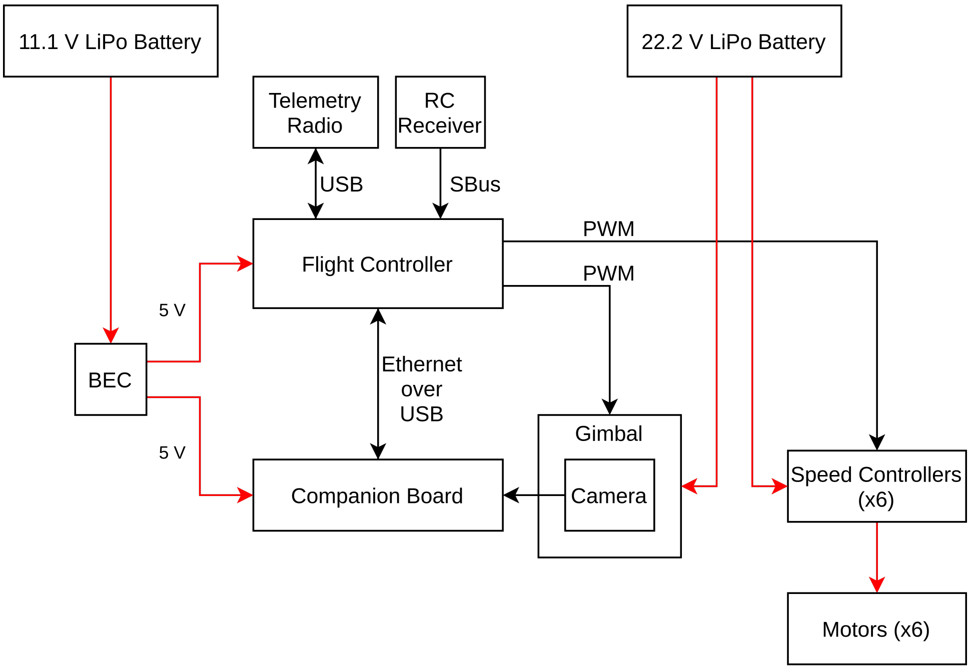


Figure 2.1: Hardware Setup

- **Speed Controllers:** the speed controllers receive a PWM signal from the flight controller which indicates a throttle value. They then provide corresponding power signals to the motors.
- **Motors:** the motors spin propellers to provide thrust in order to control the drone's position in the air.
- **Gimbal:** the gimbal controls the orientation of the camera based on PWM signals from the flight controller which indicate target angles. Its onboard IMU and driver filter the motion of the camera in order to provide a smooth camera image.
- **Companion Board:** the companion board reads an image from the camera and calculates the position of the landing pad relative to the drone. It then communicates this information to the flight controller via an Ethernet over USB connection using ROS.

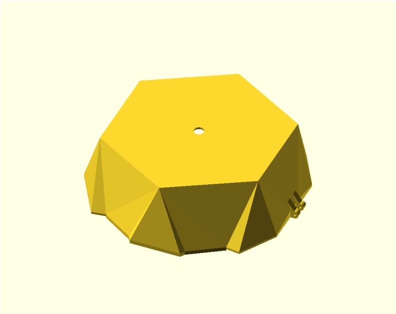
The computational components require some protection from the harsh Icelandic weather, and we therefore designed and 3D-printed a component mounting plate with a connector for a canopy. We also designed and printed cases to protect camera modules and allow them to be mounted in a gimbal with a GoPro form factor. The final versions of these components (after several iterations) can be seen in Figure 2.2. The fully assembled hexacopters are shown in Figure 2.3

2.2 WhyCode Modifications

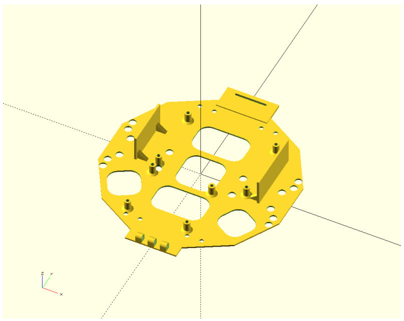
2.3 April Tag Modifications

2.4 Infrared Camera, Heavy-Lift Drone

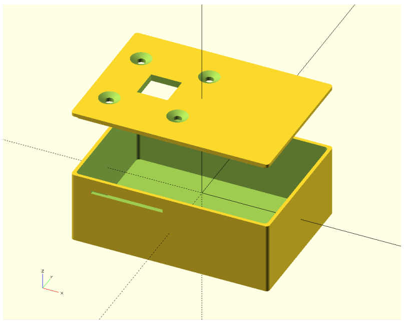
2.5 Experiments with AirSim



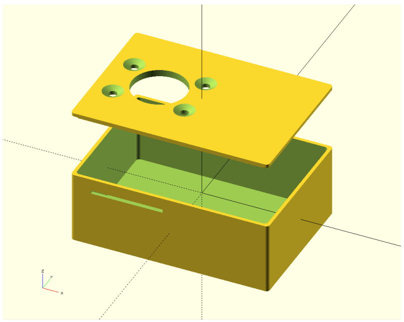
Protective Canopy.



Component mounting plate.



Google Coral camera case.

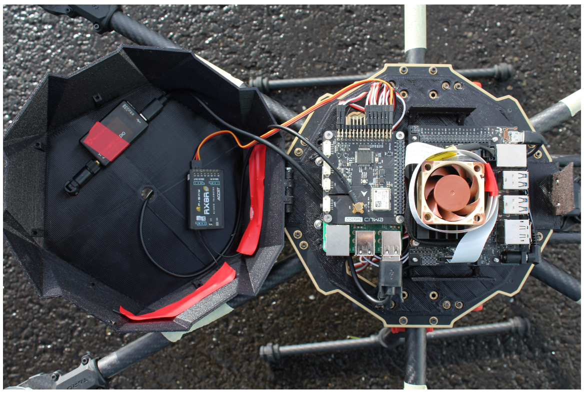


Jetson Nano camera case.

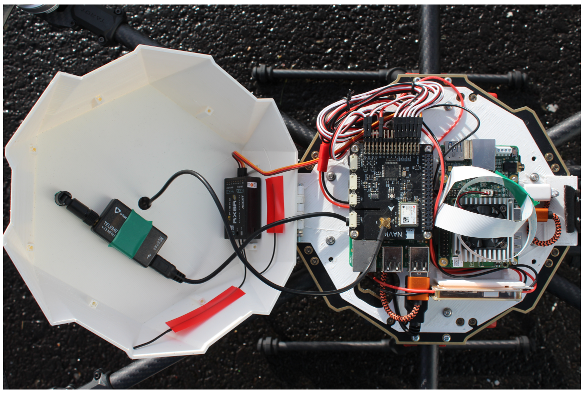
Figure 2.2: 3D printed parts for the Tarot hexacopters.

(a) The Jetson drone.

(b) The Coral drone.



(c) The Jetson drone's electronics compartment.



(d) The Coral drone's electronics compartment.

Figure 2.3: The assembled drones and their electronics compartments.

Chapter 3

Research Plan

3.1 Data Set Generation

3.2 Terrain Classifier Creation

3.3 Testing in Simulation

3.4 Testing on Physical Hardware

3.5 Risk Analysis

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