Autonomous Drone Landing

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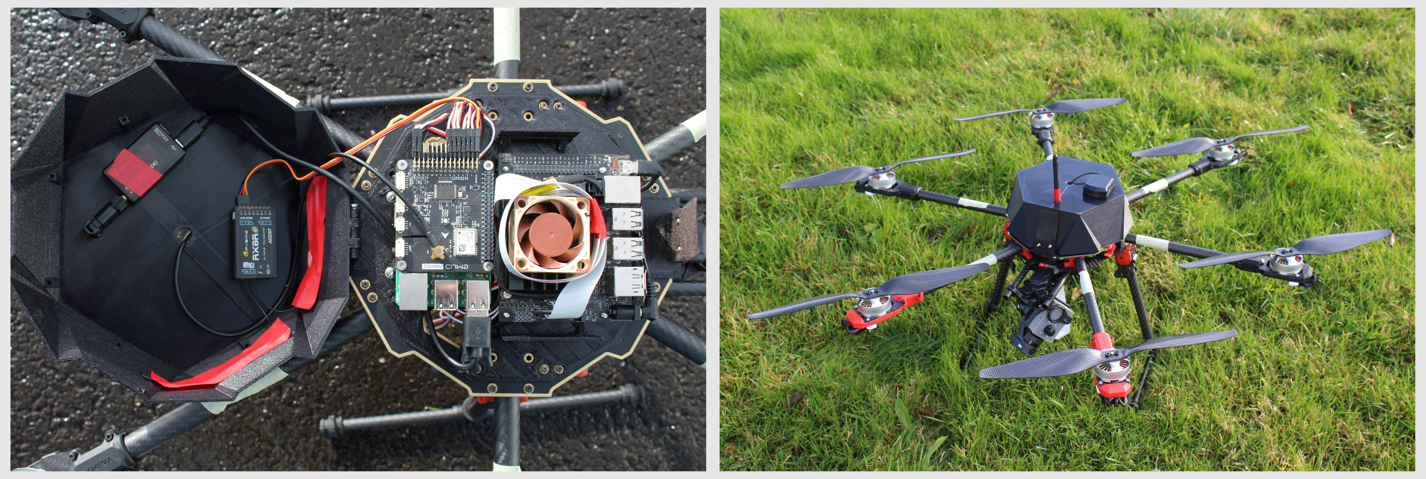
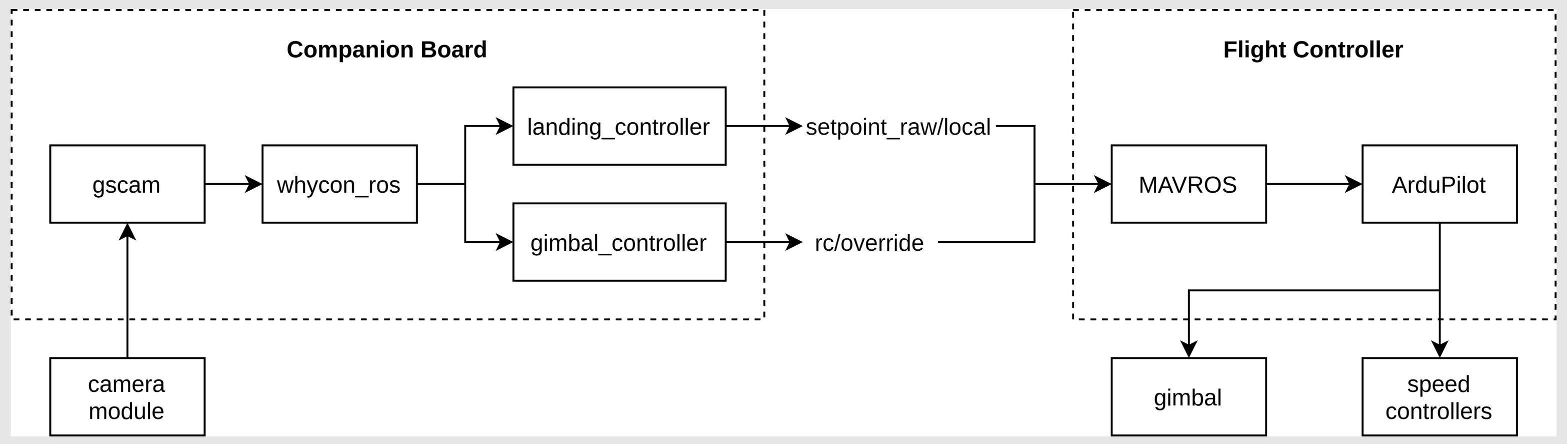
Drone Platforms

We have built two Tarot 680 Hexacopters for real world testing of autonomous navigation techniques developed in simulation. A landing pad is marked with fiducial markers which are recognized by the drone's onboard camera. The gimbal automatically aims the camera at the landing pad to track it during descent. The landing software then directs the drone to descend towards the landing pad.

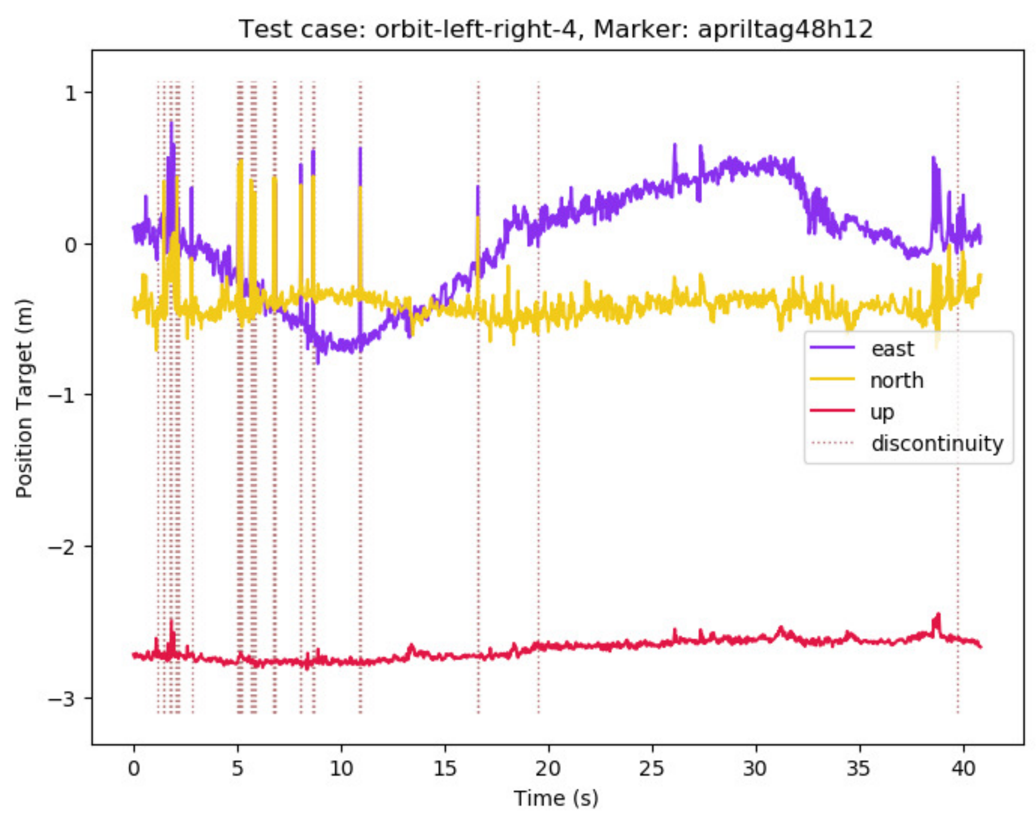




The drones were able to track and approach the landing pads but did not execute successful landings because of low GPS accuracy (they often refused to enter autonomous mode) and issues with the marker systems (orientation ambiguity). This testing phase gave information on using drones autonomous in Iceland.

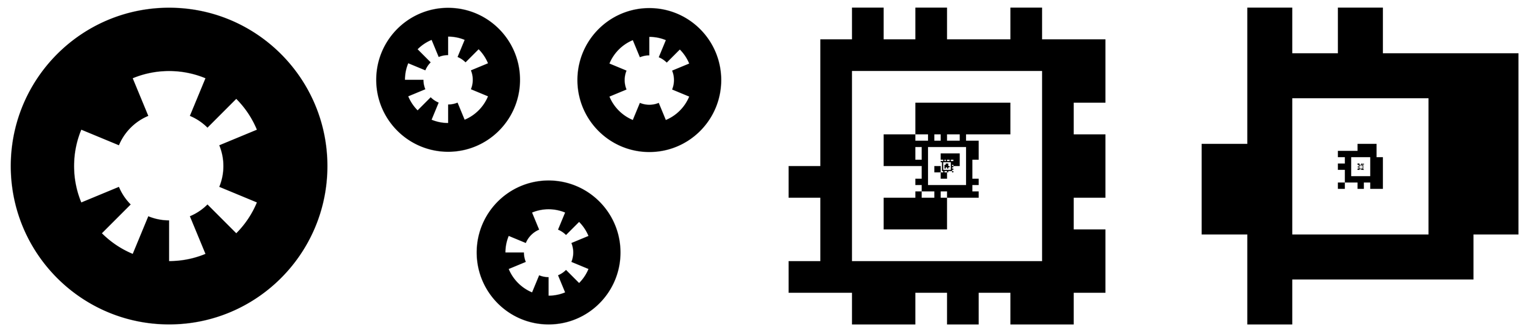
Orientation Ambiguity

Orientation ambiguity is the tendency of the orientation of fiducial markers to switch in a discontinuous way over time, as in the figure below, which represents the position of a landing pad relative to a drone. The east (left/right) and north (forward/backward) position targets have discontinuities as a result of orientation ambiguity.



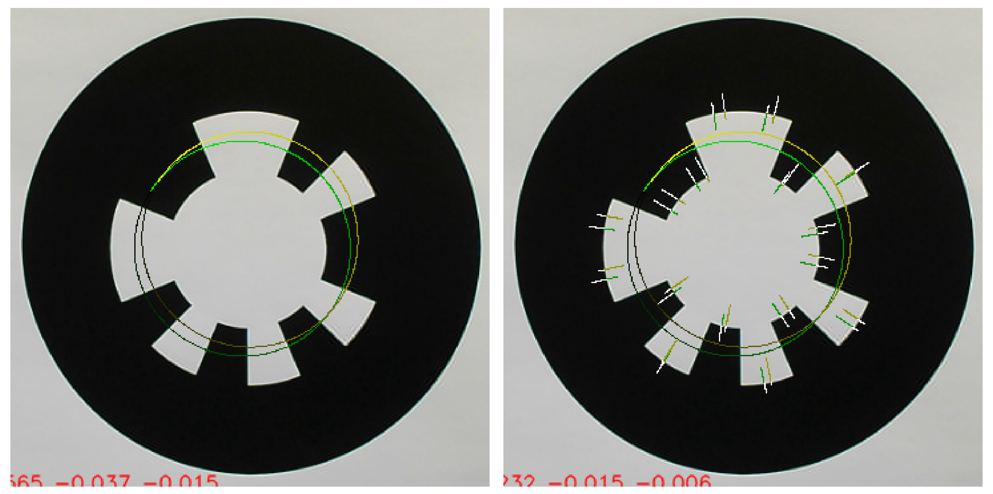
Fiducial System Modifications

We use fiducial markers to detect our landing pads, and we have modified several fiducial systems that use the markers below for our purposes: to reduce the issue of orientation ambiguity, and to provide a fast detection rate (> 10 Hz) rate on embedded hardware.



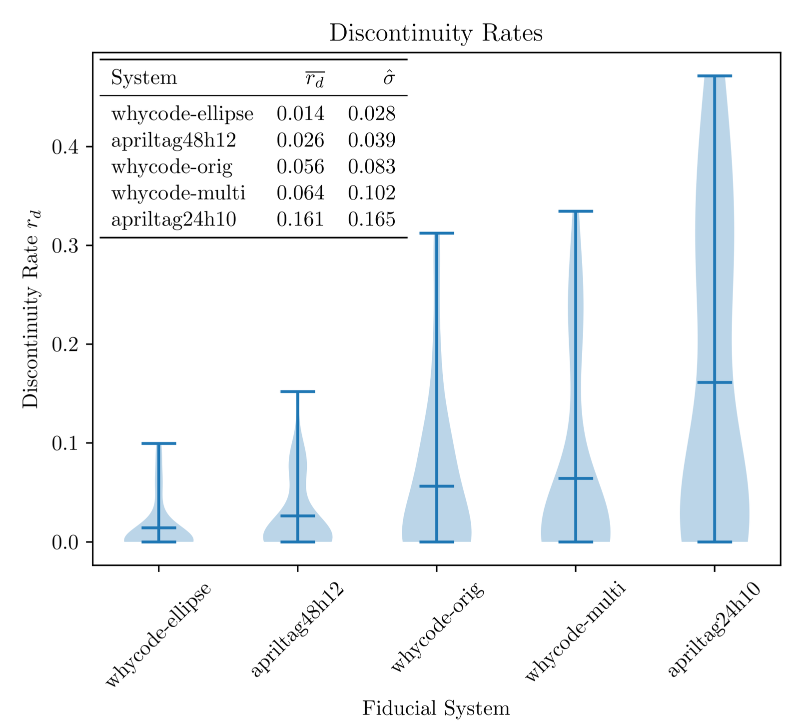
(a) WhyCode (b) WhyCode Multi (c) AprilTag 48h12 (d) AprilTag 24h10

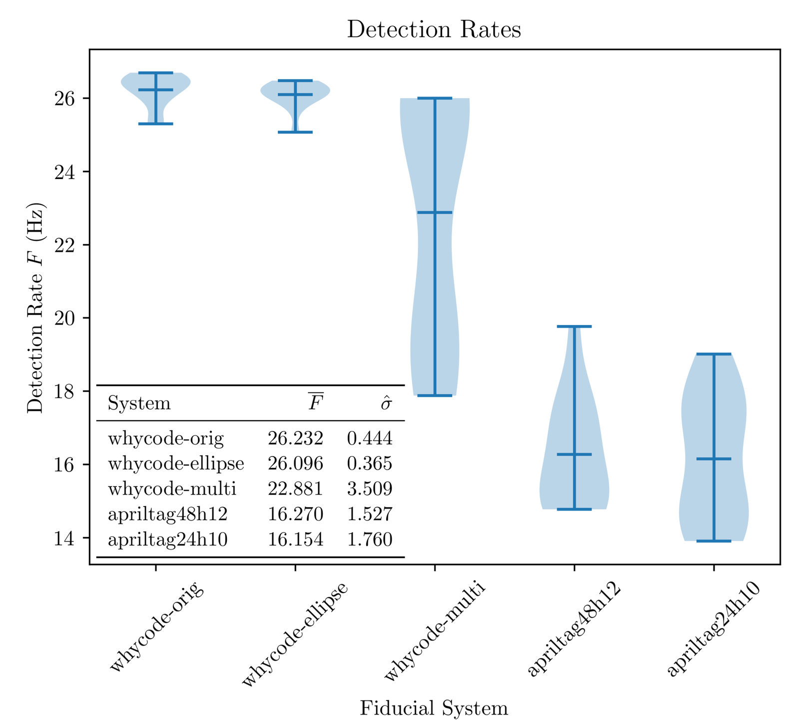
WhyCode Orig(inal) samples the marker around the ID "teeth." **WhyCode Ellipse** adds sampling locations allowing the system to better choose which circle is centered on the marker and reducing orientation ambiguity.



(a) WhyCode Orig (b) WhyCode Ellipse

WhyCode Multi calculates the plane among 3+ markers, assumes they are coplanar, and uses the orientation from that plane, not those of the individual markers. **April Tag 48h12** has a relatively low orientation ambiguity rate, but also has a low detection rate (about 2 Hz) on a Raspberry Pi 3, so we have made **April Tag 24h10** with a smaller definition for quicker detection. The difference in detection rates is not shown below because this test was done on a Raspberry Pi 4 which can handle the system.

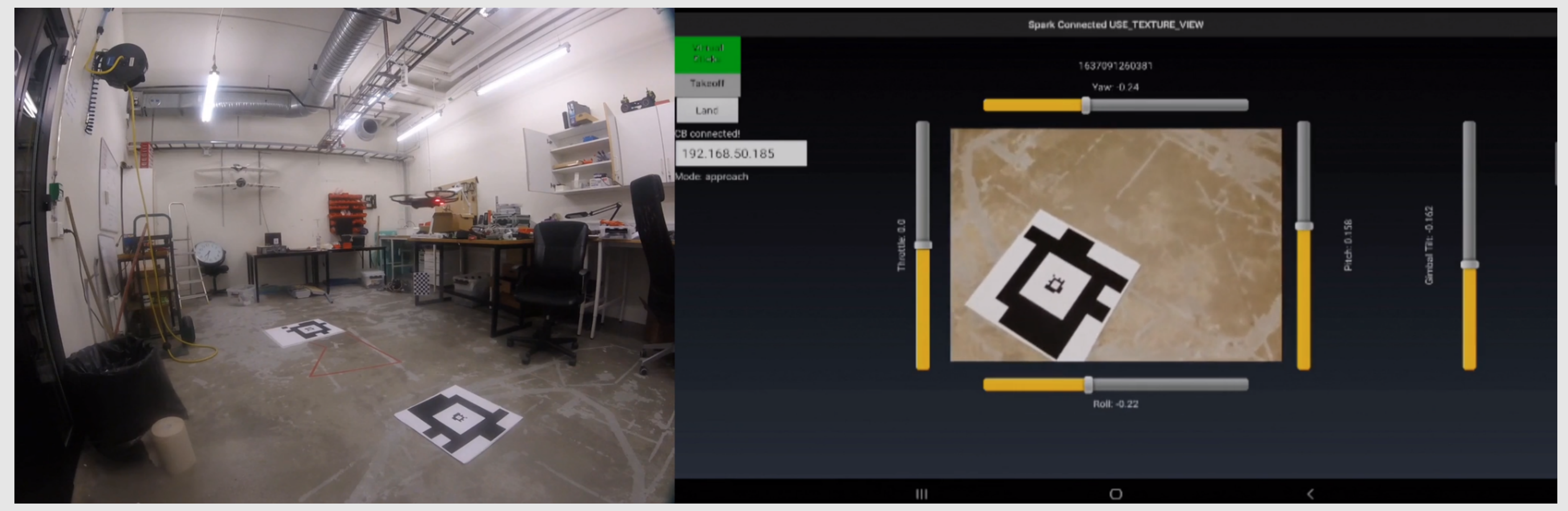




We pick our modified WhyCode Ellipse and April Tag 48h12 as the best systems in terms of discontinuity rate, with each system having an acceptable detection rate. WhyCode Multi and April Tag 24h10 do not provide benefits in terms of discontinuity or detection rate.

Autonomous Landing with DJI Spark

We have retested the autonomous landing techniques will all previous fiducial systems, using a small DJI Spark so that the tests can be conducted indoors. This required the development of an Android App to interface with the DJI Mobile SDK for autonomous control, shown below. All systems but WhyCode Multi allowed successful autonomous landings. Scan the QR code for autonomous landing demonstrations.



Future Work

Focus will be on a new autonomous landing method that can identify safe landing sites in previously unknown locations via terrain analysis. This will be integrated with the fiducial landing method to allow drones to land at marked landing sites as well as unknown sites. Additionally, we will redo the fiducial landing proof of concept with the hexacopters, using a camera with an embedded IMU to mitigate the orientation ambiguity problem.

Drone Upgrades:

- Install new flight controller
- Add optical flow/LIDAR velocity sensors to hexacopters (for GPS-free autonomous flight)
- Add depth camera (with integrated RGB camera) to hexacopters
  - Create protective gimbal mount
- Test in the field

Fiducial Landing with Hexacopters:

- Redo fiducial landing proof of concept (with DJI Spark) outdoors with hexacopters
- Use only the RGB sensor from the depth camera

Free-form Autonomous Landing Algorithm

- Develop lightweight terrain analysis method
- Use realistic synthetic sensors (depth camera)
- Test on synthetic and real data
- Carry out autonomous landings in simulation
- Carry out autonomous landings in the field

Final product will (ideally) be: a successful mission where a drone 1) autonomously takes off from a marked landing pad, 2) scouts a location to land using the terrain analysis method and lands at that location, 3) takes off again, 4) locates and lands at the original marked landing pad.