Autonomous Landing with a DJI Spark and April Tags

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Demonstration video

Problem Description

Goal

- Autonomously land a drone on a landing pad marked with a fiducial marker.
- Identify the landing pad via a gimbal-mounted, monocular camera that tracks the fiducial marker (to increase detection range).
- Distinguish between multiple landing pads and actively choose one for landing.
- Search for landing pads safely if one is not yet found.

Key Background Points

- Landing is a hard part of autonomous drone flight because it is risky and requires high precision.
- GPS alone does not provide a sufficiently accurate position estimate for landing.
- Fiducial markers can allow a drone to recognize a landing pad cheaply and accurately, unlike GPS.
- Previous methods have used a fixed, downward facing camera to identify fiducial markers on a landing pad, with the disadvantage that they can easily lose track of it.

Contribution

- **Gimbal-mounted camera** instead of fixed camera(s) used in previous work. Provides longer detection range and marker tracking, but means that the detected landing pad position is subject to occasional ambiguities.
- **April Tag Custom 24h10 family** that allows marker embedding but is more lightweight than the default 48h12 family.

Methods

- **Drone System:** DJI Spark with DJI Mobile SDK.
  A cheap and stable drone platform that can be flown indoors. The DJI Mobile SDK can accept programmatic, high-level commands to "go left," "rotate right," "decrease altitude" etc.
- **Fiducial System:** April Tag.
  A well-tested and popular fiducial system with a flexible layout, so that many aspects of the markers can be adjusted.
- **Tracking:** PID Controller.
  A PID controller adjusts the pitch rate of the gimbal in order to keep the marker in the vertical center of the camera frame.
- **Approach:** Velocity Targets
  The x, y, z components of the position of the camera relative to the landing pad are used as velocity targets, which are passed to the Mobile SDK to make the drone approach the landing pad.

Marker System: April Tag Custom 24h10

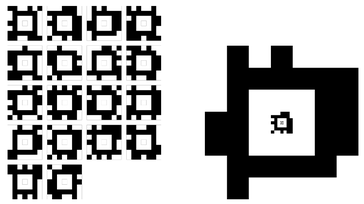

Figure 1:**Left:** all tags in the 24h10 family. **Right:** the landing pad with 3 embedded tags.

Overview

- April Tag allows embedding smaller markers inside larger markers, so the drone can see the marker even when extremely close.
- The default embeddable marker family, April Tag 48h12, is too computationally expensive for embedded hardware, e.g. Raspberry Pi.
- April Tag 24h10 is a smaller version of April Tag 48h12 that can run at a sufficiently high framerate on embedded hardware.

Additional Message Attributes

We have added the following attributes to the default April Tag ROS code for autonomous landing:

- **`position_target_enu`:** the distance from the drone to the landing pad in 3 dimensions. This is calculated by transforming the *position* of the landing pad by the inverse of the pitch and roll components of its *orientation* (ignoring yaw). It is subject to occasional incorrect readings, since it is dependent on the orientation of the marker which cannot always be determined unambiguously.
- **Normalized pixel centers** u, v of the marker, where $u, v \in [-1, 1]$ correspond to the x, y positions respectively. Values of -1 and 1 indicate the negative and positive extremes of the screen respectively, and 0 indicates the center. These are used as inputs to the PID controllers that aim the camera at the marker.

Data Flow

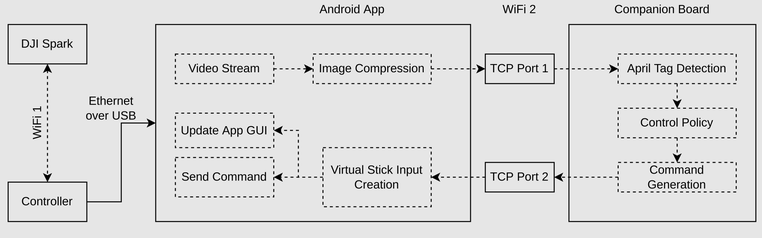

Figure 2:System data flow.

System & Behavior Overview

- Communication with the drone occurs via an Android App (required by DJI Mobile SDK).
- The app provides manual control and real time video to the user.
- April Tag processing is too expensive for the Android tablet - requires a companion board.
- Autonomous control can happen when the companion board is connected (See Figure 2).

Test Flight Behavior

- Takeoff to a height of 2m.
- Aim gimbal vertically down, rotate in yaw axis to find takeoff pad.
- Hover above takeoff pad for a few seconds.
- Point gimbal up and down while rotating in yaw axis to find a landing pad.
- Track landing pad vertically with gimbal, and horizontally with drone yaw.
- Approach the landing pad until directly above it.
- Align to landing pad's yaw.
- Descend, keeping the markers in view the entire time.
- Once at minimum altitude, commit to landing.

Results

The drone autonomously takes off, hovers above takeoff pad, detects/tracks/approaches the landing pad, and lands reliably. **Scan QR codes at the top right of this poster for demonstration videos!**

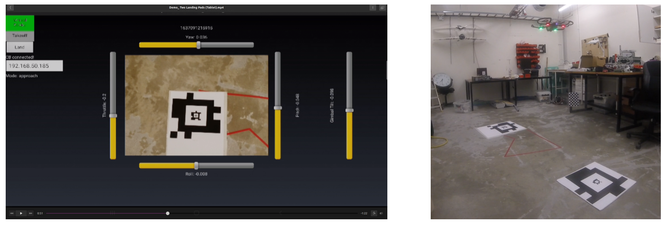

Figure 3:**Left:** view from the app. **Right:** view of the drone and landing pads.

Future Work

- Test on bigger/better drones.
- Improve the app.
- Move away from DJI Mobile SDK because it is too constraining. Use DJI Onboard SDK or ArduPilot/PX4 instead.
- Detect previously unknown landing sites (instead of using fiducial markers).