Division of Engineering Science
UNIVERSITY OF TORONTO

ROB498: Robotics Capstone Design

Challenge Task #2: Stationkeeping

Winter 2023

Task Description

Inspection drones are often required to stationkeep, or to maintain a stable hover at a fixed altitude (height) over an area of interest in order to carry out prolonged observation (where 'prolonged' is a relative term, since limited battery power is available). During inspection of a nuclear facility, for example, stationkeeping may be necessary to carefully measure radiation levels in a specific location.

Now that your drone is flight-ready, as part of Challenge Task #2, you will implement autonomous stationkeeping under the control of the Jetson Nano (i.e., fully on-board). The testing window will open on **Tuesday, February 28, 2023** and close on **Friday, March 17, 2023**. Performance on the challenge task is worth **10%** of your team's overall course grade.

Task Implementation Details

The first step, prior to attempting the challenge task, is to fully assemble all of the remaining components of your drone. You should attach the the 3D-printed chassis and Jetson Nano to the bottom of your carbon fibre frame and connect the serial cable between the Nano and the Pixhawk flight controller. Optionally, you may also wish to install the RealSense T265 tracking camera and/or the IMX219 colour camera (depending on how your team chooses to tackle Part II of the task; see below). To complete the challenge task, you must be able to send command from the Nano to the Pixhawk using the MAVLink protocol (e.g., via MAVROS). Some configuration is required to enable high-speed serial communication between the Nano and the Pixhawk.

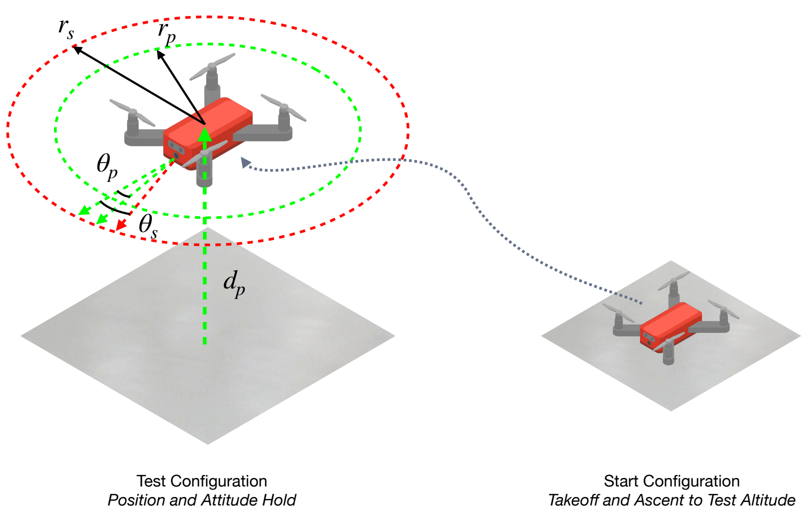

Figure 1: During the flight test, you will take off under manual control (or autonomously, if you prefer), reach a fixed altitude, and hold a stable hover at a fixed orientation for a fixed duration.

Figure 1 provides an overview of the stationkeeping task. As shown in the figure, there are two objectives for the challenge: a *primary* objective and a *secondary* objective. The overall goal is to keep your drone hovering at a fixed point in space and pointed in a fixed direction; that is, the pose of the drone relative to the fixed external (MY580) frame should not change. In reality, a small amount of drift is inevitable.

For maximum points, you should aim to meet the primary objective, which is to keep your drone from drifting outside of the 'primary' zone identified by the values in Table 1. If your drone drifts outside of this primary zone, into the secondary zone, you will still receive some points. A larger amount of drift will result in a substantial penalty—similar to Challenge Task #1 (where the goal was to ensure you could fly safely), Challenge Task #2 is designed to ensure that you are able to accurate control the pose of your vehicle. This will be important for later challenges where you will need to navigate around obstacles in the environment.

The challenge task has two parts, one carried out with the aid of the Vicon motion capture system, and one without. For both parts, the generic procedure will be as follows:

1. **Ascend to Altitude**

   Your drone will receive a *LAUNCH* command from our ground control server.[1] When the command is received, the drone should ascend to the desired test altitude and being to hover. If you are flying manually in altitude hold mode, you should switch over to autonomous (Nano-based) control.

2. **Stationkeeping Test**

   Once the TA confirms that your drone is able to maintain a (roughly) stable hover, the ground control server will send a *TEST* command, along with a test identifier. This is when the clock starts (for 30 seconds)—the TA will begin collecting a ROSbag of Vicon positioning data for offline analysis and scoring. The drone should maintain the stable hover with a fixed heading (orientation) and also maintain the same position above the ground surface.

3. **Descend and Land**

   After the test time has elapsed, your drone will receive a *LAND* command from the ground control server. At this point, the drone should descend for a soft landing (under autonomous or manual control). The ascent and descent segments are not part of the test and are not scored.

The first two steps of this procedure are illustrated in Figure 1. Importantly, at any time, your drone may receive an *ABORT* command, indicating that the test should be aborted for safety reasons.

Part I: Flying with Vicon Position Aiding

For the first part of the challenge task (worth 5% of your overall grade), your drone will have access to positioning data from the Vicon motion capture system. We will attach our 3D-printed Vicon marker holder to your drone prior to the test.

The Vicon system is accurate enough that it can be considered effectively 'noise free,' and your control algorithm should leverage this accuracy. Connection to the Vicon transform (TF) stream/channel will be via ROS, but alternatives are possible if your team elects to use a different setup.

Part II: Flying with On-Board Sensing Only

For the second part of the test, no Vicon data will be available once the *TEST* command is sent. It will be up to your team to determine how best to maintain a stable hover. You may consider, for example, implementing a simple optical flow-based feedback controller, or using the T265 tracking camera.

[1] Full details about the ground control server will be available in a separate document in the ROB498-flight repository.

Parameter	Description	Value
θ_p	Primary heading goal (desired $\pm$ maximum deviation).	$0^\circ \pm 5^\circ$
θ_s	Secondary heading goal (desired $\pm$ maximum deviation).	$0^\circ \pm 10^\circ$
r_p	Primary horizontal position goal (maximum deviation).	15 cm
r_s	Secondary horizontal position goal (maximum deviation).	25 cm
d_p	Primary altitude goal (desired $\pm$ maximum deviation).	150 cm $\pm$ 10 cm
d_s	Secondary altitude goal (desired $\pm$ maximum deviation).	150 cm $\pm$ 20 cm
τ	Flight test duration (i.e., total hover time).	30 s

Table 1: Primary and secondary flight test objectives, specified by the maximum allowable deviation from the initial pose at the start of the test.

If you choose to use a downward-pointing camera, note that all tests will take place over a textured surface (dense, painted EVA foam panels on the ground) to ensure that there is sufficient visual information (i.e., features) available for motion tracking (sample images to follow on Quercus).

Task Scoring

Your team may schedule *up to three* tests for this task during the testing window; of course, if your team successfully demonstrates the required functionality during the first test session, you may immediately move on to the next challenge task. Scoring must be quantitative rather than qualitative; as such, our scoring function is based on the amount of time (as a percentage of the total flight duration of 30 seconds) spent within each of the zones. You should consider the parameters in Table 1 as bounds on the primary and secondary flight zones: the centre-forward definition of the zone will be determined by the pose of your drone at the time when the *TEST* command is sent over the wifi link.

For example, assume that your drone begins the test period at a position of (3.45 m, 2.87 m) and at a heading angle of 46°, relative to the reference frame defined by the Vicon system. This position will be your 'zero' point (your initial pose reference). The absolute value of the position and orientation do not matter, we are only testing the ability of your drone to *hold its initial position for a period of time*. The one exception to this is the altitude bound, which is absolute (because crashing into the floor, or the ceiling, is bad).

Your drone is considered to have drifted outside of the primary zone *whenever* any of the individual criterion in Table 1 is violated. Again, for example, imagine that your drone moves 15 cm radially away from its initial x-y position but maintains a heading within 2° of its original heading. In this case, the drone would be in the *secondary* zone for a portion of the test, and points would be allocated accordingly.

The teaching team (TA and company) will collect a `rosbag` of data for the entire flight (for Part I and Part II) and will perform post-hoc analysis to determine your score. The scoring equation for each part is the same, and is:

$$S = \left(\frac{t_p}{\tau} + \frac{1}{2} \frac{t_s}{\tau} \right) \times 5\%$$

Here, the sum of t_p, the time spent within the primary zone, and t_s, the time spent in the secondary zone, cannot exceed τ. However, the sum may be less than τ; *if your drone drifts beyond the secondary zone at any time, you will receive zero points for the period that it is outside of the secondary zone*. You should implement a feedback controller to ensure that the drone attempts to move back to its initial pose, correcting for drift.