TÉCNICO LISBOA

Unmanned Aerial Vehicles

M.Sc. in Aerospace Engineering

2022/2023 - First Semester

Estimation of Motion Variables of the Parrot AR.Drone

Laboratory guide

November 2022

1 Introduction

1.1 Objectives

The exercises proposed in this laboratory focus on the design, implementation, and analysis of several estimation solutions for the roll and pitch angles of a quadrotor, both in simulation and with experimental tests using the Parrot AR.Drone. For that, the following items are addressed:

1. Modeling and characterization of the motion sensors;
2. Raw computation of roll and pitch angles;
3. Design, implementation, and analysis of steady-state Kalman filters without bias compensation;
4. Design, implementation, and analysis of steady-state Kalman filters with explicit bias compensation;
5. Study of the properties of complementary filters;
6. Implementation of an advanced solution for integrated roll, pitch, and rate gyro bias estimation.

1.2 Organization and timeline

There are two kinds of questions: theoretical questions, marked as (T), and laboratory questions, marked as (L). As a guideline, all theoretical questions should be solved before the laboratory sessions, and the simulations and experiments should be completed during the sessions.

A single-column report in pdf format with no more than 15 pages together with the matlab script files (.m), containing the code developed to answer the questions, must be submitted through fenix in the designated dates (check the course's website). Please use the cover page available in the course's website (or similar with the same information) as front page.

1.3 Academic ethics code

All members of the academic community of the University of Lisbon (faculty, researchers, staff members, students, and visitors) are required to uphold high ethical standards. Hence, the report submitted by each group of students must be original and correspond to their actual work.

2 Setup and experiments

The second laboratory resorts to some upgrades of the previous DevKit package, namely:

1. The starting script is `start_here_NAV.m` This script has a new feature that allows to replay data collected during the experiments with the drone.

2. The modes of operation in `(2) Wi-Fi control` now store in a workspace variable named `navdata` the navigation data received from the drone at a default frame rate of 200 Hz. You can also access previously acquired data sets by selecting the option `(3) Replay from stored data`.

3. The block that decodes the structure `navdata` is now an extended version, providing access to the data sampled by the motion data sensors, namely accelerometers and rate gyros.

The following experiments are considered to evaluate the various estimation solutions:

- *Experiment A:* Collect sensor data with the vehicle at rest, without disturbances from the electric motors. Run `Wi-Fi control` with the `Hover` option for about 30 seconds without activating the `take-off` command.

- *Experiment B:* Collect sensor data with the vehicle on the ground but with the rotors spinning. Run `Wi-Fi control` with the `Hover` option, apply pressure on the hull to prevent the vehicle from taking off, send the `take off` command, wait for 30 seconds, and send the `land` command.

- *Experiment C:* Collect sensor data with the vehicle at hover. Run `Wi-Fi control` with the `Hover` option, send the `take off` command, wait for 30 seconds, and send the `land` command.

- *Experiment D:* Collect motion sensor data with the vehicle responding to a step in the pitch reference. Perform the necessary changes in the simulink model `ARDroneHover.slx` to define a step reference for the pitch angle as in the experiment conducted for Laboratory 1.

- *Experiment E:* Collect motion sensor data during a short mission of the UAV. Perform the necessary changes in the simulink model `ARDroneHover.slx` to define a reference for the y coordinate with two waypoints. The initial position of the vehicle defines the origin a reference frame. After taking off, the vehicle should move to the position $[0; 0; 0.75]$ m, then to $[0; 1; 0.75]$ m, then back to $[0; 0; 0.75]$ m, and then land. Allow for a 5 second interval between changes in reference.

3 Modeling and characterization of the sensors

The main goal of this section is to model sensors and characterize the sensor noise and other disturbances that corrupt the motion sensor measurements.

3.1. **(L)** Characterize the accelerometers and rate gyro disturbances that are present on the measurements, by computing the mean and covariance of the measurements obtained in *Experiment A*.

3.2. **(L)** Repeat the previous computations for *Experiment B*. Discuss the new sources of disturbances leading to the increase of uncertainty on the measurements.

3.3. **(L)** Repeat the previous computation for *Experiment C*. Discuss the new sources of disturbances leading to the increase of uncertainty on the measurements.

3.4. **(L)** To later evaluate filtering effects, compute the pitch and roll inclinometer data from the accelerometer measurements, and identify these estimates as raw pitch and roll measurements. Comment the results.

4 Kalman filters

The main goal of this section is to design, implement (both in simulation and with experimental tests), and evaluate simplified Kalman filters for the roll and pitch angles of a quadrotor.

4.1. **(T)** + **(L)** Design, implement, and evaluate a steady-state Kalman filter for pitch estimation based on measurements of the pitch inclinometer and on rate gyro measurement w_{ym}. To tackle the filter gain computation you can use `kalman()` or `estim()` Matlab commands.

4.2. **(T)** For constant Kalman gains obtain the transfer function from pitch inclinometer measurement θ_m to pitch estimate $\hat{\theta}$ and the transfer function from the rate-gyro measurement w_{ym} to pitch estimate $\hat{\theta}$. Comment on the results.

4.3. **(T)** Discuss the impact of changing the tuning parameters Q and R.

4.4. **(T)** + **(L)** Repeat the Kalman filter design, implementation, and evaluation procedure augmenting the system with an extra state to capture the bias term on the rate gyro. For that purpose, assume that

$$\dot{b}_y = 0$$

and

$$w_{ym} = q + b_y$$

Suggestion: In the simulation phase, set an artificial bias on the measurement and plot the bias b_y vs. bias estimate $\hat{b}_y$ to guide the tuning of the filter.

4.5. **(T)** Check if the previous filters are complementary. Discuss the advantages and limitations of this class of filters.

4.6. **(L)** Discuss the results obtained and relate them to the different conditions of operation specified in experiments A to E.

4.7. **(T)** + **(L)** Repeat the previous questions for the roll estimation.

5 Integrated roll and pitch estimation

(L) Study and implement the solution proposed in P. Batista, C. Silvestre, and P. Oliveira, *"Partial Attitude and Rate Gyro Bias Estimation: Observability Analysis, Filter Design, and Performance Evaluation,"* International Journal of Control, vol. 84, no. 5, pp. 895-903, May 2011.

Note that you are only required to implement a Kalman filter for the nominal system (2) of the above-mentioned reference to partially estimate the attitude of the vehicle together with the bias of the three rate gyro components.