Unmanned Aerial Vehicles

M.Sc. in Aerospace Engineering

2017/2018 - Second Semester

Estimation of Motion Variables of the Parrot AR.Drone

Laboratory handout

April 2018

1 Introduction

1.1 Objectives

The main goals of this laboratory are the design, implementation, and analysis of several estimation solutions for the roll, pitch, and height 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, pitch, and heigth;
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

The laboratory component will take place in two sessions. At the end of the first session, the students must deliver the first report, in person. The second report must be delivered within one week after the second session. This second report is to be dropped in the mailbox of the *Área Científica de Sistemas, Decisão e Controlo, Piso 5 da Torre Norte.*

The first report consists simply of answers to all theoretical questions **(T)**. In the second report the simulation and experimental results should always be commented and, whenever appropriate, these conclusions should be supported by appropriate analytical computations.

Both reports should use the cover available in the course's webpage as a frontpage. The first report may be handwritten but electronic form is preferred.

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 on the experiments with the drone.
2. The modes of operation in `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.
3. The block that decodes `navdata` is now an extended version, providing access to the data sampled by the motion data sensors, namely accelerometers, rate-gyros, and altitude. Altitude is obtained from vision and from ultrasound range altimeters.

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

- *Experiment A:* The purpose of this experiment is to collect motion sensor data with the vehicle at rest, without disturbances from the electric motors. Thus, set the drone to work on the floor and run the `Wi-Fi control` for about 30 seconds. Do not activate the take-off command.
- *Experiment B:* The purpose of this experiment is to collect motion sensor data with the vehicle grounded but with the rotors spinning. To perform the experiment, run the `Wi-Fi control`, send the command `take off` but physically block the vehicle from taking off by applying pressure on the hull. Run the experiment for about 30 seconds.
- *Experiment C:* The purpose of this experiment is to collect motion sensor data with the vehicle at hover in the presence of disturbances, namely from the electric actuators and the aerodynamic flow around the UAV. To perform the experiment, set the drone to work on the floor, run the `Wi-Fi control` and select `Hover`. Then, send the take off command, let the vehicle hover for about 30 seconds, and then command to land.
- *Experiment D:* The purpose of this experiment is to collect motion sensor data during a short mission of the UAV. To perform the experiment, set the drone to work on the floor, run the `Wi-Fi control`, and select `Waypoint tracking`. The data corresponds to a square shape trajectory with a 1.5 m each size, with a total duration of 30 seconds. Study the corresponding m-file to see how the waypoints are defined. Do not forget to set `commands enabled` to enable reference commands (which are required for way-point following). Note that the starting and finishing positions are identical so that it is easier to assess the navigation errors at the end of the mission.

Do not forget to save the data to different files after each experiment.

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 on the motion sensor measurements.

3.1. **(L)** Characterize the accelerometers, rate-gyro, and altitude 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 *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 *Experiment C*. Discuss the new sources of disturbances leading to the increase of uncertainty on the measurements.

   3.3.1. **(L)** Notice that altitude data obtained during flight experiments may contain invalid entries. Propose and implement an adequate strategy to discard these entries.

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.

   Suggestion: To guarantee that the attitude representation is coherent with the results, you can perform extra experiments, by manually changing the pitch and roll of the quadrotor with the propellers at rest.

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, pitch, and height 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 to pitch estimate and the transfer function from the rate-gyro w_{ym} measurement to pitch estimate. Comment 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

$$w_{ym} = \theta + b_y$$

Suggestion: In the simulation phase, set an artificial bias on the measurement and plot the bias vs. bias estimate to help to tune 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)** Comment on the results obtained.

4.7. **(L)** Now that better insight into the sensors and the dynamic systems involved has been acquired, design an experiment to illustrate the characteristics of the solutions obtained.

Experiment E: The purpose of this experiment is to collect motion sensor data during a short mission of the UAV. Set the drone to work on the floor, run the `Wi-Fi control`, and select `Waypoint tracking`. The total duration of the mission should not exceed 60 seconds. DO NOT FORGET to save the data to a new file.

4.8. **(T)** + **(L)** Repeat the previous questions for the estimation of the roll and height.

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.