TÉCNICO LISBOA

Unmanned Aerial Vehicles

M.Sc. in Aerospace Engineering

2020/2021 - Second Semester

Estimation of Motion Variables of the Parrot AR.Drone

Laboratory handout

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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, 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

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 session, and the simulations should be completed during that session. The laboratory component will resort to a set of data packages that were recorded in the past.

A report in pdf format 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 planning). Please use the cover page available in the course's webpage 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 <u>original</u> and correspond to <u>their actual work</u>.

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 will not be using this functionality. Instead, select `(3) Replay from stored data` to access the pre-recorded data sets that are provided.

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, rate-gyros, and altitude. Altitude is obtained from vision and from ultrasound range altimeters.

The following experiments are considered 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. The drone was set to work on the floor and `Wi-Fi control` ran for about 30 seconds. Take-off command was not activated.

- *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, the command `take off` was sent through `Wi-Fi control` but the vehicle was physically blocked from taking off by applying pressure on the hull. The experiment lasted 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, the drone placed on the floor, and the take off command was sent through `Wi-Fi control` using the `Hover` option. The vehicle hovered for about 30 seconds, and then the command to land was sent.

- *Experiment D:* The purpose of this experiment is to collect motion sensor data during a short mission of the UAV. To perform the experiment, the drone was placed on the floor and the `Waypoint tracking` option in `Wi-Fi control` was selected. 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. 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.

Data for each of these experiments is provided along with the upgraded version of the DevKit package.

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 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, 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

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

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

4.7. **(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 to partially estimate the attitude of the vehicle together with the bias of the three rate gyro components.