Data-driven dynamical model learning mini-project

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Lab 1

Data-driven control-oriented identification of vertical dynamics of a mini-drone

The work done during this mini-project will be noted in a report and marked. You are asked to follow the instructions given below to write your report.

Instructions for writing your report

A report is a scientific document. It should be self-contained: that is, someone who has never seen the lab instructions should be able to understand the problems that you are solving and how you are solving them. All the choices you have made should be clearly motivated. Comment and explain all your plots so as to make it easy to follow your way of thinking.

Your report can be written in French or in English but **do not mix both languages**. It should be organized as follows:

- a general introduction specifying the objectives of the lab
  - ▷ a brief presentation of the expected outcomes
  - ▷ a description of the obtained results in graphical and or numerical form
  - ▷ a critical analysis of the results
  - ▷ a general conclusion explaining what has been understood during the lab and any difficulties encountered.

When working in an experimental environment, results are always important, BUT so is your ability to communicate the information with others. Any work you will submit should be neat, well-organized and easy to understand. Your report is a demonstration of your ability to understand the course you are studying as well as a reflection of your organizational skills.

Sending your report to the tutor

The report should be written in groups of two students and sent by email to the tutor in the form of a single pdf format file attached to the message by the deadline given by your instructor during the mini-project. Please indicate the following "subject" for your email when you send your report to the tutor:
`SYSID_report_Names`

This mini-project aims to offer you hands-on experience in data-driven system identification for control design of a mini-drone.

The drone we will be using is the Tello mini-drone controlled via Wi-Fi.

The objectives are the following:

1. to learn about the basics of a drone including its components and how the drone flies;
2. to identify a linear low-order model from real data

Safety warning message: during this lab, you must exercise extreme caution when handling your mini-drone. Ensure that you follow all safety instructions. Unauthorized maneuvers or negligence can lead to injuries or damage to equipment.

1.1 The Tello mini-drone

Prior to operating any experimental system, it is imperative to familiarize yourself with the various components of the system. Part of the process involves the identification of the individual hardware components, including its sensors and actuators.

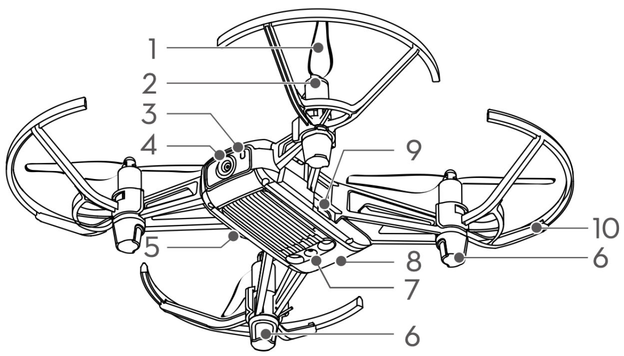
The Tello mini-drone is a small quadcopter that features a vision positioning system and an onboard camera as shown in Figure 1.1.

Figure 1.1: Tello mini-drone from DJI

Using its vision positioning system and advanced flight controller, it can hover in place and is suitable for flying indoors. Its maximum flight time is about 13 minutes. Whenever you can, connect the TELLO drone to the USB port of your PC to recharge the battery for the next test.

1.1.1 Main components

The main components of the mini-drone are presented in Table 1.1.



1. Propellers	6. Antennas
2. Motors	7. Vision positioning system
3. Aircraft status indicator	8. Flight battery
4. Camera	9. Micro USB port
5. Power button	10. Propeller guards

Table 1.1: Main components of the Tello mini-drone

1.1.2 Identification of the physical system components

Visit the official website `www.ryzerobotics.com/fr/tello` and answer the following questions from the TELLO User guide.

1. Present the onboard actuators, explaining their role in flight control.
2. Present the onboard sensors for altitude measurement and IMU (Inertial Measurement Unit) sensors for orientation and acceleration measurements.
3. Is there a GPS ?
4. How much does the mini-drone weigh?
5. Overview the communication protocol used to interface with the TELLO drone from a PC or a MAC, focusing on sending control commands and receiving sensor data.

1.2 Understanding the basics of quadcopter control

There are many types of Unmanned Aerial Vehicles (UAVs), but the TELLO mini-drone used is a quadcopter. A quadcopter is a type of helicopter which has 4 rotors. Each one of them produces thrust and torque at the same time.

To understand how a quadcopter flies, it is very important to have the concept of 6-degrees of freedom (6-DOF).
The 6 degrees of freedom is a representation of how an object moves through 3D space by either translating linearly or rotating axially as shown in Figure 1.2.

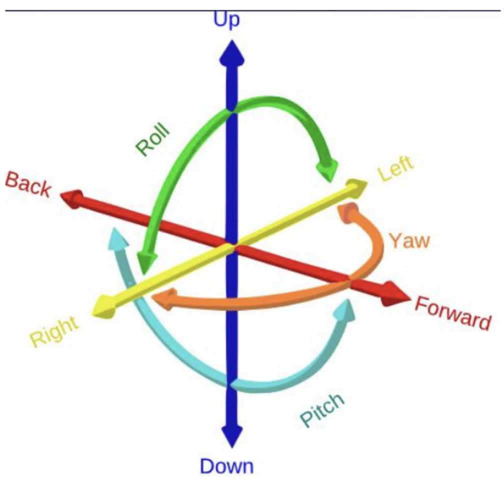


Figure 1.2: The 6 degrees of freedom

Specifically, the object can move in three dimensions, on the X, Y and Z axes (left/right, forward/back, up/down), as well as change orientation between those axes though rotation usually called yaw, roll and pitch which are defined below

- **Yaw (lacet)**: the drone rotates in place, flat, around its center of gravity. This can be likened to making a "No" sign with our head.
- **Roll (roulis)**: the drone behaves as if it wanted to roll. This can be likened to tilting our head left or right.
- **Pitch (tangage)**: the drone behaves as if it wanted to rear up or dive forward. This can be likened to making a "Yes" sign with our head.

Impact on the motors

A quadcopter is equipped with four rotors, two of which rotate clockwise and two of which rotate counterclockwise.

Hovering

When all rotors spin at exactly the same speed, the forces on the multi-rotor are equal, and the quadcopter will hover in place (fly and stabilize itself in midair).

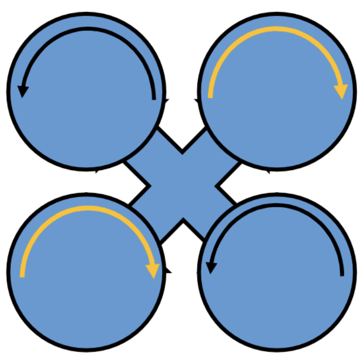


Figure 1.3: Principle of howering

For the quadcopter to be able to fly and stabilize itself in midair, the total thrust produced by the 4 rotors should be equal to the gravitational force subjected to the system.

Ascending or descending

To make the quadcopter ascend, the thrust is increased on all four rotors equally and conversely to descend.

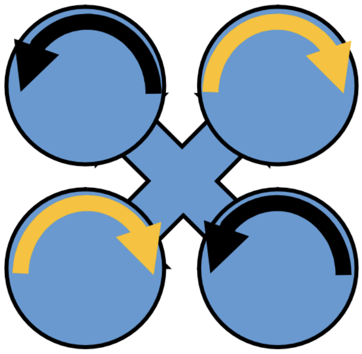


Figure 1.4: Principle of ascend and descend

Yaw

To rotate the quadcopter, we need to increase the thrust of two of the four motors. So, if we want to turn clockwise (right), we would increase the thrust towards the two rotors turning counterclockwise (left) and vice versa to turn in the other direction.

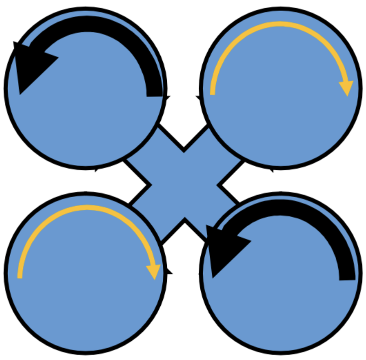


Figure 1.5: Principle of Yaw

Roll and Pitch

Finally, if we need to move forward/backward or go left/right, we will decrease the thrust of the rotors in the direction we want to move and increase the thrust towards the opposite rotors.

For the pitch movement, the rotation speed of the front motors is increased while that of the rear motors is decreased.

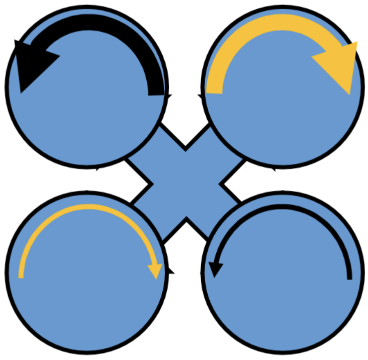


Figure 1.6: Principle of Pitch

1.2.1 Videos to know more about drone control

To known more about the basics of drone control, you can watch Brian's Douglas introduction videos to this topic:

Drone Simulation and Control, Part 1: Setting Up the Control Problem

Drone Simulation and Control, Part 2: How Do You Get a Drone to Hover?

1.2.2 Manual control

From the first video, we know that by manipulating the four motor speed in specific ways through the Motor Mixing Algorithm (MMA), thrust, roll, pitch, and yaw can be controlled directly and so we are able to control the drone in 3D space. This is the open-loop control configuration as shown in Figure 1.7 that you have used for controlling the TELLO with the App on your mobile device.

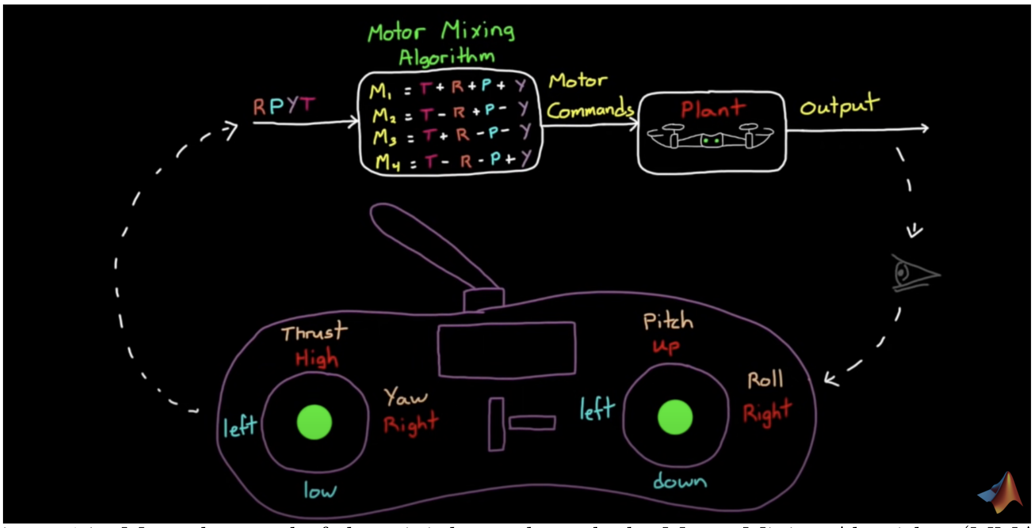


Figure 1.7: Manual control of the mini-drone through the Motor Mixing Algorithm (MMA)

1.2.3 Full closed-loop control

From the second video, we know that the full closed-loop control architecture is quite complex and looks like the one shown in Figure 1.8 with several different control loops and 6 different PID controllers.

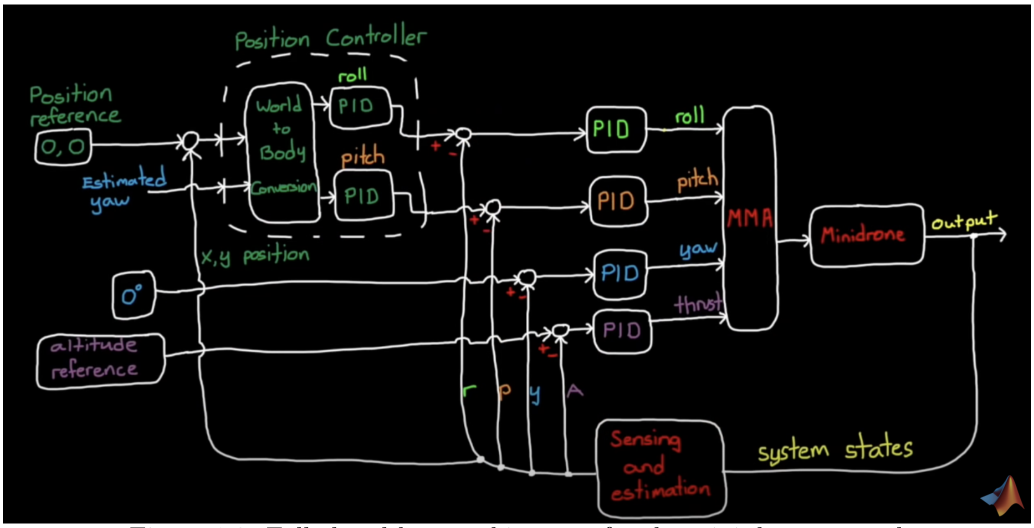


Figure 1.8: Full closed-loop architecture for the mini-drone control

1.3 Altitude control of the TELLO mini-drone

During this lab, the goal is to consider just a single loop, the altitude loop. Remember, this is independent of the other loops so we can tweak and adjust altitude without affecting roll, pitch, or yaw. To make sure they are out of the equation completely, we will just set the commands to 0 for roll, pitch, and yaw as shown in Figure 1.9.

The goal is therefore to determine a model that will be used to design a control for adjusting the thrust to get the desired altitude for the mini-drone. If we are able to measure the drone altitude then we can feed it back to compare it to an altitude reference. The resulting error is then fed into a PID controller that is using that information to determine how to increase or decrease thrust.

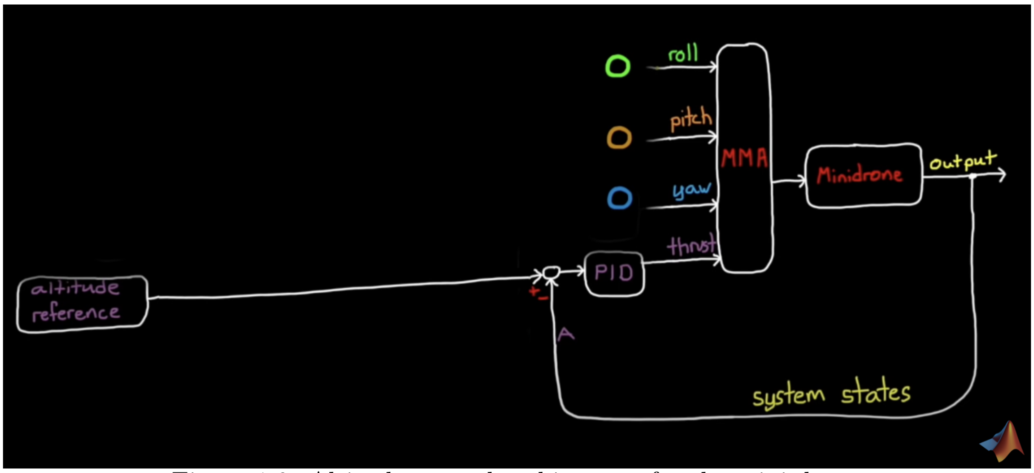


Figure 1.9: Altitude control architecture for the mini-drone

The input and output of the mini-drone altitude control system are:

- $u(t)$: motor speed in % (related in some way to the thrust generated by the 4 motors);
- $y(t)$: altitude in cm or vertical position along the Z axis of the mini-drone.

1.3.1 Download of the files required for the lab

1. Download the zipped file `Sysid.zip` from the course website and save and unzip it in your `Documents/Matlab/SYSID/` folder.
2. Start Matlab.
3. Important ! By clicking on the browse for folder icon , **change the current folder of Matlab so that it becomes your `Documents/Matlab/SYSID` folder** that contains the files needed for this lab.
4. In the Current Folder window of Matlab, click right on the folder `Documents/Matlab/SYSID` and select `add to path the selected folder`.
5. Double-click on the folder `SYSID` so that it becomes your current folder. You should see the `.m` and `.py` files needed for this mini-project.

1.4 Vertical dynamic model identification

The determination of a model is a first crucial step for the design of a feedback control system.

1.4.1 Basic step response experiments

1.4.1.1 Recording of the altitude step responses of the mini-drone

This experiment is carried out in open-loop/manual mode, i.e. there is no feedback control to the altitude. The input command alternates between a positive amplitude (up), a zero amplitude (hover), a negative amplitude (down), and then back to zero amplitude.

Warning Remember that the experiment is conducted in open loop. If there are disturbances, like small, invisible airflow, they will induce a little roll or pitch changes into the system, the thrust will then not only adjust altitude but also create some horizontal motions and the mini-drone will start to move away from the centre of the room and possibly crashes into the net. This is why it is recommended to close the door of the room when the open-loop control test is carried out.

1. Go to the room C335 with your mini-drone.
2. Log in with the following account: .\`admin_IA2R`
3. Ask the instructor to enter the password.
4. Go to the `C:/temp/Tello/SYSID/` folder.
5. Open the file `Tello_step_test_in_OL_4_altitude.py`.
6. Press once the power button to turn the mini-drone on.
7. Connect your mini-drone to the WIFI.
   Each mini-drone can be connected to the computer in room C335 when it is turned on via WIFI. You can identify your mini-UAV by removing the battery and looking inside the battery case. You should see written on a white paper
   WIFI: *TELLO-**XXXXXX*** where the six ***X*** represent the ID of your mini-UAV.
8. Place your Tello in the middle of the room with the in-front camera facing you.
9. Go outside of the cage.
10. Close the door of the room.
11. Run the python file. Choose `Select Run without debbuging` and then click on `Trust Workspace & Continue` or `Python debbuger and Yes`.

12. The mini-drone should auto-take off at about 1 m and waits for 3 seconds. Then the command sequence will be sent the rotor speed. The drone should go up to 1,50m and down to about 1m and finally auto-land.
13. If everything went well, a figure will be plotted showing the experimental response data that is also recorded in the file `DataOL_Tello.txt`.
14. Copy the .txt file on a USB key or send it to you by e-mail.
15. Delete the .txt file.
16. Go back to the C212 room.

1.4.2 Plot of the recorded step responses

1. Open Matlab and execute the `dataOL_plot.m` file to get a plot of the recorded data.
2. Determine the quantization step size for both the altitude measure and vertical velocity measure.
3. Use this first and basic test to suggest another experiment design to get more informative data to identify a model for the mini-drone vertical dynamics.
4. Apply the data-driven learning methodology to estimate and validate a model of the mini-drone vertical dynamics.

Note that for this practical case, there is thus "no correct solution (no true model)" to it, but you might use some physical insight to estimate/validate your model.

1.5 Recommendations for the oral presentation

Below is a list of the steps that should be included in your presentation for **b**oth simulation data and real-life mini-drone data you have analyzed:

1. Short description of the mini-drone (input, measured output, etc)
2. Description of the experiment design (type of inputs, dataset available, possible constraints, etc)
3. Description of the raw dataset
4. Data pre-processing (informative data selection, discard of the section with nonlinearity effects, pre-filtering, etc)
5. Model structure selection (method used and results)
6. Parameter estimation (method(s) used and results)
7. Model validation.
8. Conclusion. Discuss the strengths/weaknesses of the identified model(s) and specify which model do you recommend and why.

Your presentation will be limited to 10 mn followed by 5 mn of questions. The number of slides should be therefore limited to 12.

1.6 Troubleshooting

This section provides solutions to some issues you might encounter when using the TELLO drone during your experiments.

1.6.1 Connection issues

If you try to connect to your drone via WIFI and it takes too long with the computer you are using, just run the Python code. If the battery level is printed, then your drone is connected to the computer.

Note that your drone will automatically switch off after 2 or 3 mn. You will need to switch it on and then connect again to the WIFI before executing the Python code.

1.6.2 Calibration issues

If the Python code returns an error message after printing the battery level, it either means that your drone battery is too low (under 10 or 20 %) or needs to be calibrated.

To calibrate your drone, you first need to download the Tello app on your phone from this following link: `www.dji.com/uk/downloads/djiapp/tello`

Then, when you open the App, it will automatically try to connect your phone to a Tello drone which will open your Wi-Fi interface and show you the available devices. Now, choose your drone. As it is not an internet device, your phone might ask you if you still want to connect to it. Confirm and when you are connected, go back until you see the App again.

Once you are connected to your drone and at the main interface of the App, you should see a gear on the top left side of your screen. Click on it then to "More" and to the "..." on the left side. The first option to appear should be "IMU Status". Click on "Calibrate" on the right side of this option and follow the instructions.

If you try to calibrate your drone and the App indicates that it has been calibrated without the need to place the drone in 6 different positions, close the App. Restart your drone and do the whole process again. If it is still the same, then it means your drone cannot be calibrated. Mark it and use another one.

In this calibration instructions, it is said that you should remove the propellers. There is a metallic and flat stick in the plastic bags inside the drone box. It is the Propeller Removal Tool they are talking about. The hollow part is to be used between the propeller and the motor to which it is attached.

Before removing them, mark that there is a pair with marks near the axis. The marked propellers should be at the top left and bottom right of the drone while the unmarked fill the other slots.

Note that this calibration is necessary for the Python code to be uploaded to the drone.

English to French glossary

bandwidth	:	bande passante
crane	:	grue
closed-loop system	:	système bouclé
cut-off frequency	:	fréquence (ou pulsation) de coupure
damped frequency	:	pulsation amortie
damping ratio	:	coefficient d'amortissement
drag	:	traînée
feedback	:	contre-réaction
feedback system	:	système à contre-réaction
hoisting device	:	dispositif de levage
impulse response	:	réponse impulsionnelle
integral wind-up	:	emballement (de l'action) intégral
input	:	entrée
gain	:	gain
heading angle	:	angle de cap
linear time-invariant (LTI)	:	linéaire invariant dans le temps
motor shaft	:	arbre moteur
output	:	sortie
overdamped	:	sur-amorti
overshoot	:	dépassement
pitch	:	tangage
rise time	:	temps de montée
road grade	:	inclinaison de la route
robot arm joint	:	articulation d'un bras de robot
rool	:	roulis
root locus	:	lieu des racines
setpoint	:	consigne
settling time	:	temps de réponse
steady-state gain	:	gain statique
steady-state response	:	réponse en régime permanent
steering	:	direction
step response	:	réponse indicielle
stream	:	courant
yaw	:	lacet

time-delay	:	retard pur
time-invariant	:	invariant dans le temps
transient response	:	réponse transitoire
throttle	:	accélérateur
undamped	:	non amorti
undamped natural frequency	:	pulsation propre non amortie
underdamped	:	sous-amorti