

## Group Coursework 1

In this coursework, we aim at modelling, simulating and controlling a quadcopter drone under different conditions. The following references will be used to guide this exercise:

[1] [A. Gibiansky, Quadcopter Dynamics, Simulation, and Control](#). An approximated dynamic model of a quadcopter and some potential control strategies are described in the following document. **Please read it carefully before starting the exercise.**

[2] [A. Symington, R. De Nardi, S. Julier and S. Hailes, "Simulating quadroter UAVs in outdoor scenarios," IROS 2014](#). Another approach to quadcopter simulation. In this exercise, we will be mainly interested in their proposed wind models (Section III A.) for one of the questions.

A Matlab code baseline (`Drone.m`, `quadcopter_script.m`) is provided to visualise a quadcopter drone simulation. This template does not include any simulation of the quadcopter dynamics nor any controller, which will need to be implemented as part of the exercise.

The submission of this coursework consists of:

- 1) A written report, answering each of the posed questions individually. Explain code and provide evidence of its working condition through plots and/or print outputs as necessary.
- 2) A Matlab code that implements the simulation of a quadcopter and the requested controllers. This includes modified files `Drone.m`, `quadcopter_script.m`, and any other additional auxiliary scripts that are deemed necessary.

## Questions [Total 100 marks]

### Question 1 [Total 20 marks]

Implement a simulation of a quadcopter, following the non-linear model in [1], using the provided MATLAB visualisation code. The quadcopter should have as input the squared angular velocity  $\gamma_1, \gamma_2, \gamma_3, \gamma_4$  of each of the 4 propellers (these variables are defined at the end of page 7 in [1]). Consider the following fixed parameters:

$$m = 0.2 \text{ [Kg]}, \quad I = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0.5 \end{bmatrix}, \quad g = 9.2 \left[ \frac{\text{m}}{\text{s}^2} \right], \quad k_d = 0.1$$
$$k = 1, \quad L = 0.2 \text{ [m]}, \quad b = 0.1$$

Where:

- $m$  is the quadcopter mass
- $I$  is the quadcopter rotational inertia matrix
- $k_d$  is the friction constant (assumed equal for all x-y-z directions)
- $g$  is the gravitational acceleration
- $L$  is the length from each propeller to the centre of the quadcopter.
- $b, k$  are propeller constants as defined in [1]

To demonstrate your simulation is working, implement and run the following experiment:

- Quadcopter starts at an altitude of 5 metres
- From 0 to 2 seconds: set a constant and equal value to all the inputs  $\gamma_1, \gamma_2, \gamma_3, \gamma_4$  that perfectly compensates the gravitational force, so that the quadcopter stays in the same position (no need to implement a controller).
- From 2 to 4 seconds: increase the value of all the inputs by 20%, so the quadcopter starts lifting
- From 4 to 8 seconds set  $\gamma_4$  to zero, the drone should start rotating and eventually fall.

Submit the working code **[10 marks]**. For the written answer: explain how the code works **[5 marks]** and provide plots of the simulation that display position and orientation of the quadcopter over time **[5 marks]**.

## Question 2 [Total 30 marks]

**2a) [10 marks]** The non-linear dynamics of the quadcopter in state-space representation are described in [1], in pages 7 and 8. Derive a linearised model approximation with the shape  $\dot{x} = Ax + Bu$  around any chosen equilibrium point (justify your choice). Then discretise the linear system. You can use Matlab to help with all your calculations in this question (see: `syms`, `jacobian`, `ss`, `c2d`).

**2b) [Total 20 marks]** Implement a second simulation of the quadcopter, but now using the linear approximation derived in 2a. To demonstrate its behaviour, use the same experiment from question 1.

Submit the working code **[8 marks]**. For the written answer, explain how the code works **[4 marks]** and compare the quadcopter position and orientation computed with the linear approximation versus the original non-linear model, by plotting both trajectories side-by-side **[4 marks]**. Comment on the results **[4 marks]**.

## Question 3 [Total 50 marks]

**3a) [Total 25 marks]** Assume the entire state of the quadcopter can be measured by “perfect” sensors with 100% accuracy. Using the quadcopter simulator from question 1, implement a feedback controller that makes the drone perform the following trajectory:

- Starts at (0,0,0)
- Moves up to (5,5,5)
- Stays at (5,5,5) for 10 seconds.
- Passes through (5,-5,10), (-5,-5,6), (-5,5,2), (0,0,2).
- Lands at (0,0,0) safely (less than 0.1 m/s linear velocity when hitting the ground).

Submit the working code **[13 marks]**. For the written answer, explain how the code works **[6 marks]** and provide adequate plots of the simulated quadcopter trajectory in position and orientation **[6 marks]**.

**3b) [10 marks]** Add Gaussian noise to the robot state measurements. Choose reasonable values for the noise magnitude of each state measurement, by identifying examples of sensors that could be utilised to measure them (you can be creative here). Re-run experiment from 3a) and provide plots of trajectories under noisy measurements.

**3c) [15 marks]** Add a wind model to your simulation including two components: a mean wind field from a random direction, and a turbulent wind. You can use the wind turbulence model described in [2]. You will need to define some parameters of the model yourself. Investigate how much wind the controller is able to handle before starting to fail. Re-run experiment from 3a), and provide plots of windy trajectories.