# AMME5520: Project Part 2

Ian R. Manchester

Due date: Sunday 29th of May 11:59pm (end of wk 13)

Submit a report through TurnItIn justifying the design decisions you have made and exploring their consequences. The report must be thorough but concise (feedback from your tutor will be valuable in achieving the right balance).

All matlab code must also be submitted through TurnItIn. While you are encouraged to discuss approaches with tutors and your fellow students, all code, analysis and submitted writing must be entirely your own work.

In addition to the marks detailed below, **10 marks** will be allocated for report presentation and structure, as well as code/simulink readability and structure.

## 1 Lander Control System

This problem continues from the lunar lander question in Part 1. In Part 1 you developed a linearised model and a hover control system. In this part you will extend to a final-phase landing control system, and also investigate more realistic measurement and modelling conditions.

1. (30 marks) Using the linearised model from Part 1, design a controller that drives the system to a safe at a specified location (you can define it to be the origin). Consider the following nominal initial conditions:

   - Altitude 500m, directly above desired landing position.
   - Vertical velocity -10m/s (downwards)
   - Zero horizontal and rotational velocity.
   - Time horizon 60 seconds.

   Design a controller that achieves a safe landing (less than 0.1m/s final velocity, less than 0.1 rad/s rotational velocity) within the time limit while conserving fuel use. Using the full nonlinear model including thrust limits, investigate your controller's ability to achieve safe landing over a range of initial positions and velocities.

   Suppose there are also various unmodelled forces acting on the lander, which you can model as random with a typical size of 0.1 kN. Investigate the effect of such disturbances on the closed-loop system.

2. (25 marks) Suppose now that the full state is not directly measureable, but it needs to be estimated using on-board sensors. The sensors available are:

- An IMU giving apparent acceleration in the inertial frame[1] with typical errors of 0.1 $\text{ms}^{-2}$ and rotational velocity with typical errors of 0.5 rad/s.
- A camera system that can measure the bearing (in body-fixed coordinates) to two beacons which are located 100m to the left and right of the desired landing position. Typical bearing errors are 0.03 radians.

The system is subject to the same random forces as in the first question, and you should also model uncertainty in initial conditions.

Design closed-loop control system combing your controller from the first question with a state estimator based on the above measurements and assumptions, and examine its performance.

3. (10 marks) Real actuation systems typically have time-delays and phase lags due to sensor filtering, internal dynamics, and computation time, and furthermore the precise magnitude of actuation may be difficult to predict. Investigate the robustness of your design to phase and gain uncertainties the actuation system. How much uncertainty can it handle before the safety of the landing is compromised? Can you robustify your control design?

4. **Bonus Question (10 marks)**: investigate the use of model-predictive control to precisely specify actuation constraints and state constraints (e.g. for safety of touchdown).

# 2 Laboratory Report (25 marks)

The second component of the project is a laboratory experiment (or virtual lab for remote-enrolled students) on a rotary inverted pendulum, specified in a separate document.

**In person (CC mode) students:** Each pair of students should write one report (max 5 pages) on your findings for the laboratory questions. This should discuss your derivation of the linearised model, motivate your decision in control design, and evaluation of different controllers. The report should be included in both submissions, and please clearly indicate who your partner was.

**In person (RE mode) students:** Each student should write one report (max 5 pages) on your findings for the virtual lab. This should discuss your derivation of the linearised model, motivate your decision in control design, and evaluation of different controllers.

[1] An accelerometer measures zero acceleration in free-fall conditions. If the IMU is stationary, it measures positive vertical acceleration equal to the gravitational constant.