rEngineering Practice 2 – DBT Exercise

Instructors

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Statement of Objectives

Unmanned robotic systems are increasingly being employed in manufacturing and delivery roles. Designing a successful aerial robotic system to fulfil such roles in the most efficient manner possible, requires striking a good balance of structural, aerodynamic, propulsive and control design.

The objective of this exercise is to design, optimise and build an essential structural member (an arm) for a duo-copter, connecting the payload to its propulsive system, and a control law capable of accurately tracking altitude commands. As a simplification for the real-world scenario, the duo-copter will be constrained to vertical motion, by being attached to a cart mounted on a vertical track, and will have to lift a payload through an unknown mission profile.

The target is to minimize the cost of manufacture, maximize the accuracy which the testing mission profile is followed and minimize the total energy consumed in completing said mission.

The Testing Apparatus

The performance of your structure and control law combination will be tested on a purpose-built testing rig featuring a cart, on which the arms will be mounted, and which is capable of sliding up and down a vertical track. The mounting point is defined as the reference point for the cart's height and is measured using two LiDAR height sensors, mounted at each extreme of the vertical track. The height is defined at zero when the cart is at rest on the bottom of the track and can reach a maximum height of 144 cm.

A picture of the cart and its interface with the track is provided in Figure 1. Each sliding track is not totally frictionless and is known to create a maximum static friction force of approximately 130 g and the pads used have a coefficient of dynamic friction between 0.11 and 0.17 based on the manufacturer's datasheet. The pads are located at the four corners of the mounting cart.

Figure 1

A counterweight is attached on an identical track on the opposing side to allow for control of the effective payload weight to be actuated. For the purposes of this exercise you may assume that the cart effectively weighs approximately 150 g. Two, 1 m-long cable tracks, used to deliver power to the motors, each weighing 190 g (including the weight of the wiring) are attached to the bottom of the cart. Their other end is attached onto the side of the test rig at a height of approximately 33 cm. A closeup picture of the lower part of the apparatus is shown in in figure 5.

A picture of the testing apparatus is provided as Figure 3 and a drawing of the mounting plate, to which the structural member you design must be attached, is seen as Figure 4. A CAD file of the mounting plate, in STEP format is also provided. The structural member you design will be mounted onto the rig using two M6 hex socket button screws. The length (and thus weight) of screw to be used will be dependent on your arm's thickness.

The assembly will be actuated using two contra-rotating propellers, each attached to a brushless electric motor, controlled by an Electric Speed Controller (ESC). The ESC will be powered by a DC power supply capable of supplying a maximum current of 60 A at 12V/15V, and its throttle setting (0-100) will be controlled using the control law designed. Table 1 below details the two motor-ESC-prop combinations that you can select from. Note that both your motors must be of the same type/rating.

Table 1

Motor	Kv	ESC Rating	Motor Mass (g)	ESC Mass (g)	Prop Mass (g)
28-35	1880	40A	76	42	6 (size: 6x3x3)
35-36	1100	45A	114	40	10 (size: 7x4x3)

The thrust output and power requirement for each ESC-motor-prop combination has been tested at static conditions and is given in figure 2.

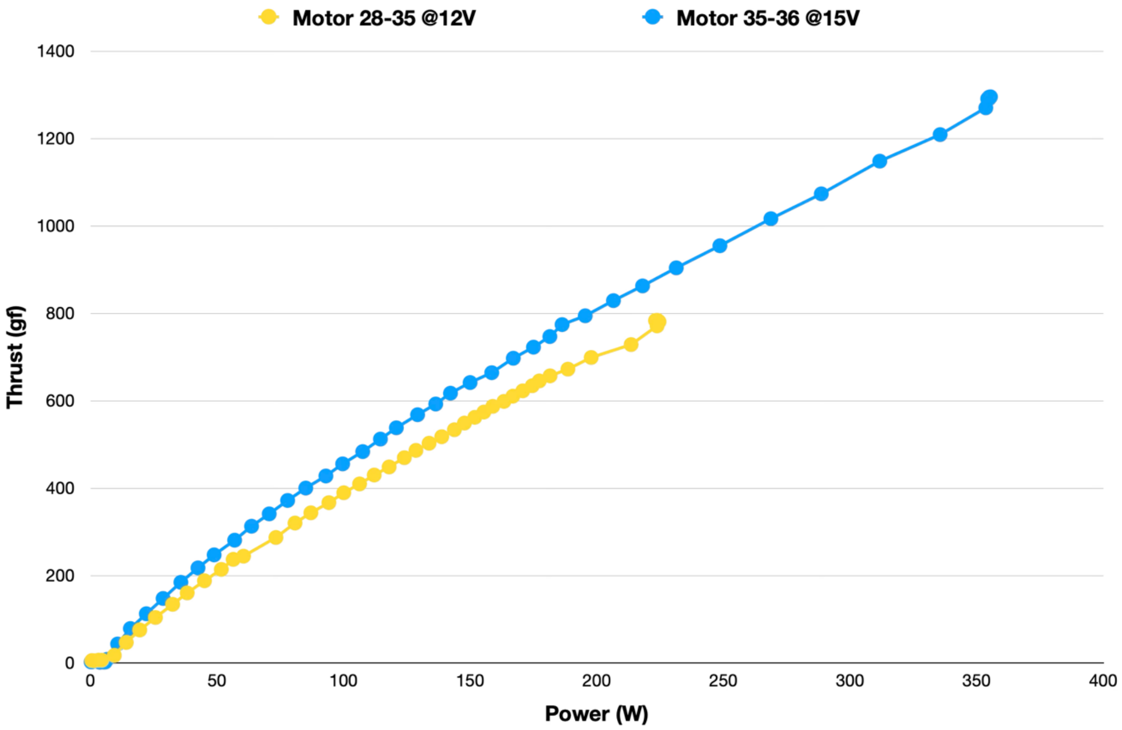

Figure 2

Input and output, such as measurements of height and power consumption, and the control of the throttle setting of the motors, are achieved using an Arduino device, connected to a computer running Simulink via a local network connection.

Figure 3

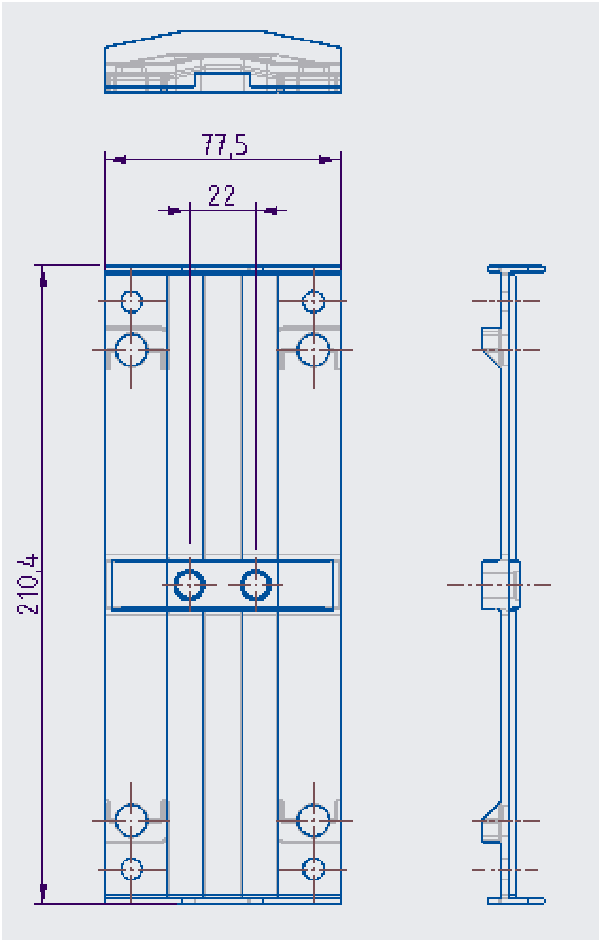

Figure 4

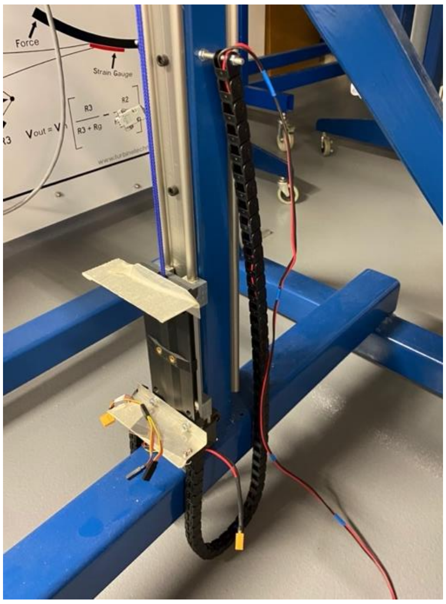

Figure 5

Deliverables from Each Group

1. **An arm for the duo-copter**. The arm should be attachable to the cart using the attachment points provided and must be able to support the motors, propellers and ESC. It must be **at least 55 cm in length for the 28-35 motor** and **at least 57.5 cm in length for the 35-36 motor**, measured as the distance between the central axes of the two motors. The arm may not extend behind the front face of the mounting plate.
   A flat top-plane must be provided for the attachment of the motors, which are attached to the arm using four M3 Socket Cap Screws arranged in the manner shown in figure 6. Mounting screws of lengths between M3x6 and M3x20, in 2 mm increments, will be provided. As shown in figure 6, a further 10 mm diameter clearance hole, aligned to the motor centreline and providing a clearance at least 20 mm below the mounting plane, must be provided**.** Only this single printed component can be in contact with the mounting plate and any screws used to secure it to the cart.

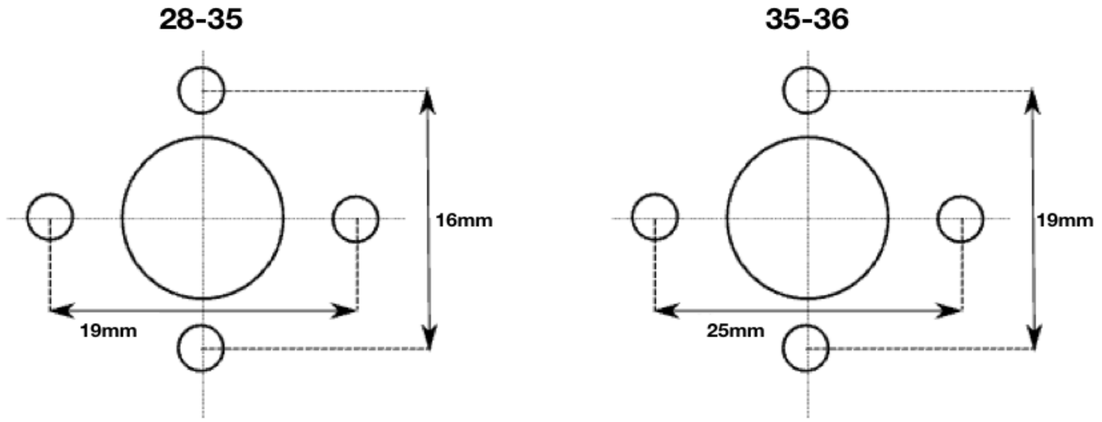

Figure 6

   The arm will be manufactured using additive manufacturing (3D printing) out of ***Nylon*** using the Markforged Mark Two printer. Using the Eiger print software[1] you will be able to fine-tune your print, predict the print cost, printing time, and export it for submission, review and manufacturing. Printing time should not exceed 28 hours. Make sure you enable the option “use brim”. The material properties are available on the vendors’ website[2].

2. **A Simulink block** with the control law coded inside it. The block must accept as inputs the actual height of the cart (given by the LIDARs) and its target height. It must provide only an integer throttle command (0-100), as an output, to drive the two DC motors. Note that both DC motors receive the same commanded throttle.

   You will need to select and tune your control law based on a theoretical model of the system that you must derive. You should test it against a number of sample mission profiles to evaluate your tuning of the controller. Note that given the finite sampling rate of height measurements, the block you create must work with discrete time signals.

3. A completed **risk assessment** for your testing session, identifying key hazards and their severity and proposing appropriate mitigating measures, such that the testing of your design can be conducted safely.

[1] You can create a free account on www.eiger.io/
[2] https://support.markforged.com/portal/s/article/Nylon-White

4. **One report**, described later in this document under "Assessment."

Assessment

1. **Design Report (Wed 28th May) – 70%**

The report will be moderated by peer assessment and should be no longer that 7 pages in length. In this report you will have to present and discuss the following:
- The overall design/multidisciplinary optimization approach your team adopted.
- The structural concept design, including the selection of your design/layout (and reasoning thereof), the method of analysis and your prediction of its performance.
- The control law, including the development of the physics model, the selection and tuning of the controller and your predicted performance (energy and tracking accuracy)

To aid the development of the physical model, we have provided the basic properties of the rig (weight of the cart, approximate coefficient of friction) and the motor-prop combination. We will consider requests for additional information; however we would expect most other parameters to be estimated or assumed based on the information available.

Your Simulink control law block must be submitted at the same time as the report in a single .zip file.

The Eiger printing setup must be defined and finalised by the report submission deadline on the Department's Eiger account. One member per team will be given access for submission. The "submitted" file should be named "DBT2-GXX-N" where XX is your group number and N is the component number (if all components cannot fit in a single print).

2. **Risk Assessment (Friday 6th June) – 5%**

The risk assessment will be assessed based on the following criteria:
- Completeness [40%], all key hazards have been identified and appropriate severity jhas been ascribed.
- Mitigation [30%], the controls proposed are reasonable, realisable and their impact has been correctly assessed.
- Emergency Actions [10%], reasonable procedures have been put in place in case of emergency.
- Presentation & Clarity [20%], the document presented is clear and concise, while providing adequate information for review.

3. **Performance (16th-20th June) – 15%**

Testing will take place over the course of one week. Basic hand tools will be provided to allow you to remove any support material from your 3D printed structures prior to testing. Each team will be offered two tests. A short period will be allowed between the two tests, during which you will be allowed to review the results of test 1 and fine-tune your controller.

The performance will be judged based on the following performance metrics obtained following manufacture and during testing:
- Tracking accuracy [40%], measured in terms of the mean-square deviation from the commanded altitude profile.
- Energy required to complete mission profile [30%], computed using direct measurements of the voltage and the current supplied to the motors.

- Cost of manufacture [30%], in terms of the amount of material consumed for fabricating the arm.

Marks will be awarded based on the group’s ranking in each of the categories above. The highest score resulting from the two runs will be used.