AE352 Team Project Spring 2024

1 Introduction

Quadcopters, also known as quadrotors or drones, are unmanned aerial vehicles (UAVs) that utilize four rotors for lift and maneuverability. Their distinct design with four propellers arranged in a cross formation allows them to achieve vertical take-off and landing (VTOL) and exceptional hovering capabilities. This makes them highly versatile for various applications, from photography and videography over search and rescue missions to defense. They are popular due to their ease of control and come in a range of sizes and functionalities.

Figure 1: Google Gemini rendering of a four axis symmetric drone.

2 Project Aim

Create a dynamical model (digital twin) of a four axis symmetric drone with 4 rotors as shown in Figure 1. Make sure to incorporate both, the dynamics of the center of mass of the drone as well as the rigid body dynamics that describes the attitude of the drone. The state of the drone as well as its attitude can only be altered by a change of speed of each rotor blade which results from a change in motor torque. The latter can be adjusted for each blade/motor individually.

3 Engineering Requirements

Engineering Requirements (ER) for this project are:

- **ER1**: The drone model shall have 6 degrees of freedom (center of mass motion plus attitude) and account for gravity and lift generated from 4 rotors.
- **ER2**: The drone shall be able to modify its state and attitude solely through increasing or decreasing the number of revolutions per second of its 4 rotor blades, as determined by the motor torques.
- **ER3**: The modeled drone shall be able to achieve the performance goals as outlined in section 4, without exhausting its power supply.
- **ER4**: The model as determined through its parameters such as mass, power consumption, engine torques and rotor blade size shall be realistic and implementable, preferably through the use of off-the-shelf parts. In particular, the mass of the drone shall be between 0.1kg and 10kg.

4 Performance Goals

To test the validity of the equations of motion derived in the project, demonstrate the done's capability to achieve the following performance goals:

1. Hover 1m above ground for 2 minutes.
2. Fly in a circle of radius 2m, at an altitude of 1m above ground at a speed of 0.5m/s for at least 1 minute.
3. Launch from ground and ascend vertically until 1m above ground. Move in a straight line 1m above ground at an average speed of 1m/s for 5m, stop (hover), yaw 90 deg to the left, move in another straight line for 5m, stop (hover), land vertically with a speed of no more than 1cm/s.

This is achieved through providing solutions to and visualization (e.g. plots of CoM position and Euler angles versus time) of the equations of motion of your model with corresponding initial conditions.

5 Reporting Requirements

The main deliverable is a team report, which has to fulfill the following reporting requirements to be counted towards your final grade.

- **RR1**: The team shall compile a report containing the following sections:
  1. List of team members,
  2. Introduction to the problem (0.5 - 2 pages),

3. A mathematical description of the problem and the model (5 pages max),
4. A detailed description of the results discussing model performance (5 pages max),
5. A list of actual contributions of team members[1] (1 page max),
6. References (if needed, no page limit).
7. A valid proposal contains all sections and has at least 5 pages.

- **RR2**: The report shall be written in 11pt font (except headings) with 1.0 line spacing.
- **RR3**: The equations of motion for the drone have to be presented as mathematical formulae with all quantities and variables explained in the text.
- **RR4**: Visualization of the model performance shall be provided in the form of plots e.g. for each degree of freedom vs time, or through alternative means of visualization.
- **RR5**: Code that has been developed in the framework of this project has to be submitted via a link to a GitHub repository.
- **RR6**: A complete Preliminary Design Review draft of the report shall be delivered electronically to Gradescope no later than April, 22, 2024, 11:59pm CST.
- **RR7**: Preliminary Design Reviews of 3 other team reports shall be delivered electronically to Gradescope no later than April, 26, 2024, 11:59pm CST.
- **RR8**: The final report shall be delivered electronically to Gradescope no later than May 3, 2024, 11:59pm CST.
- **RR9**: Every team member shall upload copies of their team report and work-plan to Gradescope by the respective deadline. Late submissions will not be accepted.

6 Team structure

A team consists of 3 members. The workload shall be split evenly between team members. The following roles are suggested:

- **Lead Engineer**: Plans and coordinates the project, ensures the project schedule is adhered to, writes the report.

[1] Consult https://casrai.org/credit/

- **Design Engineer**: Responsible for the engineering design and visualization.
- **Implementation Lead / Quality Control Engineer**: Ensures the implementation works and meets or exceeds all formal requirements.

The teams are listed here https://drive.google.com/file/d/1fdOvo_1Zv5pFWzQ0j-tJyVYcSjbofg8t/view?usp=drive_link.

7 Team Project Timeline

March 25, 2024: Announcement of Opportunity (AO) to participate in the AE352 team project. Team composition released.

April 22, 2024: Project draft report due for Preliminary Design Review (peer evaluation).

April 26, 2024: Preliminary Design Review (peer evaluation) due.

May 3, 2024: Team project due for Critical Design Review, i.e. final evaluation and grading.

8 Peer evaluation

The aim of peer evaluation is to provide every team with timely feedback on their project report, which, historically, has resulted in stronger submissions and better final grades. Each team will receive 3 projects from other groups for a Preliminary Design Review (PDR). One PDR report per proposal shall be created. Each PDR report shall evaluate the corresponding project based on final Project Evaluation Criteria (section 9). Moreover, the PDR must contain:

- A brief summary of engineering requirements and performance goals that are not yet achieved.
- A brief written description of at least 2 major strengths of the project that demonstrates engineering excellence.
- A brief written description of at least 2 major weaknesses of the project that need to be improved before final submission.
- A paragraph on how each of the identified weaknesses can be addressed in the remaining time.

PDR reports shall be anonymous and between 1 and 3 pages in length.

9 Project Evaluation Criteria

The following evaluation system shall be used:

1. Compliance with all reporting requirements: Compliant / Non-compliant. Non compliant reports - including incomplete and/or missing PDR reports for other teams - mean this project will count as 0 points towards your final grade.

2. Project quality (100 points):

   (a) Excellent (90-100 points): The project fulfills all engineering requirements (ER1-ER4) and credibly demonstrates that all performance goals are met.

   (b) Good (70-89 points): The project fulfills all engineering requirements (ER1-ER4) and successfully demonstrates all but one performance goal.

   (c) Fair (50-69 points): The project fulfills all engineering requirements (ER1-ER4), and successfully demonstrates at least one performance goal.

   (d) Poor (0-49 points): The project violates engineering requirements (ER1-ER4), and/or cannot credibly demonstrate any performance goal is achieved.

3. Bonus (20 points): The project contains a listing of off-the-shelf components that can be used to turn their model into reality.

10 Instructor Remarks

Participation in this project is highly recommended as it will make up 25% of your final grade. Only complete, original (non-plagiarized) projects that have been delivered on time will count towards your final grade in AE 352. You may assume control of the torques is instantaneous, by changing initial conditions of the dynamical model. Accounting for air drag is great, but not required. Questions to the instructors regarding the team project will be answered exclusively during office hours.

11 Resources

- UIUC propeller testing website
- Amateur drone design website
- Momentum Theory
- Disk Loading

- Attitude Dynamics (for Spacecraft)
- condynsate