RMIT UNIVERSITY

EEET2610 – Engineering Design 3

Design and control of a quadcopter

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What's next...

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Abstract

This document presents the description of the course EEET2610: Engineering design. The course is project-based: the students are invited to form a group of 5-6 members from different programs and to complete a design project. **At the end of the semester, they should successfully build and control a quadcopter with four motors**. This project will greatly contribute in your engineering portfolio, as it combines elements of mechanical design, electrical design, app design, and project management.

The project is divided into smaller projects called work packages (WP). Work packages are further divided into milestones and deliverables. Deliverables are tangible achievements that complete a work package and that are presented to stakeholders. Milestones are more conceptual and correspond to smaller and achievable tasks to achieve a milestone.

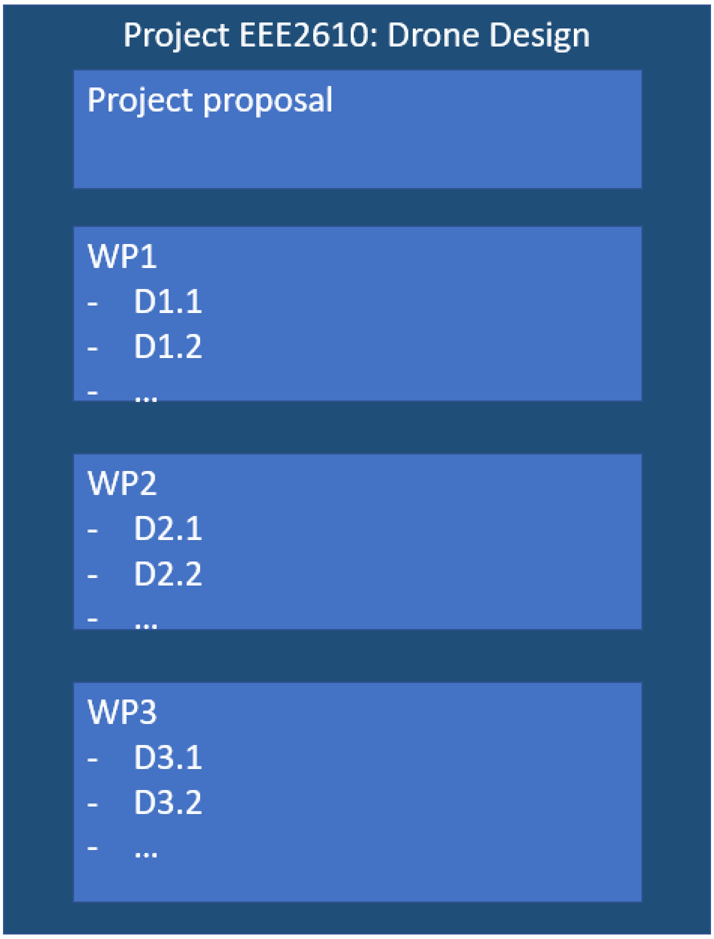

Figure 1: Structure of the project

1. Introduction

Drones and UAVs are becoming more popular in military, agriculture, and surveillance area. In particular, drones may be useful for delivering goods and complete “the last-mile” between the provider and the customer [1]. The understanding of its functioning and challenges start with the study of its components, such as BLDC motors and propellers, which are the core elements of the propulsion of a quadcopter. The project offered in Engineering Design 3 (ED3) is to build and understand the fundamentals of a quadcopter with the design of an inverted pendulum powered with propellers.

Figure 2: Skywalker Quadcopter: a flying ground vehicle [2]

The Skywalker quadcopter shown in Figure 2 is a drone that increases its endurance with a wheel on the floor. The wheel provides support during low-altitude navigation and the thrust can be increased as needed to fly over obstacles. Its principle is based on the two-DOFs inverted pendulum in the pitch and roll orientation. The aim of ED3 is to replicate this mechanism. However, since the semester consists of twelve weeks only, the course focuses on the design and control of drone.

The project is separated into the following work packages:

- *Project proposal*
- *WP1: Design of the drone – CAD Modelling, PCB Design, Assembly guide*
- *WP2: Unit testing – Remote controller, motors, and sensors*
- *WP3: Control and validation of the drone – Integration of the different components together*

It is recommended to spend approximately 6-7 weeks on the project proposal, WP1, and WP2. The WP3 is the most challenging work package and should take approximately 5-6 weeks.

2. Project Proposal

The project proposal is not included in a work package as it corresponds to the prior literature required to understand the context and the background of the mechanism. The project proposal consists in the following section:

- Abstract
- Introduction
- Task description
- Time management with a Gantt chart
- Resources management with a bill of material (BOM)
- Presentation of potential stakeholders
- Risk analysis with a table of risk and probability
- Team introduction and team contract
- Conclusion
- References
- Appendix (if any)

Please refer to Canvas for more details about this assignment.

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3. Work package 1: Design of the drone

The design and development of the drone in the project will be guided. Designing, building, and testing a mechatronic system within 12 weeks is challenging, which is why the task must be well prepared and distributed between the team members.

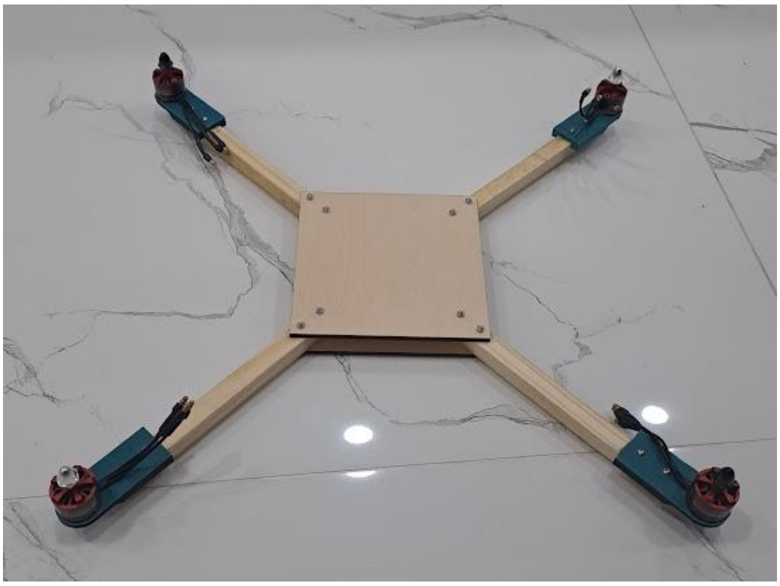

Figure 3: Drone prototype

One of the first tasks is to design the drone. The fundamental design is given in Figure 3. The drone consists of four motors attached on four beams, which are fastened on two plywood plates. The span of the drone is approximately 50cm. The deliverables are given in the following subsections and consist of:

- D1.1: CAD modelling
- D1.2: Wiring diagram and PCB design
- D1.3: Set-by-step assembly guide

Note: for the WP1, you will have help to get started with the project. A design is already made, but as students and future professional, you are required to understand and to improve the initial design.

3.1. D1.1 – CAD modeling

Fusion 360 or SolidWorks can be used. The aim is to understand the size of the drone, its assembly, and the bill of material including all the fasteners required to build the system. This deliverable should include:

- The CAD model of the drone (cf. Figure 4)
- A bill of material
- Technical drawing is not required, but highly appreciated. The key dimension of the drone is mandatory.

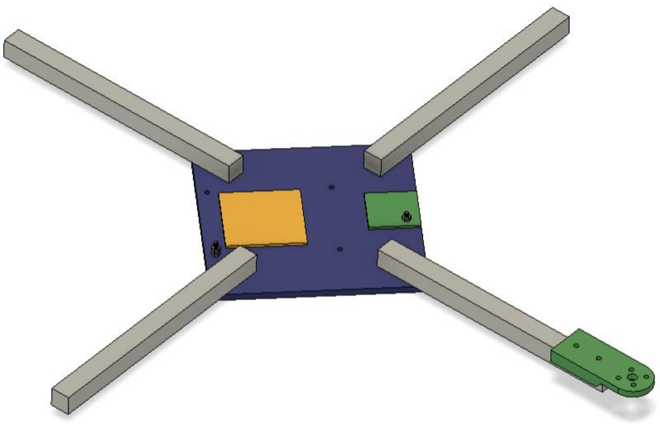

Figure 4: CAD Model of the drone (Fusion 360). The interface (green) at the end of the wood beam has been 3D printed.

3.2. D1.2 – System Wiring and PCB design

There are several electronics components to connect: motors, ESC, microcontroller, GPS module, IMU module, remote controller. A clear wiring diagram must be provided, so that another person can replicate the results. Two programs can be used for the wiring diagram, one is EasyEDA (cf. Figure 5 and Figure 6), the other one is Candence. With EasyEDA, it is possible to wire the different components of the system, configure the routing for a potential PCB, and have a 3D rendering of the final product.

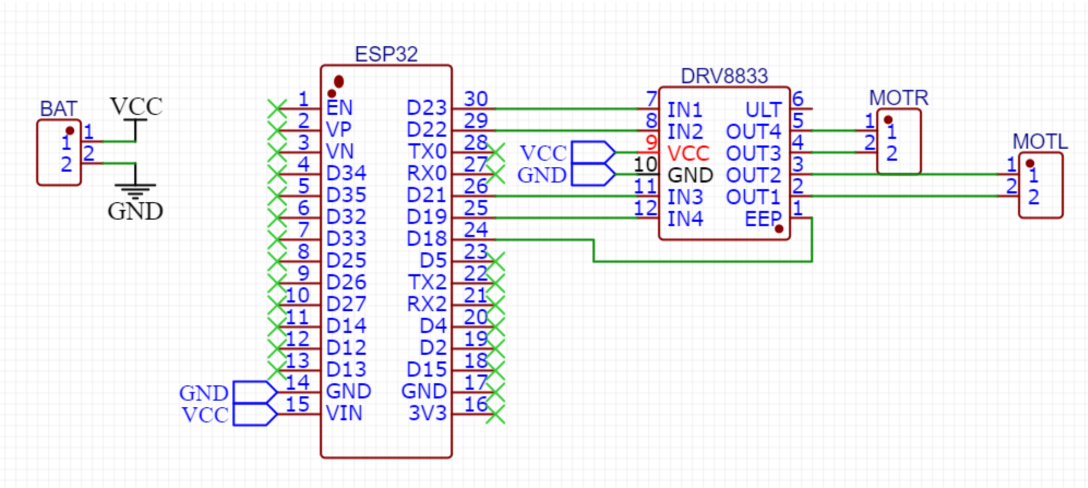

Figure 5: Wiring Diagram example on EasyEDA. Note that this is not the wiring diagram of the drone!

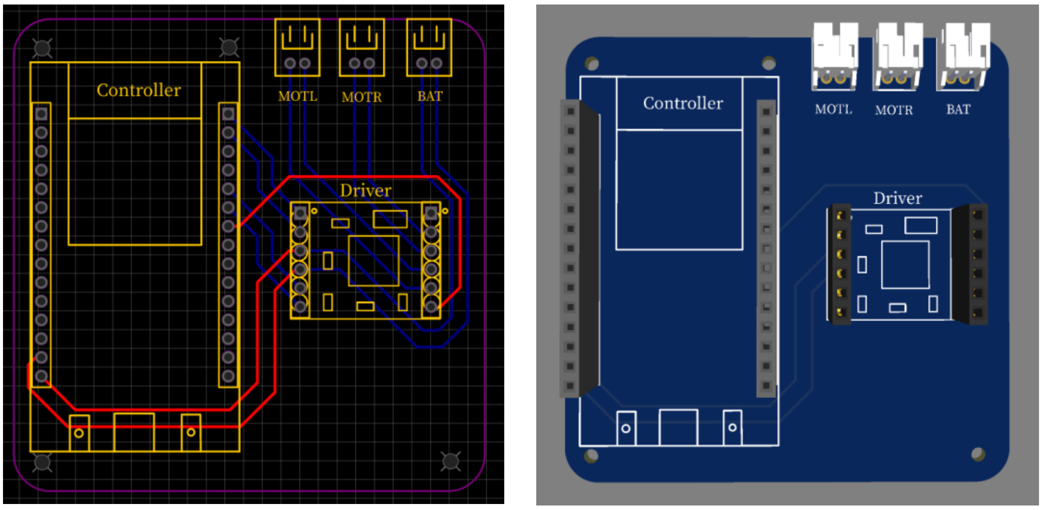

Figure 6: Routing and 3D model of the electronic board.

3.3. D1.3: Detailed step-by-step assembly guide

The assembly of the drone should be documented, mechanical and electrical wiring included. It should include the justification of the components. For example:

> *Wood offer good strength-to-weight ratio compared to steel or aluminum. Carbon fiber is popular for drone frame, but is more expensive, less available, and less flexible in terms of design in the prototyping phase.*

A justification such as “because the lecturer told us so” is not acceptable.

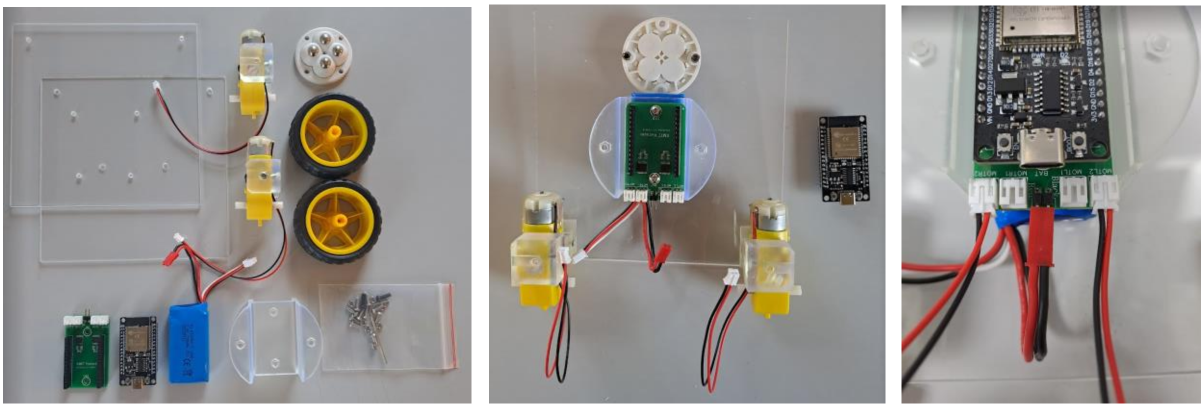

Figure 7: Detailed assembly of a system is performed with many pictures.

4. Work package 2: Unit testing

The drone includes the following components:

- The remote controller, based on a joystick, push button, and potentiometer
- A driving unit, based on a propeller, motor, electronic speed controller (ESC), and a battery
- Sensors, which includes an inertial measurement unit (IMU) and a GPS

All of these components must be tested individually before integrating them together. The deliverables are given as follows:

- D2.1: Design of the remote controller
- D2.2: Calibration and functioning of the driving unit
- D2.3: Testing and validation of the sensors

It is up to the student group to validate the results following a scientific approach with data acquisition and critical thinking. Copy/paste of code without data to back up your claim is not sufficient to confirm the functioning of your system.

4.1. D2.1 Design of a remote controller for the drone

The remote controller is based on a joystick to control the pitch and the roll of the drone. The yaw rate is controlled with two push buttons for positive and negative velocity. The thrust is control with a potentiometer. You should be able to communicate wirelessly through the communication protocol called **espnow**, which is a communication protocol available between two ESP32.

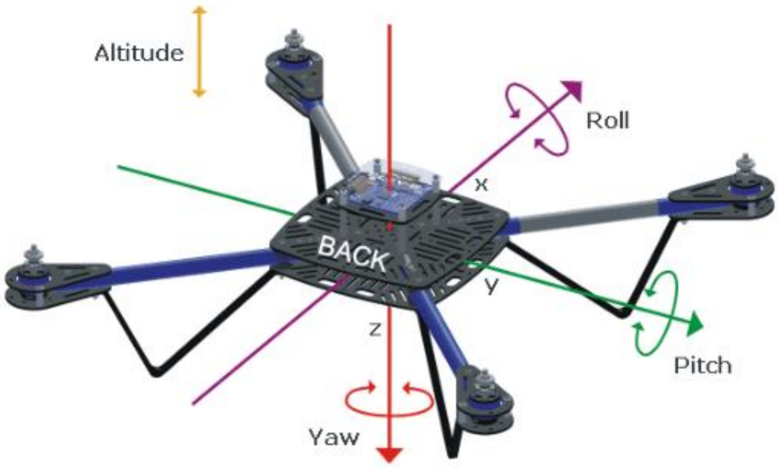

Figure 8: Pitch, roll, and yaw rotation [3]

Figure 9: Joystick, push button, and potentiometer to control the drone.

4.2. D2.2 Calibration and functioning of the driving unit

To drive the drone in the different direction propellers are rotated by motors. The speed of the motor is adjusted with an electric component called an ESC. The ESC is attached to the battery and to the microcontroller, the latter is sending speed command to the ESC. The ESC must be calibrated before used, otherwise it would not work in its entire range of functioning. The students should learn how to control one single driving unit (propeller, motor, ESC, battery), before controlling four of them for the drone.

Warning: the propeller are quite large (1045) and can be dangerous when rotated a high speed. You will acquire the propellers only when you have integrated safety features on your system to turn off the drone rapidly.

Figure 10: A typical ESC and a BLDC motor

4.3 D2.3 Testing and validation of the sensor

There are two main sensors used in this project:

- The inertial measurement unit (IMU) based on the MPU6050. The sensor outputs the angle rate (gyroscope) and the acceleration. The angles (pitch, roll, yaw) must be inferred from the sensors' reading.
- The GPS: the GPS gives the latitude, longitude, and altitude. The students should verify the accuracy of the sensor by performing live position tracking with the GPS.

The student should be able to measure the distance between two ESP32 until the communication through espnow is lost.

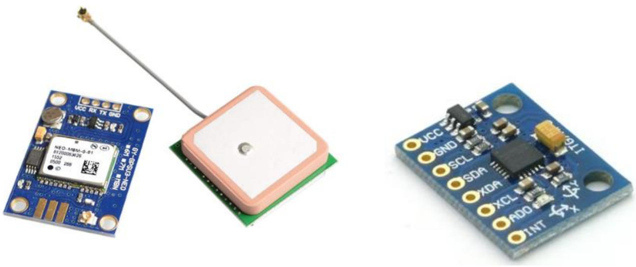

Figure 11: The GPS module with its ceramic antenna and the IMU module based on the MPU6050.

5. Work package 3: Control and validation of the drone

The integration of each individual unit to build the final drone is the most challenging part. The difficulties that the students may experience are listed as follows:

- PID controller: this may be by far the most time-consuming task, in particular the understanding and the tuning of the controller.
- Error in the wiring: even though the WP1 prepare the student of the wiring of the system, it appears that 20% of the group will invert the ground and the battery cable, burning and destroying the entire system.
- Error in the assembly: the CAD modelling represents a perfect model of the system. However, the real physical drone has imperfections and must consider the cable management. Thus, some adaptations will always occur.

The deliverables for this work package is given as follows:

- D3.1: PID tuning of the drone for the pitch and the roll
- D3.2: Safety implementation for the drone emergency stop
- D3.3: Thrust and yaw control of the drone

5.1. D3.1: PID tuning of the roll and pitch

The tuning of the PID controller will mainly be experimental, but a table including the PID parameter should be given in the report to understand the method for tuning the system. The tuning of the yaw angle is not required. You will experiment with the MPU6050 soon enough, but this module is poor at estimating the yaw angle, as it lacks a magnetometer.

5.2. D3.2: Safety implementation for the drone emergency stop

The drone can be quite dangerous to manipulate and it is not recommended to use the propeller until the PID controller is making sense and safety measure has been implemented to turn off the drone in case of emergency.

5.3. D3.3: Remote control of the drone

The drone should be controlled safely in the different degree of freedom, namely:

- The pitch and roll should move the drone in the horizontal plane
- The control of the yaw rate should rotate the drone around the vertical axis
- The thrust control should elevate the drone

All of these movements should be tested independently.

6. Group work and team management

During extended group work with people from different background, tension may arise between individuals, which is totally normal and will occur in the professional and personal life. Problems that are quite common are:

- You have an idea, but the other group members do not agree or do not listen.
- You have an idea, but you feel like the discussion has already moved on.
- You feel like you are participating, but the other group members do not agree and blame your lack of pro-activeness.
- You feel like your teammates are not participating enough or are missing meetings.

Other cases can arise. You may refer to the following options to alleviate potential group problems:

- Tutorial sessions are used for technical questions and potential moderation between the group members. The lecturer and the other groups present at the tutorial sessions will be happy to give their opinion and objective observation.
- Bi-weekly meetings are set up during the semester. You can address your problem during these meetings session. They will be reported in the minutes of meetings.
- The group contract is essential to set ground rules between all members. An example of basic rules are given thereafter. If one student fail to follow them, then its behavior may collectively be reported to the lecturer and the grade of the concerned student may be altered. An alternative punishment, without going through the lecturer, could just be a cup of coffee to be offered to the other team members as an act of forgiveness.
    - Set a (rigid) weekly group meeting: e.g., Friday 13:30pm for at least 30 min. There is always something to observe, to note, or to discuss about.
    - Each member should verbally contribute at least for 5 minutes during the meeting: to present the current work, challenges, or the on-coming tasks.
    - Split the tasks: this project must be divided into smaller deliverables, and each individual can work independently on them. Power point presentation, report writing, components purchasing, prototype assembly, and coding are tasks that can be performed in parallel.
    - Only five minutes of meeting are graded in this course. However, after every group meeting, each student should have a clear understanding of their personal tasks, which should be written in a shared file.

7. Conclusion

Some recommendations are given as follows:

- Ordering items takes time. Try to order in advance and prepare preliminary works before the arrival of the components (this should be considered in your project proposal.
- During experimentation, mechanical or electrical components may get damage. Be sure to order spare parts and to keep yourself safe: a propeller even rotating at low speed can easily damage your eyes.
- This is a guided project. You are more than welcome to introduce your own creativity in your work.

References

[1] C. Chen, S. Leon and P. Ractham, "Will customers adopt last-mile drone delivery services? An analysis of drone delivery in the emerging market economy," *Cogent Business & Management,* vol. 9, p. 2074340, 2022.

[2] N. Pan, J. Jiang, R. Zhang, C. Xu and F. Gao, "Skywalker: A Compact and Agile Air-Ground Omnidirectional Vehicle," *IEEE Robotics and Automation Letters,* vol. 8, p. 2534–2541, 2023.

[3] S. Juan, S. Etigowni, S. Hossain-McKenzie, M. Kazerooni, K.-I. Davis and S. Zonouz, "Crystal (ball): I Look at Physics and Predict Control Flow! Just-Ahead-Of-Time Controller Recovery," 2018.