Course notes, week 40

UAS platforms, Control surfaces, Prototype building

Jes Jepsen jegj@mmmi.sdu.dk
Frederik Mazur Andersen fm@mmmi.sdu.dk

1 Agenda

During the four modules with us you will get to build, calibrate and fly a drone, similar to the one in figure 1. The four lectures will be in the SDU UAS Test Center[1] at the H.C. Andersen Airport.

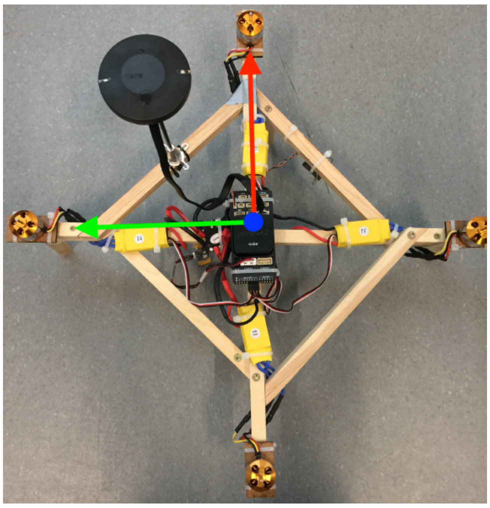


Figure 1: A drone from last year's course.

For our own logistics, we need to know how many TEK cars we need to have available weekly for transportation. We recommend that you handle transportation to the SDU UAS Test Center yourselves, so, by default, we will assume that you don't need transportation from TEK. However, if you would like a ride forth and back between TEK and the SDU UAS Test Center, please put in your name in this spreadsheet.

Practical details for those who needs a ride to the SDU UAS Test Center and back:

- Meeting point is in front of the TEK building (the revolving door) at 8:10 at the very latest. The cars leaves at 8:15 sharp, so please aim to be on time.
- We will leave SDU UAS Test Center at 11.45

In addition, it is not possible to buy anything out there except for what you would expect to buy in a vending machine, so remember to bring the food and drinks you need for the day.

The plan for the four lectures are:

- **Week 40:** The first module, you will get to design and build your own drones

[1] SDU UAS Test Center, Beldringevej 252, 5270 Odense

- **Week 41:** The second module, you will be setting up and calibrating the drone before performing the first indoor test flights.
- **Week 48:** The third module, you will perform your first manual outdoor test flights and collecting data for a flight mission.
- **Week 49:** The last module, you will get to test your previously developed path plan software and perform planned flights.

If you have any issues or questions during these modules, please write us an email or come to our office: Ø27-604-2.

Agenda:

- Introduction to the SDU UAS Test Center, including a tour of the facilities and safety instructions
- Module theory and introduction to exercises.
- Exercises.

The goal for today is get done with building the drone frame, including mounting all the necessary electronics, so that you are ready to perform your first indoor flight during next lecture.

2 Theory presented in class

2.1 UAV platforms

When speaking of modern UAVs, they can be put into three main categories: Fixed-wing, multirotor and VTOL. See figures 2, 3 and 4 for examples.

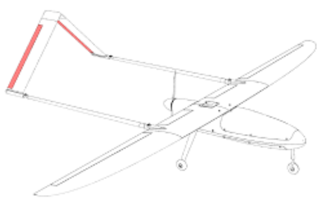


Figure 2: Fixed-wing UAV

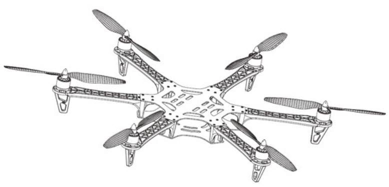


Figure 3: Multirotor UAV

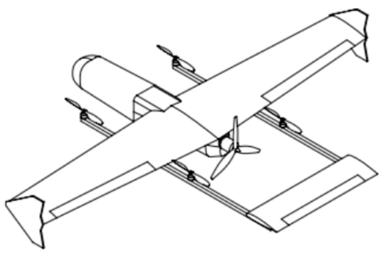


Figure 4: VTOL UAV

A fixed-wing UAV has the advantage that the physical embodiment of the drone creates lift, meaning that if you cut off propulsion, the drone will glide and remain airborne for some time. This also means that it is typically capable of extended flight. The disadvantage is that it typically requires some space for take offs and landings. A multirotor UAV has the advantage of requiring very little space for take offs and landings and is capable of precise landings. However, due to its embodiment, if propulsion is cut off, it will fall like a brick. A large portion of the energy is being used at staying airborne, which results in a drastically reduced flight time, compared to fixed-wing. The VTOL (Vertical Take Off and Landing) is the combination of the good characteristics from the fixed-wing and the multirotor. A VTOL is capable of directing its thrust, which enables it to take off and land like a multirotor. Once airborne, it can shift its direction of thrust (or turn off the multirotor propellers) and fly like a fixed-wing UAV. The disadvantage of the VTOL is the added complexity.

2.2 Drone Components

A typical multirotor consists of the components seen in figure 5.

Blue signifies data cables, while orange is power. A dashed blue and orange cable is both. Here follows a short explanation of the individual components.

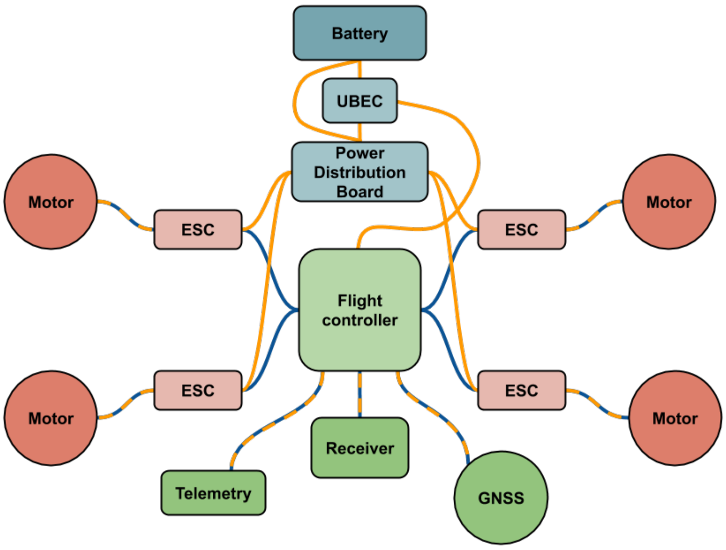
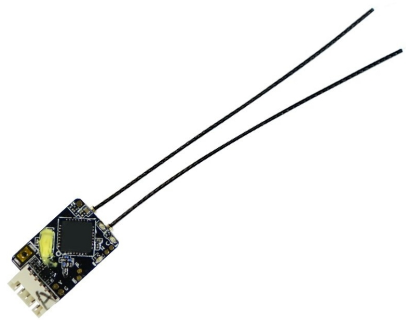


Figure 5: A system diagram of the quadcopter components.

2.2.1 Receiver and Transmitter

The receiver (figure 6b) picks up the radio signals send by the transmitter (figure 6a) and relays these to the flight controller.

(a) Taranis Q X7
Source: RC-Netbutik



(b) R-XSR receiver.
Source: RC-Netbutik

Figure 6: Transmitter and receiver setup

2.2.2 Flight controller

The flight controller is the Pixhawk 4 Mini (figure 7), which is widely used at the SDU UAS Center. This is the brains of the drone. As it can be seen in figure 5, it is the central unit, which really ties the components together. It was the leap in the computational power to weight ratio, which paved the way for the multirotor. Balancing a platform of multiple propellers, keeping the right side up, requires a fast computer and good control algorithms. Since the flight controller meassures the drones movements and attitude, it must be placed at the center of the drone.

Figure 7: *The Pixhawk 4 mini flight controller.*
Source:

PX4 Developer guide:

- Pixhawk 4 Mini Wiring Quick Start
- Pixhawk 4 Mini Flight Controller

2.2.3 Motors, propellers and Electronic Speed Controller (ESC)

The motors used in multirotor drones are Brushless DC Motors (BLDCs), and the control of each BLDC is done by using an ESC, which basically is changing the magnetic fields inside the motors in order to make it rotate. An ESC typically takes a Pulse Width Modulation (PWM) from the flight controller, which will define the relative speed with which the motor should turn. The provided motors, ECSs and propellers are from the T-Motor Air Gear 450[2] Combo set (figure 8), which consist of

- AIR2216 880kv
- T1045 self-locking propellers (CW/CCW) in plastic
- AIR20A V2 compact ESC

You should look at the following source, in order to get a basic understanding of BLDCs:

- https://www.renesas.com/us/en/support/technical-resources/engineer-school/brushless-dc-motor-01-overview.html.

IMPORTANT: Never power up the UAV system with the propellers mounted, unless it is before a test flight either in the indoor environment or an outdoor environment.

Figure 8: *T-Motor Air Gear 450.*
Source: T-Motor store: Air Gear 450

PX4 Developer guide:

[2] T-Motor store: Air Gear 450

- ESCs and Motors
- PWM Servos and ESCs (Motor Controllers)

Video Guide(s)

- RC Basics - Understanding Electronic Speed Controllers (ESC)

2.2.4 Battery

Multirotor UAVs are typically powered by LiPo batteries, which you learned about in the UAV power systems module. You will be provided a 4 cell 5000mAh from Gens Ace (figure 9)

Figure 9: *Gens ace 5000mAh 14.8V 45C Lipo Battery*
Source: Gens Ace shop: Gens ace 5000mAh 14.8V

2.2.5 Power Distribution Board (PDB) and Power module

As the name describes, the PDB distributes the power. It is distributed from the the battery to the ESCs. A power module provides a regulated power supply for the flight controller, along with information about battery voltage and current[3]. You will be provided the Holybro Micro Power Module (PM06), which is both a PDB and a Power Module (figure 10).

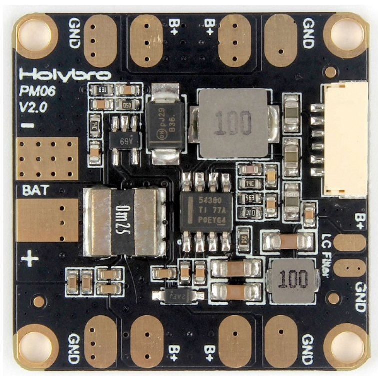


Figure 10: *Holybro Micro Power Module (PM06)*
Source: PX4 Dev: Holybro Micro Power Module (PM06)

PX4 Developer guide:

- Power Modules
- Holybro Micro Power Module (PM06)

[3] PX4 Dev Guide: Power Modules

2.2.6 Global Navigation Satellite System (GNSS)

A drone can fly without a GNSS. However, such a module is needed for outdoor positioning (figure 11).

Figure 11: *Pixhawk 4 GPS Module.*
Souce: 3DXR: Pixhawk 4 GPS Module

PX4 Developer guide:

- GPS and Compass
- HEX/ProfiCNC Here2 RTK GPS

2.2.7 Telemetry

The telemetry module is also optional, but when present provides communication with a ground control station (figure 12).

Figure 12: *mRo telemetry 433 MHz modules.*
Souce: mRobotics store: mRo SiK Telemetry Radio V2 433Mhz

PX4 Developer guide:

- Telemetry Radios/Modems
- SiK Radio

2.3 Design considerations

Conceptually there are three main different quadcopter frame designs (with little variation when compared to other specific frame designs for drone racing, etc.). These three designs are the plus configuration, the X configuration, and the H configuration. The configurations differ when inspecting the motor placement and the direction of the UAS. There are a few pros ans cons when comparing these designs but these are more or less defined by the purpose of the UAS operation (i.e. photography, agile flight, etc.). The quadcopter designs[4] are illustrated in figures 13, 14, and 15.

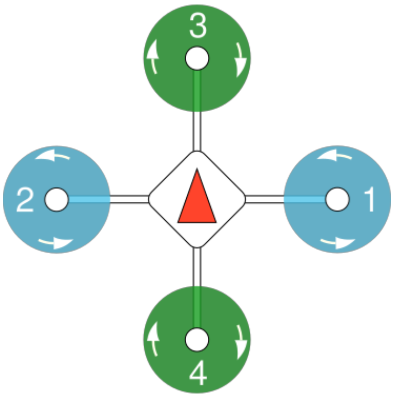


Figure 13: Quadcopter plus configuration.

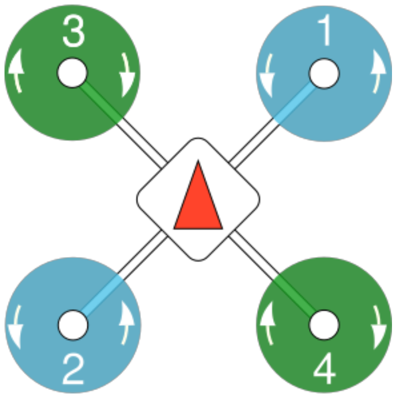


Figure 14: Quadcopter X configuration.

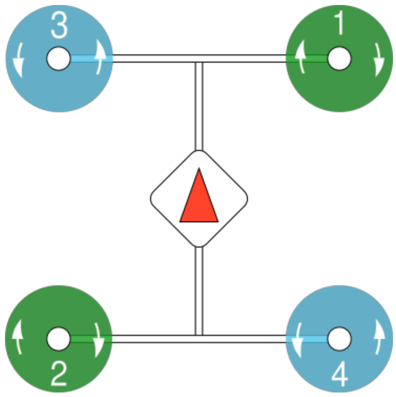


Figure 15: Quadcopter H configuration.

The general motor output mapping for the PixHawk 4 Mini is defined as the following:

- MAIN1: motor 1
- MAIN2: motor 2
- MAIN3: motor 3
- MAIN4: motor 4

Figures 13, 14, and 15 illustrates these outputs. You must choose one of these three designs for your drone. Be very careful to ensure that the motors are in the right order and spin the correct way. This is done by powering on the finished drone **WITHOUT PROPELLERS ATTACHED**, applying throttle and observing the motor rotations. If a motor rotates the wrong way, simply swap two of the three ESC wires.

When working with the electronics, please be very gentle with the cables, as the wire plugs on the Pixhawk can easily break.

Finally, ensure that the center of mass of your drone is centered between the propellers and that it is at the height of the propellers or lower, in order to ensure stable flight.

3 Drone safety

When testing and operating drones, you must adhere to a set of rules and regulations. While drones seem like toys, they most certainly are not. Even plastic propellers can do great damage. You cannot fly or test a drone in a public place or within city limits. This means that flying anywhere on Campus, indoors or outdoors, is prohibited. When flight tests are conducted indoors, it must be in a room with restricted access, and where only people involved with the flight are present. Flying in the hallways at TEK, for instance, is therefore not allowed. However, flying in the SDU UAS Center hangar at the airport is fine. If at any point you are in doubt about where you are allowed to fly, please ask and we will guide you.

[4] https://dev.px4.io/en/airframes/airframe_reference.html

4 Exercises

The exercises are parted into a frame building part (primarily woodworking) and a UAV construction, where the actual construction of the UAV is done.

4.1 Frame Building

Section 2.3 introduces the basic concepts about quadcopter frame types. Consider the fact that each group has a limited amount of wood to construct the frame. Remember to consider the mountings of the drone components. Most can be mounted with zip ties.

4.2 UAS Construction

Now that you have build your quadcopter frame, the next step is to install all drone components onto the frame. Do this based on the systems diagram in figure 5.

The groups should, as a prerequisite to the construction, carefully read the PixHawk 4 Mini Wiring Quick Start at `https://docs.px4.io/master/en/assembly/quick_start_pixhawk4_mini.html`. Additionally, remember to consider the past theory taught in this course when placing the different components such as antennas. If doubt arises ask the supervisors.

Remember that under no circumstance are the groups allowed to power on any electronics without notifying and getting approval by the supervisors.