Course notes, week 46

UAS platforms, Control surfaces, Prototype building

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1 Agenda

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

For our own logistics, we need to know how many TEK cars we need to have available weekly for transportation. Because of the COVID-19 situation, we will 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, but if you would like a ride forth and back, please write an email to either jegj@mmmi.sdu.dk or fm@mmmi.sdu.dk.

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.
- **FACEMASK REQUIRED** and you have to provide one yourself.
- We will leave SDU UAS Test Center at 14.30

Keeping in mind the latest SDU COVID-19 measures, and that the airport contains many different kinds of rooms. We will be following the basic "face mask or visor when moving around" rule, and this applies to all rooms (the hangar, student area, labs, etc.). Moreover since we sometimes have various researchers and other companies working in the lab spaces, try to keep a 2m distance to people not associated with the IDT course. We will give you a more detailed explanation of this, once we all meet at the SDU UAS Test Center, but remember to wear a face mask or visor when you enter the building.

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

- **Week 46:** During this, the first module, we will go over UAS platforms and building dos and don'ts. Then you will get to build your own drones.
- **Week 47:** The second module will be about setting up and calibrating the drone before performing the first indoor flight tests.
- **Week 48:** The third module will be manual outdoor flying 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.

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

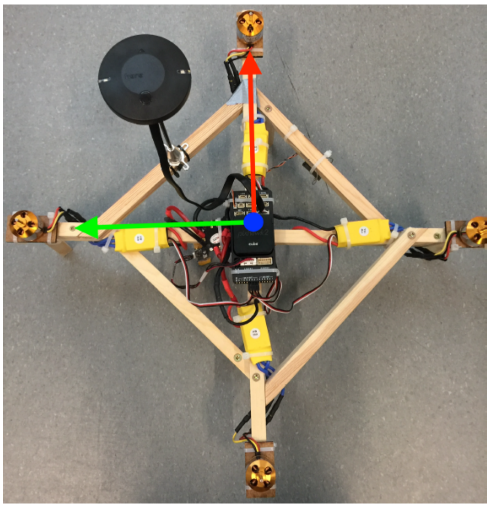

Figure 1: A drone from last year's course.

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.

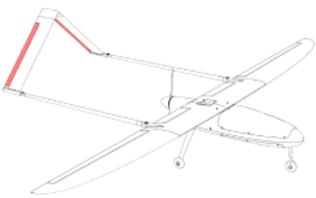

Figure 2: Fixed-wing UAV

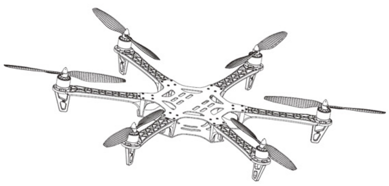

Figure 3: Multirotor UAV

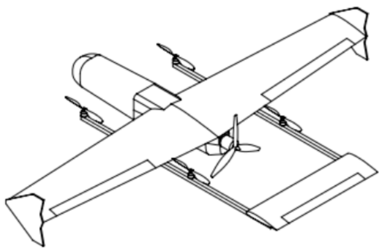

Figure 4: VTOL UAV

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.

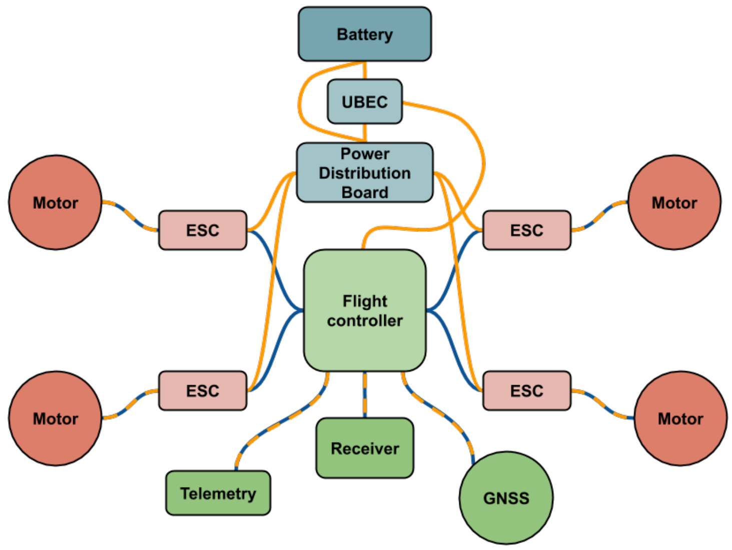

Figure 5: A system diagram of the quadcopter components.

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.

2.2.1 Receiver and Transmitter

The receiver (figure 6) picks up the radio signals send by the transmitter (figure 7) and relays these to the flight controller.

Figure 6: The Spektrum receiver.

Figure 7: The Spektrum transmitter.

2.2.2 Flight controller

The flight controller is the Pixhawk 2.1 (figure 8), 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.

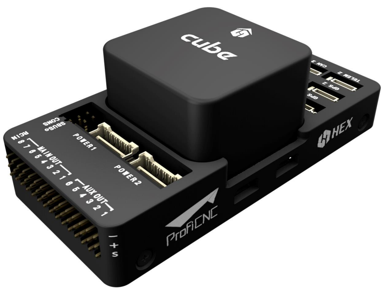

Figure 8: *The Hex Cube Black flight controller.*
Source: PX4 Dev Guide: Hex Cube Black Flight Controller

PX4 Developer guide:

- Cube Wiring Quick Start
- Hex Cube Black Flight Controller

Video Guide(s)

- (1/9) Introduction to PixHawk 2.1: Introduction
- The Cube Pixhawk 2 Autopilot and Flight Controller Explained - All Versions Carrier Boards
- PixHawk/Mission Planner/ArduPilot Build for Beginners: Introduction

2.2.3 Motor

The motors used in multirotor drones are Brushless DC Motors (BLDCs). They have several advantages, which will not be listed here. 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.

2.2.4 Electronic Speed Controller (ESC)

Changing the magnetic fields, in order to control the BLDC is done by an ESC. An ESC takes a Pulse Width Modulation (PWM) or Pulse Position Modulation (PPM) signal from the flight controller, which will define the relative speed with which the motor should turn. It is powered by the Power Distribution Board (PDB).

PX4 Developer guide:

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

2.2.5 Battery

Multirotor UAVs are typically powered by LiPo batteries, which you learned about in the UAV power systems module.

2.2.6 Power Distribution Board (PDB)

As the name describes, the PDB (figure 9) distributes the power. It is distributed from the the battery to the ESCs.

Figure 9: *Power Distribution Board*

2.2.7 Universal Battery Elimination Circuit (UBEC) / Power module

The power module provides a regulated power supply for the flight controller, along with information about battery voltage and current[2] (figure 10)

[2] PX4 Dev Guide: Power Modules

Figure 10: *Power Brick Mini for Pixhawk 2.1.*
Source: 3DXR: Power Brick Mini

PX4 Developer guide:

- Power Modules

2.2.8 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: *Here2 GPS.*
Souce: 3DXR: Here 2 – GPS with CAN / Serial M8N

PX4 Developer guide:

- GPS and Compass
- HEX/ProfiCNC Here2 RTK GPS

2.2.9 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[3] are illustrated in figures 13, 14, and 15.

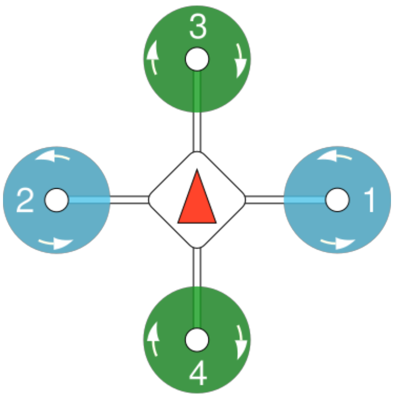

Figure 13: Quadcopter plus configuration.

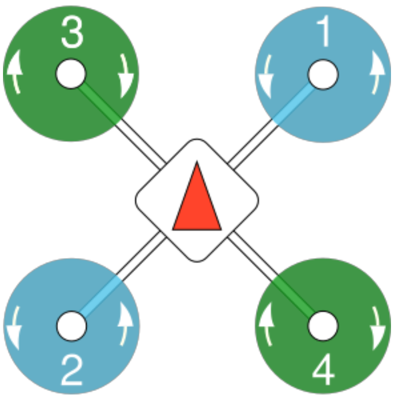

Figure 14: Quadcopter X configuration.

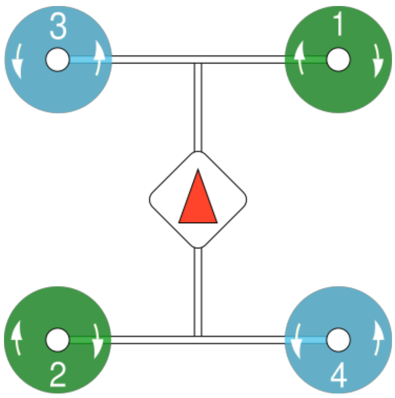

Figure 15: Quadcopter H configuration.

The general motor output mapping for the PixHawk 2.1 Cube is defined as the following:

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

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

- 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 Pixhawk 2.1, 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 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. Figure 16 illustrates all different PixHawk 2.1 Cube components and their connections[4].

The groups should, as a prerequisite to the construction, carefully read the PixHawk Cube Wiring Quick Start at `https://docs.px4.io/en/assembly/quick_start_cube.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.

[4] `https://docs.px4.io/en/assembly/quick_start_cube.html`

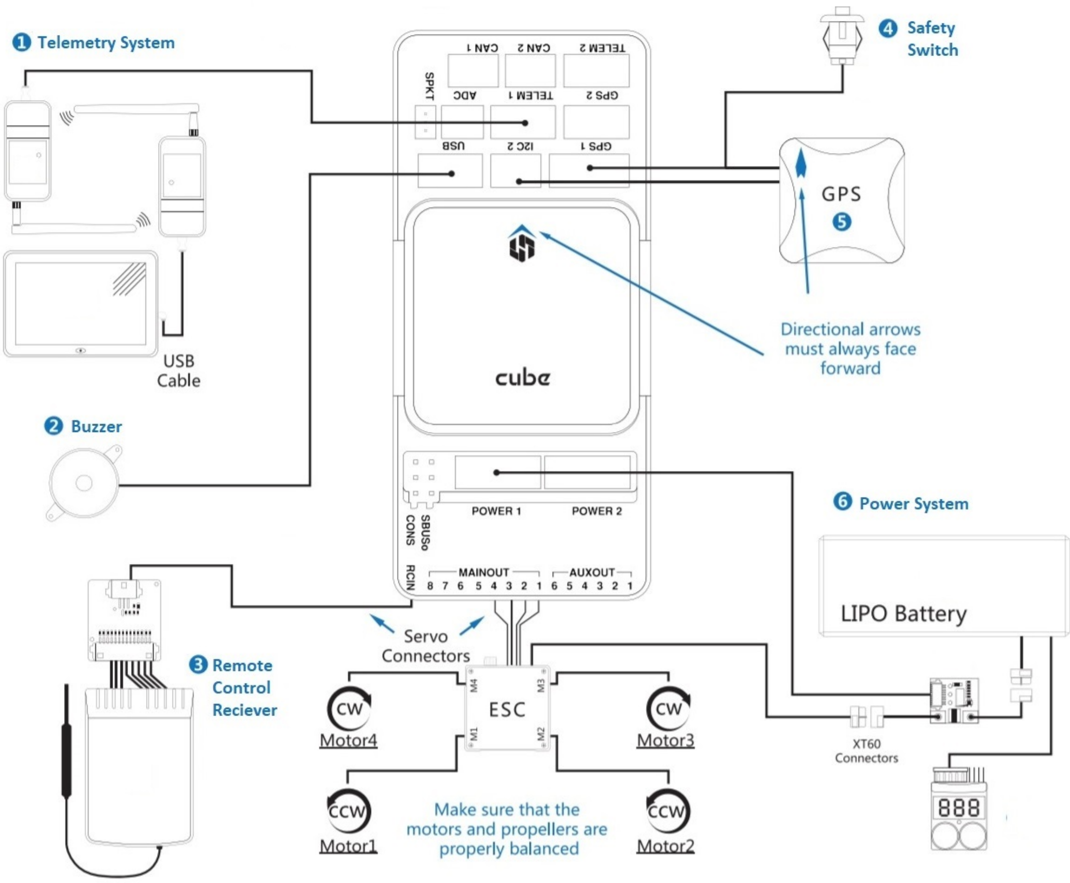

Figure 16: This figure illustrates the setup of the PixHawk 2.1 Cube. Notice that the RC link here is connected to the SPKT port and not the RCIN. for further information about this setup the reader is referred to the reference.