# Course notes, week 47

UAS platform calibration, Indoor flight tests

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

## 1 Agenda

The goal for today's module is setting up the firmware and calibrating the drone before performing the first indoor flight tests. Therefore, in order to get quickly started it would be ideal if your drones are either fully finished or close to. On that note, we have a few questions for you to ask yourselves before Friday:

- Does the arrow on your GPS point in the same direction as the arrow on your flight controller?
- Is this direction the forward direction of your drone?
- Have you fully charged your LiPo battery?

This module will take you through the steps from having built a drone to get it to fly. We will go through the following:

1. Drone setup - flight modes, etc.
2. Drone calibration.
3. Drone tuning.
4. Practical information about indoor flight.

## 2 Theory presented in class

### 2.1 Drone setup in QGroundControl

#### 2.1.1 Firmware setup

QGroundControl can be used to update the firmware of Pixhawks, SiK telemetry modules and various PX4 devices such as cameras. When building a new drone, it is a good idea to start with a fresh firmware install. There are two common flight stacks for the Pixhawk, Ardupilot and PX4. At the SDU UAS Center, we use the latest stable branch of PX4 (see PX4 Dev Guide: Loading Firmware).

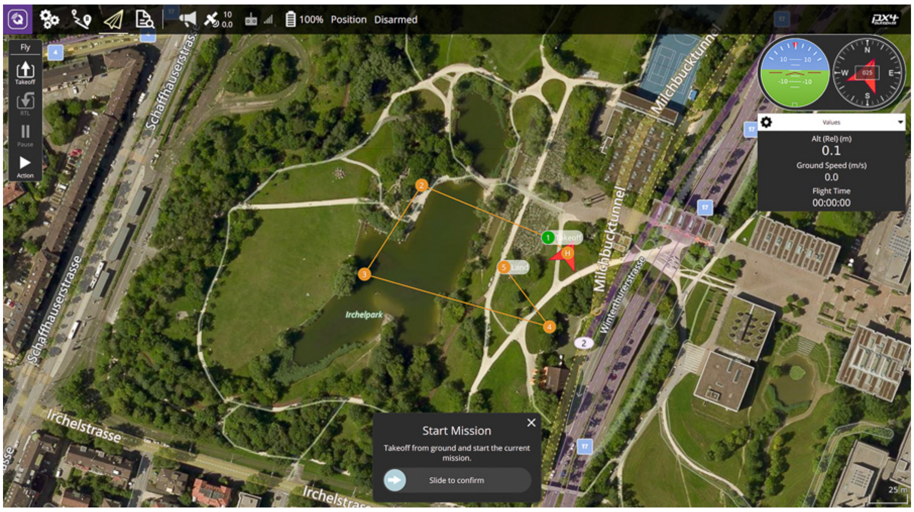



Figure 1: *QGroundControl's user interface view.*
*Source: QGroundControl User Guide*

**QGroundControl User Guide:**

- QGroundControl User Guide
- QGroundControl Quick Start
- Download and Install

### 2.1.2 Defining the airframe

When the firmware has been installed, it is time to define the drone's configuration, in order to get correct flight behaviour. If a drone has an uncommon shape, it is possible to define a custom configuration. However, your drones should all have a typical configuration which can be found in the software.

- Airframe setup (see PX4 Dev Guide: Airframe Setup)

### 2.1.3 Sensor calibration

Now it is time to calibrate the drone sensors. The flight controller has internal sensors, such as IMUs, magnetometers and barometers. Apart from these, the Here2 GNSS modules have an internal IMU as well, from which the Pixhawk uses the magnetometer. First, the compasses are calibrated, by rotating the drone around all its axes. Then, the gyroscopes are calibrated by placing the drone on a level surface and holding still. Then the accelerometer is calibrated by holding it still in all orientations. Finally, the horizon is leveled.

- Flight Controller/**Sensor Orientation** (see PX4 Dev Guide: Flight Controller/Sensor Orientation)
- **Compass** calibration (see PX4 Dev Guide: Compass Calibration)
- **Gyroscope** calibration (see PX4 Dev Guide: Gyroscope Calibration)
- **Accelerometer** calibration(see PX4 Dev Guide: Accelerometer Calibration)
- **Level Horizon** calibration (see PX4 Dev Guide: Level Horizon Calibration)

#### 2.1.4 Transmitter setup

Now it is time to setup the transmitter. All control inputs will be calibrated. This is done every time either the receiver or the transmitter is replaced, in order to make sure to get the full range out of the transmitter.

- **Transmitter** / Radio Setup and Calibration (see PX4 Dev Guide: Radio (Remote Control) Setup)

#### 2.1.5 Flight modes

We use different flight modes depending on the kind of flying to perform. When tuning the drone, we use Acro. When the drone has been tuned, we use three modes, set on a three-position trasmitter switch. The three modes are: Manual, Position and Mission:

**Manual** In manual mode, the drone will always balance itself when no pitch and roll control inputs are given. However, if it is windy, it will drift, and the altitude will be defined by the throttle.

**Position** In Position, the drone will use its GPS fix (if present) to maintain position, when no roll and pitch input is given. In addition, if the throttle stick is centered, it will maintain its current altitude.

**Mission** Mission mode is self explanatory. Typically it is used by setting the drone in mission mode and arming it. If everything is well, the drone will take off and perform its mission.

**PX4 Developer guide:**

- PX4 Flight Modes Overview
- PX4 Flight Modes (Multicopter)
- Radio (Remote Control) Setup

#### 2.1.6 Kill-switch

The kill-switch is a safety switch that immediately stops all motor outputs, so be careful only to use it during a flight in the event of a serious problem or emergency where you are not able to activate Return mode or make a manual controlled landing.

Assign a two-position switch on the transmitter as a kill-switch

- **1. position**: Kill-switch enabled
- **2. position**: Kill-switch disabled

#### 2.1.7 Battery setup

Now it is time to configure the battery. You will have to define the number of cells of the battery, the full voltage per cell and the empty voltage per cell. Finally, you will set the voltage divider, such that the measured battery voltage is correct.

- **Battery** and Power Module Setup (see PX4 Dev Guide: Battery and Power Module Setup)

#### 2.1.8 ESC calibration

The ESCs will have to be calibrated. This is done in order to ensure that the full range of the ESCs is utilized. Remember: all ESC calibration happens with propellers OFF!

- **ESC** Calibration (see PX4 Dev Guide: ESC Calibration)

#### 2.1.9 Fail Safes

The flight controller has a number of built in fail safes, which can be convenient. The relevant once will be mentioned here.

**RC Loss** In case of RC loss, which is loss of transmitter control, we do not want the drone to remain hanging in the air or in any way keep flying, as this could result in crashes. The default fail safe action here is return mode, where the drone will fly back home and land. While this sounds smart, there may be obstacles in the way of the drone, and as you do not have control, you cannot avoid an impending crash. Therefore, we use the land mode instead, which will cause the drone to slowly land on the spot.

**Data link loss** Data link loss fail safe should be disabled for the kind of flying you will perform, as the transmitter is the primary control source.

**PX4 Developer guide:**

- Safety Configuration (Failsafes)

**QGroundControl User guide:**

- QGroundControl: Safety

#### 2.1.10 Changing parameters

A few parameters have to be modified. This is done under the parameters tab in QGroundControl. Use the search bar to find the mentioned parameter.

**Circuit breaker** First, disable the safety switch on the GNSS module by finding the parameter CBRK_IO_SAFETY and changing it to disable the switch.

**Disarm when landed** Ensure that the drone disarms when landed by setting the COM_DISARM_LAND parameter to zero.

**GNSS position** If the GNSS module has been placed anywhere but on top of the cube, you will have to change the EKF2_GPS_POS_[X,Y,Z] parameters. Remember that the frame is North East Down (NED), with the cube at the center.

**PX4 Developer guide:**

- Finding/Updating Parameters

## 2.2 Drone tuning

After the setup, calibration, and additional drone setup has been conducted using QGroundControl you have a drone that is *ready to fly*. The next step is to ensure that the flight is stable. In order to do so we need to adjust the controller loop.

As a prerequisite to understand the setup of the flight stack, that is the software running on the Flight Controller, you will have to thoroughly read and get a conceptual understanding of the software architecture of the px4[1]. The software architecture of the px4 flight stack is illustrated in figure 2.

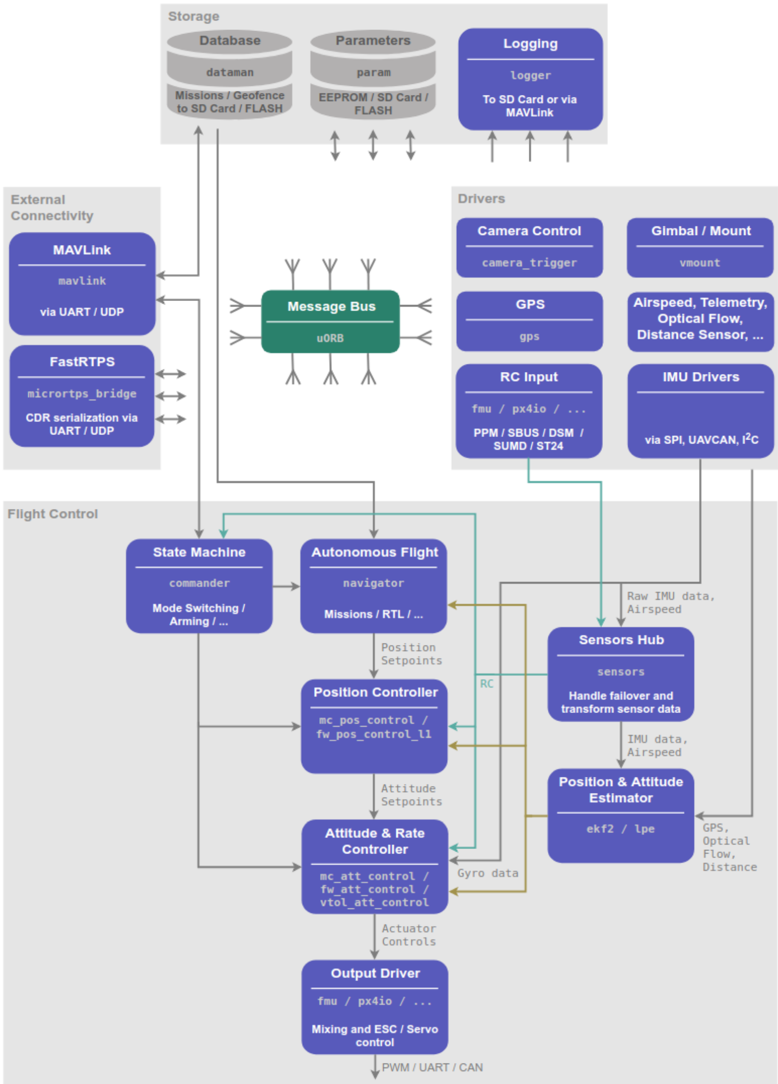
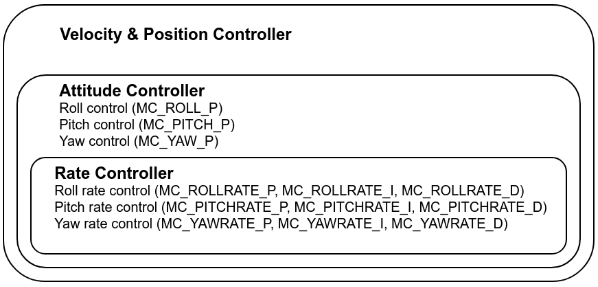



Figure 2: Overview of the PX4 flight stack, the reader should especially notice the contents, inputs, and outputs of the Flight Control block. Illustration from https://dev.px4.io/master/en/concept/architecture.html.

For an understanding of how these controllers work the reader is referred to PX4 official controller overview: https://dev.px4.io/master/en/flight_stack/controller_diagrams.html. This will not be something that will be covered in depth/touched upon here, as these are subjects in your other courses. A conceptual illustration of the control loops is illustrated in figure 3.

[1]Reference to software architecture: https://dev.px4.io/master/en/concept/architecture.html




*Conceptual illustration of control loops*

Figure 3: Conceptual illustration of the control loops in the PX4 flight stack, note that the different variable names originates from `https://docs.px4.io/master/en/config_mc/pid_tuning_guide_multicopter.html`. The reader should notice that the outer most loop, the position and velocity control loop, is not included in this tuning setup, the reader is referred to `https://dev.px4.io/master/en/flight_stack/controller_diagrams.html` for an more in depth explanation of the outer most control loop.

The outer most control loop, the position and velocity loop, is thoroughly explained at: `https://docs.px4.io/v1.9.0/en/config_mc/advanced_mc_position_tuning.html` and will not be subject to the tuning conducted in this lecture. The tuning conducted will originate from `https://docs.px4.io/master/en/config_mc/pid_tuning_guide_multicopter.html` which consists of the tuning of the rate controller (the inner most loop) and the attitude controller (the second loop)[2].

## 3 Drone safety for indoor flight

Indoor drone flight has some safety pros and cons. The pros are that the drone cannot fly away, it is possible to control who is near the drone and the weather is never an issue. However, since the space is more confined, you typically fly closer to yourself, which is an increased risk in case something goes wrong. In addition, it is typically not possible to acquire a proper GNSS signal, and it is generally recommended not to operate the drone in any mode requiring GNSS, such as Position. When we fly in the SDU Hangar, there are a couple of safety requirements:

- When flying inside the Hangar, always make sure that the safety net is closed and no one is inside.
- If you have to enter the area while the drone is flying, wear a helmet and safety glasses. Being struck by a drone or its propellers can cause severe injuries.
- Do not fly near other people.
- Be mindful of each other and warn the people in the vicinity before taking off.

Always Remember, never power up the drone with the propeller mounted, unless it is before a test flight.

## 4 Homework for this module

Have finished building the drone platform, so that it is ready to be calibrated and tuned.

It would be beneficial to carefully read all the references introduced in section 2.2 (with the exception of the references to the tuning of the position and velocity control loop, these are optional). Additionally, you do have time in the lecture to read it again and ask the supervisors for any questions that might arise.

[2]The most important control loop is the rate controller, by experience, the attitude control loop is *usually* fine.

# 5 Exercises

## 5.1 Configuration and calibration

This exercise will be going through the steps mentioned in 2.1.

## 5.2 Tuning

**This part is done with propellers on, so when tuning these parameter, place the drone inside the flight volume in the Hangar and ensure that safety net is closed and no one inside the flight volume.**

### 5.2.1 Spinning motors

First, we want to make sure that the motors always spin when the drone is armed. The purpose of this is twofold. If the motors always spin when armed, there is no risk of getting near an armed drone and the suddenly have the propellers spin. The second reason is that a drone in the air could potentially turn off some of the motors if heavily tilted, which could result in a failure.

The motors are made to always rotate when armed under

- **Setup > Parameters**, and search for PWM_MIN, or
- **Setup > Tuning**, where you can both tune the minimum and hover throttle

Increase the value slightly and try to arm the drone. If the propellers do not spin, disarm the drone and repeat. Stop increasing as soon as you reach a value at which the motors spin when armed and the throttle is at zero.

**Remember** to setup a kill-switch for your system (see section 2.1.6)

### 5.2.2 Hover throttle

The hover throttle should be adjusted. This is done so that when later on using Position mode, the drone will keep its altitude when the throttle stick is centered. The drone is set to either Acro or Manual and taken into the air. While the pilot keeps the drone at a level height, an observer reads the number highlighted in figure 4. This number denotes the throttle percentage. When the number at hover is known, the pilot lands the drone. Under parameters in QGroundControl, type MPC_THR_HOVER in the search bar. Enter the number read from the screen and press save.

**QGroundControl User Guide:**

- QGroundControl User Guide: Tuning (Basic tuning)

### 5.2.3 Rate and Attitude Controller

The next step is to thoroughly follow the tuning guide for the rate and attitude controller at `https://docs.px4.io/master/en/config_mc/pid_tuning_guide_multicopter.html`.

For overview purposes the most important parts of tuning the Rate and Attitude controller can be summerized as:

- Disable MC_AIRMODE (in the parameter list in QGroundControl).
- The Rate controller is the inner-most loop with three independent PID controllers to control the body rates: Roll rate control, Pitch rate control, and Yaw rate control.
- The Rate controller can be tuned in Acro mode or Manual/Stabilized mode:


Figure 4: The Spektrum transmitter. Notice the read circle highlighting the throttle percentage on the screen.

  - Manual/Stabilized mode is simpler to fly, but it is also more difficult to see if the attitude or the rate controller needs more tuning.
  - Acro mode is harder to fly, but it gives you a better indication if the attitude or the rate controller needs more tuning. If you choose this mode, disable all stick expo.

- The most important part of the rate controller is the **P**roportional part (so that the drone it not dull or in other way unstable). This can be done using trial and error or by uploading the log to `https://logs.px4.io/upload` and then using the PID analysis tool to the response of the drone according to the tune.
- The Attitude controller is often fine by default but otherwise adjust: Roll control, Pitch control, and Yaw control
- If the drone tilts too much adjust the limits: Maximum roll rate, Maximum pitch rate, and Maximum yaw rate.
- At the end, remember to enable MC_AIRMODE, and your drone is ready to fly.

**QGroundControl User Guide:**

- QGroundControl User Guide: Tuning (Advanced tuning)