UAV Laboratory: X500 Quadcopter + Pixhawk 4 assembly, setup and flight.

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Contents

Chapter 1

Introduction

During these lab sessions we will work on the assembly, calibration and operation of a quadcopter. In particular, we will deal with the Holybro X500 Frame Kit (see [Holybro, 2019b]).

After completing the lab sessions, a lab results presentation will be required. You can find more details in ??.

1.1 Objectives

- Familiarize with some UAV subsystems by being able to manipulate them during the assembling, checking and calibration process.
- Understand how different subsystems interact with each other through different communication protocols.
- Learn how to follow a procedure in a systematic way, being able to identify and deal with ambiguous parts or lacks of information in the procedures, as well as proposing changes.
- Deal with assembling and setup errors by debugging to identify the root cause and exploring different solutions.
- Become proficient in operating basic lab equipment.
- Gain familiarity with flight control systems.
- Explore the potential of a Mission Planner.
- Make an initial contact with UAV operation and flight.
- Make an initial contact with flight data analysis.
- Be able to analyze and interpret flight data.

1.2 Main elements

1.2.1 Frame

The frame is the structure where the different parts of the drone are attached. In our particular case, we will be using a Holibro X500 frame kit (see figure 1.2). It is a 410*410*300 mm, carbon fiber, quadrotor in X shape.

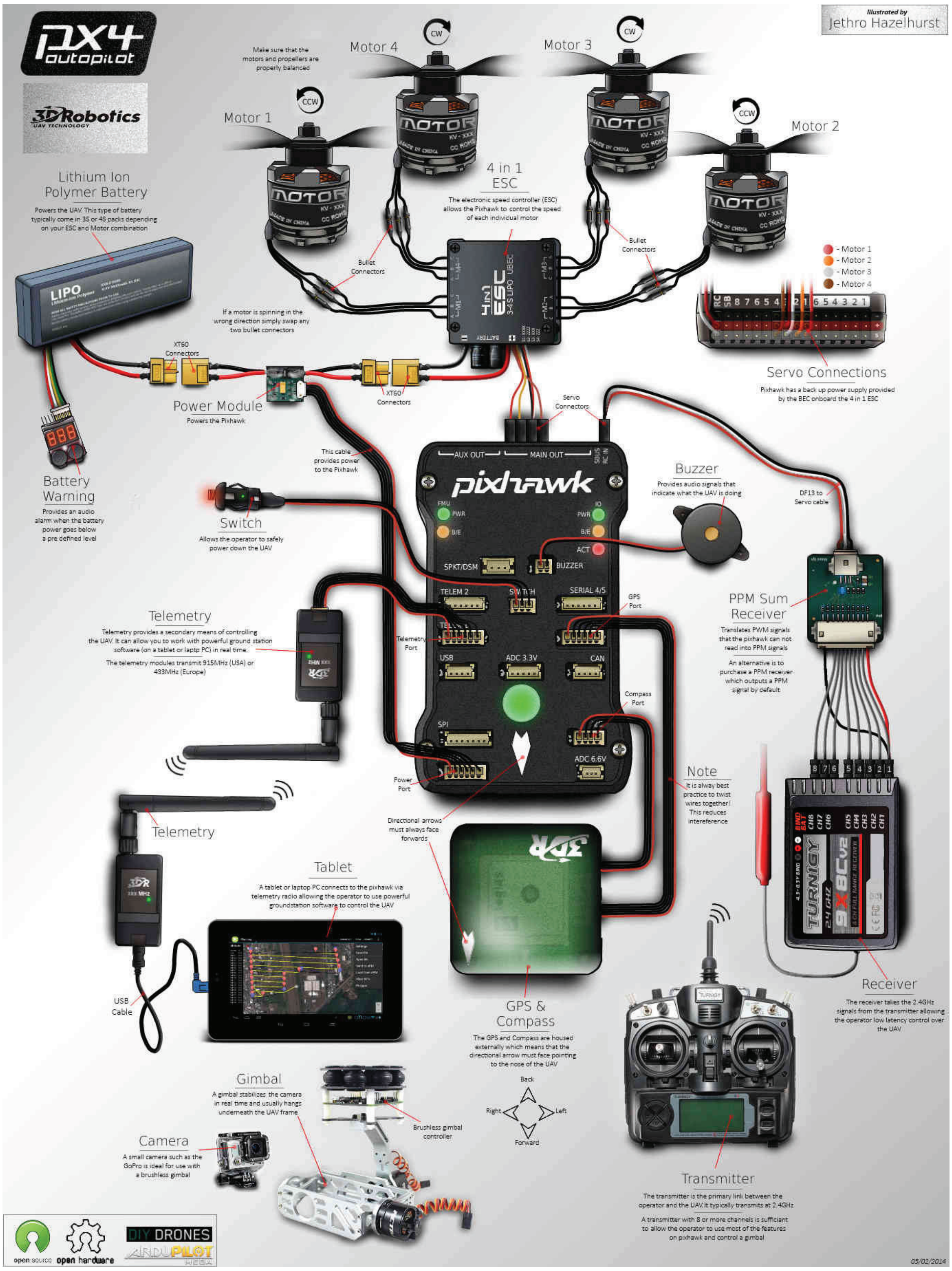


Figure 1.1: Quadcopter elements

Figure 1.2: Holybro X500 Frame

Figure 1.3: Holybro 2216/880 KV Motors: CCW (left), CW (right)

1.2.2 Motors

A brushed motor relies on the contact of the rotor with the power supply to create a magnetic field that drives the rotation. The physical contact between this two parts limits the performance (generates friction, disipates energy in heat form), requires more maintenance and shortens the lifespan.

However, a brushless motor consists of a certain number of coils along a central stator. Around the stator, a rotor with permanent magnets is found. A magnetic field is created by supplying current to the coils. This magnetic fields drives the movement of the rotor by switching the current from one coil to the next one. The motor rotation rate can thus be controlled by the speed at which the current is switch over along the coils.

Probably, the most relevant motor parameter is the kV rating. It indicates how many revolutions per minute the motor can achieve per Volt applied when no load is applied (no propeller).

A picture of the motors we will use is shown in 1.3. Note that CCW (counter-clockwise) motors have a silver screw on the top and CW (clockwise) have a black one. The spinning direction can be changed by switching two wires of the three that connect the ESC to the motor. So, basically, *CW and CCW motors are still the same motors, apart from the prop shaft threads which have opposite direction.* That means for a CCW motor, the prop nut is secured by turning clockwise. And for CW motors, the prop nuts needs to be rotated anti-clockwise in order to fasten.

1.2.3 Electronic Speed Controllers

The Electronic Speed Controller (ESC) is the responsible of powering the motor stator coils to rotate at the commanded speed.

An Electronic Speed Controller (ESC) is an electronic circuit that acts as the interface between the pilot's commands and the individual drone motors. There are several types of ESCs in the market, but brushless motors require a 3-phase ESC. These are easily distinguished by the presence of three soldering pads that are meant to connect to the three motor phases of a brushless motor, as shown in figure 1.4.

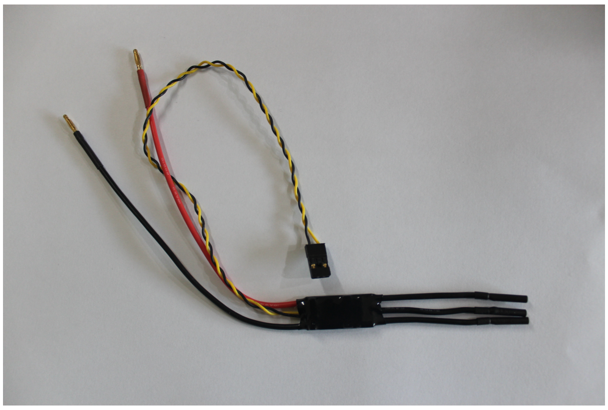


Figure 1.4: Holybro 20 A ESC

Figure 1.5: Motors and propellers

1.2.4 Propellers

The propellers (see figure 1.5) are in charge of generating the aerodynamic forces that allow the drone to fly. The forces depend on: number of blades, shape, size, curvature, pitch, and rotation speed fundamentally.

Note that the rotation of each propeller produces not only a force on the vehicle, but also a moment that makes the drone spin in the opposite direction to the propeller (action-reaction law). For this reason, not every propeller spins in the same direction. In our particular case two motors will rotate clockwise and the other pair will rotate counter-clockwise (see figure 2.28). Controlling the speed of the motors to generate a moment imbalance allows to rotate the drone around its vertical axis.

Moreover, in a quadcopter the imbalance of forces on different arms will be able to modify the drone attitude (pitch and roll). Orienting the forces with the attitude in different directions allows the drone's directional movement (forward/backward and lateral).

1.2.5 Power

Our drone will be powered with a Lithium polymer battery (LiPo) like the one shown in figure 1.7. Our LiPo is connected to the power management board (figure 1.8) which distributes the energy to the motors and rest of drone components. LiPo batteries have gained popularity due to the higher energy density they are able to store and high discharge rates (amount of power they can provide). On the other hand, they have a limited lifespan (few hundred of cycles), have a sensitive chemestry that can lead to fire and

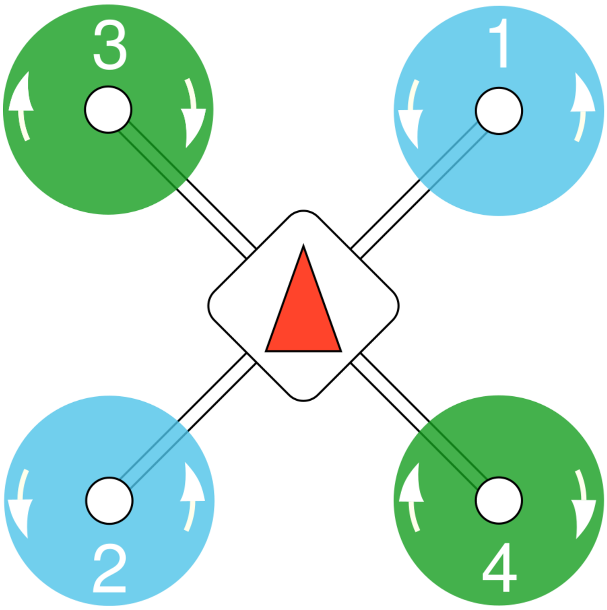


Figure 1.6: X frame motor numeration

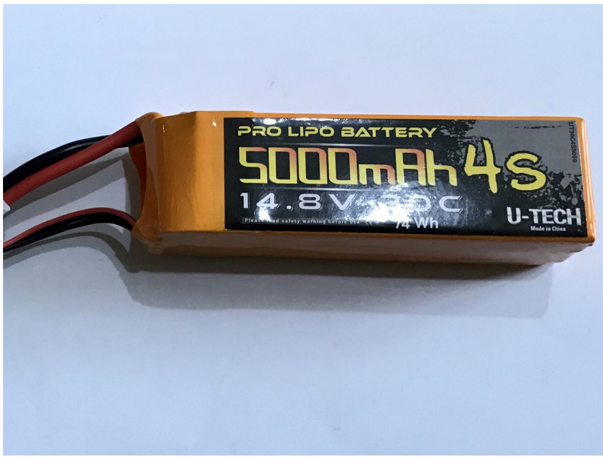


Figure 1.7: Lithium polymer battery

special attention must be paid to charging, discharging and storage.

A LiPo cell has a nominal voltage of 3.7V (when fully charged they reach 4.2 V and their minimum safe charge is 3.0 V). Voltage directly influences the RPM of the electric motor.

The capacity of a battery measures how much energy it can hold. It is measured in milliamps hour (mAh). It determines how long we can fly the drone before recharging.

The C Rating is an indication of how fast we can discharge the battery safely and without harming it. For a 5000 mAh capacity and 30C discharge rate, the battery can provide a current of 30x5 = 60 A (C rate per capacity expressed in Ah).

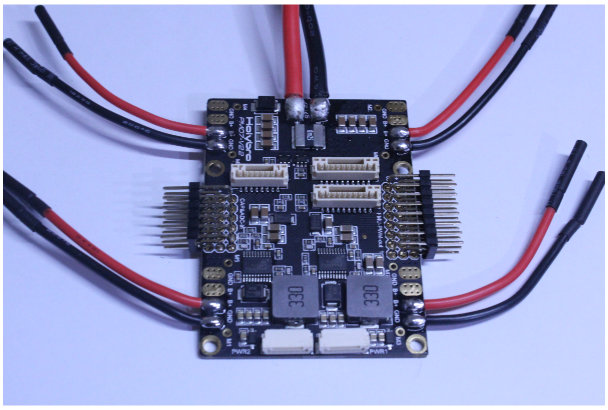


Figure 1.8: Power Management Board

1.2.6 Flight controller

Essentially, a quadrotor can be controller by changing the rotation speed of the different motors to produce the required forces and moments. However, that would be a really challenging task for a pilot that would require tremendous skills given the unstable nature of the vehicle. To ease this tasks, drones are equipped with a flight controller.

The flight controller will gather information from different sensors to estimate the state of the drone (position, velocity, attitude, accelerations, angular rates...). Based on the controller inputs, given by the pilot or the AP it will construct a desired state (reach a position, ascend or descend at a given rate...) and will determine the necessary actions to meet that inputs (motor rotation speeds). The type and level of vehicle automation will be determined by the selected *flight mode*. Autonomous modes require no pilot actions at all like: automatic take-off, landing, return to home, follow a route... Manual modes enable certain levels of assistance to command the vehicle, for example: hold position against wind, auto-stabilization, acrobatic tricks...

The autonomous modes are specially useful when triggered in the failsafe mode: to protect and recover your vehicle if something goes wrong. Some failsafe areas include: low battery, RC loss, GNSS loss, geofence breach (vehicle going out of intended area)...

Then, we can say that the flight controller acts as the drone's brain. In our case, we will use Pixhawk 4 hardware, that runs PX4 software. See figure 1.9. You can get more information about this device in the quick start guide [Holybro, 2018a] and the data sheet [Holybro, 2018b].

What is PX4?

PX4 is an *open source* flight control software for drones and other unmanned vehicles. The project provides a flexible set of tools for drone developers to share technologies to create tailored solutions for drone applications. PX4 provides a standard to deliver drone hardware support and software stack, allowing an ecosystem to build and maintain hardware and software in a scalable way.

PX4 is part of Dronecode, a non-profit organization administered by Linux Foundation to foster the use of open source software on flying vehicles. Dronecode also hosts QGroundControl, MAVLink & the SDK.

You can learn more about PX4 in `https://px4.io/software/software-overview/`.

Figure 1.9: Pixhawk 4 Flight Controller (left) and GPS (right)

1.2.7 Sensors

A sensor is a device that detects and responds to some type of input from the physical environment. The output signal of the sensor, normally, a electrical signal needs a calibration to be transformed to engineering units.

Drones are equipped with a number of sensors whose outputs are fed into the flight controller to estimate a *state* and calculate the necessary controls for the demanded tasks. Some of the sensors are covered in this section.

GNSS

Global Navigation Satellite System (GNSS) refers to a constellation of satellites providing signals from space that transmit positioning and timing data to GNSS receivers. The receivers then use this data to determine location. Examples of GNSS include Europe's Galileo, the USA's NAVSTAR Global Positioning System (GPS), Russia's Global'naya Navigatsionnaya Sputnikovaya Sistema (GLONASS) and China's BeiDou Navigation Satellite System.

Drones use GNSS to determine their position. Once known, this position can be maintained in a stable hover or can be used to navigate to a waypoint in a predetermined flight path. Position information is also really useful for some drone missions such as geolocalized pictures.

IMU

IMU stands for Inertial Measurement Unit. This device consists of: a three axis accelerometer, a three axis gyroscope and usually a magnetometer.

Accelerometers register accelerations in three orthogonal axis, gyroscopes measure the angular velocity around each axis and the magnetometer detects the magnetic field components. These measurements allow to characterize the dynamics of the drone and also to estimate the attitude.

Figure 1.10: FS-i6X Radio Control

1.2.8 Radio Controller

The Radio Control (RC) is used to manually control the vehicle. It consists of a remote control unit with a transmitter. In this lab, we will use FS-i6X (figure 1.10).

The transmitter sends the control positions to the receiver installed in the drone. This unit is connected to the flight controller, which determines how to interpret the commands based on the current autopilot flight mode and vehicle state, and drives the vehicle motors and actuators appropriately. The user manual of our receiver can be consulted in [FlySky RC Model Technology, 2016b].

Before you can calibrate/use a radio system you must bind the receiver and transmitter so that they communicate only with each other.

An important quality of an RC system is how many channels it supports. The number of channels defines how many different physical controls on the remote control can be used to send commands to the vehicle (e.g. how many switches, dials, control sticks can actually be used).

You can learn more about our RC by checking the user manual in [FlySky RC Model Technology, 2016a].

Chapter 2

Drone assembly: Holybro X500 + Pixhawk4 Build

This chapter provides full instructions for assembling the kit. **It is an adaptation of PX4 User Guide > Airframe builds > X500 (Pixhawk 4)**, which, in turn, has been provided by "Dronecode Test Flight Team". Many tables, enumerations, figures . . . from the web have been used. The text and some sections have been adapted to the particularities of this lab.

2.1 List of materials

References [Holybro, 2019a] and [Holybro, 2019b] will be useful for the frame. Details about the flight controller can be checked in [Holybro, 2018a] and [Holybro, 2018b]. The RC manual is [FlySky RC Model Technology, 201 and its receiver is described in [FlySky RC Model Technology, 2016b]. The telemetry module manual can be consulted in [Holybro, 2018c].

- **Frame:** Holybro X500.
- **Flight controller:** Pixhawk 4.
- **GNSS system:** Pixhawk 4 GPS module.
- **Radio controller:** Fly Sky FS-i6X emitter and FS-x6B receiver.
- **Telemetry:** Holybro telemetry radio V3.
- **Battery:** U-TECH LiPo 4S 5000 mAh 30C.
- 4 x **Propellers** - 1045: 2 x clockwise (CW) with black cap, 2 x counter-clockwise (CCW) with silver cap.
- 4 x **Motors** - 2216 KV880: 2 x CW (black screw), 2 x CCW (silver screw).
- **Power Management Board** - PM07
- Power and Radio Cables
- Battery Strap.

Figure 2.1: Full X500 Kit

2.1.1 Hardware

This section lists all hardware for the frame and the autopilot installation.

Item	Description	Quantity
Socket cap screw	Used for motor fixing, stainless steel screw M3*5	16
Carbon fiber tube - Arm	Diameter: 16mm length: 200mm	4
Motor base	Consists of 6 parts and 4 screws 4 nuts	4
Slide bar	Diameter: 10mm length: 250mm	2
Battery mounting board	Thickness: 2mm	1
Battery pad	3mm Silicone sheet black	1
Pylons	Engineering plastic embedded with copper nut	2
Cross countersunk head screw	Stainless steel M2.5*5mm	12
PAN/TILT platform board	Thickness: 2mm	1
Hanger rubber ring gasket	Inner hole diameter: 10mm black	8
Hanger	Engineering plastic embedded with copper nut	8
Carbon fiber - Bottom plate	The thickness of 2mm	1
Socket cap screw	Stainless steel M2.5*6mm	8
Nylon stud	Black M3*6+6	4
Nylon screw	Black M3*6	4
Carbon fiber - Top plate	Thickness: 1.5mm	1
Pan head screw	Metal black M3*30mm	16
Nylon strap	U- shape, of 16mm carbon fiber tube	16
Nylon nut	Black M3	4

Item	Description	Quantity
Locknut	Metal black M3	16
Socket cap screw	Metal black M3*8mm	8
Landing gear - Vertical pole	Carbon fiber tube+engineering plastic+fastener	2
Landing gear - Cross bar	Composed of carbon fiber tube and multiple parts	2

2.2 Package

Items	Package
Pixhawk 4	1
Pixhawk4 GPS MODULE	1
I2C splitter Board	2
6 to 6 pin cable (power)	3
4 to 4 pin cable (CAN)	2
6 to 4 pin cable (Data)	1
10 to 10 pin cable (PWM)	2
8 to 8 pin cable(AUX)	1
7 to 7 pin cable(SPI)	1
6 to 6 pin cable(Debug)	1
PPM/SBUS out cable	1
XSR receiver cable	1
DSMX receiver cable	1
SBUS receiver cable	1
USB cable	1
'X'type folding pedestal mount	1
70mm & 140mm carbon rod standoff	2
6*3 2.54mm pitch Horizontal Pin	1
8*3 2.54mm pitch Horizontal Pin	2
Foam Set	1

2.2.1 Electronics

Item Description	Quantity
Pixhawk 4 autopilot	1
Power Management PM02 (Assembled)	1
Motors - 2216 KV880 (V2 Update)	4
Pixhawk 4 GPS	1
Fully assembled Power Management Board with ESCs	1
433MHz Telemetry Radio / 915MHz Telemetry Radio	1

2.2.2 Tools needed

The following tools are used in this assembly:

Figure 2.2: X500 Components for Frame

Figure 2.3: X500 Full Package Contents

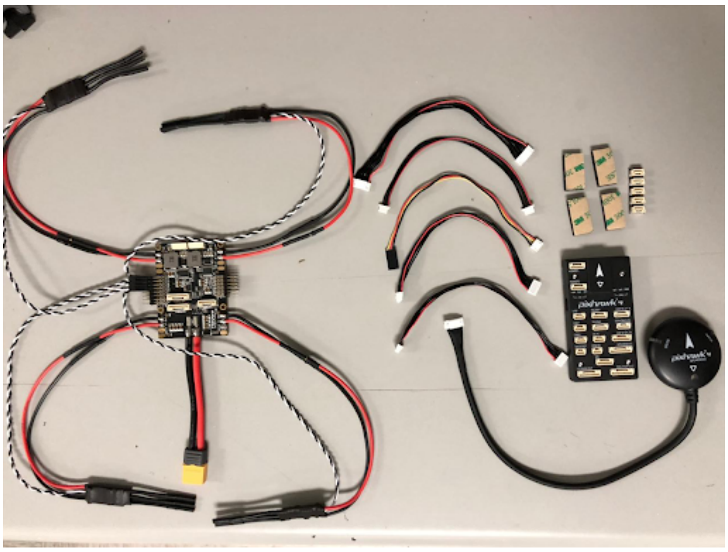


Figure 2.4: X500 Electronics

Figure 2.5: X500 Full Package Contents

- 1.5 mm Hex screwdriver
- 2.0 mm Hex screwdriver
- 2.5 mm Hex screwdriver
- 3mm Phillips screwdriver
- Wire cutters
- Precision tweezers

Figure 2.6: Landing Gear

Figure 2.7: Assembled Landing Gear

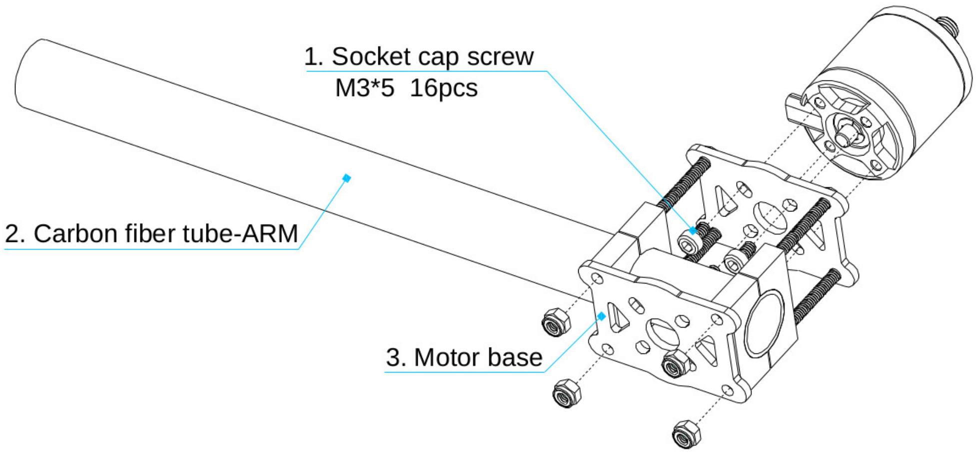


Figure 2.8: Motor base assembling scheme

2.3 Assembly

Step 1

We are going to start by assembling the landing gear to the vertical pole. Unscrew the landing gear screws and insert the vertical pole, see figures 2.6 and 2.7.

Step 2

We proceed to arm the motor holder by using 4 U-shaped nylon straps to attach the holder to the carbon fiber arm as shown in figure 2.8. The final result is shown in 2.9.

Step 3

Attach the power management PM02 to the bottom plate as shown in figures 2.10 and 2.11. You will need the screws shown in 2.12. It is recommended to connect the two 6 wires (5 black, 1 red) power cables

Figure 2.9: Motor

Figure 2.10: Power management board position.

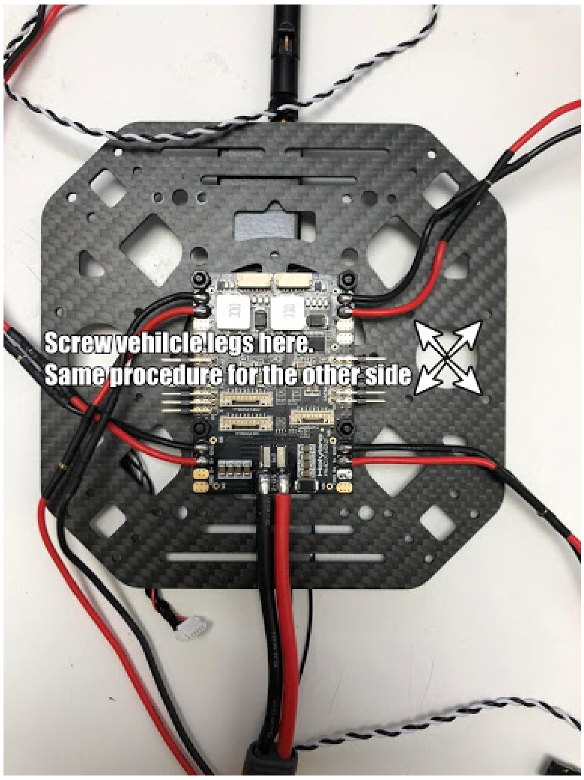


Figure 2.11: Power management board.

at the PWR1 and PWR2 sockets (Fig. 2.13), which will later be connected to the controller POWER1 and POWER2 sockets.

Step 4

Assemble the lower plate to the landing gear. Screw the landing gear with a vertical pole to the bottom plate. The lower plate has 4 holes use the M3X8 screws, a total of 8 pieces, 4 on each side.

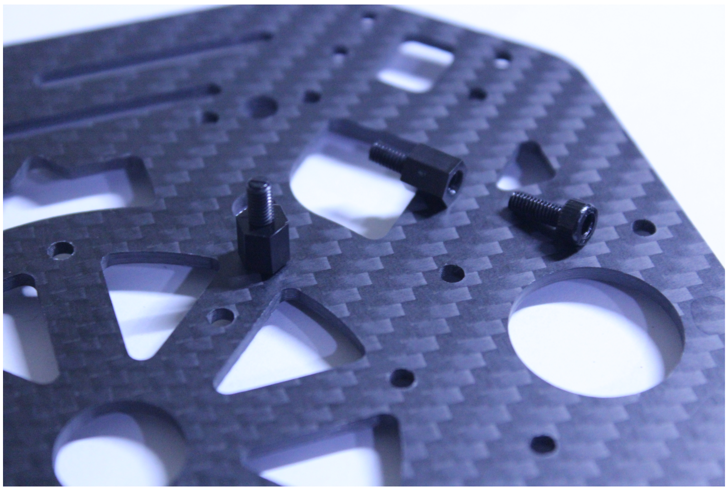


Figure 2.12: Screws and studs for PM attachment

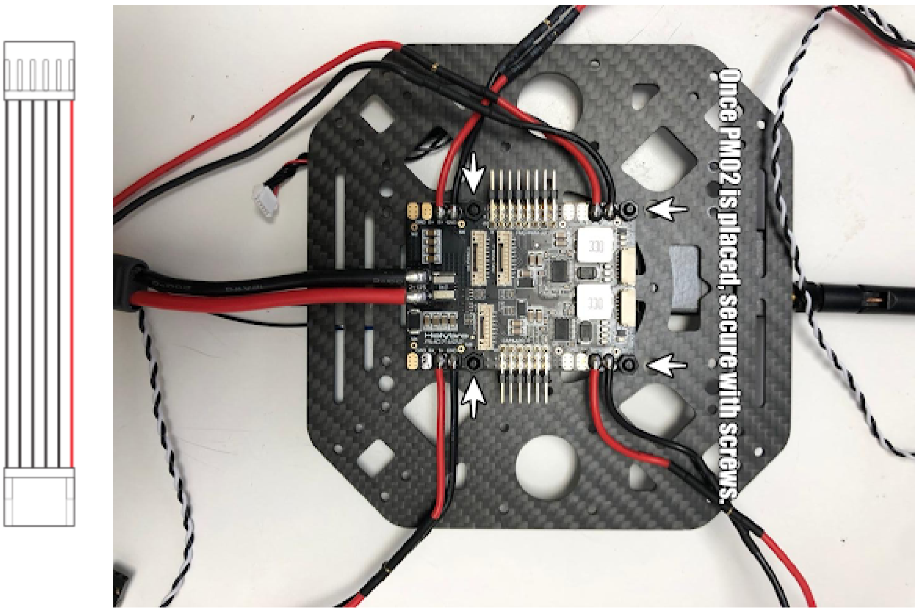


Figure 2.13: Power management board and six-to-six pin power cable

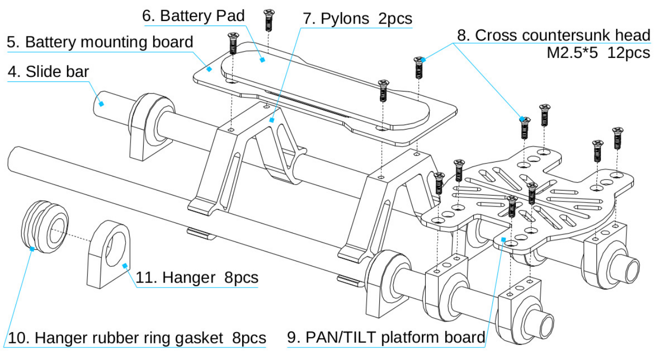


Figure 2.14: Battery holder scheme 1

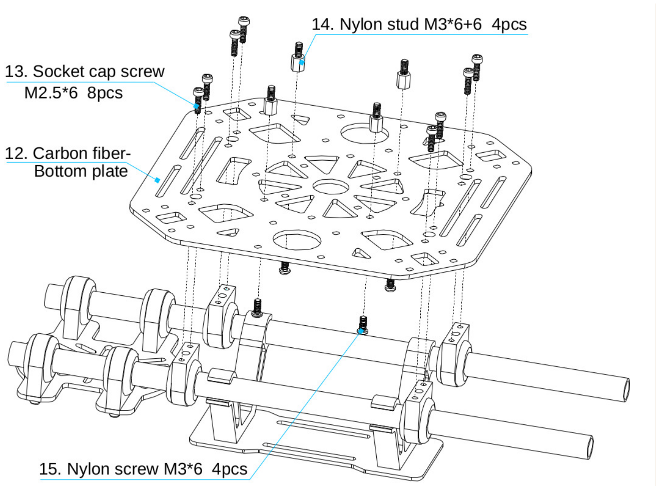


Figure 2.15: Battery holder scheme 2

Figure 2.16: Battery mount 1

Figure 2.17: Battery mount 1b

Step 5

Assembling the Battery Mount to the frame. For this we will need the M2 5X6 screws and the battery mount. See figures 2.16 and 2.17. Insert the long rods to the small rings see figure 2.18 and 2.19. With the battery holder completely armed, screw it where arrow shown in the image as shown in figure 2.20; keep in mind GPS module will be facing front.

Figure 2.18: Battery mount bars

Figure 2.19: Battery mount rings

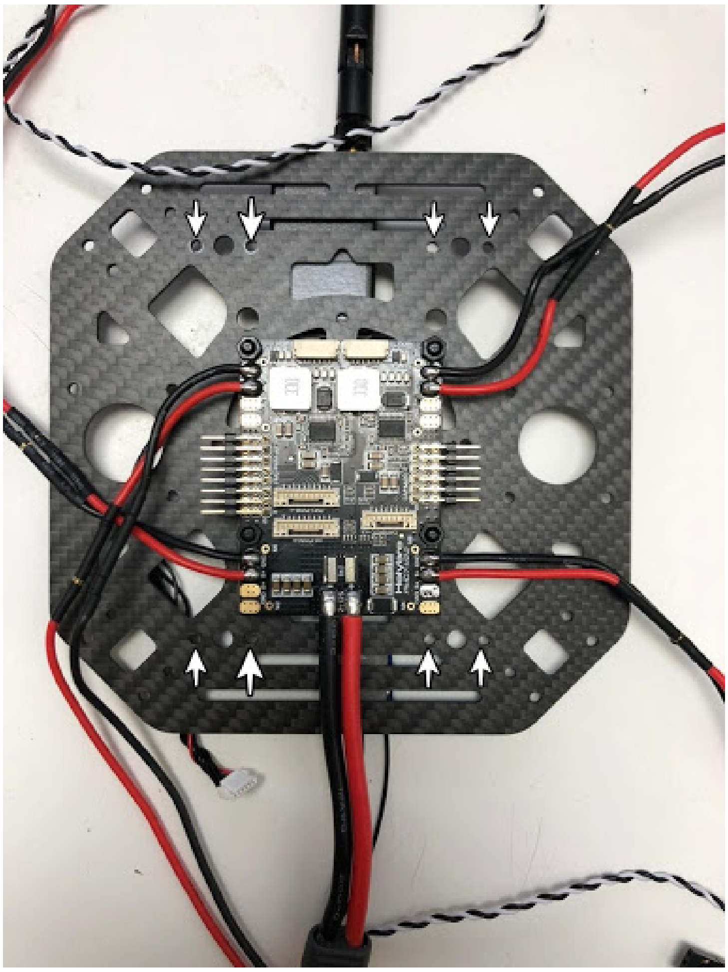


Figure 2.20: Battery holder

Figure 2.21: Holybro telemetry radio

Figure 2.22: 3M tape on TM radio

Figure 2.23: SBUS-iBUS connection for Pixhawk 4 and RC receiver.

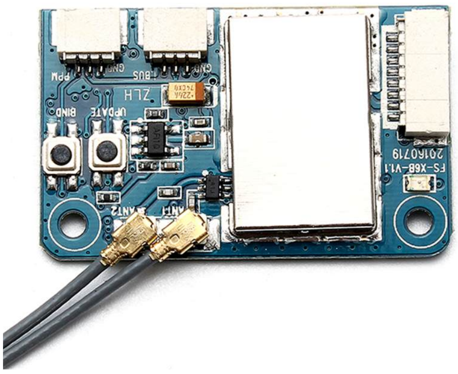


Figure 2.24: RC receiver

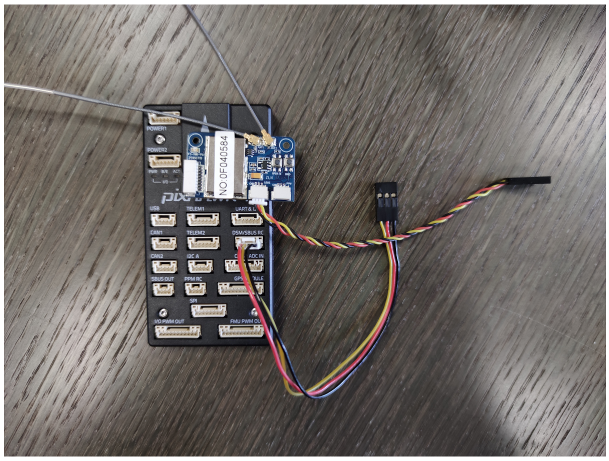


Figure 2.25: RC receiver connections

Step 6

The next step is to take the Holybro telemetry radio and attach it onto the frame. Use 3M tape (see figures 2.21 and 2.22) to attach it to the underside of the plate facing rearwards.

Step 7

Attach the RC receiver (figure 2.24) to the top of the bottom plate facing forward with the antennas pointing outwards. You will find it in the RC box. The iBUS port of the receiver must be connected to the SBUS socket of the controller (2.25). As none of the wires in the RC pack can fit the iBUS (receiver) and SBUS (controller) connection as in Fig. 2.23, we will need to connect one cable with iBUS connection to another cable with SBUS connection, by splicing the cable or using female-female jumper wires.

Step 8

Take the ESC and push it in the Arm tube as shown in figure 2.26 . Connect the ESC power cables to the Power Management Board. **Be very careful of this connection, the exchange of polarity in power cables can burn the ESC.**

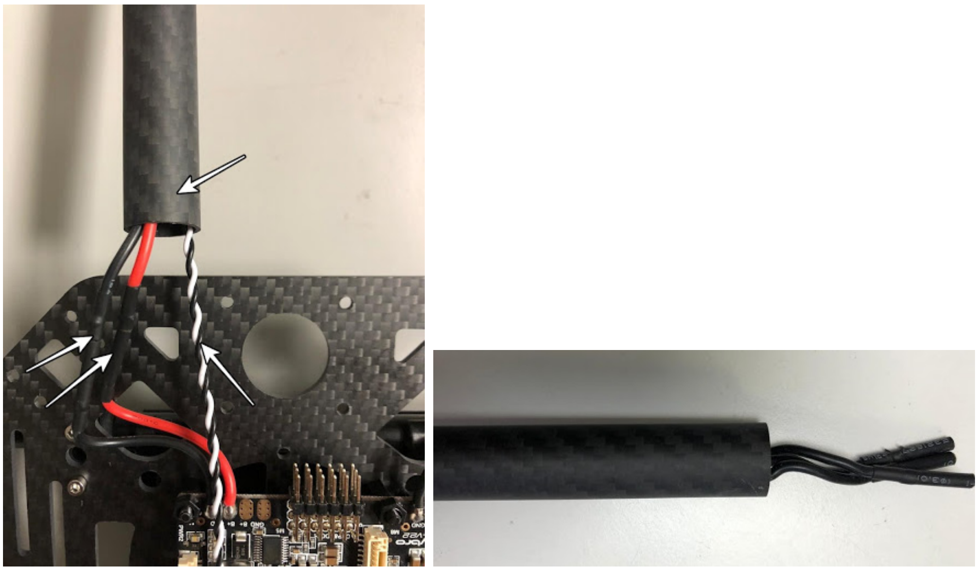


Figure 2.26: ESCs and vehicle arms.

Step 9

Connect ESC signal pins to the 8x3 horizontal PWM signal pin (Fig. 2.27):

- connect the black cable to – signal at the bottom
- connect the white/yellow cable to S signal on the top
- motors are numbered on the 8x3 horizontal PWM signal pin in the following way (Fig. 2.28): 1 front right; 2 back left; 3 front left; 4 back right.

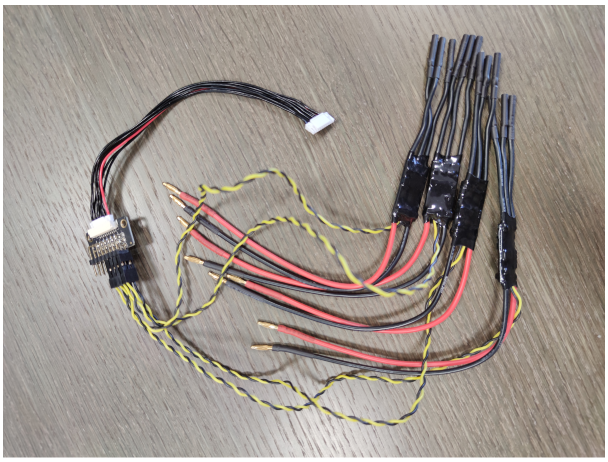


Figure 2.27: 8x3 horizontal PWM signal pin

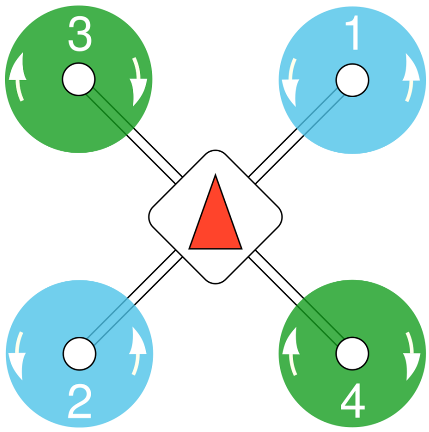


Figure 2.28: X frame motor numeration

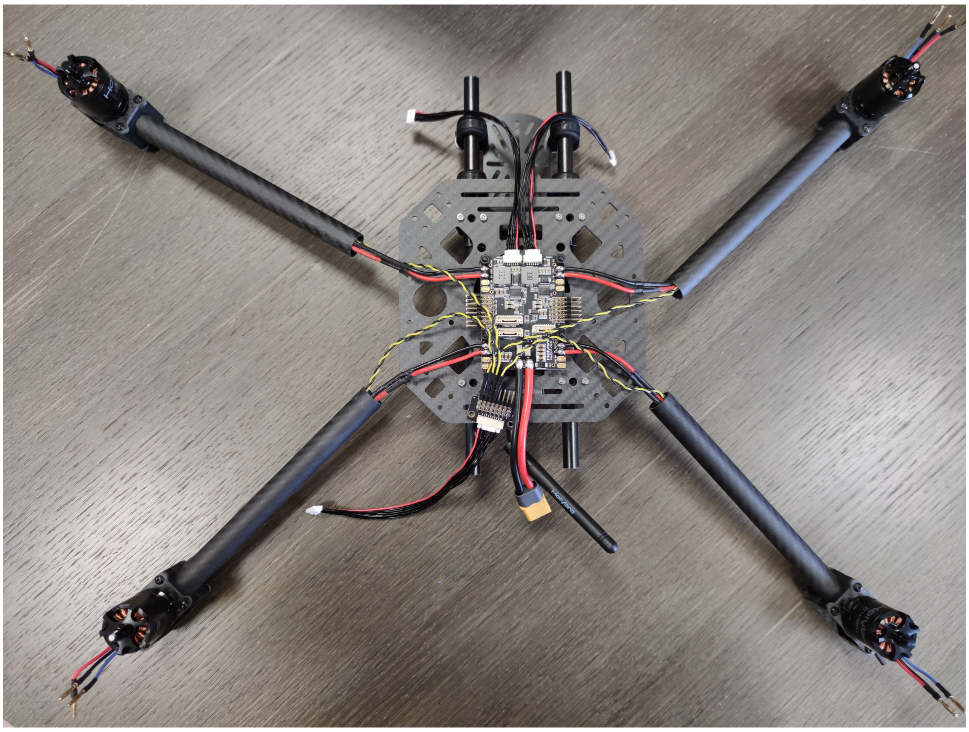


Figure 2.29: Motor, ESC, and power management board connections.

CCW motors have silver screws on top and CW motors have black ones on top (Fig. 2.29). *CW and CCW motors are still the same motors, apart from the prop shaft threads which have opposite direction.* That means for a CCW motor, the prop nut is secured by turning clockwise. And for CW motors, the prop nuts needs to be rotated anti-clockwise in order to fasten.

Assemble the 8x3 horizontal PWM signal pin to the 10 to 10 pin cable (which will later be connected to the I/O PWN OUT socket on the controller). Fix the 8x3 horizontal PWM signal pin to the mounting plate with cable zip ties (brida).

Step 10

Connect Motors cables to ESC as in Fig. 2.30. To change the rotation direction, we can switch any two of the three cables. **Verify the rotation direction of the motors before connecting propellers.**

Step 11

Assemble arm to main body. With 4 more U-shaped nylon straps attach the arm with the motor installed to the body of the vehicle as shown in figure 2.31, this way you also attach the bottom plate to the top plate. Keep in mind to have the arm tube a bit pushed in to that it can be kept securely in place as shown in the Red Square from figure 2.31.

Step 12

Mounting the GPS on the frame. For this, we will need the Pixhawk 4 GPS and the mounting plate.

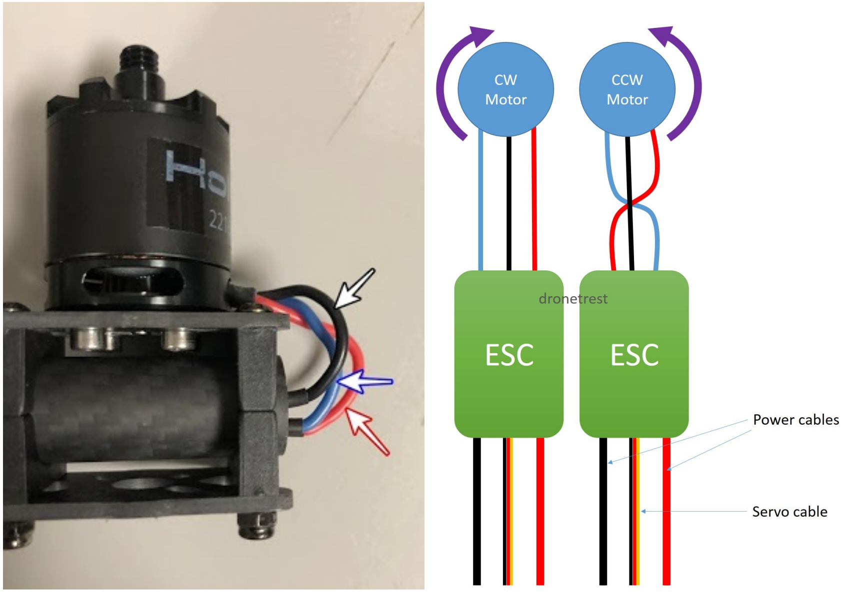


Figure 2.30: Motors and ESC connection

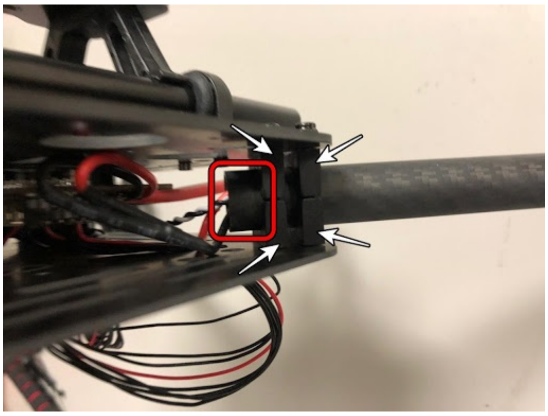


Figure 2.31: Arm assembly.

Mount GPS mast to the plate, use the 4 screws see the red circle in figure 2.32, keep in mind that the plate is mounted to the battery holder tubes as indicated by the arrows in figure 2.32.

Use the tape and stick the GPS to the top of the GPS mast, see figure 2.33. The arrow of the GPS must face forward.

Step 13

Pixhawk 4 wiring. The Pixhawk 4, which has several different wires and connections with it. Included below is a picture of every wire needed with the Pixhawk and how it looks when connected.

Plugin Telemetry and GPS module to the flight controller as seen in figure 2.34; plug in the RC receiver, all 4 ESCs to the flight controller as well as the power module as shown in figure 2.35.

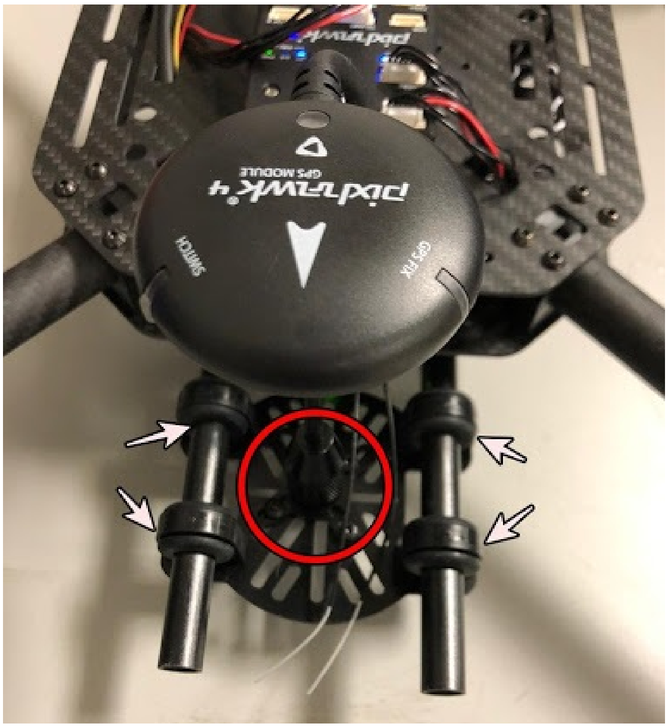


Figure 2.32: GPS 1

Figure 2.33: GPS 2

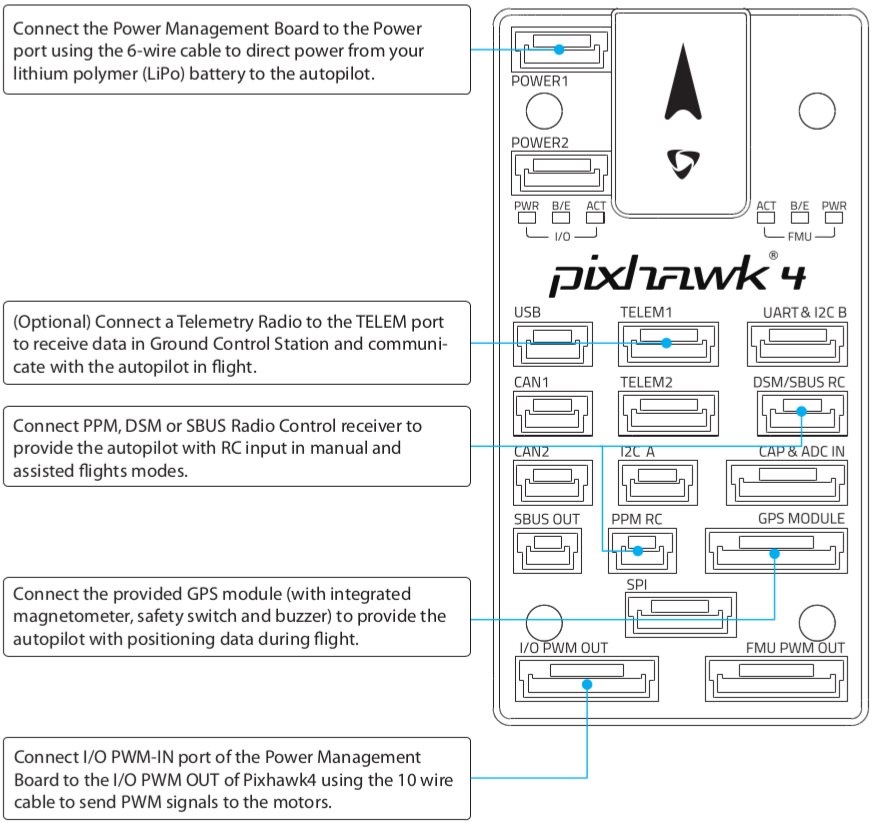


Figure 2.34: Pixhawk 4 wiring 1

Figure 2.35: Pixhawk 4 wiring 2

Figure 2.36: Assembled Kit

Chapter 3

Drone Setup

In order to configure the drone we will use QGroundControl (QGC). QGC provides full flight control and vehicle setup for PX4 or ArduPilot powered vehicles. It runs on Windows, OS X, Linux, iOS and Android. With QGC we will be able to: load the firmware into the vehicle, calibrate the different sensors, configure the vehicle, manage the mission planner, get telemetry information…

QGC relies on MAVLink to communicate with the drone. MAVLink is a very lightweight *messaging protocol* for communicating with drones (and between onboard drone components). Message protocols consists on a set of rules to allow different entities of a system to transmit information to each other. These rules cover the format used for the messages (header, payload...), the way different elements are identified (address), how messages are routed and delivered, error and loss of information checking, acknowledgement of correct reception…

Other Ground Control Stations (GSS) that can communicate with the vehicle by exchanging MAVLink messages are: Mission Planner (only windows), APM Planner, MAVProxy (command line interface) and Droid Planner (android devices).

3.1 Install and configure PX4

QGroundControl is used to install firmware onto the flight controller hardware, specify an airframe and configure the core sensors that PX4 needs to be present on every vehicle (compass, GPS, gyro etc.). This section contains *essential* configuration topics: firmware, airframe, sensor modes, battery, motors…

> **Tip** Before starting this section you should Download QGroundControl and install it on your **desktop** computer (*QGroundControl* does not support vehicle configuration on mobile platforms).

> **Note** This section is adapted from PX4 User Guide → Basic Configuration trying to focus on our current hardware. More information can also be obtained from PX4 User Guide → Advanced Configuration (vehicle-specific tuning, and less-common sensors and peripherals).

3.1.1 Loading Firmware

Generally you should use the most recent *released* version of PX4, in order to benefit from bug fixes and get the latest and greatest features.

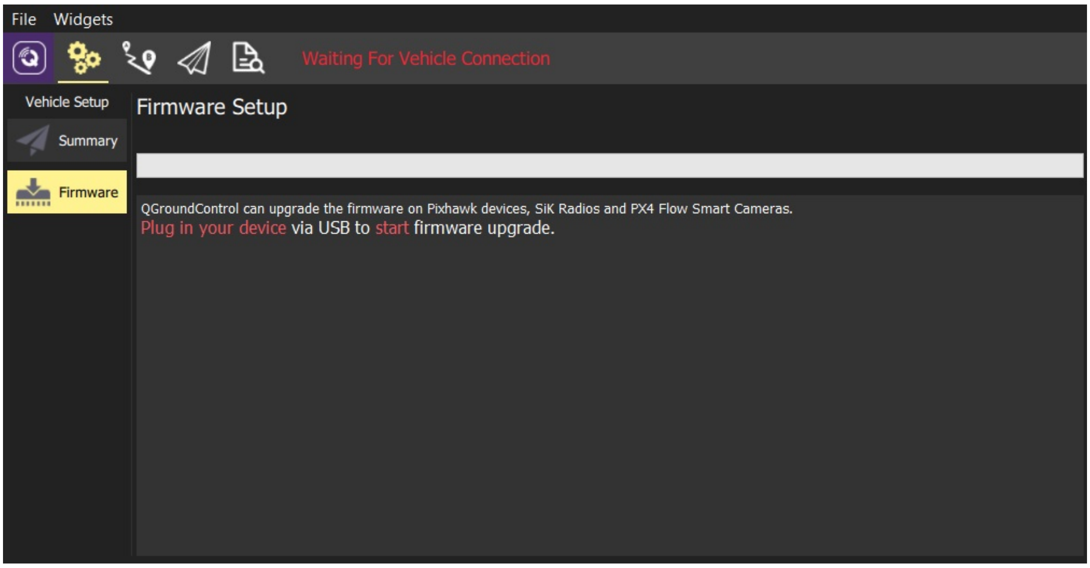


Figure 3.1: Firmware disconnected

Caution Before you start installing Firmware all USB connections to the vehicle must be *disconnected* (both direct or through a telemetry radio). The vehicle must *not be* powered by a battery.

1. First select the **Gear** icon (*Vehicle Setup*) in the top toolbar and then **Firmware** in the sidebar. See figure 3.1.
2. Connect the flight controller directly to your computer via USB.

   Note Connect directly to a powered USB port on your machine (do not connect through a USB hub).
3. Select the **PX4 Flight Stack X.x.x Release** option to install the latest stable version of PX4 *for your hardware*(autodetected). See figure 3.2.
4. Click the **OK** button to start the update. The firmware will then proceed through a number of upgrade steps (downloading new firmware, erasing old firmware etc.). Each step is printed to the screen and overall progress is displayed on a progress bar.
5. Click the **OK** button to start the update. The firmware will then proceed through a number of upgrade steps (downloading new firmware, erasing old firmware etc.). Each step is printed to the screen and overall progress is displayed on a progress bar (figure 3.4). Once the firmware has completed loading, the device/vehicle will reboot and reconnect.
6. You will need to connect the computer to each telemetry transmitter using the same USB cable and update the firmware as as shown in Fig. 3.5.

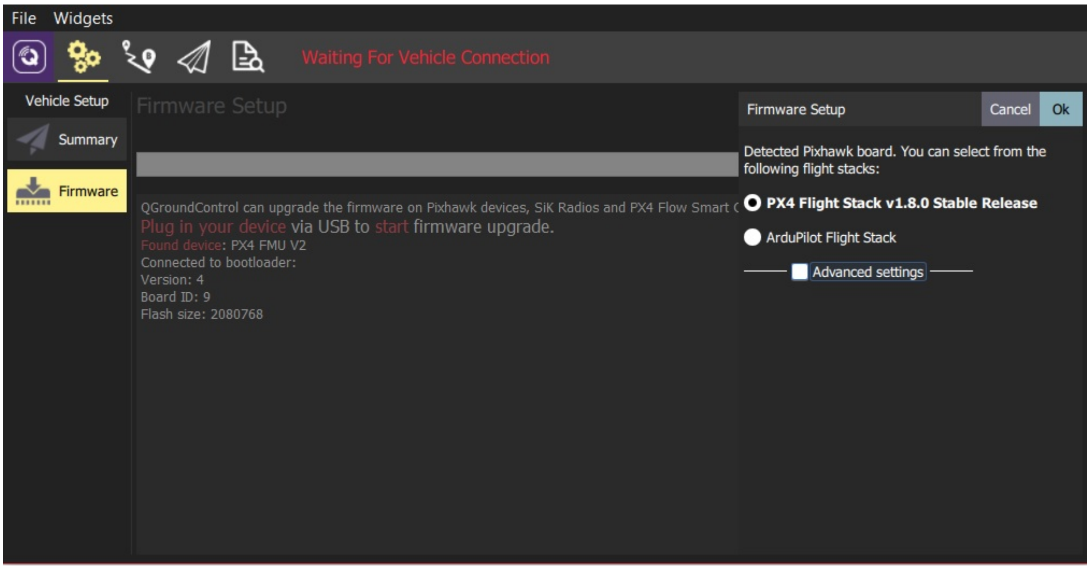


Figure 3.2: Install PX4 default

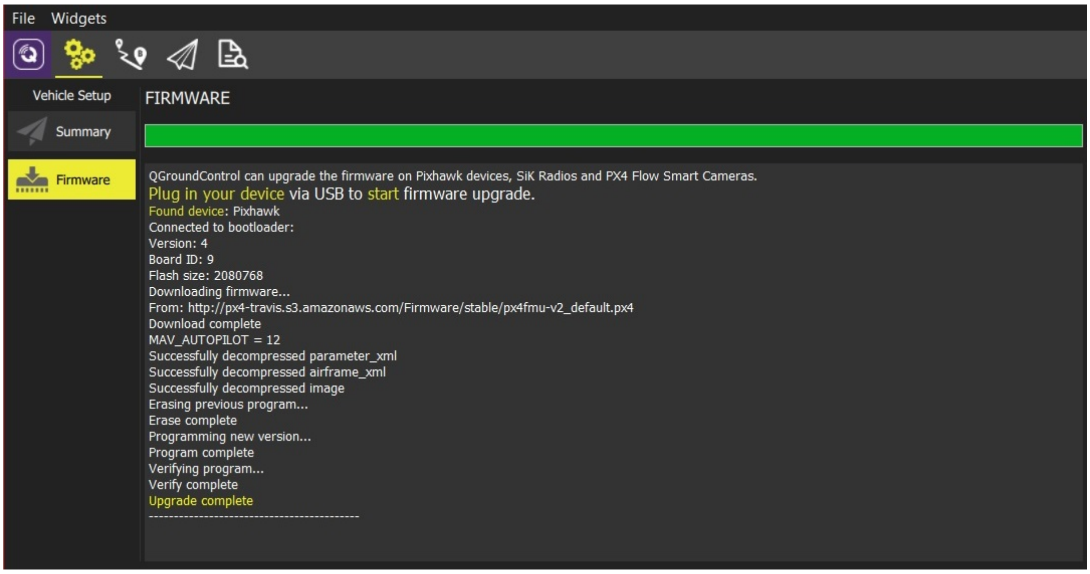


Figure 3.3: Firmware upgrade complete

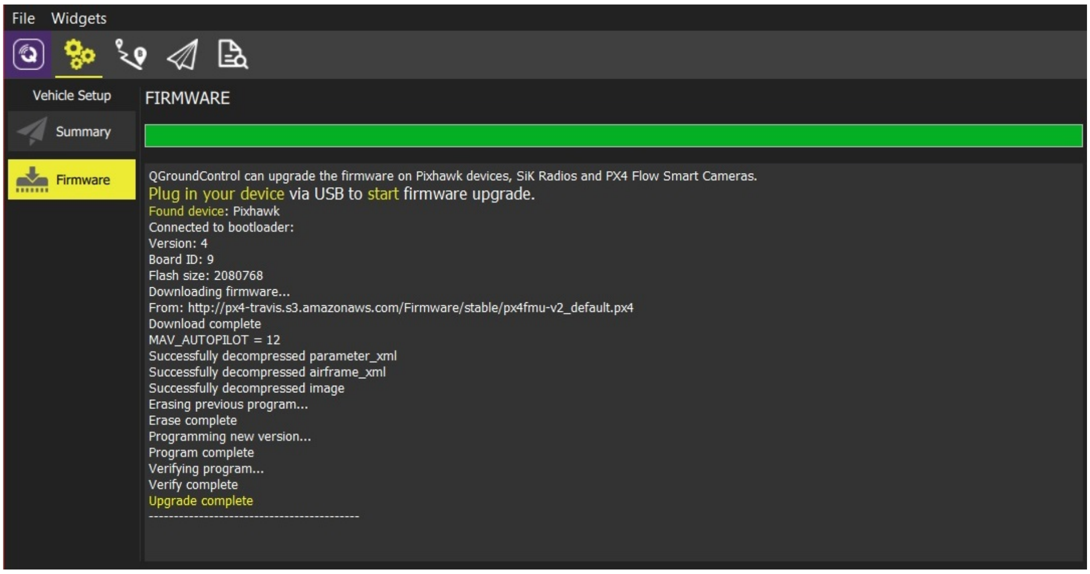


Figure 3.4: Firmware upgrade complete

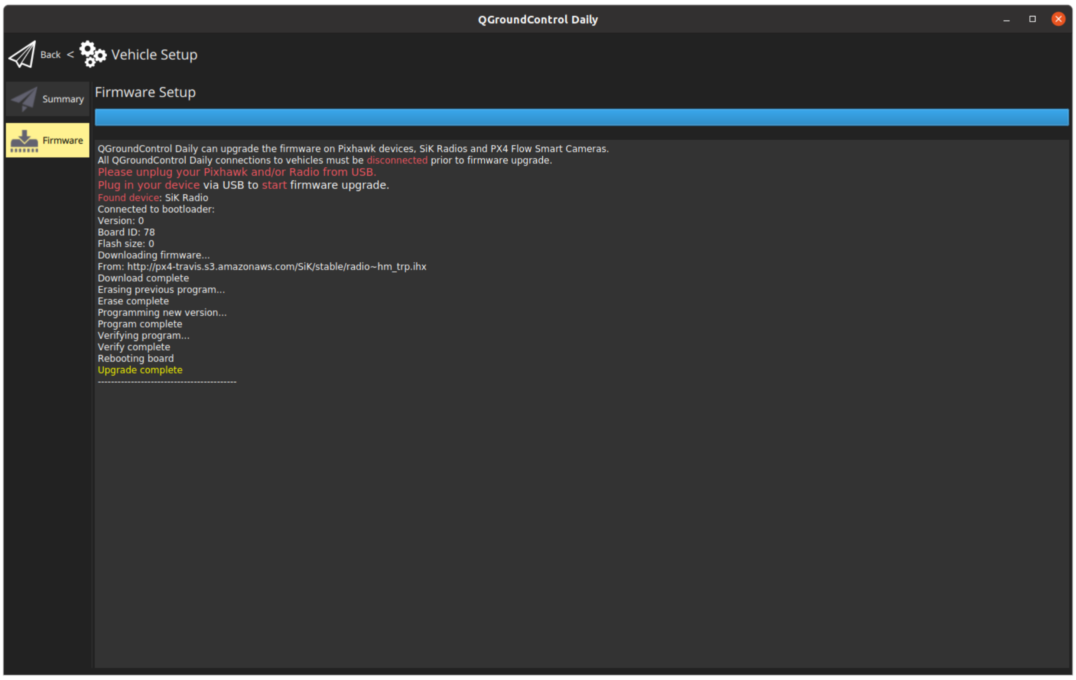


Figure 3.5: Firmware upgrade for telemetry.

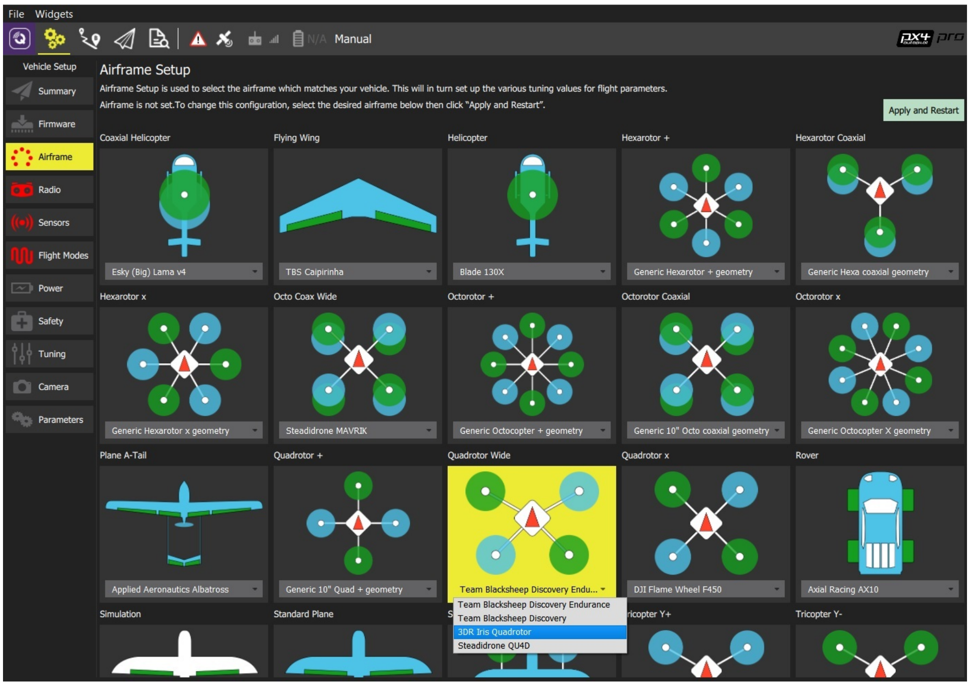


Figure 3.6: Airframe apply prompt

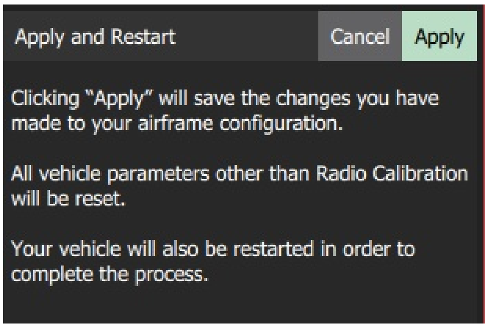


Figure 3.7: Airframe apply prompt

3.1.2 Airframe Setup

After installing firmware you need to configure the firmware parameters for your specific airframe. In our case, we will choose **Quadrotor X: Holybro S500**.

To set the airframe:

1. Start *QGroundControl* and connect the vehicle.
2. Select the **Gear** icon (Vehicle Setup) in the top toolbar and then **Airframe** in the sidebar.
3. Select the broad vehicle group/type that matches your airframe and then use the dropdown within the group to choose the airframe that best matches your vehicle (example in figure 3.6).
4. Click **Apply and Restart**. Click **Apply** in the following prompt to save the settings and restart the vehicle (figure 3.7).

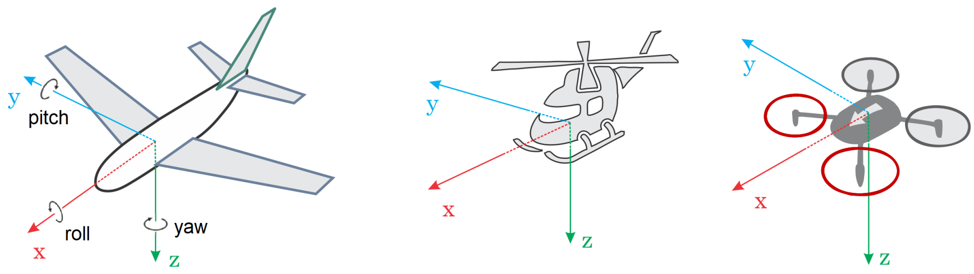


Figure 3.8: Airframe heading

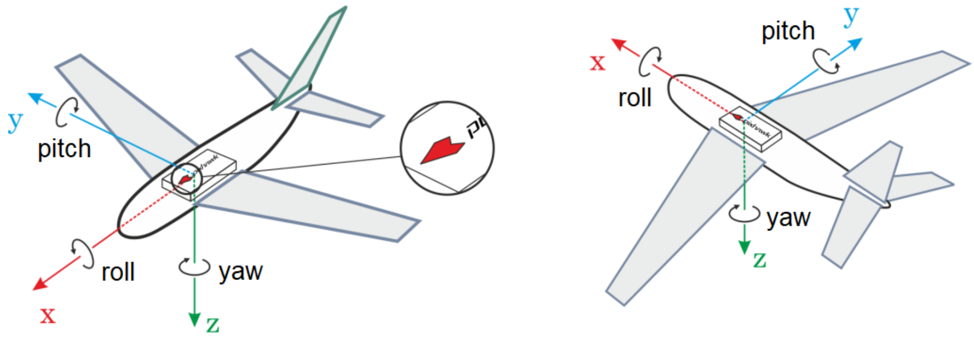


Figure 3.9: Airframe rotations

3.1.3 Flight Controller/Sensor Orientation

By default the flight controller (and external compass(es), if present) should be placed on the frame top-side up, oriented so that the arrow points towards the front of the vehicle. If the board or an external compass are mounted in any other orientation then you will need configure this in the firmware.

Roll, pitch and/or yaw offsets of the flight controller are calculated relative to the vehicle around the forward (x), right (y), down (z) axes as shown in figure 3.8.

The axes to rotate around stay the same from one rotation step to the next one. So the frame to perform the rotation in stays fixed. This is also known as *extrinsic rotation*. See figure 3.9. The vehicles shown in figure 3.10 have rotations around the z-axis (i.e. yaw only) corresponding to: `ROTATION_NONE`, `ROTATION_YAW_90`,`ROTATION_YAW_180`,`ROTATION_YAW_270`.

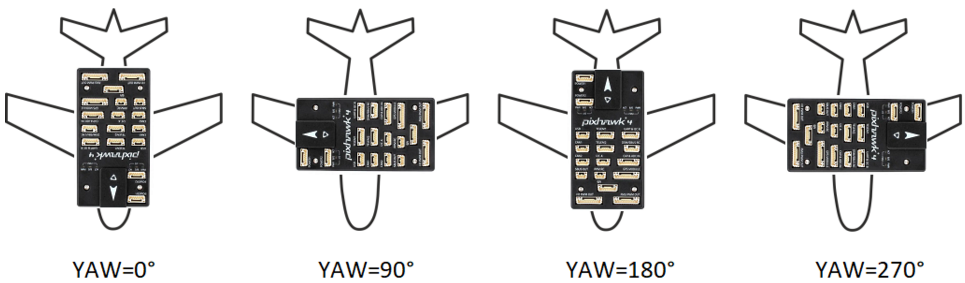


Figure 3.10: Yaw rotation

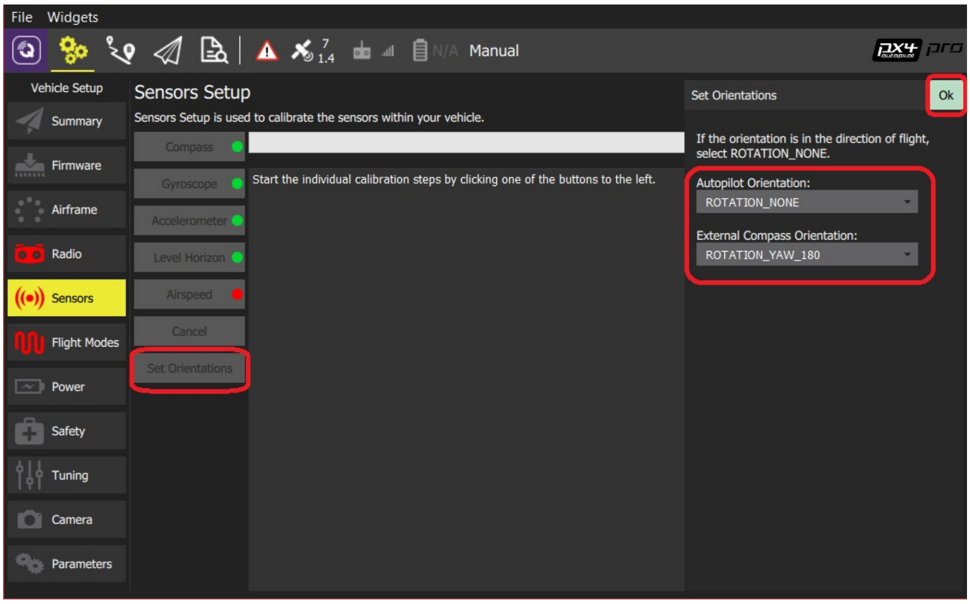


Figure 3.11: Set sensor orientation

Setting the Orientation

> **Note: It is recommended to perform all the calibration steps using telemetry (instead of wired).** Plug the battery to the vehicle (make sure that TM unit has been installed and plugged to the Pixhawk 4 board), connect the USB to the computer and launch QGroundControl.

To set the orientations:

1. Start *QGroundControl* and connect the vehicle.
2. Select the **Gear** icon (Vehicle Setup) in the top toolbar and then **Sensors** in the sidebar. (See figure 3.11)
3. Select the **Set Orientations** button.
4. Select the **AutoPilot Orientation** as calculated above. In our case is `ROTATION_NONE`.
5. Select the **External Compass Orientation** in the same way (this option will only be displayed if your vehicle has an external compass).
6. Press **OK**.

As the controller orientation will not perfectly coincide with a levelled horizon, the level horizon calibration will compensate for small miss-alignments.

3.1.4 Compass Calibration

The compass calibration process configures the magnetometer. You will need to calibrate your compass on first use, and you may need to recalibrate it if the vehicles is ever exposed to a very strong magnetic field, or if it is used in an area with abnormal magnetic characteristics. Indications of a poor compass calibration include multicopter circling during hover, toilet bowling (circling at increasing radius/spiraling-out, usually constant altitude, leading to fly-way), or veering off-path when attempting to fly straight.

QGroundControl will guide you to position the vehicle in a number of set orientations and rotate the vehicle about the specified axis.

> **Note** If you are using an external magnetometer/compass (e.g. a compass integrated into a GPS module) make sure you mount the external compass on your vehicle properly and connect it to the autopilot hardware. Once connected, *QGroundControl* will automatically detect the external magnetometer.

The calibration steps are:

1. Choose a location away from large metal objects or magnetic fields.
2. Start *QGroundControl* and connect the vehicle.
3. Select the **Gear** icon (Vehicle Setup) in the top toolbar and then **Sensors** in the sidebar.
4. Click the **Compass** sensor button. See figure 3.12. You should already have set the Autopilot Orientation. If not, you can also set it here.
5. Click **OK** to start the calibration.
6. Place the vehicle in any of the orientations shown in red (incomplete) and hold it still. Once prompted (the orientation-image turns yellow) rotate the vehicle around the specified axis in either/both directions. Once the calibration is complete for the current orientation the associated image on the screen will turn green. See figure 3.13.
7. Repeat the calibration process for all vehicle orientations.

Once you've calibrated the vehicle in all the positions *QGroundControl* will display *Calibration complete* (all orientation images will be displayed in green and the progress bar will fill completely). You can then proceed to the next sensor.

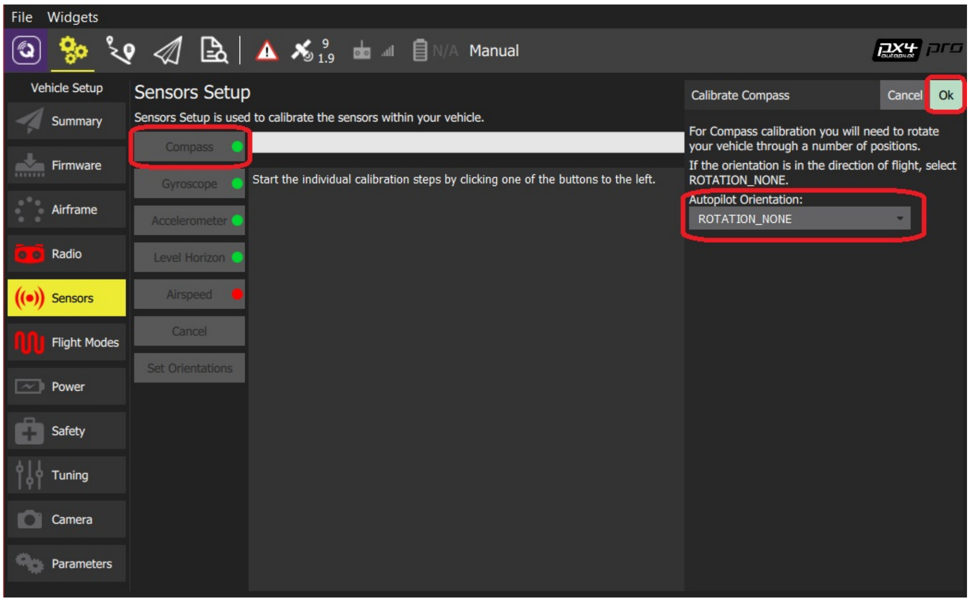


Figure 3.12: Select Compass Selection PX4

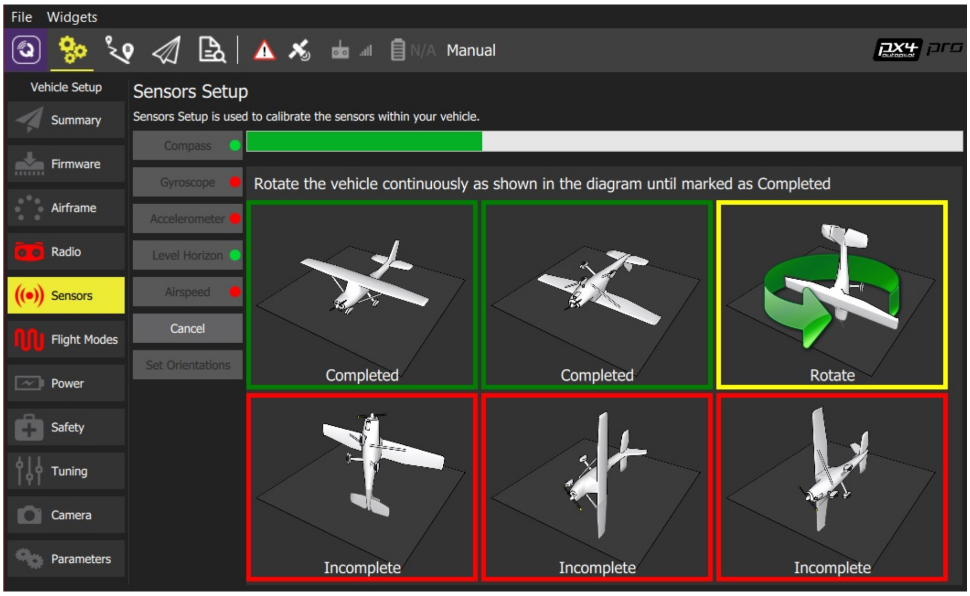


Figure 3.13: Select Compass calibration PX4

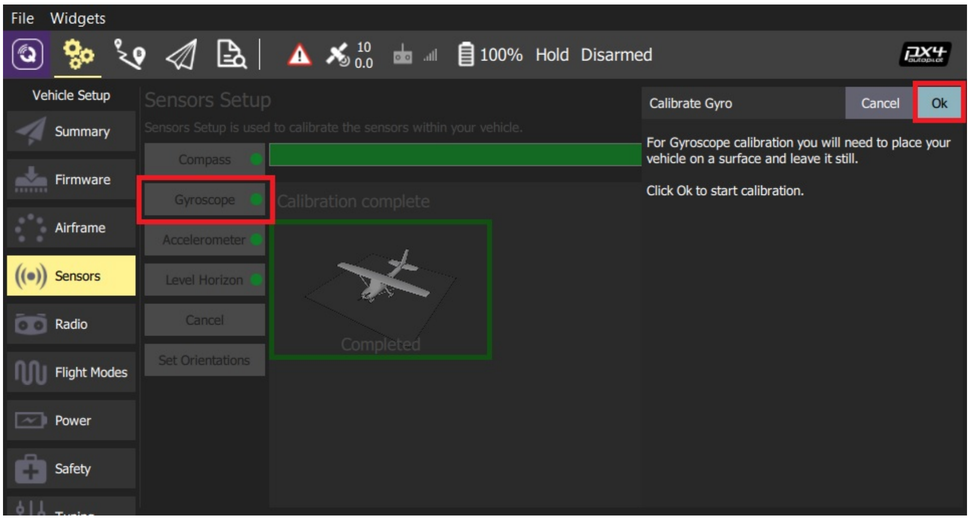


Figure 3.14: Select Gyroscope calibration PX4

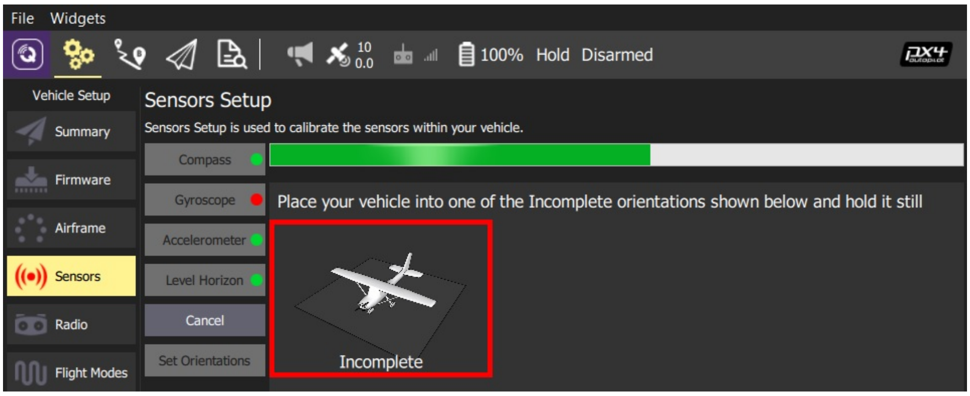


Figure 3.15: Gyro calibration in progress on PX4

3.1.5 Gyroscope Calibration

QGroundControl will guide you to place the vehicle on a flat surface and keep it still. The calibration steps are:

1. Click the **Gyroscope** sensor button. See figure 3.14.
2. Place the vehicle on a surface and leave it still.
3. Click **Ok** to start the calibration. The bar at the top shows the progress (figure 3.15).
4. When finished, *QGroundControl* will display a progress bar *Calibration complete*.

Note If you move the vehicle *QGroundControl* will automatically restart the gyroscope calibration.

3.2 Accelerometer

You will need to calibrate your accelerometer on first use or if the flight controller orientation is changed. Otherwise you should not need to recalibrate (except perhaps in winter, if you have a flight controller that was not thermally calibrated in the factory).

> **Note** Poor accelerometer calibration is generally caught by preflight checks and arming-denied messages (QGC warnings typically refer to "high accelerometer bias" and "consistency check failures").

QGroundControl will guide you to place and hold your vehicle in a number of orientations (you will be prompted when to move between positions). **This is similar to compass calibration except that you hold the vehicle still (rather than rotate it) in each orientation**.

The calibration uses a least squares 'fit' algorithm that doesn't require you to have "perfect" 90 degree orientations. Provided each axis is pointed mostly up and down at some time in the calibration sequence, and the vehicle is held stationary, the precise orientation doesn't matter.

The calibration steps are:

1. Start *QGroundControl* and connect the vehicle.
2. Select the **Gear** icon (Vehicle Setup) in the top toolbar and then **Sensors** in the sidebar.
3. Click the **Accelerometer** sensor button.
4. Click **OK** to start the calibration.
5. Position the vehicle as guided by the *images* on the screen. Once prompted (the orientation-image turns yellow) hold the vehicle still. Once the calibration is complete for the current orientation the associated image on the screen will turn green.
6. Repeat the calibration process for all vehicle orientations.

Once you've calibrated the vehicle in all the positions *QGroundControl* will display *Calibration complete* (all orientation images will be displayed in green and the progress bar will fill completely). You can then proceed to the next sensor.

3.2.1 Level Horizon Calibration

You can use *Level Horizon Calibration* to compensate for small miss-alignments in controller orientation and to level the horizon in the *QGroundControl* flight view (blue on top and green on bottom).

> **Tip** Leveling the horizon is highly recommended, and will result in the best flight performance. This process can also be repeated if you notice a constant drift during flight.

To level the horizon:

1. Start *QGroundControl* and connect the vehicle.
2. Select the **Gear** icon (Vehicle Setup) in the top toolbar and then **Sensors** in the sidebar.

3. Click the **Level Horizon** button.
4. Place the vehicle in its level flight orientation on a levelled surface.
5. Press **OK** to start the calibration process.
6. Wait until the calibration process is finished.

After the orientation is set and level-horizon calibration is complete, check in the flight view that the heading in the compass shows a value around 0 when you point the vehicle towards north and that the horizon is level (blue on top and green on bottom).

3.2.2 Remote Control Setup

Firstly, we must configure the radio remote control. Enter the main menu by pressing and holding OK button, then select the “System setup”.

- Set the controller name, you can choose the name of your group. To save the setting you just need to press and hold CANCEL button until you go back to the menu.
- Ensure “Type select” is in “Airplane or Glider”
- Navigate to “RX Setup” and then“Output mode”, then select “PWM” and “S-BUS”.

Go Back to the main menu and enter the “Functions setup” menu. Select ”Aux. Channels“. We will change Channel 5 to ”SwA“ (we will use it for arm and disarm) and Channel 6 ”SwC“ (we will use it for flight mode selection). If SwA and SwC options do not appear in the choices, you need to go back to the “System setup” menu, select “Aux switches” and turn on these options. You can check this example: https://www.youtube.com/watch?v=cGYFRCEQ2Ps.

Bare in mind that you must turn on your controller with all the switches up and sticks down.

PX4 needs to be able to detect when the signal from the RC controller has been lost in order to be able to take appropriate safety measures. RC receivers have different ways of indicating signal loss:

- Output nothing (automatically detected by PX4)
- Output a low throttle value value (you can configure PX4 to detect this)
- Output the last received signal (*cannot be detected by PX4* as it looks like valid input)

In the “system setup” menu, navigate to “RX setup” menu and enter “Failsafe”. Select Channel 3, move the throttle stick totally down (-100%) and press the down button to turn fail safe on. Save the configuration by pressing and holding cancel button twice. You can check this example for Failsafe setting: https://www.youtube.com/watch?v=4DGZOaQOzJU.

Secondly, before you can calibrate the radio system the receiver and transmitter must be connected/bound. The process for binding a transmitter and receiver pair is hardware specific (see your RC manual for instructions). In our case: you will know that they are not bound if once the drone is powered and the controller is on, the red light is the receiver is blinking.

In order to bind them you have to:

- Turn off the controller and power off the drone.

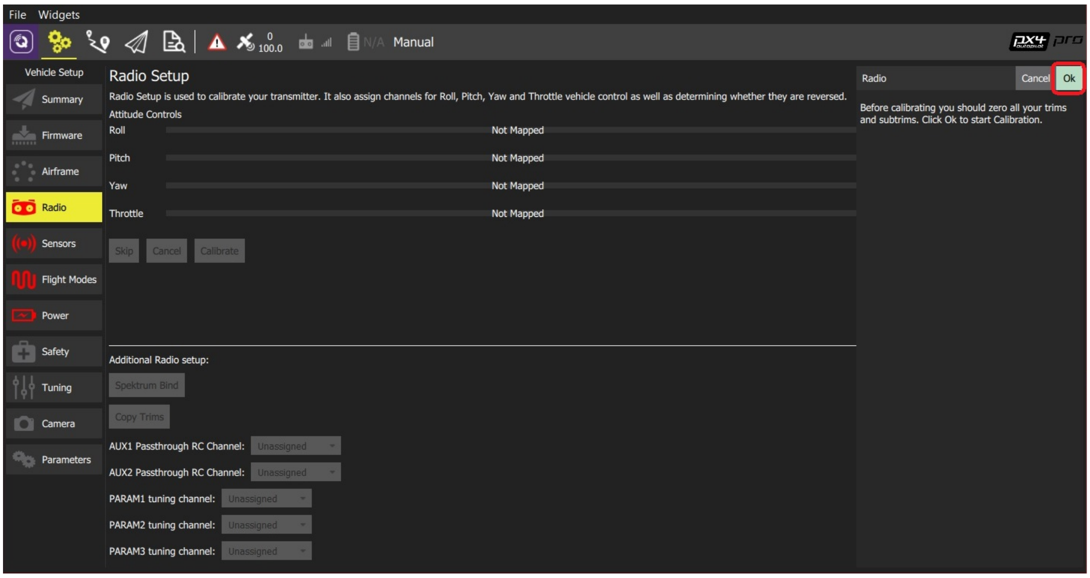


Figure 3.16: Radio setup - before starting

- Pushing and holding the bind button of the receiver power on the drone. The receiver will start blinking quickly.
- In the controller, push the bind button down (you can find it in the front down left) and turn it on. It will show a message in the screen saying "RXBinding".
- The receiver should start blinking slowly. Once that happens, turn off the drone and the controller.
- Turn on the drone, turn on the controller. The receiver should have a non-blinking red light.

You can check this example for binding: https://www.youtube.com/watch?v=msGpx8vEHsQ.

You can watch this video if you prefer: https://youtu.be/S6svAP7f1oY?t=249.

Once the controller is configured and bound to the receiver, we can perform the calibration using QGroundControl. The calibration process is straightforward - you will be asked to move the sticks in a specific pattern that is shown on the transmitter diagram on the top right of the screen. To calibrate the radio:

1. Turn on your RC transmitter.
2. Start *QGroundControl* and connect the vehicle.
3. Select the **Gear** icon (Vehicle Setup) in the top toolbar and then **Radio** in the sidebar.
4. Press **OK** to start the calibration. See figure 3.16.
5. Set the transmitter mode radio button that matches your transmitter (this ensures that *QGroundControl* displays the correct stick positions for you to follow during calibration). See figure 3.17
6. Move the sticks to the positions indicated in the text (and on the transmitter image). Press **Next** when the sticks are in position. Repeat for all positions.
7. When prompted, move all other switches and dials through their full range (you will be able to observe them moving on the *Channel Monitor*).
8. Press **Next** to save the settings.

Radio calibration is demonstrated in the autopilot setup video here (youtube).

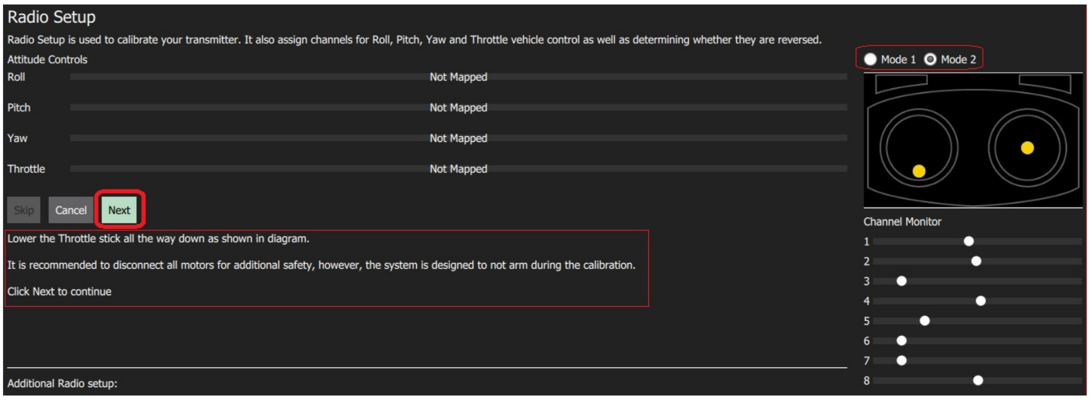


Figure 3.17: Radio setup - move sticks

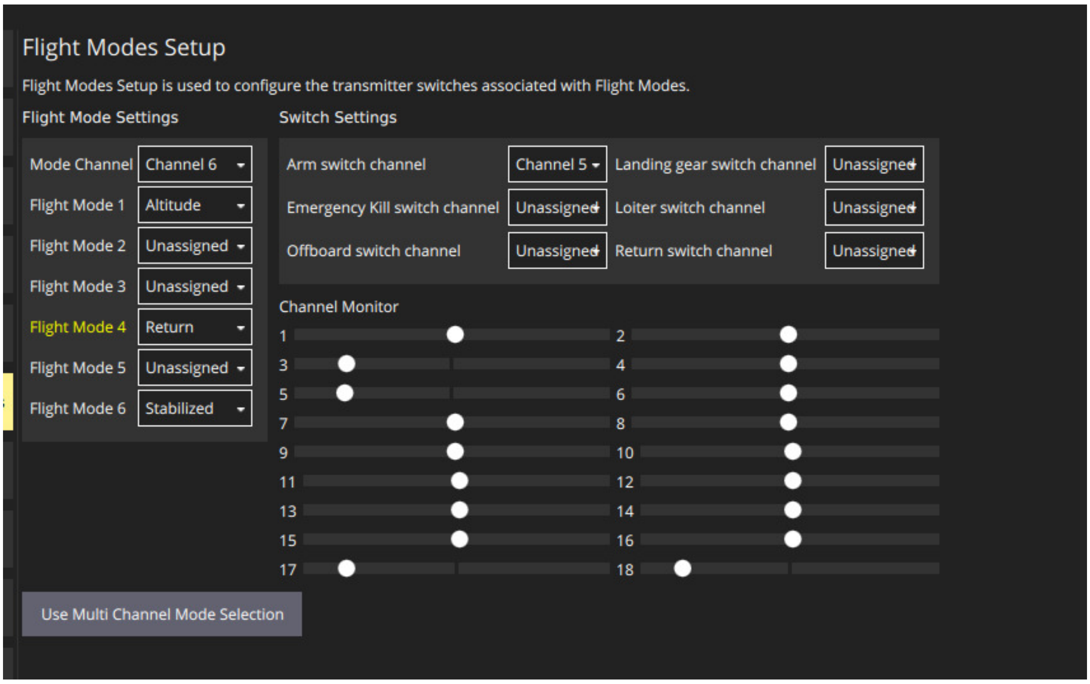


Figure 3.18: Flightmode configuration.

3.2.3 Flight Mode Configuration

Flight Modes provide different types of *autopilot-assisted flight*, and *fully autonomous flight* via missions or offboard (companion computer) control. Different flight modes allow new users to learn flying with a more forgiving platform than provided by basic RC control alone. They also enable automation of common tasks like taking off, landing and returning to the original launch position.

PX4 allows you to select flight modes from a ground station (see Fig.3.18) or from a radio control transmitter. If radio control and tablet are both connected, either system can change the mode and override the previous setting.

This section explains how to map flight modes to the switches on your radio control transmitter.

Note You must already have configured your radio in order to set flight modes.

What Flight Modes Should I Set?

New users should consider setting one or more of the following modes, which make the vehicle much easier to fly:

- **Stabilized** - Roll and pitch sticks control the angle of the vehicle (attitude), the yaw stick controls the rate of rotation above the horizontal plane, and the throttle controls the engines speed. The multicopter will level out and stop once the roll and pitch sticks are centered. The vehicle will then hover in place/maintain altitude - provided it is properly balanced, throttle is set appropriately, and no external forces are applied (e.g. wind). The craft will drift in the direction of any wind and you have to control the throttle to hold altitude.
- **Position** - Roll and pitch sticks control velocity over ground in the vehicle's forward-back and left-right directions (similar to a car's accelerator pedal), and throttle controls speed of ascent-descent. When the sticks are released/centered the vehicle will actively brake, level, and be locked to a position in 3D space — compensating for wind and other forces.
- **Altitude** - Roll and pitch sticks control vehicle movement in the left-right and forward-back directions (relative to the "front" of the vehicle), yaw stick controls rate of rotation over the horizontal plane, and throttle controls speed of ascent-descent. When the sticks are released/centered the vehicle will level and maintain the current altitude. If moving in the horizontal plane the vehicle will continue until any momentum is dissipated by wind resistance. If the wind blows the aircraft will drift in the direction of the wind.

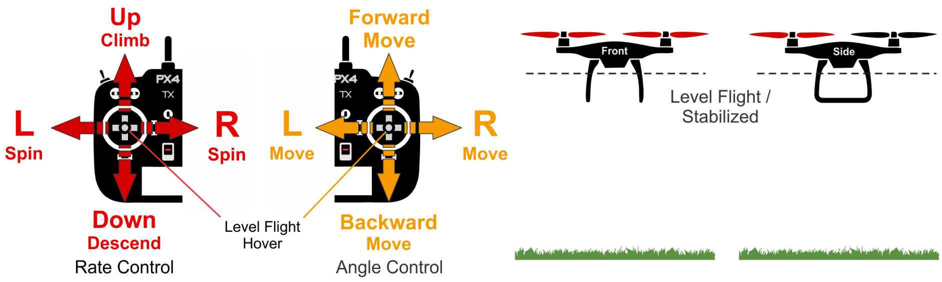
Mode	Left Stick Up/Down	Left Stick Left/Right	Right Stick Up/Down	Right Stick Left/Right
Stabilized	Engines speed	Yaw rate	Pitch angle	Roll angle
Altitude	Altitude	Yaw rate	Pitch angle	Roll angle
Position	Altitude	Yaw rate	Forward velocity	Lateral velocity
Acrobatic	Engines speed	Yaw rate	Pitch rate	Roll rate

It is also common to map switches to:

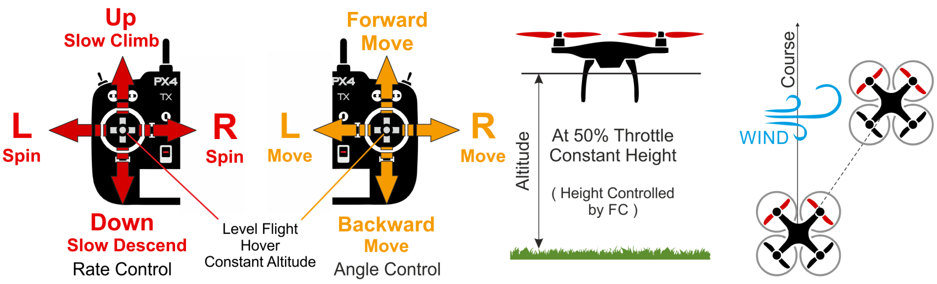
- **Acrobatic** (Do not use it!) - Roll, pitch and yaw sticks control the rate of angular rotation around the respective axes and throttle is passed directly to control allocation. When sticks are centered the vehicle will stop rotating, but remain in its current orientation (on its side, inverted, or whatever) and moving according to its current momentum.
- Return - This mode raises the vehicle to a safe height and returns to the launch position.
- Mission - This mode runs a pre-programmed mission sent by the ground control station.
- Kill Switch - Immediately stops all motor outputs (the vehicle will crash, which may in some circumstances be more desirable than allowing it to continue flying).

3.2.4 Battery

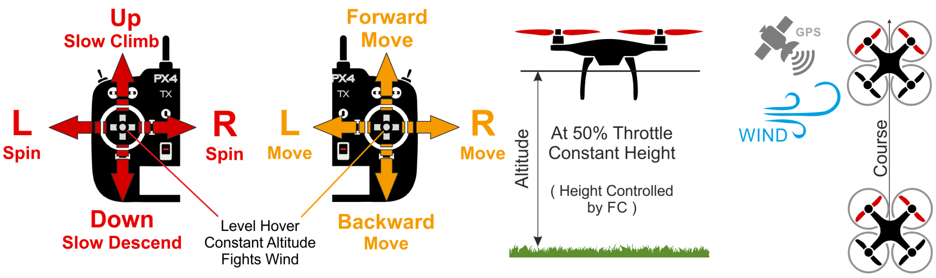
This topic explains how to configure power settings. The goal of the power setup is to provide a good estimate of remaining battery percentage (and capacity), so that the vehicle is not used to the point that it runs out of power and crashes (or the battery is damaged due to deep-discharge).



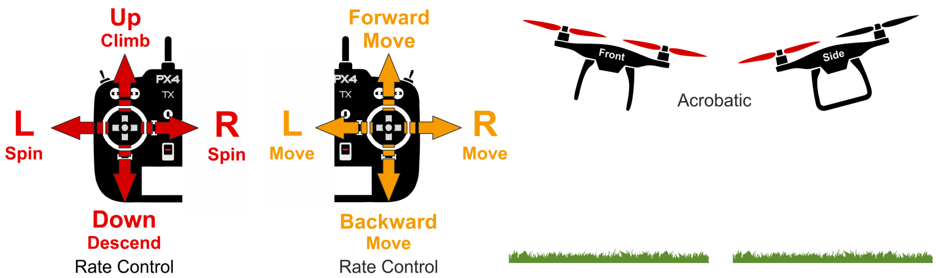
(a) Manual stabilized.



(b) Altitude.



(c) Position.



(d) Acrobatic.

The basic battery settings configure PX4 to use the default method for capacity estimate. This method compares the measured raw battery voltage to the range between cell voltages for "empty" and "full" cells (scaled by the number of cells).

> **Note** This approach results in relatively coarse estimations due to fluctuations in the estimated charge as the measured voltage changes under load.

To configure the basic settings for battery 1:

1. Start *QGroundControl* and connect the vehicle.
2. Select the **Gear** icon (Vehicle Setup) in the top toolbar and then **Power** in the sidebar.

You are presented with the basic settings that characterize the battery (figure 3.20). The sections below explain what values to set for each field. This sets the number of cells connected in series in the battery. Typically this will be written on the battery as a number followed by "S" (e.g "3S", "5S").

> **Note** The voltage across a single galvanic battery cell is dependent on the chemical properties of the battery type. Lithium-Polymer (LiPo) batteries and Lithium-Ion batteries both have the same *nominal* cell voltage of 3.7V. In order to achieve higher voltages (which will more efficiently power a vehicle), multiple cells are connected in *series*. The battery voltage at the terminals is then a multiple of the cell voltage.

If the number of cells is not supplied you can calculate it by dividing the battery voltage by the nominal voltage for a single cell. The table below shows the voltage-to-cell relationship for these batteries:

Cells	**LiPo** (V)	LiIon (V)
1S	3.7	3.7
2S	7.4	7.4
3S	11.1	11.1
4S	**14.8**	14.8
5S	18.5	18.5
6S	22.2	22.2

Enter data for your battery/power module from its data sheet: number of cells (4), full voltage per cell (4.1 V), empty voltage per cell (3.6 V).

QGroundControl can be used to calculate appropriate voltage divider:

1. Measure the voltage from the battery.
2. Click Calculate next to the Voltage divider field. On the prompt that appears:

- Enter the measured voltage.
- Click Calculate to generate a new voltage-divider value.
- Click Close to save the value into the main form.

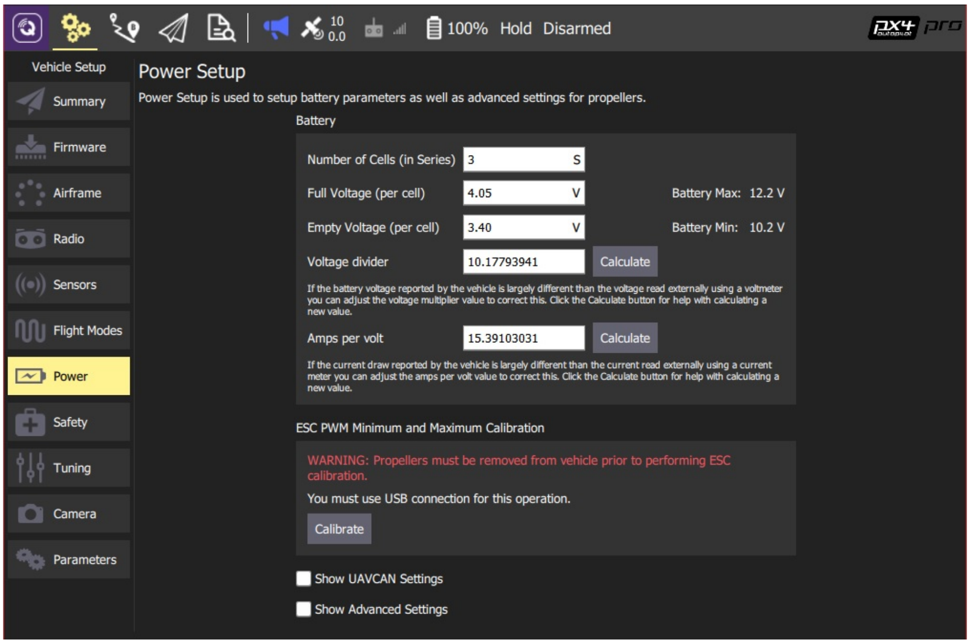


Figure 3.20: QGC Power Setup

ESC PWM Minimum and Maximum Calibration

To calibrate the ESC max/min PWM values:

- Remove the propellers.
- Connect the vehicle to QGC via USB (only).
- Click Calibrate button.

3.2.5 Motors

After the airframe is setup and configured you should validate the motor assignment and spin direction, and the servo response.

- Remove all the propellers.
- Enable safety switch. Note that our drone has a safety switch (placed in the GPS module) and it must be pressed before motor testing is allowed.
- Slide the switch (”propellers are removed - Enable motor sliders“) to enable motor sliders.
- Adjust the individual sliders to spin the motors and confirm they spin in the correct direction. Motors will spin for three seconds.

If one or more of the motors do not turn in the correct direction according to the configured airframe, they must be reversed: swap 2 of the 3 motor cables (it does not matter which ones).

Chapter 4

Flight

4.1 Checklists

4.1.1 Assembly and configuration checklist.

1. Structural integrity checks.
   (a) Visually inspect that there are no missing screws or caps.
   (b) Look for broken or cracked structural parts. Pay special attention to unions holding the drone arms, motors and landing gear.
   (c) Finalize by slightly loading and twisting arms and landing gear to ensure that they do not move or rotate.
2. Electrical connections.
   (a) Check that the cables connected to the appropriate ports.
   (b) Ensure one by one that all the connections are firmly inserted in their respective plugs. Do this by pushing the cable to the connection and then by slightly pulling to check that it stays inserted.
   (c) Ensure that all the wiring will remain between the two plates and that none of them can go out and be hit by the propeller.
3. Engines.
   (a) **Without installed propellers**, connect the drone to the ground station using the USB cable and repeat engines tests to ensure that they all work and rotate in the appropriate direction.
4. Safety configuration.
   (a) Connect the drone to the ground station using the USB cable and navigate to the safety configuration.
   (b) Ensure that all the options are matching figure 4.1. Pay special attention to the fields in red.
5. Flight Modes.
   (a) Connect the drone to the ground station using the USB cable and navigate to the flight modes configuration.
   (b) Ensure that SwC in **top** position corresponds to **stabilized**.
   (c) Ensure that SwC in **middle** position corresponds to **position**.

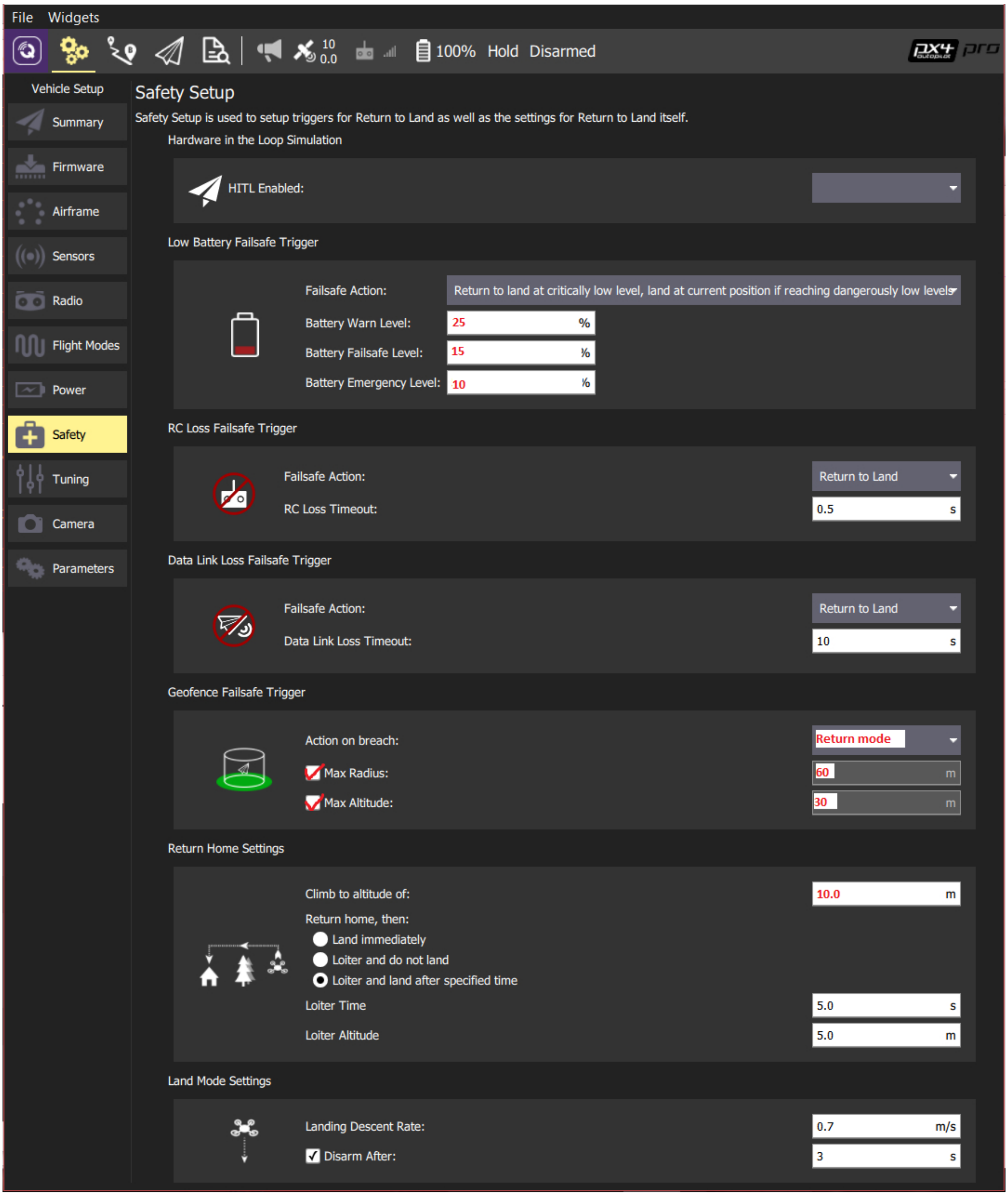


Figure 4.1: Safety setup.

(d) Ensure that SwC in **bottom** position corresponds to **altitude**.

6. Telemetry.

   (a) **Ensure that no other drone is powered at the same time as yours.**

   (b) Connect the telemetry unit to the computer using the USB connector.

   (c) Power up the drone by connecting the battery.

   (d) Check that you have a succesfull connection with the drone: in the top bar you see the remaining battery, selected flight mode, armed status. . .

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