Self-learning Material: Developing a UAV Version 2

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Introduction

The utilization of self-composed UAVs (Unmanned Aerial Vehicles) for algorithmic research has become a prevalent practice within the field of robotics. As students exploring robot-related topics in the AAE department at PolyU, it is not uncommon to encounter the need for constructing flying robots to accomplish various research objectives. This reference material aims to provide a clear and concise account of the process involved in building a UAV, catering specifically to students with limited prior experience in this domain.

The primary objective of this material is to present a comprehensive guide that effectively conveys the necessary knowledge and skills required to undertake the construction of a UAV. Emphasizing simplicity and clarity, the material is meticulously structured to captivate readers' interest, while avoiding any unnecessary complexity that may hinder comprehension and retention of information.

Within the pages of this guide, readers will find step-by-step instructions, insightful observations, and practical tips derived from firsthand experiences. The intent is to equip students with the essential understanding and confidence to embark on their UAV-building journey. By diligently following the guidelines presented in this reference material, readers will acquire the proficiency to construct a UAV customized to meet their specific research objectives.

It is our sincere hope that this reference material will serve as a valuable academic resource, fostering an environment conducive to successful UAV construction and facilitating the accomplishment of desired outcomes. The readers can find the self-learning video through the link below:
https://www.youtube.com/watch?v=nNRvqX-NhFk

This material is divided into two parts, which are:

- **Hardware components and assembly**

  This includes the components you require to build your UAV and how to assemble all the parts together. You will have a detailed bill of matters and guidance on assembly. Please do care about the safety notice, or you may get hurt.

- **Flight control software**

  This includes the software of flight control and a detailed introduction on how to use it to fly your robot. The details will be explained in both Linux and Windows operating systems.

Hardware components and assembly

Here are your bills of the matter:

Table 1: Bills of materials

items	number
UAV frame	1
motors (CW)	2
motors (CCW)	2
propellers (CW)	2
propellers (CCW)	2
Electric Speed Controller	4
Flight Controller	1
Battery	1
Power Module (PM02)	1
Remote controller	1
Controller Signal receiver	1
Onboard computer*	1
USB connection*	1

*Note: * means the equipment you need for high-level development*

Before you start composing, an important notice is that the CW and CCW should be installed in sequence, as the differential thrust is important for the flight aerodynamics of the quadrotor. Since we are using the Pixhawk 4 autopilot as the flight controller, it is required to install the motors as the figure.1 shows. The upward is the normal direction of UAV, clockwise(CW) motors should be installed on 3, and 4, while the counterclockwise (CCW) should be installed on 1 and 2. This is essential for the flight of the quadrotor.

And the overview of all the components should be like Figure.2:

Figure 2 should present all the components you may get from the administrator. However, I suggest that the first thing you need to be aware of is the overview of basic connections. This is easy and the writer mapped it below. Please take a close look at it simply because of my bad drawing. However, this

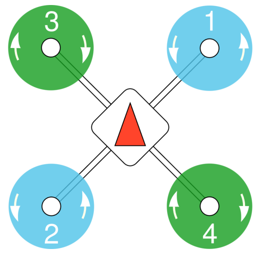

Figure 1: The airframe of Quadcopter X

Figure 2: Overview of Components

schematic fully illustrates the connection, the details will be put in parts located in the next few pages.

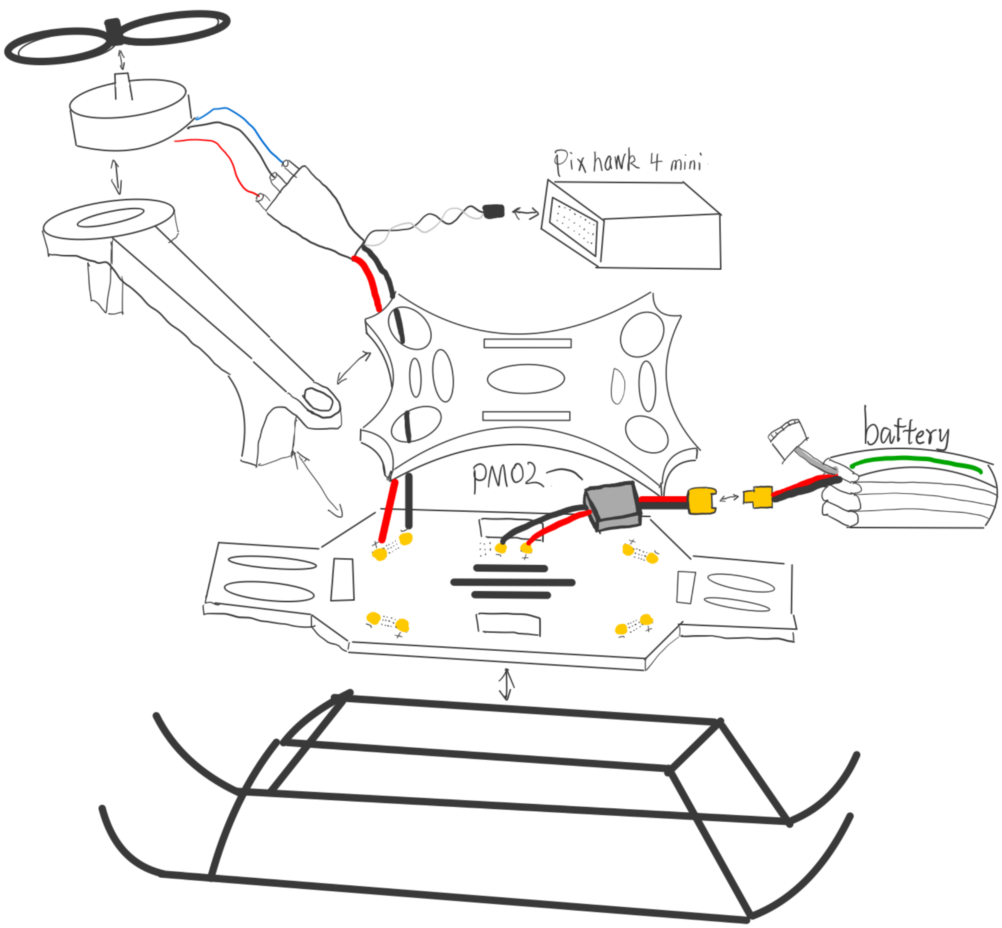

Figure 3: Overview of Connections

Step 1

For the first step of composing the UAV, let's begin with installing the motors on the arms. There are supposed to be two sets of bolts provided, one set for fixing the motors on the frame, and another set to link each component to the main frame. Just have a try and choose the suitable set of bolts. The final product should be like Figure 4:

Figure 4: Install motor on frame arm (step 1 finished)

There should be 4 sets of the frame arm, please make sure you have installed all 4 of them in this step. Then we could continue to the next step.

Step 2

Since the motor is installed, the differential thrust between motors is the way to control the movement of the UAV, it is required that a controller is used to control the power of motors to achieve different states. This controller is called Electronic Speed Controller (ESC), which has 2 wires (red and black) for feeding in the electricity and getting throttle signals (the signal wire with jumper wire interface, whose color is black and white). The appearance of ESC is shown in Figure 5:

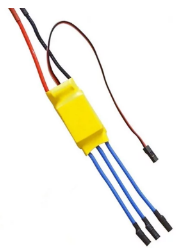

Figure 5: Electronic Speed Controller (ESC)

For step 2, plug all the black wires of the motor into the middle socket of the ESC first. This is to make sure that we can distinguish and adjust the motor spinning direction easily, if the wire connection is wrong, just switch the socket of red wire and blue wire. Then, when connecting the motor to the ESC, make sure that for all CW motors and CCW motors, the wire connection is conducted as Figure 6 shows. (Notice: The brand on ESC is facing inward, so if you flip the UAV frame, you should not see the holybro brand on the ESC)

This is the way that the writer composed his UAV, just to provide some convenience for your assembly. Feel free to have a try and see how it works in your trial flight.

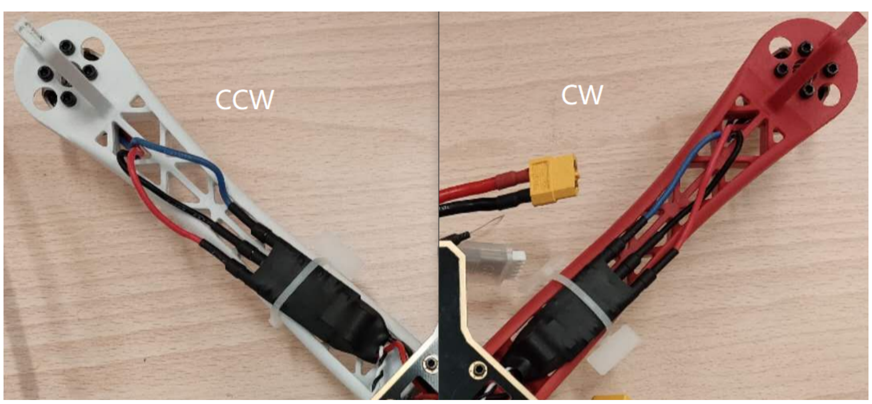

Figure 6: The ESC and motor connection of CW and CCW

Then, after confirming and conducting the wire connection, your product should look like this in Figure.7. make sure that the ESC will not move around and hit the propeller, it should be fixed on the frame arm using a Nylon cable tie.

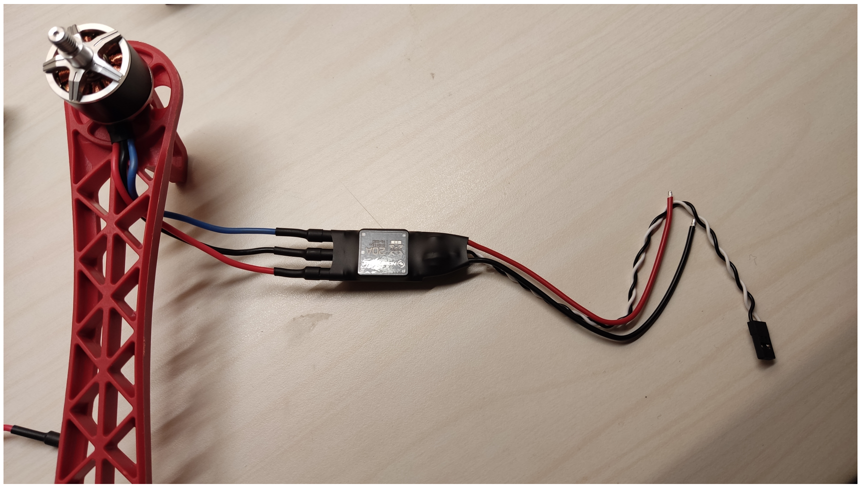

Figure 7: Overview of UAV arm assembly (step 2 finished)

Step 3

Here we come to step 3 of this project.

In this step, you need to define the positive direction of the UAV first, since you need to solder and connect your UAV arms to the chassis. Figure 1 illustrates how you should install your UAV arm according to the positive direction. In this top-view diagram, the positive direction is upward. As the former context illustrated, 1 and 2 are the positions for CCW installation, while 3 and 4 are the positions for CW installation.

Therefore, before starting soldering, choose the positive direction and put your CW and CCW arms in the corresponding location, and we can move on.

Since electricity should be provided to all 4 motors, you probably noticed what the bottom plate of the chassis looks like.

There are a few copper sheets attached to the bottom plate for the wire connection. The plate connects the battery and the motors, providing electricity to the ESC.

Yes, it acts as a wire. And, yes, you need to solder the wire on the board. So please be careful and use the soldering machine to operate based on the instructions. You may find the soldering tutorial in the link attached:

https://www.youtube.com/watch?v=Qps9woUGkvI.

You can find the tools in the tool closet in FJ005. Or contact Mr. LYU Mingyang and get the tool from him. You can find the contact on the last page.

Soldering Guidance:

- Before you heat the iron up, cut the rubber on the wire to make sure enough copper is exposed for your soldering
- Connect the tool to the power and adjust the temperature to 300 Celsius, and wait for 1 minute for the iron to heat up.
- Put the iron on the copper plate on the chassis bottom plate for 5 seconds, heat the plate up, and put some tin on it.
- Use the tape to fix the wire on the plate, and the exposed copper wire shall be fixed on the copper plate. Remember, red wire to "+" and black wire to "-"
- Put the iron on the wire for 3 seconds, heat the exposed copper wire up, and put some tin on it.
- Used the glue gun to seal the intersection after it was cold

After it cools, the whole component should look like the Figure 8 shows.

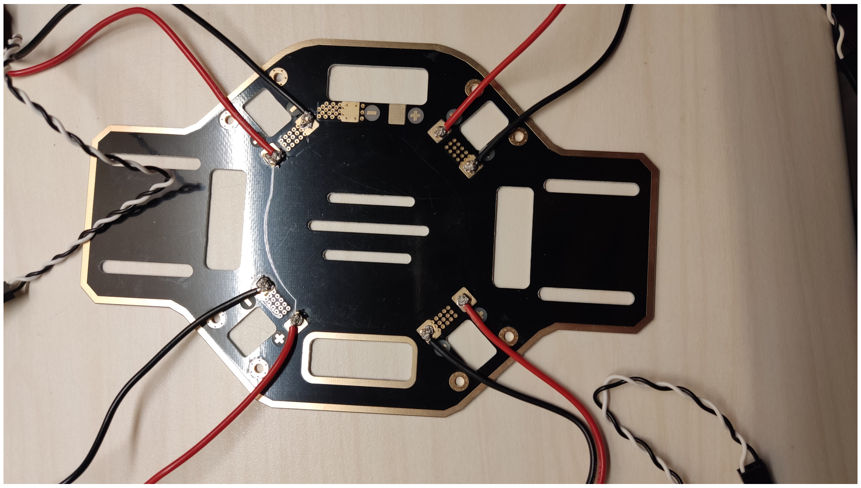

Figure 8: soldering ESCs on the bottom plate of chassis

The next step is to solder the PM02 on the bottom board to connect the battery. First, you need to cut the wire and leave the socket and PM02 module, for the connection between the battery and PM02. For soldering the PM02, since the wire is thick, I suggest putting some tin on the wire at first and soldering it to the tin on the copper plate.

The final product of this step should look like Figure 9. Step 3 ends here.

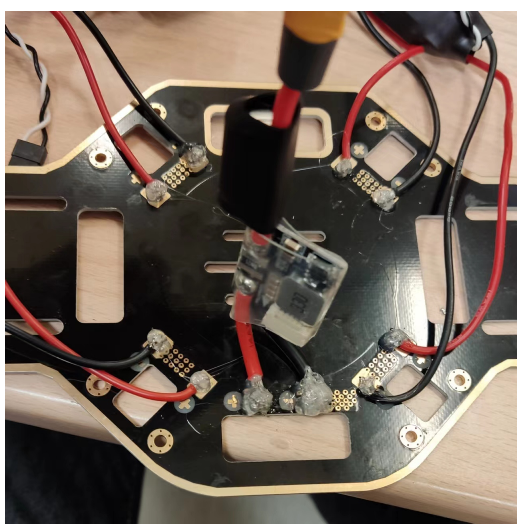

Figure 9: Soldering PM02 on bottom board (finish of step 3)

Step 4

Now you've already made progress in connecting the basic electric circuit, you need to install each component on the chassis and let it act as a completed flying robot. Before you do this step, use another pack of bolts to fix the UAV arms on the chassis and complete the UAV frames.

After that, use the Nelon ties to fix your ESC on the UAV arms and tie up the electrical wire. In addition, make sure your PM02 socket is fixed in a position where your battery plug could easily reach (e.g. one of the UAV arms), and leave the throttle signal line of the ESCs spare.

Then let's continue.

First, you need to decide where to put your flight controller and battery and make sure they are as symmetric as possible so that your flight performance can be improved. What I suggest is to put the flight controller in the top plate of the chassis, since you may need to install multiple sensors and telecommunication components in your later experiments. And I'm pretty sure that you would not want to remove your top chassis plate every time you install the component. Therefore, my deployment of the battery and flight controller is illustrated in Figure 10.

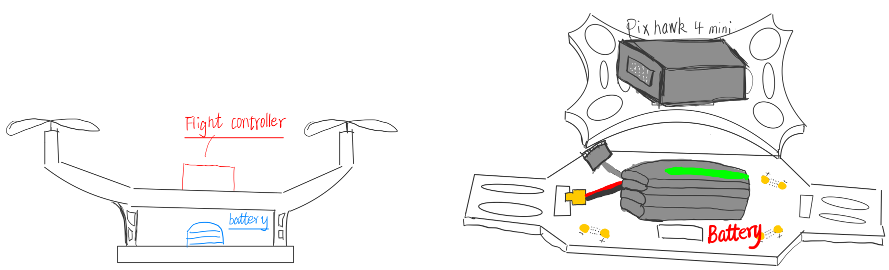

Figure 10: deployment of the battery and flight controller

Before you attach the flight controller to the top plate of the chassis, please be aware that you should use foam tape to stick the Pixhawk flight controller instead of the normal tape or glue gun. This is because the flight controller is sensitive to the vibration of the whole frame, the foam tape could provide a buffer to vibration and enable better flight stability.

Additionally, before you going to do this, I strongly suggest you go through Step 5, to write the firmware and airframe first.

Here is the reason. To adjust the sensors inside the flight controller, you need to spin the flight controller with different UAV poses. It is an easy job if you only take the flight controller out and spin it. However, if you do this after your installation, you may need to spin the whole UAV to adjust everything (Man! I scratched my arm by doing this...).

Figure 11: jst-gh wire

Anyway, it's your choice, just be careful.

After you installed the flight controller on the top plate, I suggest you use some materials (e.g. Velcro cable tie) to make a small battery cabin and fix the battery, while using the Velcro cable tie to make a simplified gate on one side of the cabin. This is simply because you need to open the gate and take your exhausted battery out while reloading another, how to design the cabin is not illustrated here. There are a lot of holes and gaps on the two plates of the chassis, and I believe you can do this.

In the last step, attach the flight controller to the centre position of the upper board and point your flight controller in the positive direction that you selected.

To provide power to Pixhawk 4 mini, plug the jst-gh wire into PM02 socket and the power socket on the Pixhawk 4 mini. In case you don't know what the jst-gh wire is, I attach a graph here for illustration.

Connect the throttle signal line into the pinhole of Pixhawk 4 mini according to Figure 1, where the order number on the motor is exactly the pinhole number.

After the connection, fix the wire using the Nelon tie again.

At last, the receiver R9DS should be connected to the flight controller to generate the throttle signals. The R9DS receives the signal from the remote controller. For its connection, you could find the wire in your package, one side of which is jumper wire and another side is jst-gh wire.

Connect the jst-gh side to the "RC-IN" socket on the pixhawk 4 mini, while plugging the jumper side into the R9DS. The exact plugin location is circled in Figure 12. The blue light will be omitted from R9DS if the wire is correctly connected.

Then Step 4 is completed.

Your final product might look like Figure 13.

Connecting the battery, you will hear the motor emitting the "beep" sound regularly. This is because ESC does not detect throttle signals. If you followed my advice and wrote the airframe into the PX4, the beep sound will only be emitted once and everything is ready.

Figure 12: Connecting R9DS

Figure 13: Final assembly of UAV

Flight control software

Step 5

The software debugging Pixhawk 4 mini is QGroundControl. It could be installed on the Windows OS and Linux OS, depending on what you want to achieve. If further development is required, Linux is preferred as your developed Robot operating system (ROS) code is installed in Linux. However, I recommend Windows OS for the first debugging, since no nasty specifications are required for operation (such as port permission and software permission).

Firmware

- First thing first, connect your flight controller to your computer and install the QGroundControl.

  Note: DO NOT connect the flight controller with your battery being connected, and DO NOT install your propellers on the UAV when debugging your UAV.

- Write the firmware to your flight controller.

  Click on the logo → Vehicle set up → firmware

  It may require you to replug your Pixhawk 4 mini and write the firmware. The firmware should be PX4 Flight Stack X.x.x Release.

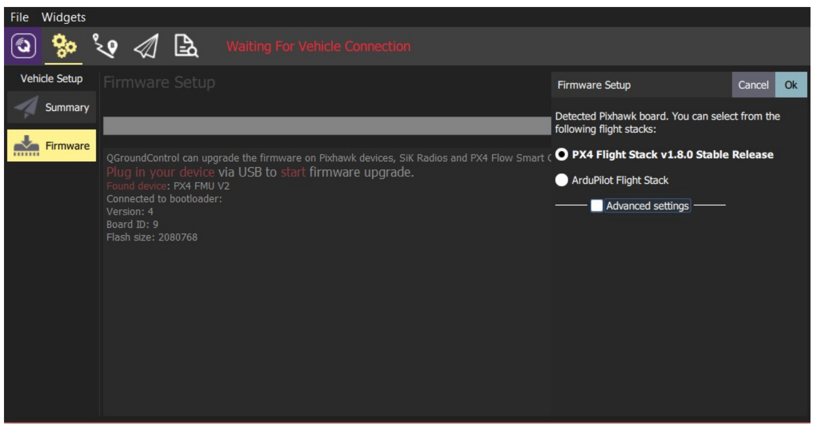

Figure 14: Firmware writting

- Click the OK button to start the update.

  Once the firmware has completed loading, the device/vehicle will reboot and reconnect.

Airframe

Next, the airframe should be installed because the source code will be embedded into the flight controller for controlling the whole UAV.

- Click on the 'Airframe' → Choose Qradrotor X → open the bar and choose 'generic type' Airframe

  If you choose another type, all four motors will keep on beeping regularly. This is simply because the ESC cannot receive the thrust signal.

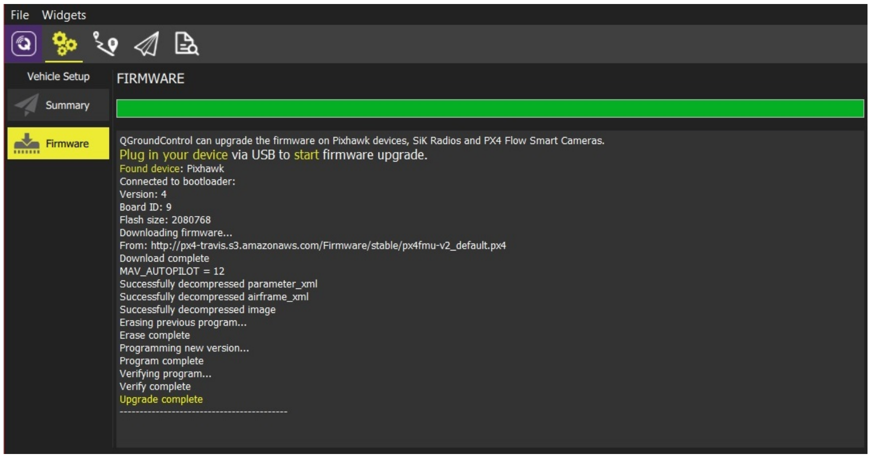

Figure 15: Firmware writing finished

- Click Apply and Restart.

  Click Apply in the following prompt to save the settings and restart the vehicle.

Sensor calibration

Next, reconnect your aircraft and select 'sensor' in your menu, it is time to calibrate it.

Select the Set Orientations button, and select Autopilot Orientation. Normally it is Rotation_None if you followed this material. I shall provide the calculation graph here.

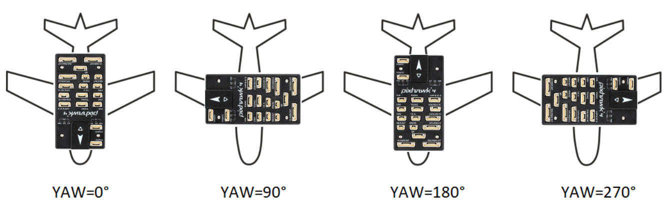

Figure 16: Rotation calculation graph

Select the External Compass Orientation in the same way, if you have it. At last, click OK.

Next, calibrate all your sensors on the left bar according to the instructions shown on QGroundControl. The reason that I recommend you do this before putting the flight controller on the aircraft is that you need to spin this aircraft to calibrate the sensor, just like what I mentioned before.

The sensors you should calibrate include a compass, gyroscope, accelerometer, airspeed and level horizontal calibration.

Step 6

After everything is done, you should make your joystick connected with your receiver (R9DS). Here are the steps:

- Make sure your receiver is connected with power and your propellers are uninstalled. The throttle joystick should be located in the lowest.
- Place the remote control and receiver horizontally with a distance of about 50 centimetres between them.
- Turn on the power switch of the remote control, supply power to the R9DS receiver, and the receiver starts to slowly flash.
- Press and hold the pairing key (ID SET) on the side of the receiver for more than 1 second. The LED light on the receiver will start to flash rapidly, indicating that it is pairing and searching for the closest remote control.
- When the indicator light stops flashing, it means that pairing is complete, and the main interface of the remote control will also display signal bars.

Then, connect your flight controller to the computer, go to the settings and click the Radio. On this page you can calibrate your remote controller, just follow the instructions.

In the next step and last step, you should assign the flight modes on the different Channels. The default mode is the manual mode, the UAV is simply controlled with the remote. Other modes you need are the stabilized mode (only functional when you have GPS or offboard information about altitude) and the kill switch. The kill switch makes sure the UAV can be stopped immediately when things go wrong.

Inside the 'radio', you can find the channels corresponding to all the buttons on your remote controller. After you made your decision, go to 'flight modes' to assign the mode to the channel you selected. All values are automatically saved as they are changed.

Here is the link that helps you figure out the flight mode:
https://docs.px4.io/main/en/getting_started/flight_modes.html

Then, you can start your trial flight in FJ005.

Trial Flight

Before starting this, uninstall your propeller and connect the flight controller to the computer to test the motors. Connect the battery and go to 'motors' or 'power'. Then, slide unlocks and adjust the button corresponding to No.14 motor, and see if the motor is operative.

Then, the trial flight is ready. Deploy the net and put the UAV inside. Install the propellers on 4 motors, connect your battery, and put the UAV in the middle of the test area.

Put your throttle joystick to the lowest, then slide it to the right. This is how you unlock the UAV on the remote controller.

Next, power up your throttle slowly, be careful, and don't push too much, or it will hit the ceiling. Then, you could feel free to try the movements and train your control skills, but remember to use your kill switch when something goes wrong.

That should be all the steps for building the basic UAV. This material will be updated from time to time with new content added, which relates to the companion computer and connection, with the ROS development and Linux operation. Thank you for reading this and contact me at robert.jeff.lv@gmail.com if you have further questions.