

Quadrotor Build: Hardware, Software, and Tools

I've been making a book report out of the many interesting aspects revealed by a simple hobby drone. We've covered electro-mechanics of motors and propellers, fluid mechanics around propellers, simplified, "classical" single-input, single-output (SISO) axis control design and multi-input, and multi-output (MIMO) linear quadratic regulator (LQR) concepts to this point.

The background on the LQR gets down to the Calculus of Variations, solving the matrix Ricatti equation, and other topics that deserve many deep-dives, but if I go that path I might run out of air! It's time to pull together a platform and a set of tools to use in proving our design ideas to date.

I have not yet covered a companion to the controller design: the state estimator. That's going to be a Kalman filter that blends gyroscope, accelerometer, GPS, compass, and a barometer to estimate orientation and position of our platform. We're going to circle back on this because I'm going to be starting with a flight controller that has a considerable amount of sensor and software support built-in. I'll likely start with the state estimators available, and take these as feedback to code modifications I'll make to implement the MIMO paper design.

It's time to get a platform and a test stand up-and-running! We'll prove some of our ideas, and chase new concepts as we go! Let's Build!

Test System Requirements

The goal is to take paper designs and realize them in hardware, make adjustments to the designs based on testing, and observe our analytical approach results in flight. To do this we need hardware, software, and tools.

A former colleague of mine is a member of the Ardupilot team. Ardupilot is an open-source flight controller stack and encompasses a range of mission planning, simulation, tools and techniques. We'll be using Ardupilot and related tools.

Flight Controller Hardware

Pixhawk2 (Cube Black) is a well-supported platform by Ardupilot. The "cube" is the insert to the breakout module with various connector interfaces. The entire module is less than 4" long by 2" wide. This will mount within our copter frame. At the time of this writing Pixhawk4 is available.

The, "Pixhawk" is generally the interface module for a, "cube" (orange below) that contains the inertial and other sensors package together with the microprocessor. The module supports cable connectors to various sensor, media, and communications peripherals.

CubePilot ecosystem

here3 RTK GNSS
Dual band and carrier resolution CMR protocol. Built-in compass and a 400P IMU

hereflow Optical flow module
A novel and compact module, integrated with custom ISP image sensor, ultra-precise range finder, ultra-precise sensor, and a 400P IMU

hitec Servo
TinySRT gear servo, CMR protocol, Wide voltage range, anti-PFC

hereRTK Multi-band RTK GNSS
Dual-band carrier, Triple band, dual Constellation RTK, 1PPM GPS, 100Hz PD, built-in RTK protocol, and working in the remote's ultra-precision solution

Telemetry
High performance telemetry. Specifically designed for applications requiring long range reliable wireless communication

Lightware Lidar
LIDAR is suitable for working where low weight, and power budget. Can be used for obstacle, light and object avoidance.

IR-LOCK sensor
Provides precision landing and target recognition. Returns by loading itself to a sensor located on the landing position.

hereLink RC, telemetry, and video transmission all-in-one
HereLink is a compact integrated system. Video resolution up to 1080P@30FPS. Operating distance of up to 20km. Comes with built-in SPI and UART, and is highly customizable for QGC.

GREMLY Gimbal
Fly 3-axis industrial grade gimbal made for GSD Pro 4.

Step down module(12v)
Step-down power module for remote that requires regulation on power output. See the MTK and Lidar.

cube Open source autopilot
Equipped with a high-performance 32-bit processor, triple redundant IMU, inertial controlled and vibration isolated IMU, switchable 3.3V/5V I/O output, and standard CAN/UART communication, used to identify nearby aircraft.

MAACH Power module
High-precision current and voltage sensing, supports high voltage with high current sensing.

APF ESC
APF motor ESC are equipped with 32-bit 32-transistor. Features include PWM frequency filtering, and active phase current charge protection.

FLIR Thermal Camera
One Pro 4 is high-resolution industrial thermal camera designed for small UAV.

hereLink Remote Unit

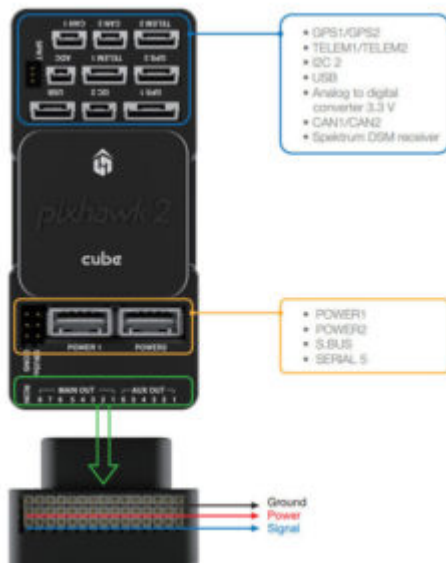
MAACH Battery
Advanced battery management system, improving efficiency.

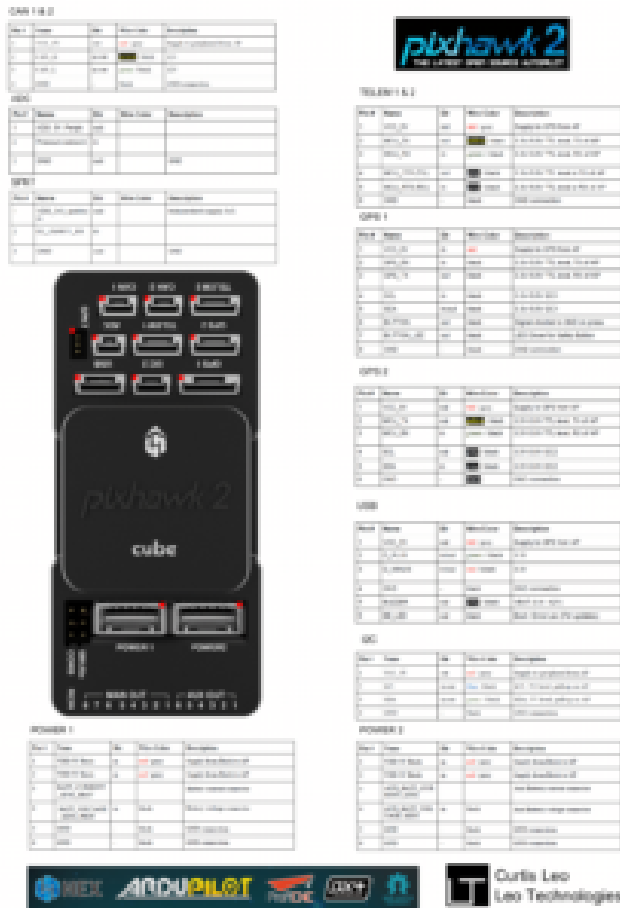
UB-MOTORS UB Motors
Suitable for different kinds of industrial tasks.

Power distribution board

DXF

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Pixhawk2 platform with the Cube Black Flight Controller

Flight Controller Software

Ardupilot, “Copter” is our code platform starting point. I chose to go native Linux for my development environment as I have a laptop running Ubuntu. The Ardupilot tool set-up instructions cover Mac and Windows, but I went the straight Linux route. In my experience it’s easiest that way for projects like this, as the Windows environment tools can be a bit of a pain requiring VMs and such. I didn’t study Ardupilot Windows set-up in-detail so maybe it’s not a problem. In any case, just know that in what follows I’ll be giving you the Linux tool suite details.

Ground Station

Mission Planner

OK I lied, I'm using my Windows machine to run MissionPlanner from Ardupilot. Once we get set-up we're able to use this tool to hook directly to our cube above via USB or telemetry radio. It fairly short-order we get to a point where we're loading our own builds and able to see live sensor data in Mission Planner from the above hardware sitting on our bench.

Telemetry

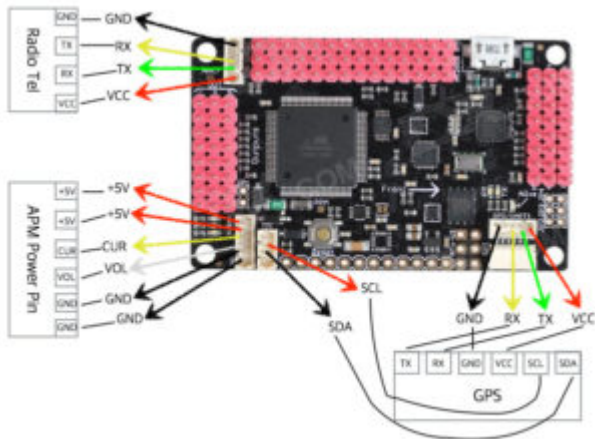
When you first get going on the Ardupilot build-load cycle you can use a USB cable from your development machine to the Cube. Soon after, either for convenience on the bench or definitely when you need to fly you'll need a radio link.



900MHz APM Radio Kit

I chose the 900MHz radios below (approved in US, most other places you'll need to go 450Mhz). They're plug-and-play between "Telemetry 1" connector on the PixHawk module above and a USB serial port on the Mission Planner PC. I'm able to connect at 57600 Baud with these radios (set 57600 on the PC side and it will just, work. If 115200 works for you that's great).

I had to hack the cables that came with the radios I bought because the connector does not match the mating connector on the PixHawk. I used the pinout description for the PixHawk2 above and this APM radio reference pinout below to figure how to wire my 4-wire radio interface to a hacked cable into the PixHawk. This board here has nothing to do with our design. I just used this picture for the, "Radio Tel" description.



APM Radio Pinout

My hack worked. I Recommend you find a radio that has the proper cable end for a PixHawk2. There are many APM2.6 and higher Telemetry Radio options available through Amazon or other outlets. I didn't notice the connector issue until I received my radios, so dig a little and you can avoid my hack.

Quadrotor Platform

I picked a platform well-built for the PixHawk2, the EDU-450 Drone Kit. I purchased it here. It includes the motor electronic speed controllers (ESCs), 880 Kv motors.



EDU-450 Drone Kit



Simulation Environment

Ardupilot SITL

The Ardupilot codebase includes a software in-the-loop (SITL) simulation environment. This permits the flight controller outputs to actuate a software model of a quadcopter, which then feeds-back sensor inputs to the flight controller software. Implementation of the physics model and simulation can be accomplished a number of ways. There appear to be a handful of 3D graphics rendering simulation environments.

Real Flight and FlightGear

RealFlight and FlightGear appear to offer quality 3D graphical simulation. This looks good for presentation-quality simulation. I followed the Ardupilot SITL guide to get FlightGear going, but I'm more comfortable with Matlab for coding details of our quadcopter mechanical model, introducing disturbances and other aspects that will test the robustness of our designs.

I'm less interested in the graphics of the simulation than the performance details so I'll be using the Matlab simulation environment through Ardupilot SITL.

Matlab

Ardupilot SITLs JSON simulation option permits SITL to output data to Mathsoft's Matlab or Simulink. Consider a modest investment in Mathsoft's home-use license if you're interested in this approach. Specifically, I'll be using SITL's Matlab option. Follow the link to a quality demonstration video.

This is the basic idea:

- SITL runs the control loop on the flight controller simulation machine

- SITL connects to a Matlab instance on same or other computer via specified IP
- The Flight Controller output's platform state information like altitude as well as rotor command outputs via the JSON payload.
- The Matlab server processes these data through a mechanical model of the platform.
 - The rotor commands through this model result in updates to roll, pitch, yaw, and altitude.
- These modeled state outputs from the simulated, "real platform" feed back to SITL via the JSON response to the flight controller.
- The Flight Controller processes these changes as sensor inputs.

This process repeats at a sampling rate. In this manner we can modify and test our real-time control code.

We can also change our physics model. Perhaps we degrade performance of a motor or propeller, introduce wind, or other disturbances. This, "real world" situational simulation will be done through modifications and enhancements of the Matlab code used to model an actual platform.

We will then be able to test the robustness of the controller code and make enhancements as needed. We'll iterate considerably in this environment before we attempt to fly our design.

Stationary Test Stand

I'll be adding an entirely new Ardupilot attitude controller to implement the Linear Quadratic methods. I'll do a lot of work on the bench with software simulators. Then I'll graduate to real hardware, but to prevent crashing around and to permit controlled experiment analysis of the attitude control methods I'll want a stationary test stand.

A company called MINDS-i education markets a gimbal rig demonstrated in the following video. This is exactly what I need, but this would be both too small for my rig and also too expensive for me, especially because I can build one in my shop!

I'll do a separate post covering the construction of my gimbal test stand. For now, the MINDS-i demo video illustrates the 3 rotational degrees of freedom (roll, pitch, yaw) it will allow. It prevents the 3 translational (X,Y,Z) degrees of freedom that would crash it all over the shop as I work to refine the control schemes!

What Next?

Upcoming posts will jump around between Ardupilot coding of the Linear Quadratic attitude controller, test stand build, bench software-only simulations, and any topics the implantation phase floats to the surface.

We're finally going to get busy building and realizing the math and the methods!