Make: Drones

Teach an Arduino to Fly

by David McGriffy

Make: Drones

Teach an Arduino to Fly

David McGriffy

MAKER MEDIA™
SAN FRANCISCO, CA

Table of Contents

What Makes a Drone Possible

1

The quadcopter glides gently through the sky, using every subtle variation in the atmosphere to its advantage, performing that delicate dance with the air that we call flight.

Doesn't quite sound right, does it?

Let's face it, a quadcopter doesn't so much dance with the air as arm wrestle. Usually the quadcopter wins. Some days the sky wins.

No, the beauty of a drone is not in the graceful curve it cuts through the sky or the subtle shape of its wings. It has no wings, of course. In fact, among the best things about our modern multirotors are all the parts they *don't* have. No wings. No control surfaces and no servos to move them. No complex collective pitch hubs. No stall speed, timed turns, or holding patterns. We have stripped flying down to its bare essentials. We have four moving parts that push us upward, and the rest is in the control system (Figure 1-1).

Figure 1-1 *A micro drone in a mint tin*

And now we are getting closer to where the beauty lies.

As with the most interesting people and the best books, the *real* beauty of the multirotor drone is on the inside. An ArduCopter-based drone has four main inputs from two joysticks and four outputs to its motors. To compute those four outputs from those four inputs, it uses nearly three hundred parameters. At first it may appear that this is so complex as to be magic, but it's not. It's engineering. And precisely because of all the parts it doesn't have, a drone turns out to be a wonderful platform to learn about engineering principles.

The algorithms used in drone control systems are basic, important, and beautiful. You'll discover that learning how to use them will be fun and interesting. But these methods have been around for decades. So whatever the aesthetics, they are not the breakthrough that made modern quadcopters possible. And make no mistake: there *have* been breakthroughs.

I have flown radio control aircraft off and on for many years and have watched them with great interest since I was a kid. There have long been RC helicopters, but they were expensive and very hard to fly. Then there were toy helicopters, but to watch them fly is to know that they *belong* in the toy aisle. The military built cruise missiles, but they cost millions. Then one day a friend brought a quadcopter into the office. It would fit in your hand and it flew like an aircraft, not just a toy. And the punch line? It cost $20! Now that's what I call a breakthrough.

So I bought one, then another, then a bigger one. Then I built one from scratch and started to modify the flight control code. After many crashes and much thought, I am now ready to say what has changed: motors, batteries, and control systems.

Drones Versus Quadcopters

You will see several terms for the flying things we will build here. Some take "drone" to mean only a military system or vehicle that can fly autonomous missions. Since it is by far the shortest, easiest word for it, I intend to use the word "drone" for just about anything that can fly without a human on board. The military actually calls them unmanned aerial vehicles (UAVs) and the FAA calls them unmanned aerial systems (UASs), but I use enough acronyms in my life without using one where a one-syllable word like "drone" will do. The term "multirotor" leaves out fixed-wing aircraft and traditional helicopters, but describes everything we will build here. The term "quadcopter" describes an even more limited class—only those with four, not six or eight, props—but still covers all of our projects. We will use these words to differentiate our drones from fixed-wing or six-rotor vehicles when needed, but also sometimes just for variety.

Motors

That first little quadcopter I saw at the office, like most micro drones, used tiny electric motors. They are smaller but look essentially the same as the small DC motors I bought 10 to a bag as a kid, but those were nowhere close to powerful enough to lift themselves. It turns out that there is an essential difference between the quadcopter motors and the motors I was familiar with. Like many motors these days, they use rare earth magnets, but that's not the essential difference. These "coreless" motors (Figure 1-2) are optimized for aviation.

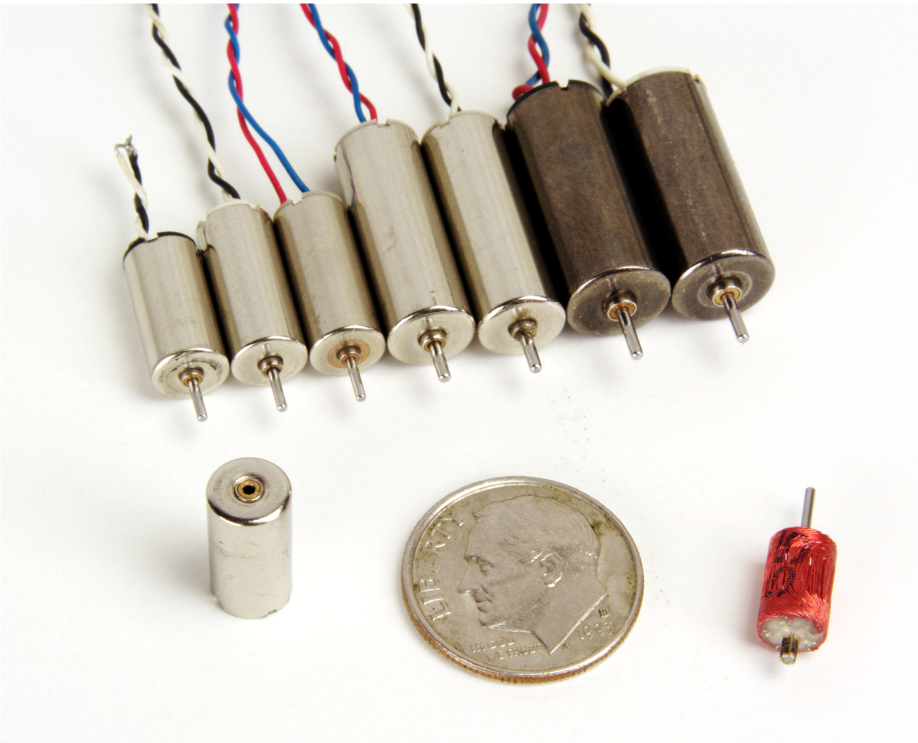

Figure 1-2 *6 mm, 7 mm, and 8.5 mm coreless motors*

The windings in small motors, like nearly all electric magnets, are generally made around a core of some ferrous material like iron. This makes the magnets more efficient—electrically efficient, that is. It turns out, however, that weight is more important than energy efficiency in aviation, so someone thought to take out that heavy core, and our tiny, flight-ready motors were born.

These coreless motors, used in smaller drones, are often called "brushed" to differentiate them from the sort of motor used in larger multirotors, which have no brushes. In most motors, brushes riding on a series of contacts control which windings get energized in what order. In a brushless motor, first developed for floppy disk drives (see Figure 1-3), electronics control the windings instead of contacts, making a simpler, longer-lasting motor.

Figure 1-3 *Modern drones and old floppy drives use similar brushless motors*

Like the drones they fly in, brushless motors gain mechanical simplicity at the expense of control system complexity. Each of the four motors in a brushless quad has to have its own little processor, always watching the back current on the unused coils to determine position, and adjusting the current to the other coils to achieve the speed commanded by the central flight controller.

Batteries

I suppose it should come as no surprise that the power plant is one of the important technologies in a drone. It has always been so in aviation. From that first piston engine that Orville made according to Wilbur's design, to Whittle's first jet engine, to the rocket that Chuck Yeager flew, advances in power have driven advances in aviation. And each new power plant comes with its new fuel source.

For our modern electric aircraft—and this means mostly drones, though there are a few experimental human-carrying electric aircraft—the fuel source is a battery. The most common battery technology used by drones today is the LiPo, or lithium polymer battery, as seen in Figure 1-4.

Figure 1-4 *A selection of 1S and 3S LiPos*

LiPos come in all sizes and shapes, from batteries the size of a thick postage stamp to batteries the size of a suitcase that can literally run your house or your car. Their capacities and capabilities vary accordingly. They can be rather finicky things compared to say, nickel–metal hydride (NiMH) batteries. LiPos don't like to be left fully charged for long but don't want to be stored completely empty either. Treat them wrong and it is pretty easy to ruin them, or worse. They have a bit of a reputation for catching on fire, but with a few reasonable precautions LiPos will allow us to do things no other batteries will.

Control Systems

In between the batteries and the motors is the control system. Even the tiniest micro drone has several subsystems, including radio receivers, gyros, accelerometers, and, of course, a processor to tie it all together. Since each of these components is just a little black chip on a circuit board that looks much like those out of any modern consumer electronics gadget, people may be less aware of the advances that have made modern drone control systems possible.

Before looking at what's new, however, it's worth pointing out that some parts of these little control systems date back years or even decades. The processors used are fairly modern, but the microcontrollers of several years ago could have done this job as well. On the software side, the algorithms used, including the Kalman filter and PID controller, have been used by control systems engineers since long before the microprocessor was invented.

Having acknowledged the great work of engineers past, however, some aspects of drone control systems do represent new breakthroughs. The general shrinking of electronic components in both physical size and power consumption makes smaller drones possible. Modern design and manufacturing techniques allow these tiny chips to be integrated into task-specific circuit boards that can be economically made in small numbers. A flight controller, containing all the subsystems mentioned above and more, can be put on a single board that you could lose in a shirt pocket.

At least one of the chips on that little board represents a breakthrough that is more specific to aviation: the gyro. Gyroscopes have been used to stabilize aircraft since Lawrence Sperry demonstrated his gyroscopic stabilizer apparatus on a Curtis C-2 biplane to a French audience in June 1914. As mentioned earlier, radio-controlled helicopters were notoriously hard to fly, so someone eventually made a gyroscopic stabilizer for them. The first models used physical spinning disks, just like the children's toys, and thus were rather large and heavy for all but the biggest model helicopters. The price of a single axis stabilizer would buy a complete midsized quadcopter today.

Now we can get three gyros and three accelerometers in a single chip (Figure 1-5) and they only cost a few bucks, even in small, maker-friendly quantities. And this brings us to one more breakthrough and pleasant surprise. It's nothing new for a consumer gadget like a drone to be made more cheaply in China. What makes this new world of micro aviation so exciting for makers is that Chinese manufacturing has resulted in a range of drone parts that we can buy in single units, mix and match, and make into our own designs.

Figure 1-5 *A gyroscope module and its inspiration*

For all these innovations, we are yet at the beginning of the drone revolution. As of this moment, the FAA has just announced new rules for commercial drone use; and many types of activities, like package delivery, are not allowed at all. The drones themselves are only just starting to add safety features like collision avoidance and recovery parachutes that will make them safe and reliable enough to share the airspace with each other and with other aircraft. The first international drone racing championship was just held, and everywhere drones are being used in classrooms to excite kids and teach engineering concepts.

And teaching engineering concepts brings us back to what we will do in this book. We will take the tools we are already familiar with—an Arduino, some motors, and a battery—and we will teach them how to fly. In the process, we will learn some basic engineering that can be used in making anything from robots to coffee pots. Then, when the construction is complete and the tuning is done, when you have put in the hours and learned to control your drone, you will be rewarded with one of humanity's oldest dreams: flight, an experience made deeper because your understanding made it possible.