Let's Make a Drone

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Designing the Drone Top Down

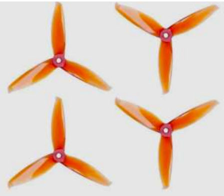
Let us design our drone "top down" – from specifications to components.

What do we expect from our drone? . . .

First of all – it should fly!

We'll need powerful motors with propellers which push air downwards, so that the drone rises up in reaction. We'll use 4 such motors.

Due to rotation of propellers, the drone itself will try to rotate in the opposite direction. To prevent this, we'll use two propellers rotating clockwise while the other two rotate anticlockwise, with the tilt of propellers so adjusted that all push the air downwards.



What do we need to make the drone?

- The motors will need to be driven with heavy currents – and we should be able to control their speeds.
- so we need motor drivers which can supply the required drive voltages and currents and can control their speed using Pulse Width Modulation.
- We also need a source of power – a high current battery is required.
- We should minimize the weight of all components, so that it is easy for the drone to get air-borne. In particular, the frame should be made with a light, but strong material.

What else do we need to make the drone? . . .

The Drone should be stable in its flight.

- How do we determine what PWM data to send to the electronic speed controllers such that it is stable? – We need sensors to determine the current angular orientation and angular speeds of the drone to adjust the relative speeds of the four motors. So we need a sensor card for this.
- Who will send PWM data to the motor driver (– the electronic speed controller)? Obviously, some sort of micro-controller is required and we'll use our familiar Arduino Nano for it.

How do we command the drone?

We should be able to control the flying drone from the ground..

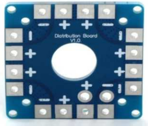
- We should be able to send commands to the drone from an Earth position. This requires some wireless connectivity.
- There are several options for it – to cut costs, we'll use a mobile as the transmitter and an on-board WiFi unit to receive the data.

- We'll use a node-MCU with WiFi to receive commands and to pass these on to the Arduino Nano.
- The node MCU is also a micro-controller card like Arduino Nano. It uses a 32 bit ARM micro-controller and has an on-board WiFi unit.

What else do we need

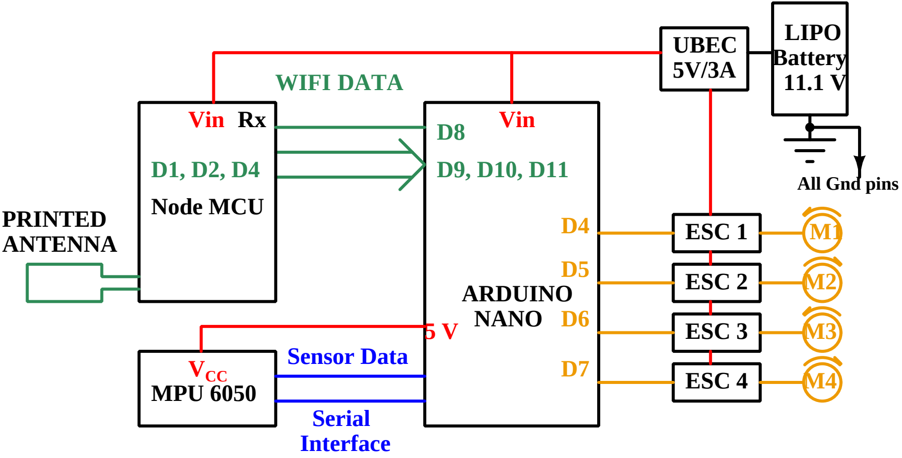
We have listed most of the modules we need to perform the required functions on the drone.

- in addition to these, we need to generate 5 V from the battery voltage to power various boards.
  This is done using a switch mode buck converter.
- To distribute power to different components, we need a power distribution board and various wires and connectors.
- For securely mounting all these components, we shall need mechanical parts such as mounting brackets, nuts and bolts etc.



A list of all components required for the project is called a Bill of Materials or BOM.

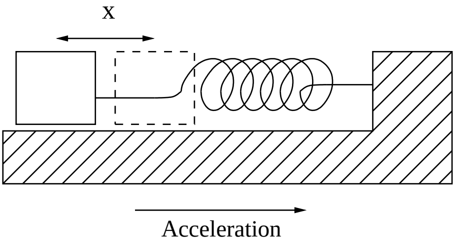
Putting it all together



Measuring Acceleration

Accelerometers actually measure force. Then $a = F/m$.

One way of measuring acceleration is through the use of an inertial mass.



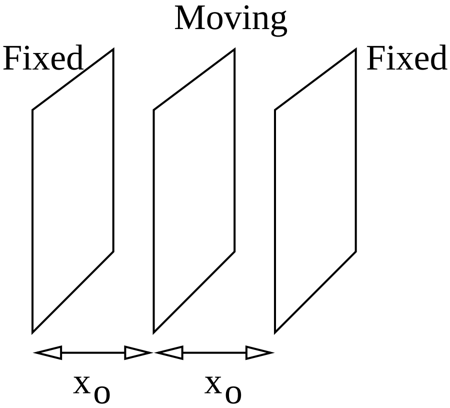
The frame (shown hashed) is rigidly coupled to the moving body. There is an inertial mass which is constrained to move along the direction of motion. It is fixed to the frame through a spring.

As the body **accelerates** to the right, it leaves the inertial mass behind, stretching the spring by x. Then,

$$-ma = kx \text{ so } a = -\frac{k}{m}x$$

Differential Capacitance measurement

How do we measure very small displacements?



$$\Delta C = \frac{\epsilon A}{x_o - x} - \frac{\epsilon A}{x_o + x}$$

$$= \epsilon A \frac{(x_o + x) - (x_o - x)}{x_o^2 - x^2}$$

$$\text{so } \Delta C = \frac{2\epsilon A}{x_o^2 - x^2} x$$

ΔC is linear in x if $x << x_o$.

To ensure this, we use the principle of force feedback.

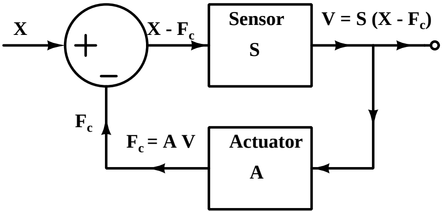
Principle of Force Balance

There is a trade off between sensitivity and range.
A sensitive sensor can be overloaded by a large input value.

How can we control a large value with good sensitivity?

This can be done by using force balance.

- Let $\mathbf{X}$ be a large value of some measurand (say force).
- We balance it with a *controlled* force $\mathbf{F_c}$, and measure the small resultant $\mathbf{X} - \mathbf{F_c}$ with good sensitivity.
- Since $\mathbf{F_c}$ is known, we can now calculate $\mathbf{X}$.



- A feedback loop subtracts $\mathbf{F_c}$ from $\mathbf{X}$ and adjusts $\mathbf{F_c}$ such that $\mathbf{X} - \mathbf{F_c}$ is very small.
- A sensitive sensor measures the small value $\mathbf{X} - \mathbf{F_c}$, producing an output $V = S(\mathbf{X} - \mathbf{F_c})$.
- This output is applied to an actuator, which produces the balancing force $\mathbf{F_c} = AV$.

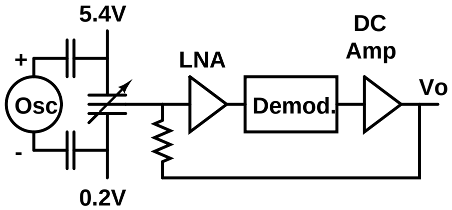
$$\mathbf{F_c} = AV = AS(\mathbf{X} - \mathbf{F_c})$$

$$\mathbf{F_c}(1 + AS) = AS\mathbf{X}$$

$$\mathbf{X} = \mathbf{F_C}(1/AS + 1) = AV(1/AS + 1) = V(1/S + A)$$

Thus V is a *linear* measure of X.

Accelerometer IC ADXL 150



Block Diagram of Accelerometer ADXL 150

- The oscillator produces out of phase signals which cancel when the moving plate is exactly centred.
- If the plate is displaced upwards, a positive phase signal is amplified by the Low Noise Amplifier LNA.
- It is detected by the phase sensitive detector (Demod).

The DC output of the detector is amplified and applied back to the centre plate.
A more positive DC bias on the centre plate reduces the electrostatic force w.r.t. the upper plate and increases it w.r.t. the lower plate, which brings it back to the centre.

Tilt Sensing for the Drone

- Our sensor board MPU 6050 contains 3 accelerometers aligned with x, y and z axes.
- 3 ADCs (with 16 bit resolution) convert the DC output of each accelerometer to digital values.
- These values are placed in $3 \times 2 = 6$ registers which are 8-bits wide and which can be read by Arduino through a serial interface.
- We measure tilt by measuring acceleration due to gravity along the three axes.
- If the drone is upright, g is felt only by the vertical axis and acceleration along the other two axes is zero.
- If there is a tilt, the angle of tilt can be computed from the ratio of the components of g along the three axes.

Measurement of Angular Velocities

- Apart from the 3 accelerometers, the MPU module 6050 contains a 3 axis gyroscope and a small microprocessor to handle serial communication and data storage.
- Isn't it amazing that 3 accelerometers, a 3 axis gyroscope, 6 ADCs with 16 bit resolution and a small micro-processor with local memory can be bought for a mere 200 Rs.?

- The gyroscope measures angular velocities around the three axes.
- Angular velocities are measured using the Coriolis force associated with a spinning body.

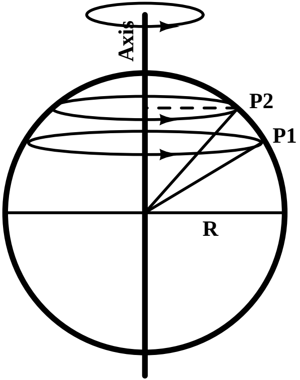
Coriolis Force

Consider a spinning spherical body like the Earth.

- An object on the spinning body will be thrown off along a tangent at its location due to its inertia. This is the centrifugal force.
- The object needs a force towards the centre of the spinning body to keep it at its position on the surface. This force is the centripetal force, – provided by gravitation in case of the Earth.
- If the object is not static on the spinning body, but moves towards one of the poles, there is another force which acts on the body.
- This force is the Coriolis force. It is the force which makes cyclones move clock wise in the norther hemisphere and anti-clockwise in the southern hemisphere.

Coriolis Force

- Consider an object moving from point P1 to point P2 on a spinning spherical body like the Earth.
- When viewed from a static frame outside the spinning body, the object has a velocity from West to East, which is maximum near the equator and zero at the north and south poles.
- As the object moves from P1 to P2 (northwards), it would keep its initial West to East velocity due to inertia.



- However, the Earth is moving at a lower velocity at point P2. Therefore the object will drift ahead of the Earth towards East.
- Thus it appears to have a force acting on it, pushing it eastwards. This is the Coriolis Force.

Coriolis Force

Coriolis force has been known for a long time.

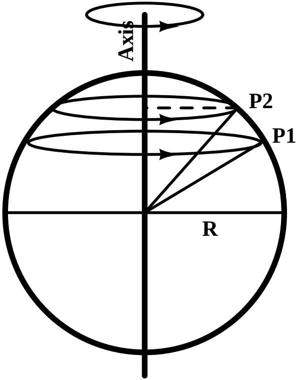
An interesting aside ...

Here is a quote from the Wikipedia:

> *"In 1674, Claude Francois Milliet Dechales described in his* Cursus seu Mundus Mathematicus *how the rotation of the Earth should cause a deflection in the trajectories of both falling bodies and projectiles aimed toward one of the planet's poles.*
>
> *Riccioli, Grimaldi, and Dechales all described the effect as part of an argument* **against** *the heliocentric system of Copernicus.*
>
> *In other words, they argued that the Earth's rotation should create the effect, and so failure to detect the effect was evidence for an immobile Earth!"*

Measurement of angular velocity using Coriolis Force

- Coriolis force is proportional to the angular velocity.
- It will be observed only when the object moves along the axis of rotation. This effect is used in MEMS based gyroscopes.
- An inertial mass is made to vibrate along the axis of rotation.
- Coriolis force will try to displace the inertial mass perpendicular to its motion.



- This movement can be measured as was done for an accelerometer, using force balance technique.

Gyroscope to measure angular velocities

The sensor board MPU 6050 contains:

1. Three accelerometers – one along each axis, with three 16 bit ADCs to report acceleration values in digital format.
2. Three mechanical oscillators – one along each axis, which constitute a gyroscope for angular velocity measurement. Three additional 16 bit ADCs are used to convert the output voltages from the gyroscope to a digital format.
3. It can accept inputs from an external 3-axis compass to provide a complete 9-axis output to report the motion status of an object.
4. It contains a more than 100 data registers, which contain calibration and status data to represent the motion state of an object.
5. The MPU 6050 module supports a serial data transfer protocol (I^2C) which allows access to this data from an external controller without needing too many pins.

Calibration of the drone

- The system frame in its static state will not be exactly perpendicular to the gravitational force. The initial tilt value has to be recorded and accounted for when in flight.
- Similarly, the gyroscope may have some initial offset. This has to be measured and compensated during subsequent measurements.
- Each motor has a dead range where a low value of PWM drive produces no movement at all. Therefore a range of low PWM values has to be excluded from the motion control algorithm. This range needs to be programmed during initialisation and calibration.
- In the user interface, the amount of finger movement on the touch screen of the mobile phone used to control the drone has to be mapped to the dynamic range of useful PWM range. This will vary from phone to phone and needs to be calibrated.

Motion Control for the Drone

Speeds of rotation of the four motors on the drone are controlled based on:

1. User control based on the throttle, yaw, pitch and roll values set by the user through mobile communication.
2. PID based control values required for stabilizing the drone. These are determined through an algorithm which keeps track of set values and actual values for each of the 6 axial parameters (angular position and angular velocity).
3. Coefficients for proportional, integral and differential errors need to be optimized empirically for stable operation.

PRECAUTION

The drone contains thin and sharp blades of the propellers rotating at a very high speed.

These can cause serious harm if they colloid with people or objects.

Always use guards around the propellers and exercise extreme care when attempting to fly your gnome!

Have fun building and flying your drone . . .

Do learn the underlying principles for all the mechanical design, hardware and software used for making your drone fly.