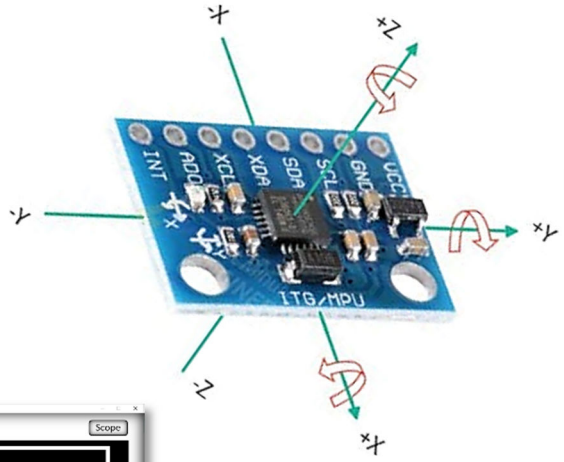
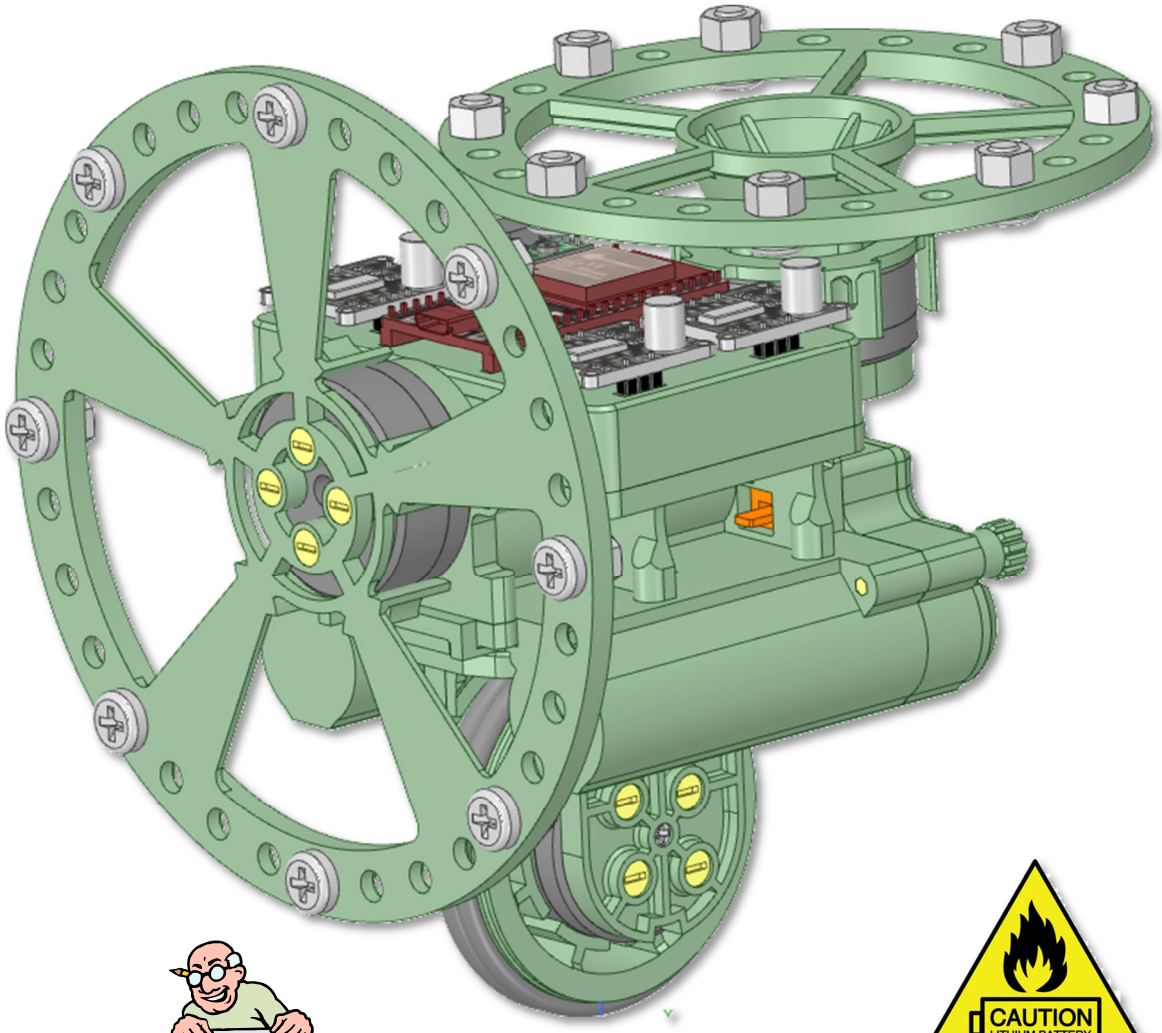
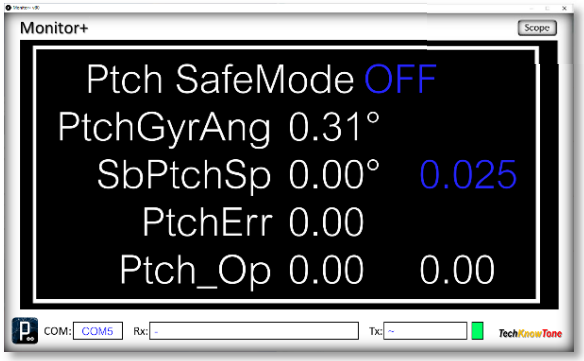
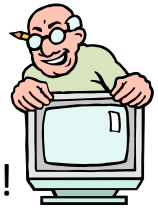
Uni-Bot (ESP32)

Calibration





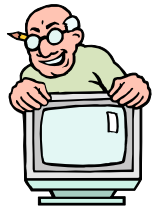




+ESP32

Calibration is an essential process!

CAUTION



Lithium batteries can be extremely dangerous, if not handled and cared for properly. This design does not include any form of current limiting circuit, like a fuse. So, care must be taken to ensure that the wiring guidelines are followed accurately, that checks are made for short-circuits, and that battery polarities are marked, and they are inserted the correct way round. Failure to do so, could result in an explosive fire.

Charging Practices: Always remove batteries from your project to charge them. Use a charger, designed for the battery used, and from a trusted supplier. Choose a flat, non-flammable surface to charge on, away from flammable materials. Never leave unattended when charging. Don't charge overnight. Monitor charging to ensure charge characteristics are as expected. Only pair batteries with similar characteristics. Do not overcharge, or leave charging for prolonged periods. This increases the risk of damage and fire.

Battery care & maintenance: Stop using a battery if it is swollen, damaged, dented or leaking. Never charge a damaged battery. Never allow a Lithium battery to discharge below 3.2 volts, as cell damage will occur. Avoid extreme temperatures. Do not charge or store batteries in very hot or cold environments. Don't cover batteries whilst charging, as this can trap heat, causing overheating.

In case of fire: Get out and stay out. If a fire starts, leave immediately, and call the fire brigade. For low voltage Lithium batteries, water is a safe extinguisher.

Built-in Monitoring: Most of my project designs include code, and circuitry, to monitor battery voltage, whilst in use. This code then seeks to alert the operator, when the battery has reached a critical low voltage, before shutting down power consuming circuitry; including the micro. Time should therefore be spent on calibrating this feature, as a precaution, for good battery management and maintenance.

Carefully dispose of batteries that damaged, or discharged below their critical voltage.

Battery Voltage Health Monitoring

See Lithium discharge curve obtained from the internet. In this analysis the lipo battery consists of three identical batteries connected in series.
Assume fully charged 11.1v battery max voltage is V_{BM} >= 12.9v max
Set battery warning point at V_B = 10.5v (3 x 3.5v)
Set battery critical point at V_{BC} = 9.9v (3 x3.3v)

The ESP32 is powered via a voltage regulator connected to the 3.3v pin.
V_{ADC} == 4095 on 12-bit converter (4095 max).
If we use a 10k resistor feeding A0 and a 3k3 resistor to GND, we get a conversion factor of 13.3v == 4095, or 3.25mV/bit, or 307.9 bit/v
Using a Multimeter I determined the following V_{ADC} values for corresponding threshold voltages:

MAX: (100%) V_M = 12.3v, gave A0 = 3841 on V_{ADC} (3 x 4.1v)

HIGH: (80%) V_H = 11.4v, gave A0 = 3402 on V_{ADC}

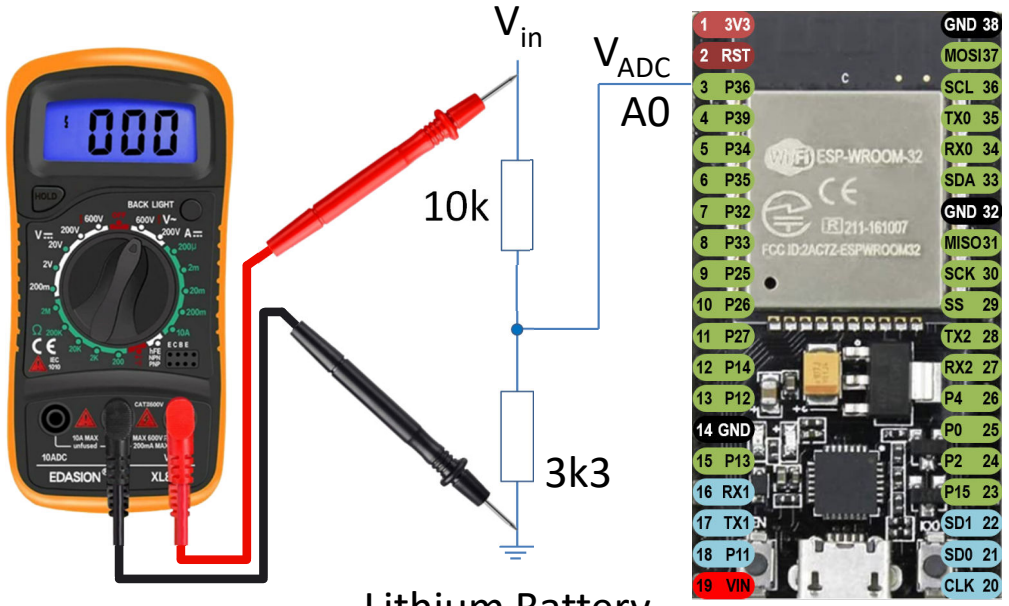
WARNING: (20%) V_B = 10.8v, gives A0 = 3175 on V_{ADC}

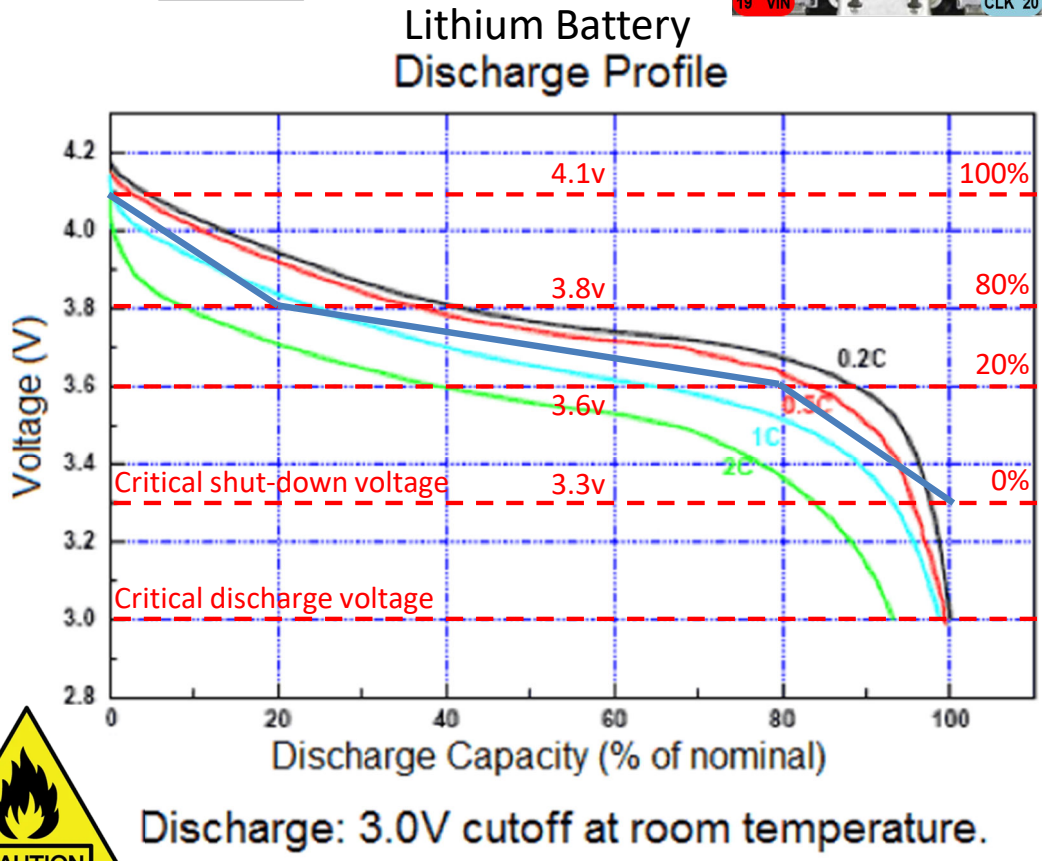
CRITICAL: (0%) V_{BC} = 10.0v, gives A0 = 2895 on V_{ADC} (3 x 3.3v+)

The code will sample the battery voltage on power-up to ensure it is sufficient, then at every 40ms interval, calculating an average (1/20) to remove noise. It also detects no battery as USB mode.

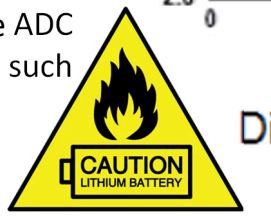
In the code I have assumed a discharge curve ranging from 12.3v (100%) to 10.0v (0%) capacity, using the overlay lines shown. The rate of discharge is monitored and used to predict the life of the battery in use.

Note: If connected to USB port with internal battery switched OFF the ADC will read a value 5 volts (A0 = 1919) or less. So if the micro starts with such a low reading it knows that it is on USB power.





Discharge: 3.0V cutoff at room temperature.



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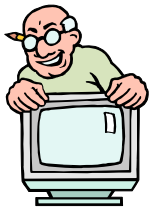
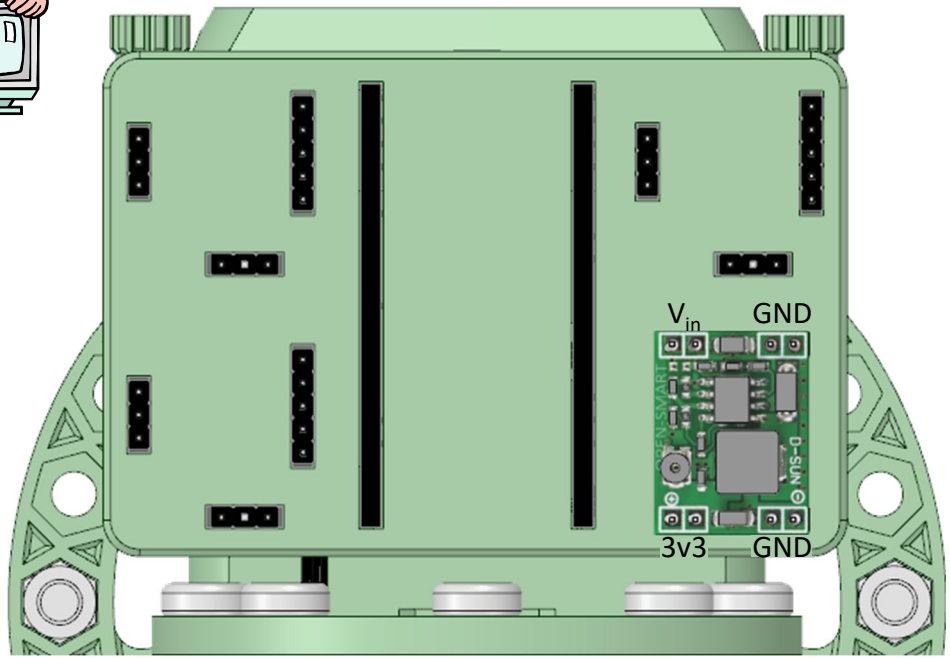
Voltage Regulator



Set up the voltage regulator independently using an external power supply and multimeter, before you plug in the micro and drivers. The input voltage source should be > 8 volts, and we trim the regulators output to achieve 3.3 volts. This is normally done by turning the small potentiometer on the pcb in a clock-wise direction, to reduce the output voltage.

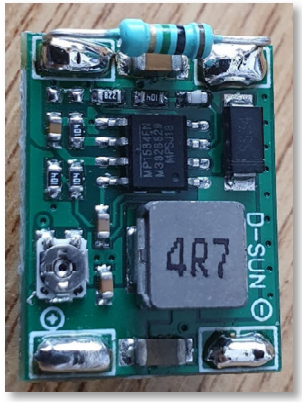
Once the robot is wired and assembled, plug in the voltage regulator, ensuring the correct orientation, with the potentiometer and inductor towards the lower edge. Install the three batteries, and check that the output of the voltage regulator is at 3.3 volts.

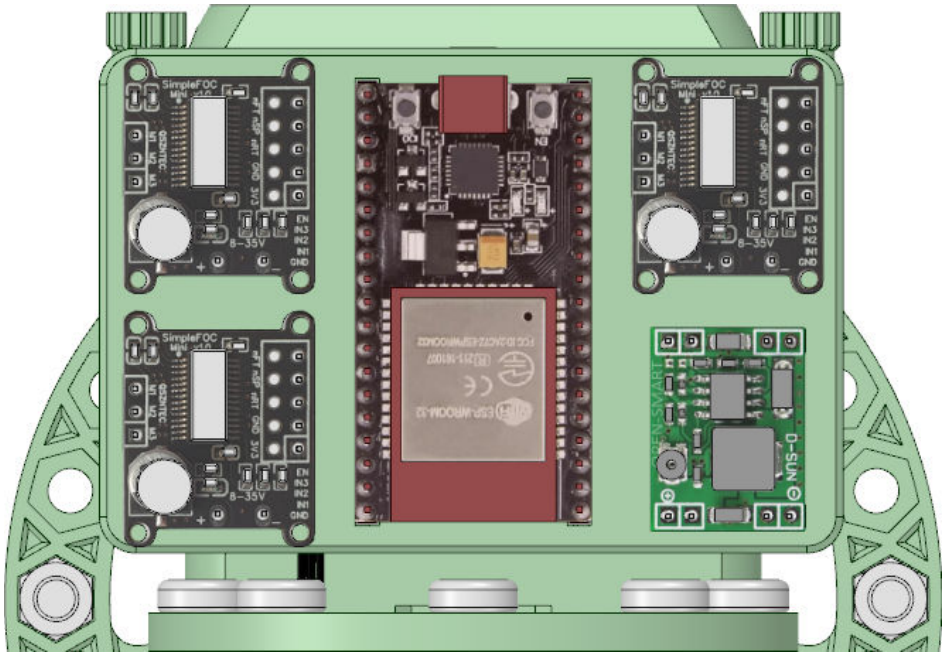


Now insert the ESP32 micro, with the power off, and download the code into it. When power is re-applied, this should confirm that the RGB LED's are working. All three SimpleFOC mini drivers power LEDs should also light up.

The accuracy of the analogue to digital converter (ADC) in the ESP32 can be improved by calibrating it's measurements against a multimeter, whilst using an adjustable voltage supply. This is important for setting the correct motor PWM values, to prevent them over-heating.

I soldered a 1MΩ resistor across the voltage regulators input pins, to make it easier to attach an external power supply for these measurements, and obtained the following values to enter into the code:





```
10.0v == #define BatCritical 2895
11.4v == #define BatHigh 3402
12.3v == #define BatMax 3841
         #define BatPin 36
10.8v == #define BatWarn 3175
```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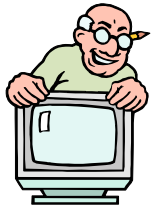
MPU6050A Orientation

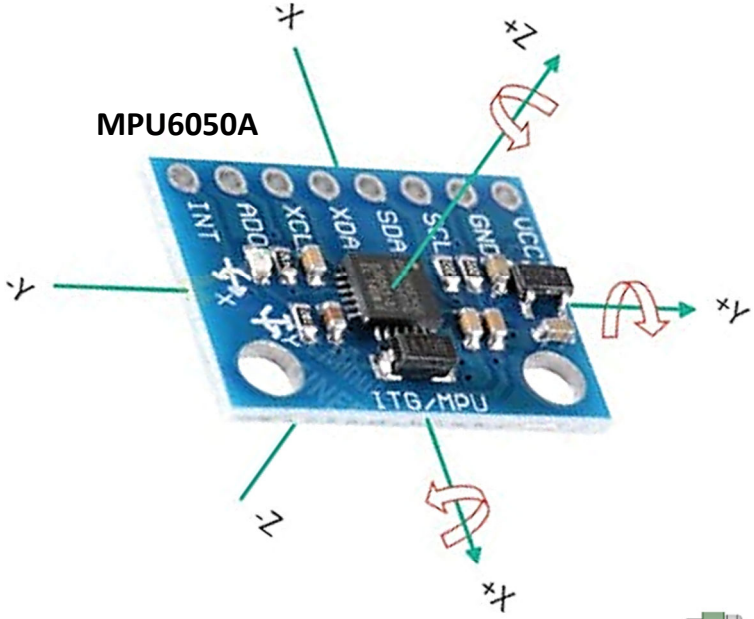


With the MPU6050 mounted on the right leg as shown, the following applies:

Pitch - Z gyro, -ve tilt forwards, +ve tilt backwards
- Y accelerometer, -ve lean forwards, +ve lean backwards

Roll - Y gyro, +ve tilt right, -ve tilt left
- Z accelerometer, -ve lean right, +ve lean left

Yaw - X gyro, +ve turning right ,-ve turning left
- X accelerometer, , -ve upright, +ve upside down

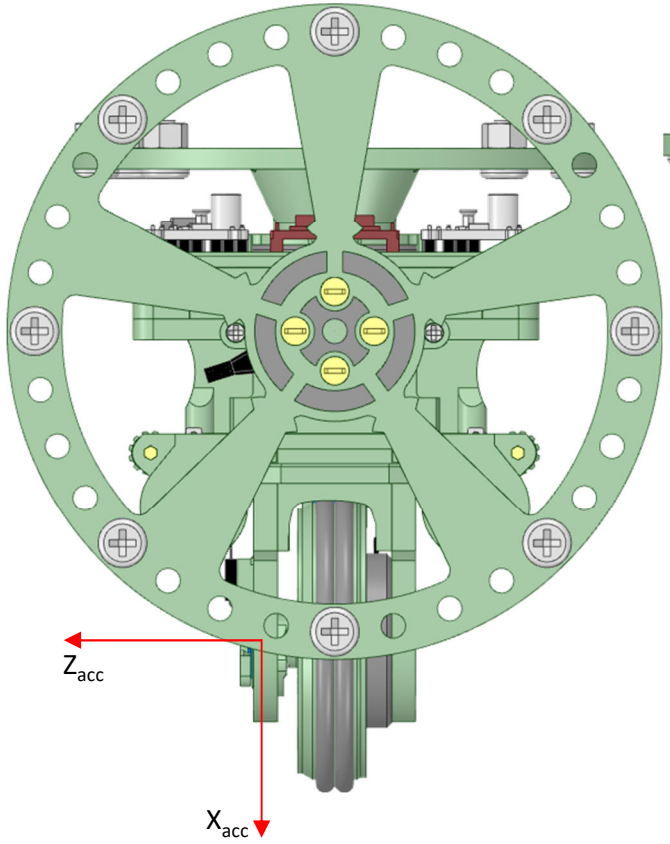


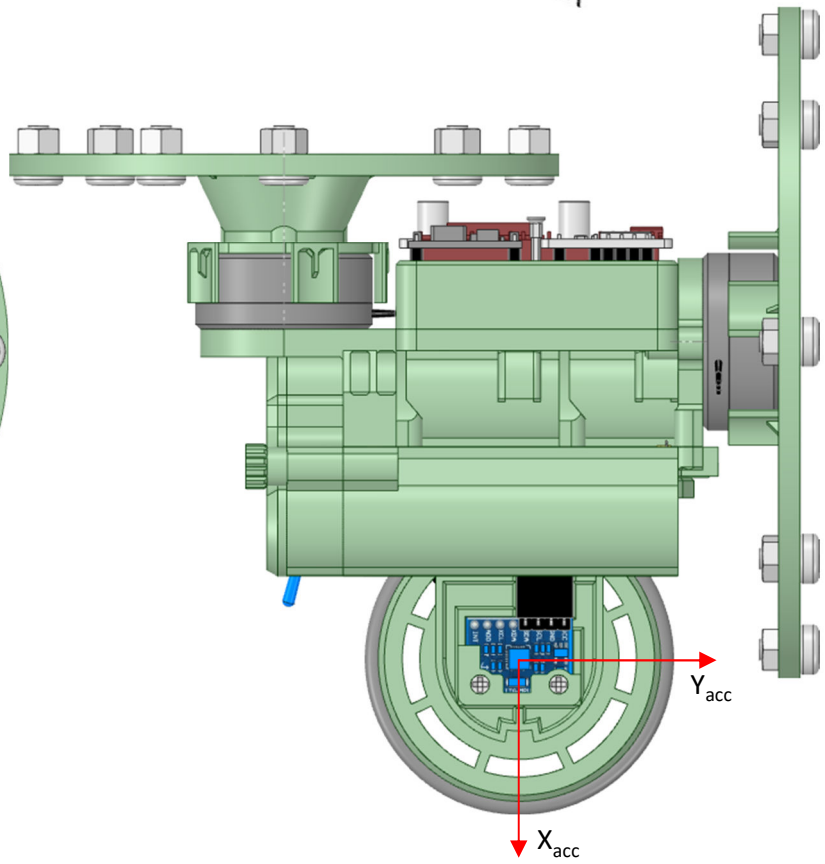
Note that the X-axis accelerometer is pointing downwards, when the robot is upright and balancing. Hence it is greatly influenced by gravity and give a max negative reading.

The X-axis value is negative because the gravitational force is acting on the sensor as if it were accelerating upwards, and therefore in the opposite direction to the polarity indicated by the diagram.

The MPU6050 sensor values will contain offsets, due to manufacturing tolerances, and may not give maximum values. We therefore need to determine these offsets, and then remove them in our code, so as to improve the overall accuracy of the system.

The next page explains how you do this.





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Uni-Bot Pitch PID Adjustment

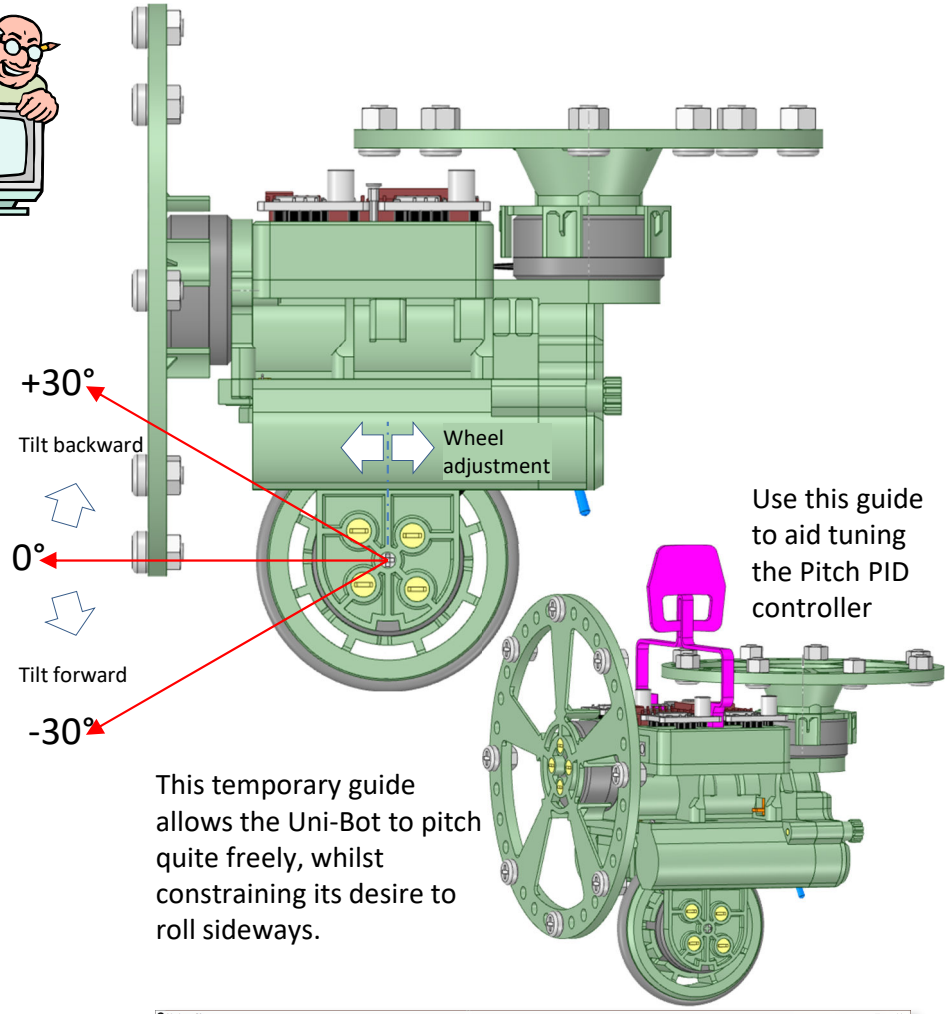
The aim is to balance the Uni-Bot using the 'Pitch' PID controller code, when the robot is level, at 0° facing forwards. The drive wheel is mounted on an adjustable slide to make this possible; however, the position of the drive wheel will depend on what weights you have fitted to the roll and turn reaction wheels, respectively, and the distribution of weight within the robot. So the angle at which the robot can be balanced my not be 0° initially, and we use the self-balancing nature of the code to find the set-point for balance; a code variable named SbPtchSp.

If the pitch start angle, PtchStartAng, is set to 0° initially, then this is the starting point for the auto-adjustment of SbPtchSp. If this isn't the point of balance, the robot will naturally fall forwards or backwards, developing an error signal in the PID controller, which in turn will move the drive wheel to compensate for this out of balance state. The code senses this condition, and automatically adjusts the balance setpoint SbPtchSp to counter this behaviour. The robot will drive back and forth, for a few moments initially, until SbPtchSp is at the correct value.

To start with, the position of the drive wheel may be such that the robots natural pitch balance is out by several degrees, and the auto-adjustment code can't compensate for this. If this is the case the robot will have a tendency to run off, forwards or backwards, depending on the error. We can fix this, by adjusting the start angle, giving the code a greater chance of achieving balance.

If the robot wants to drive backwards, then adjust the start angle to a negative value, say -2.00° and try it again. And if the robot wants to drive forwards at the start, then make the start angle a positive value, like +2.00°.

Through a process of trial and error we are adjusting the position of the drive wheel, such that the start angle can be set to 0°, and the automatic self-balance set point SbPtchSp adjustment ends up very close to that value.



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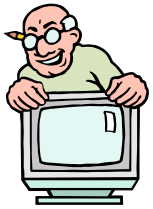
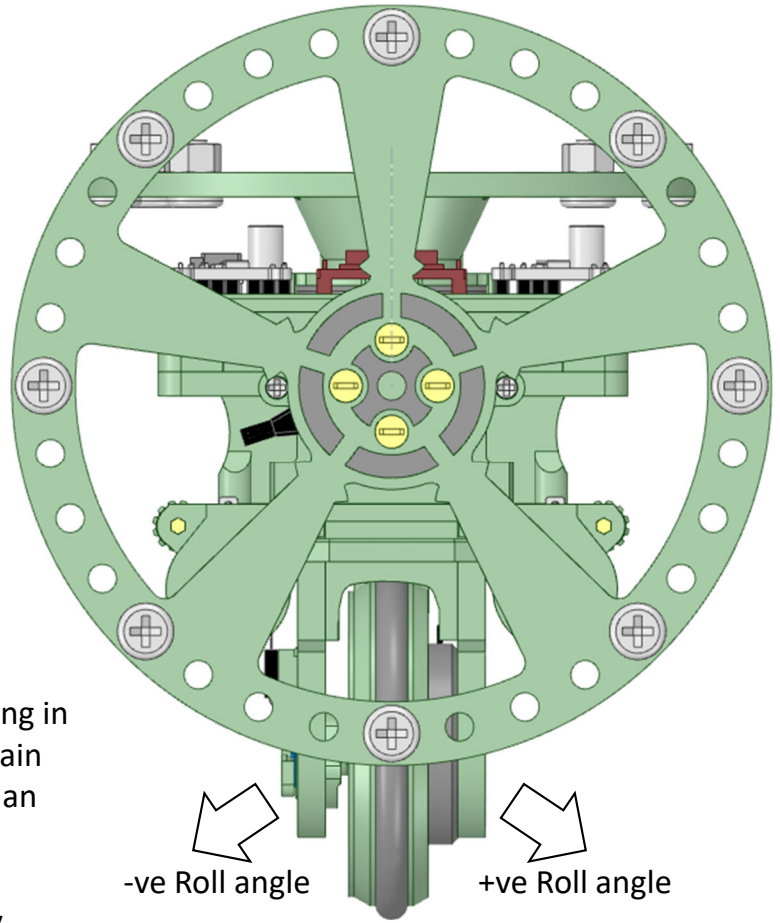
Uni-Bot Roll PID Adjustment



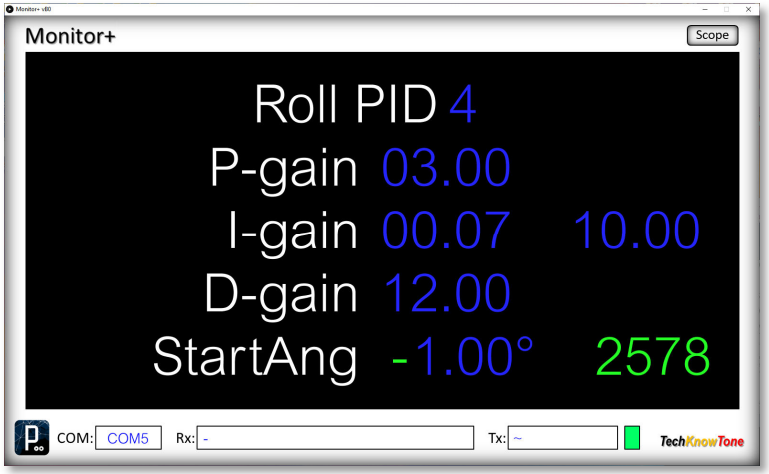
Tune the Pitch PID controller, using the 'Guide' attachment before attempting to tune the Roll PID controller. As this will give you experience of tuning a controller before attempting the greater challenge. As with the Pitch PID controller, you can adjust the Roll PID coefficients simply by clicking on the blue digits in the Monitor+ app. Any changes will be lost when the micro is reset, so you note them down and make changes to the code, once you have values that you want to use.

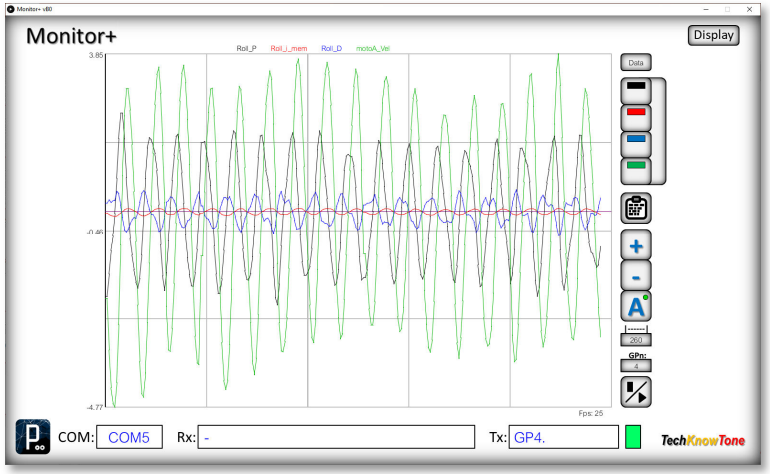


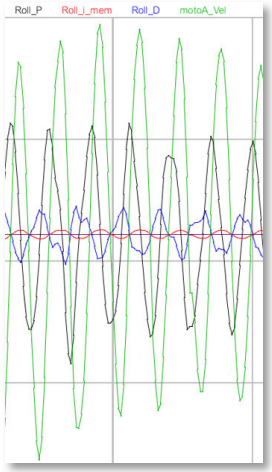
The Roll PID controller is very sensitive to being given the correct start angle, which is the angle at which the controller becomes active during the initiation process (see video). The self-balancing adjustment will make for some allowance in this initially, so you observe the angle to which the system is trying to get to and set that as the start angle. You will see from the Monitor+ screen shot below, that my Uni-Bot Roll PID self-balances at -1.00° and that is my start angle in code.

Using GPn = 4 in the 'scope' display, enables you to view what is happening within the Roll PID controller whilst the Uni-Bot is self-balancing. You should expect to see the motor velocity changing in in a sinusoidal fashion, as the robot sways from side to side about the balance point; with the P-gain term dominating the output, whilst the D-gain provides corrective action, and the I-gain provides an underlying sinusoidal trace in response to small changes in angular error.

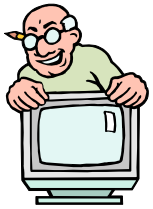
If you use the same arrangement of reaction wheel weights as me, you should come up with very similar Roll PID coefficients.







Uni-Bot Turn Speed Adjustment



We know that the turning force exhibited by a reaction wheel is proportional to its rate of acceleration. To increase the turning force developed, we either add weights to the wheel or increase its rate of acceleration. But adding too much weight will affect the robots ability to balance, and its pitch self-balance setpoint. And we can't just keep accelerating the wheel, due to max speed limitations of the BLDC motor and the SimpleFOC driver. So there is a compromise to be had here.

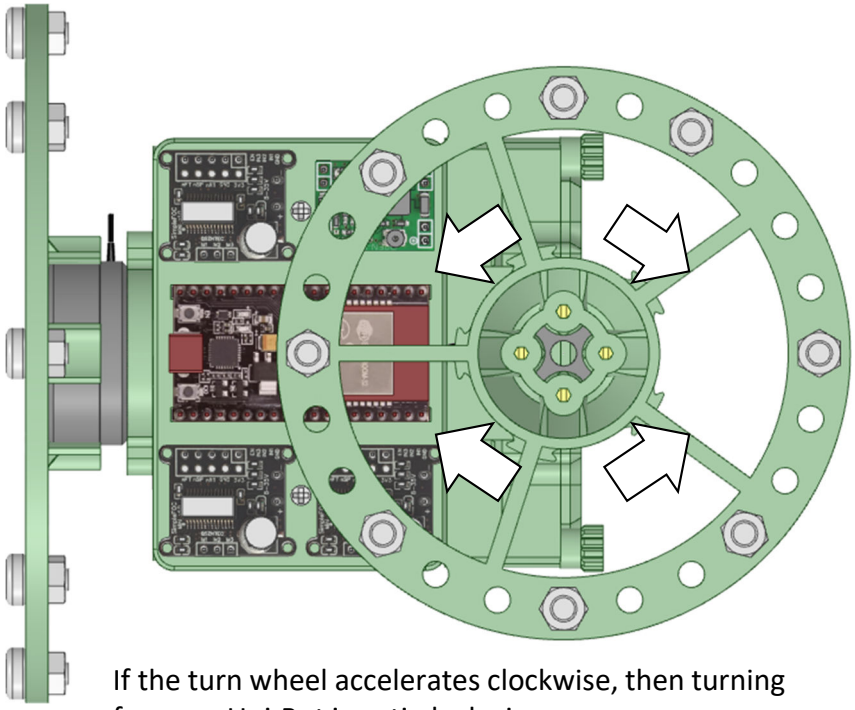
So I chose to use eight M5 nuts and bolts on the turn wheel, as acceleration test suggested that would be more than enough to turn the robot round. With those weights added, I needed to determine a practical max. rate of acceleration to achieve suitable turning, and also a minimum rate of deceleration to apply when slowing the wheel down.

The 'Turn Control' screen was coded to achieve this. Using this display you can click on the blue digits to set values for max acceleration and min deceleration, whilst using the Wii Nunchuk controller to trigger the demand.

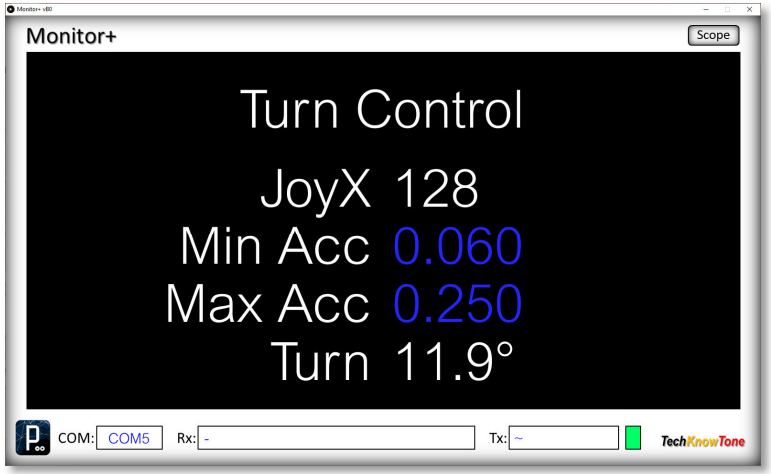
The aim is not to have the Uni-Bot turning like a spinning top, when a demand is applied, and for the wheel to slow down relatively quickly, so that further demands can be applied.

The Monitor+ screen shot here shows the values which I came up with, for my Uni-Bot. You may like this, or determine a more/less aggressive turning characteristic for your robot.

The ratio of Max/Min appears to be in the order of 4:1



If the turn wheel accelerates clockwise, then turning force on Uni-Bot is anti-clockwise.
If the turn wheel accelerates anti-clockwise, then turning force on Uni-Bot is clockwise.



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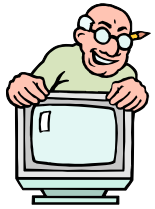
MPU 6050A Orientation

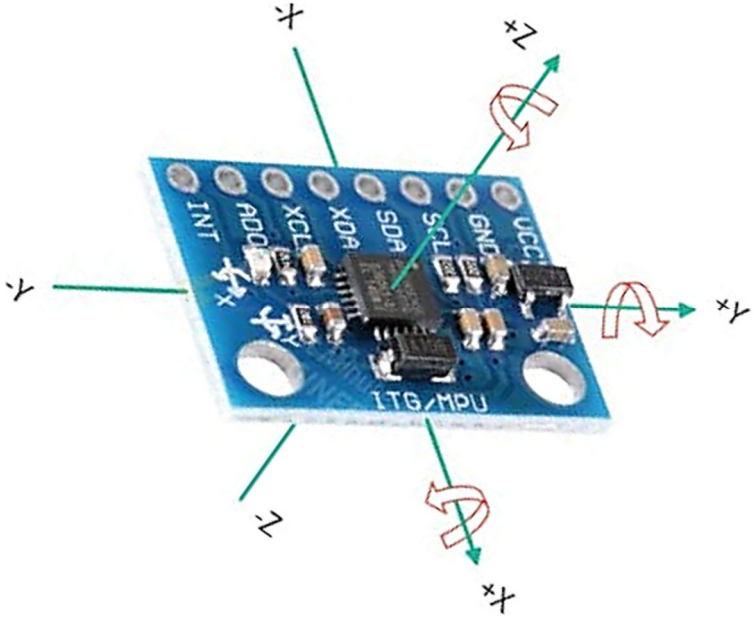


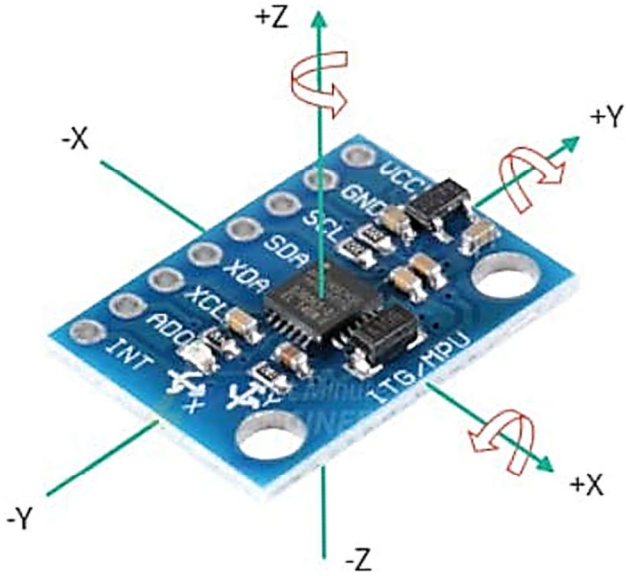
With the MPU6050 mounted on the rear as shown, the following applies:

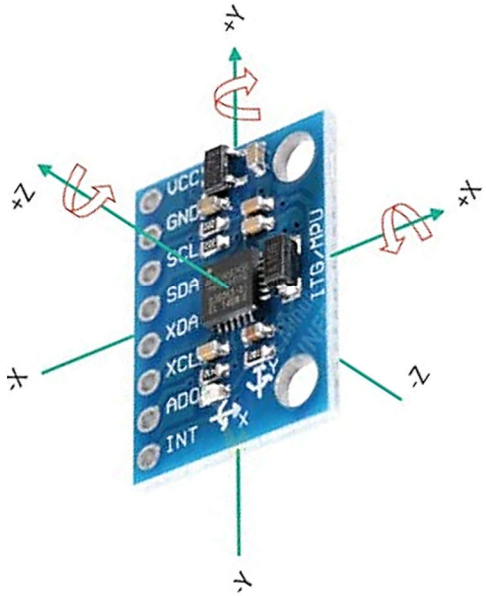
Pitch - Z gyro, -ve tilt forwards, +ve tilt backwards
- Y accelerometer, -ve lean forwards, +ve lean backwards

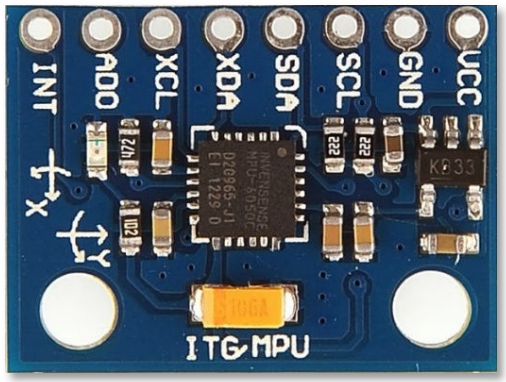
Roll - Y gyro, +ve tilt right, -ve tilt left
- Z accelerometer, -ve lean right, +ve lean left

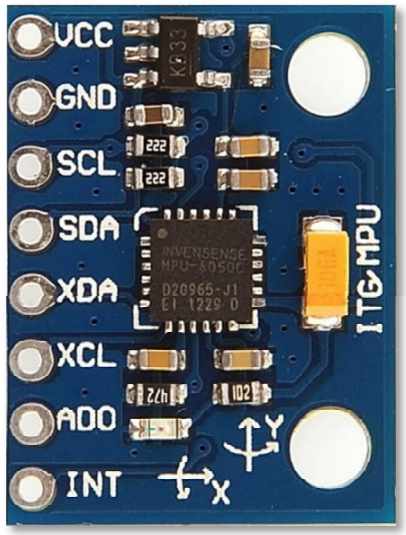
Yaw - X gyro, +ve turning right ,-ve turning left
- X accelerometer, , -ve upright, +ve upside down











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