DYNAMIC FLIGHT CONTROL SYSTEM INTEGRATION FOR TOTEM Q330 DRONE

Mechatronics Engineering Department

Mechatronic System Design Project

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ABSTRACT

In this project, we upgraded a quadcopter's performance, which will increase the stability of the quadcopter using some sensors, actuators, and an Arduino microcontroller to control the speed and navigation of the quadcopter. We successfully tuned and calibrated a PID controller to achieve stabilization on each axis of rotation, resulting in a stable drone.

PROBLEM STATEMENT

In the realm of unmanned aerial vehicles (UAVs), particularly quadcopters, there exists a pressing challenge: mitigating the adverse effects of vibrations and drifting from the intended flight path. These disturbances can arise from diverse sources such as motor imbalances, wind gusts, or imperfect hardware calibration, disrupting the quadcopter's trajectory and failing mission objectives.

To overcome this challenge, it is imperative to develop a robust control strategy leveraging PID controllers within the framework of a Controller software. This entails a comprehensive exploration of PID tuning techniques to effectively attenuate vibrations and minimize drifting, ensuring the quadcopter maintains a stable and accurate flight path under varying environmental conditions and operational demands.

SPECIFICATIONS

- **Total weight:** 455g
- **Frame weight:** 155g
- **Frame wheelbase:** 325mm
- **Motor weight:** Approx. 30g with wires
- **Motor Diameter:** 27.9mm
- **Motor Height:** 31.7mm
- **Shaft Diameter:** 3mm
- **Driver Weight:** 25g
- **Driver size:** 32*24*7mm
- **Battery Size:** 12.0 * 10.0 * 2.0 (cm)
- **Battery Gross Weight:** 0.15 (kg)
- **Motor-rated thrust** 524 g
- **Battery voltage** 14.8V
- **Battery capacity** 4000 mAh
- **Battery discharge rate** 80%
- **Watts to lift 1Kg** 170W
- **Accelerometer range** (-23768 – 23767)
- **Vibration-free acceleration** 1g

MODELLING AND SIMULATION

• Modelling:

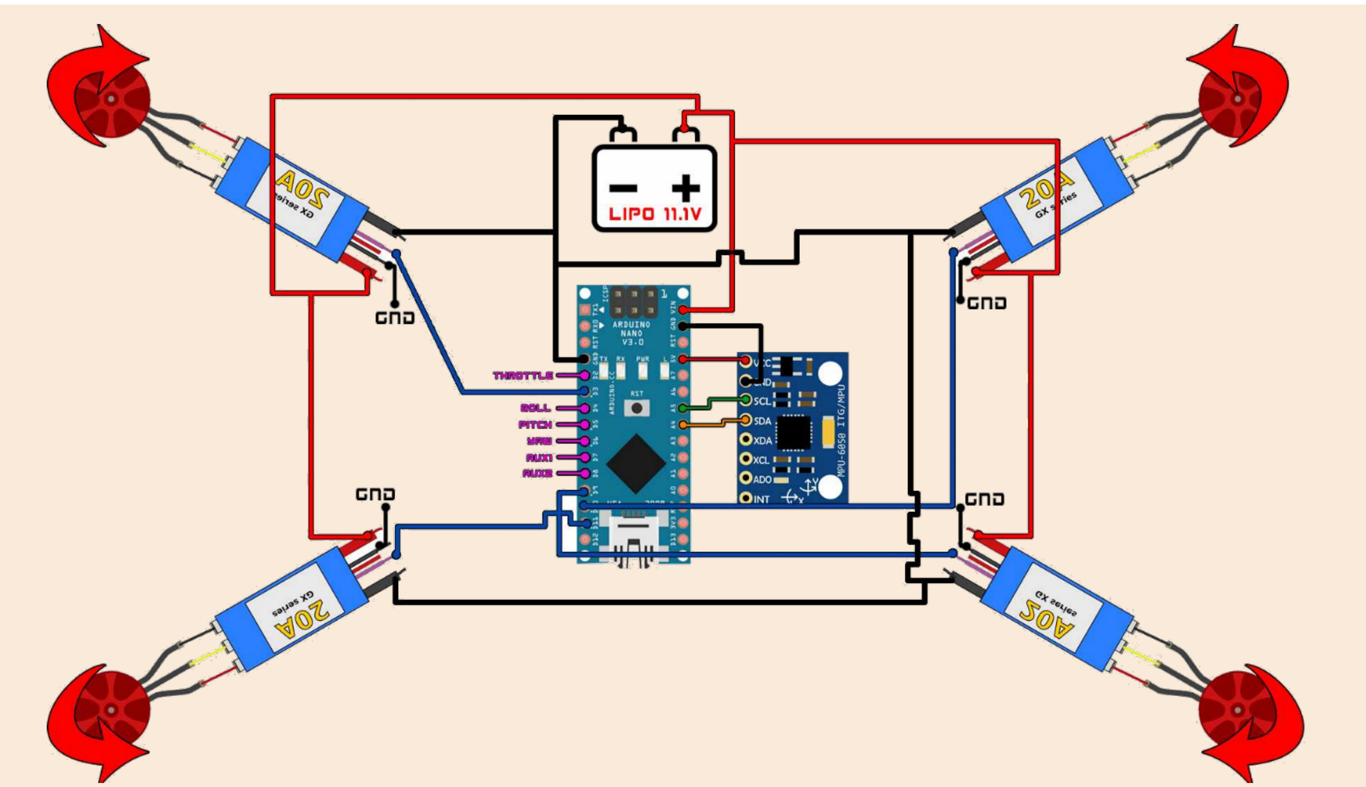

Figure 1: system model.

The model's essential parts consist of:

1. Brushless motors.
2. ESC(Electronic speed controller).
3. Microcontroller(Arduino Nano).
4. MPU6050 gyroscope.
5. Power source(Lipo-battery).
6. Radio Receiver and transmitter.

- **To make sure that the drone flies without the motor overheating and vibrating:**

  $total\ weight\ of\ the\ drone = Drone\ weight + Battery\ weight = 455 + 150 = 605\ g$

  So we need to generate at least 2:1 of the drone weight which is about 1200g of thrust to have stable flight, now we check on our motor.

  Motor rated thrust= 524g.

  Since we have a quadcopter , we have 4 motors, then $max\ thrust = 4 \times 524 = 2096g$ of thrust power which is capable of flying this drone. So our picking for therse motors was correct (2096>1200g).

- **Now we need to check if the battery can give us a reasonable flight time:**

  Our battery specs are: **14.8V battery voltage, 400 mAh of capacity, 80% discharge rate, watts to lift 1 kg= 170 watts.**

  $$To\ calculate\ the\ flight\ time = \frac{Capacity \times discharge\ rate}{Amps\ draw\ (AAD)}$$

  $$AAD = \frac{All\ up\ weight \times P}{V}\ , \qquad \boldsymbol{P: power\ to\ lift\ 1\ kg, V: Battery\ voltage}$$

  $$AAD = \frac{605g \times 170\ watts}{14.8\ V} = 6.95\ V$$

  $$flight\ time = \frac{0.4 \times 0.8}{6.95} = 0.046h\ \times 60 = 27.6\ mins\ , \boldsymbol{which\ is\ great\ fly\ time}.$$

  so the battery selection is optimal.

- **To make sure we get a stable flight:**

  We need to make sure we get acceleration of 1g or less on any one of the rotation axis. Taking the x-axis for the example, the simulation gave us a value of 16384 (The range is from -32768 to 32767), and with this information, we can find the acceleration by the formula:

  $$Acceleration = \frac{acceleration\ axis\ raw\ data \times full\ scale\ range}{65536}, we\ use\ a\ measuring\ range\ of\ \pm 2g$$

  $$\boldsymbol{For\ x - axis}: Acceleration = \frac{16384 \times 4}{65536} \approx 1g$$

  1g means we get a vibration-free drone when maneuvering, which is optimal for our application.

• Simulation:

Using MultiWii software configuration as a simulator involves setting up the software to simulate quadcopter flight dynamics on the computer

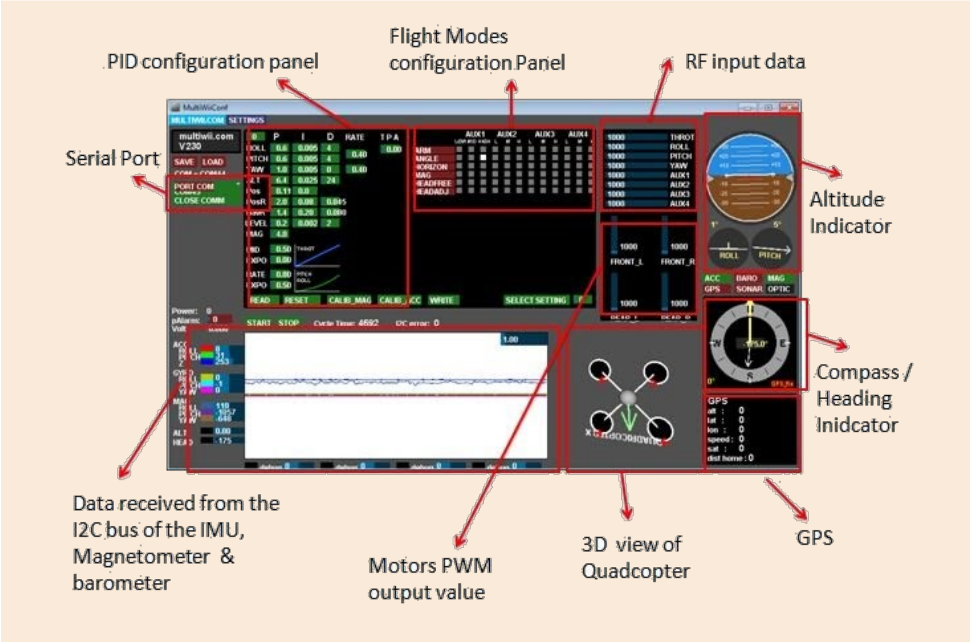

Figure 2: multiwii simulator parts.

We tried to simulate the Drone Performance before and after adding a PID controller and tuning it and we got the following result:

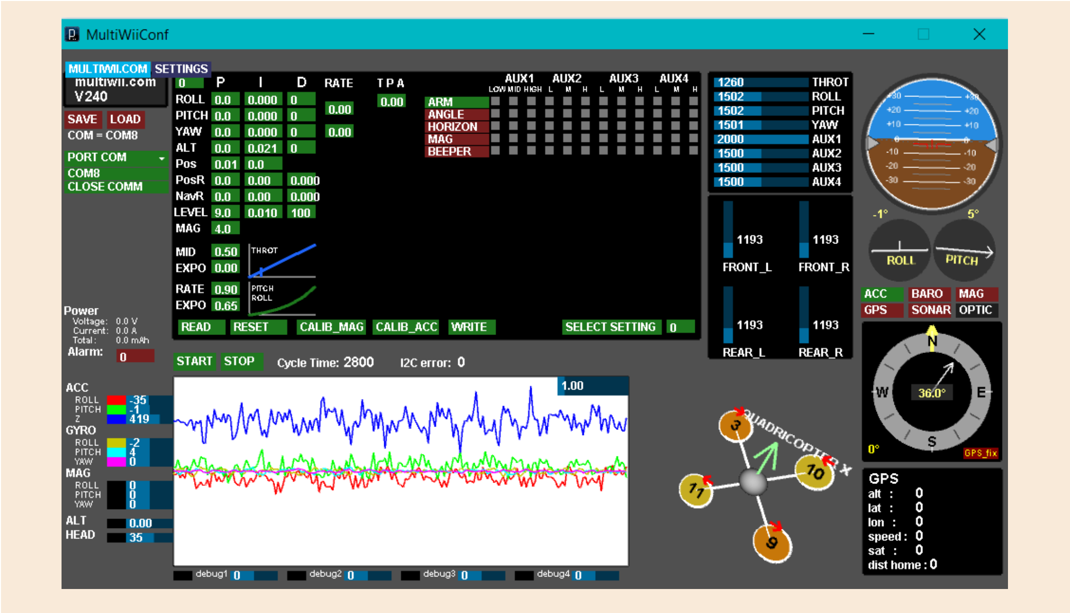

Figure 3: system performance before tuning.

It is obvious that we got a poor performance rich with vibration and instability due to not having a proper controller and all this data is being generated from the gyroscope that acts as a feedback device so to decrease the number of vibrations we will make a difference which will enhance the performance of the quadcopter.

PID controller Tuning:

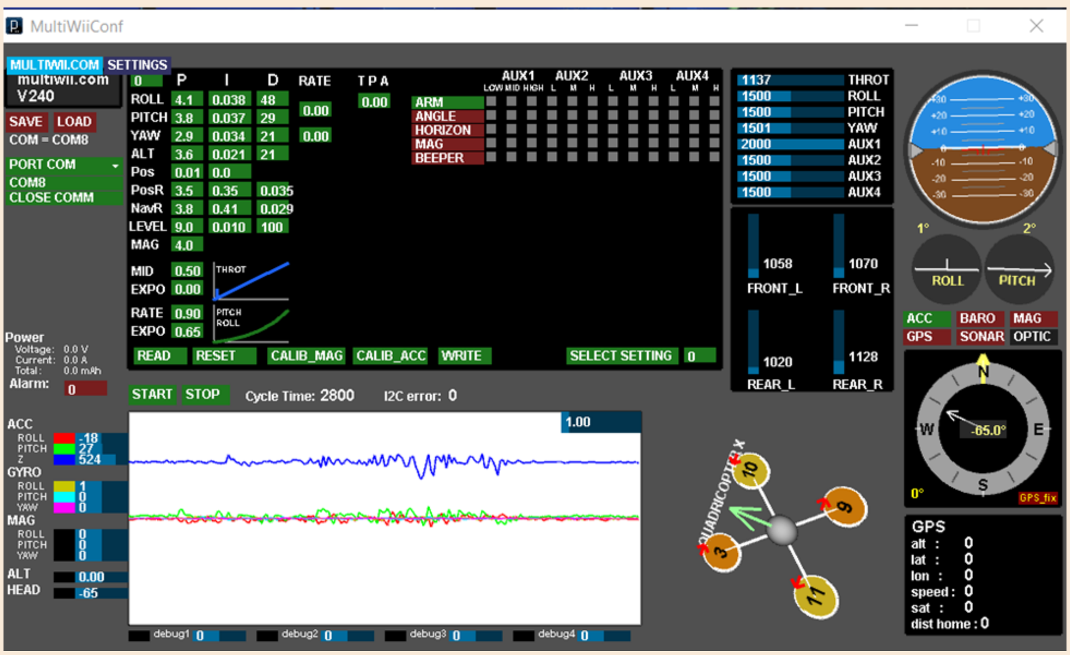

Figure 4: system performance after tuning.

Since the PID controller's function can be visualized as a dynamic plot of control output (motor speed adjustments) over time, as time progresses, the controller's adjustments should converge to stabilize the aircraft, resulting in a smoother trajectory indicative of the desired orientation being maintained.

By trail and error technique we reached these PID gains to have low instability performance and we can clearly see the difference in the simulation graph with very low disturbances compared to the simulation before tuning the quadcopter.

SELECTION OF ACTUATORS

• EMAX RS2205 RaceSpec Motor - Cooling Series

Figure 5: EMAX RS2205 RaceSpec Motor.

Brushless motors are favored in quadcopters due to their superior efficiency, offering longer flight times and enhanced performance without the friction and wear associated with brushes.

The RS2205 motor is known for its high-power output and efficiency, making it suitable for fast acceleration and agile maneuvers. Its optimized design allows for efficient energy conversion, maximizing flight time and performance.

The RS2205 motor has a lightweight design, contributing to the overall agility and responsiveness of the drone. This is crucial for racing drones, where speed and maneuverability are paramount.

EMAX offers a range of customization options for the RS2205 motor, including different KV ratings (speed/torque ratios) and propeller mounting options. This allows drone enthusiasts to tailor the motor's performance to their needs and preferences.

Cooling fins significantly reduces heat soak by at least 30%. This “cool” feature allows the RS2205 to not only have a longer-lasting motor but also harness the power of N52 magnets. The N52 magnets Use the highest-grade magnets. Better acceleration, stopping power, and sustained RPMs during high kv.

• ESCs driver

ESCs (Electronic Speed Controllers) are essential for brushless motors in quadcopters, acting as intermediary devices that translate signals from the flight controller into specific commands for the motor. They electronically commutate the motor's phases, ESCs also offer variable speed adjustment, and safety features like thermal and over-current protection.

SELECTION OF CONTROLLER

• Arduino Nano

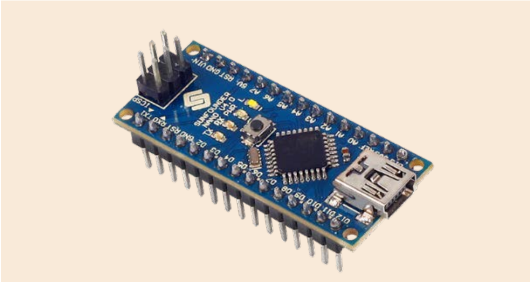

Figure 6: Arduino nano.

The Arduino Nano is a small, complete, and breadboard-friendly board. It offers similar connectivity and specifications as the Arduino UNO board but in a smaller form factor. The Nano comes with pin headers for easy attachment to a breadboard and features a Mini-B USB connector2.

The Arduino Nano is a popular choice for drone due to its ease of use, affordability, and vast community support. Also :

- **Versatility:** Arduino boards, such as the Arduino Nano, provide a platform for programming and controlling various components of the drone, such as motors, sensors, and communication devices. They offer digital and analog input/output pins, communication interfaces, and compatibility with a wide range of sensors and modules.

- **Customization:** By leveraging Arduino's capabilities, you can customize your drone's functionality and create a unique flying experience. Whether you're a beginner or an experienced DIY enthusiast, building a drone with Arduino allows you to tailor it to your specific requirements.

SELECTION OF FEEDBACK DEVICES

MPU6050 gyroscope:

- ### Rotation Sensing

A gyroscope is a device used for measuring or maintaining orientation and angular velocity. Gyroscopes are commonly used in navigation systems, stabilizing systems for vehicles and aircraft, and various other applications where precise orientation sensing is necessary. They utilize the principle of angular momentum to detect changes in orientation.

The MPU6050 consists of a 3-axis Gyroscope with Micro Electro Mechanical System(MEMS) technology. It is used to detect rotational velocity along the X, Y, and Z axes as shown in the below figure.

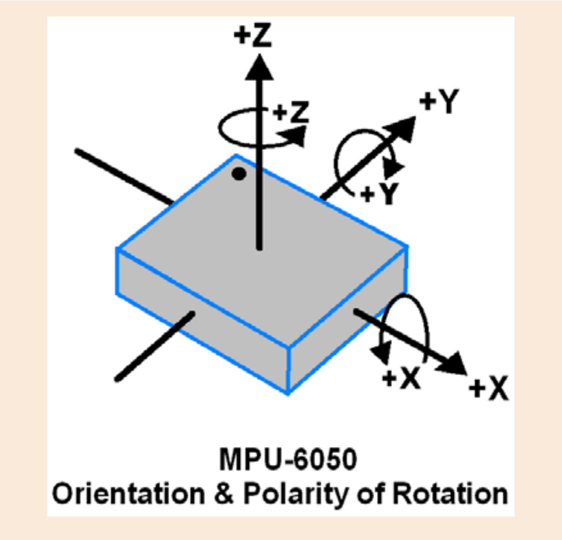

Figure 7: MPU6050 rotation sensing.

The gyroscope measures the angular velocity measured in degrees per second. In order to obtain angle of rotation about x/y/z axes, the angular velocity measurements need to be integrated over time. This is easily done by multiplying the current angular velocity by the time elapsed since the last measurement and accumulating the product. While gyro measurements are very stable and noise free, they have a tendency to drift over time.

• Acceleration Sensing

The MPU6050 consists 3-axis Accelerometer (an accelerometer is a device that measures the vibration, or acceleration of motion, of a structure). It is used to detect the angle of inclination along the X, Y, and Z axes as shown in the below figure.

The accelerometer works on the principle of piezo electric effect, the ability of certain materials to generate an electric charge in response to applied mechanical stress.

The reading of accelerometer is converted to an acceleration value by mapping the reading from the reading range to the measuring range.

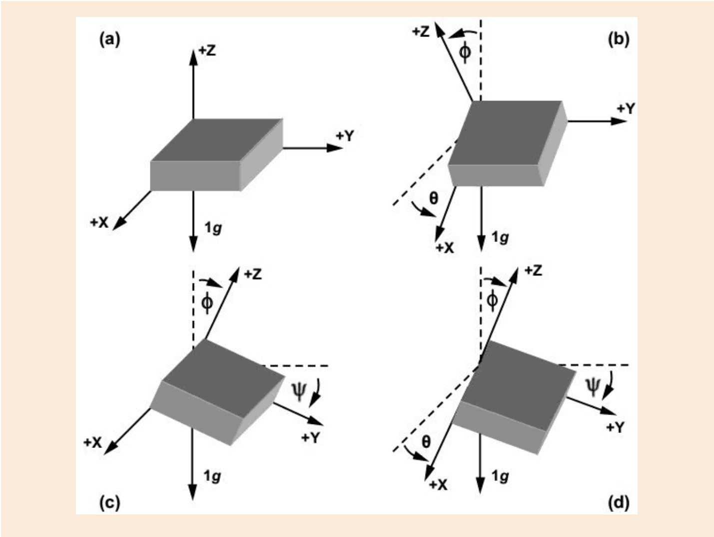

Figure 8: MPU6050 acceleration sensing.

RESULTS AND DISCUSSION

The result of our project is that we obtained a vibration-free system that does not have any drifting or instability within it by implementing a PID controller, and then tuning the PID gains (Kp, Ki, Kd).

The brushless motors boast a higher power-to-weight ratio, crucial for lifting payloads, and are more durable with longer lifespans, brushless motors can achieve higher RPMs, enabling faster speeds and agile maneuvers, while generating less electromagnetic interference.

CONCLUSION

PID tuning for the Totem Q330 drone is a dynamic and iterative process that requires a combination of theoretical understanding, practical experimentation, and careful analysis. With dedication and attention to detail, operators can fine-tune PID parameters to achieve the desired flight characteristics and enhance the overall performance of the drone.

Starting with default or recommended PID values, manual tuning involves incrementally adjusting the proportional, integral, and derivative terms while observing the drone's response during flight.

The MPU6050 gyroscope serves as a crucial sensor for providing accurate real-time data on the drone's orientation and rate of rotation. By utilizing the gyroscope data in conjunction with the PID controller, precise adjustments can be made to the motor speeds, ensuring smooth and stable flight even in challenging environmental conditions. Additionally, the selection of high-performance motors like the EMAX RS2205 RaceSpec Motor - Cooling Series, paired with efficient ESCs, provides the necessary power and responsiveness required for dynamic flight maneuvers. The ESCs play a vital role in controlling the speed and direction of the motors based on input commands from the flight controller, enabling rapid adjustments to maintain stability and responsiveness during flight. Together, the integration of these components enhances the overall performance and maneuverability of the Totem Q330 drone.

REFERENCES

- **Selection of feedback devices:**
  1- https://www.electronicwings.com/sensors-modules/mpu6050-gyroscope-accelerometer-temperature-sensor-module
  2- https://docs.sunfounder.com/projects/ultimate-sensor-kit/en/latest/components_basic/05-component_mpu6050.html

- **Selection of motor:**

  https://emaxmodel.com/products/emax-rs2205-racespec-motor-cooling-series?fbclid=IwZXh0bgNhZW0CMTAAAR3e3myf3DQ86AqobZMWZ19f5WuwwKeHj1vHNpf9pw4BVNk8swcm7TGB1a4_aem_AfIvCtryiq_7yx7_JRkm0CITtncGTrVqvjN4HfD9J1jqFo_QRaRQm4M2EbB_iE6lWpZMZeUaCUdrWRJLZNEdBP5l

- **Modelling and simulation:**
  1- https://www.omnicalculator.com/other/drone-motor?fbclid=IwZXh0bgNhZW0CMTAAAR2NgvLz4-j_0ckNtL1_H1u02n4QFUGEdvEneCHvwshpnB7S9mGmzmRvMpE_aem_AfIGVDaVvH1BV6SMDbSPNNfUU7oFLTmePUg4bG6J4R5hVFQdeKKfyltn-_fFPYnc9BB6XLVE5KoMFztFC_aLI_NT
  2- https://dl.btc.pl/kamami_wa/hk_26588_40.pdf?fbclid=IwZXh0bgNhZW0CMTAAAR3e3myf3DQ86AqobZMWZ19f5WuwwKeHj1vHNpf9pw4BVNk8swcm7TGB1a4_aem_AfIvCtryiq_7yx7_JRkm0CITtncGTrVqvjN4HfD9J1jqFo_QRaRQm4M2EbB_iE6lWpZMZeUaCUdrWRJLZNEdBP5l
  3- https://l.facebook.com/l.php?u=http%3A%2F%2Fwww.multiwii.com%2Fsoftware%3Ffbclid%3DIwZXh0bgNhZW0CMTAAAR2GIJIEu2t2RiI3Q6H0ssBgbaOqermY5apBkGWNF-jBZCvFCn_4uc4wGBs_aem_AfIA6w1xXYEhkjVwBcUmdoPSnmZLgMe1drfXZcm8jKqzN3z310ItwnhSYg-C2K-Gg9G_KmLencDjZEw5esVjl_wt&h=AT2TG5D8J6vqb6gWxP9QJek_eLfKzKaiiR5oidpuj3cF_Vj7re748jcWN-F_1Ir6HOGC2IoUJ9Z3IiIdLsFvnL-xzlNLQ1YNNTnFgJIAC0ZjDmozeEbl0lhGdUr4xl8N3tUtqC2psDl99S4

4- https://loveinsuar.live/product_details/19590224.html?fbclid=IwZXh0bgNhZW0CMTAAAR0InMKoMc_v9V1KD5XdByaCDMALAGoOuuvloOP6mUNw1tYgk3rqoqo0UbE_aem_AfJB46mJy9fZQpBRGodruTUYIHeWpUXSGdJPlikuQSRrQujZli5RnJwi4V6P1a0HENNyQkOjvcJZ9E35jRNfutwn

- **Arduino nano:**

https://wiki-content.arduino.cc/en/Guide/ArduinoNano

APPENDIX

MPU6050 gyroscope:

5.1 Gyroscope Features

The triple-axis MEMS gyroscope in the MPU-60X0 includes a wide range of features:

- Digital-output X-, Y-, and Z-Axis angular rate sensors (gyroscopes) with a user-programmable full-scale range of ±250, ±500, ±1000, and ±2000°/sec
- External sync signal connected to the FSYNC pin supports image, video and GPS synchronization
- Integrated 16-bit ADCs enable simultaneous sampling of gyros
- Enhanced bias and sensitivity temperature stability reduces the need for user calibration
- Improved low-frequency noise performance
- Digitally-programmable low-pass filter
- Gyroscope operating current: 3.6mA
- Standby current: 5µA
- Factory calibrated sensitivity scale factor
- User self-test

Figure 9: Gyroscope features of MPU6050

5.2 Accelerometer Features

The triple-axis MEMS accelerometer in MPU-60X0 includes a wide range of features:

- Digital-output triple-axis accelerometer with a programmable full scale range of ±2*g*, ±4*g*, ±8*g* and ±16*g*
- Integrated 16-bit ADCs enable simultaneous sampling of accelerometers while requiring no external multiplexer
- Accelerometer normal operating current: 500μA
- Low power accelerometer mode current: 10μA at 1.25Hz, 20μA at 5Hz, 60μA at 20Hz, 110μA at 40Hz
- Orientation detection and signaling
- Tap detection
- User-programmable interrupts
- High-G interrupt
- User self-test

Figure 10: Accelerometer features of MPU6050.

The MPU-60X0 includes the following additional features:

- 9-Axis MotionFusion by the on-chip Digital Motion Processor (DMP)
- Auxiliary master I^2C bus for reading data from external sensors (e.g., magnetometer)
- 3.9mA operating current when all 6 motion sensing axes and the DMP are enabled
- VDD supply voltage range of 2.375V-3.46V
- Flexible VLOGIC reference voltage supports multiple I^2C interface voltages (MPU-6050 only)
- Smallest and thinnest QFN package for portable devices: 4x4x0.9mm
- Minimal cross-axis sensitivity between the accelerometer and gyroscope axes
- 1024 byte FIFO buffer reduces power consumption by allowing host processor to read the data in bursts and then go into a low-power mode as the MPU collects more data
- Digital-output temperature sensor
- User-programmable digital filters for gyroscope, accelerometer, and temp sensor
- 10,000 *g* shock tolerant
- 400kHz Fast Mode I^2C for communicating with all registers
- 1MHz SPI serial interface for communicating with all registers (MPU-6000 only)
- 20MHz SPI serial interface for reading sensor and interrupt registers (MPU-6000 only)

Figure 11: additional features of MPU6050.

Arduino nano:

Features

- **ATmega328** Microcontroller
  - High-performance low-power 8-bit processor
  - Achieve up to 16 MIPS for 16 MHz clock frequency
  - 32 kB of which 2 KB used by bootloader
  - 2 kB internal SRAM
  - 1 kB EEPROM
  - 32 x 8 General Purpose Working Registers
  - Real Time Counter with Separate Oscillator
  - Six PWM Channels
  - Programmable Serial USART
  - Master/Slave SPI Serial Interface
- **Power**
  - Mini-B USB connection
  - 7-15V unregulated external power supply (pin 30)
  - 5V regulated external power supply (pin 27)
- **Sleep Modes**
  - Idle
  - ADC Noise Reduction
  - Power-save
  - Power-down
  - Standby
  - Extended Standby
- **I/O**
  - 20 Digital
  - 8 Analog
  - 6 PWM Output

Figure 12: Arduino nano features from the datasheet

EMAX RS2205 RaceSpec Motor - Cooling Series:

Specifications:

Model: RS2205

KV: 2300kv

Weight: Approx. 30g with wires

Wire AWG: 20AWG

Stator Diameter: 22mm

Stator Height: 5mm

Figure 13: motor specifications.

Shaft Diameter: 3mm

Configuration: 12N14P

Motor Diameter: 27.9mm

Motor Height: 31.7mm

Prop Adapter Shaft Thread: M5

Input voltage: 3S-4S (12.6 - 16.8v)

KV2300 With HQ5045 BN Max.thrust:1024g

KV2600 With HQ4045 BN Max.thrust:763g

Figure 14: motor specifications.