SWARM Research task 2
Kshitij Nigam 2025

Contents:

2.1 Electronic Components

<u>Flight Controller (FC):</u>

The flight controller is like the brain of the drone.

It's an electronic board, which consists of several components mainly like the processor and the sensor, and any other required component required to support the circuit. This component is known as a micro-controller and is called the brain cause it:

It's a circuit board with sensors that interpret the drone's movements and respond to the pilot's commands.

1. **Reads inputs** (like sensor values)
2. **Processes data** (computes, makes a decision on the basis of some parameter)
3. **Send an output** (like move left or right).
4. *REPEAT*

Flight controllers can be generalised into 2 main types:

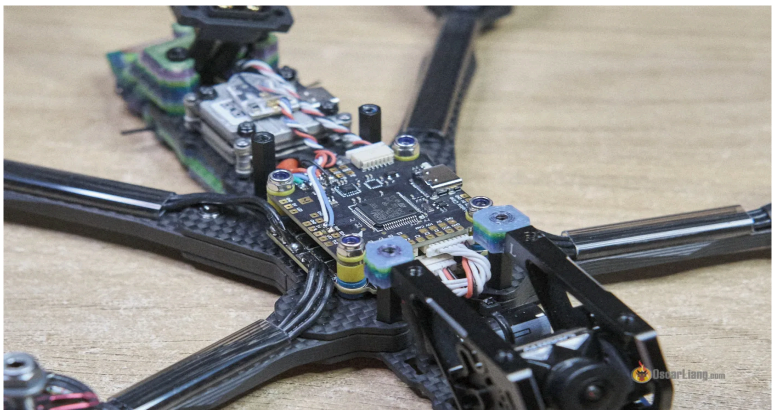
1. Regular FC
2. All in one (AIO) FC

Regular FC:

- ***A separate board dedicated mainly to processing flight data and commands.***
  - The flight controller is on its own board**.**
  - ESC and FC are in a stack (separate boards mounted on top of each other)

Use Case:

- Common in bigger drones.



Pros:

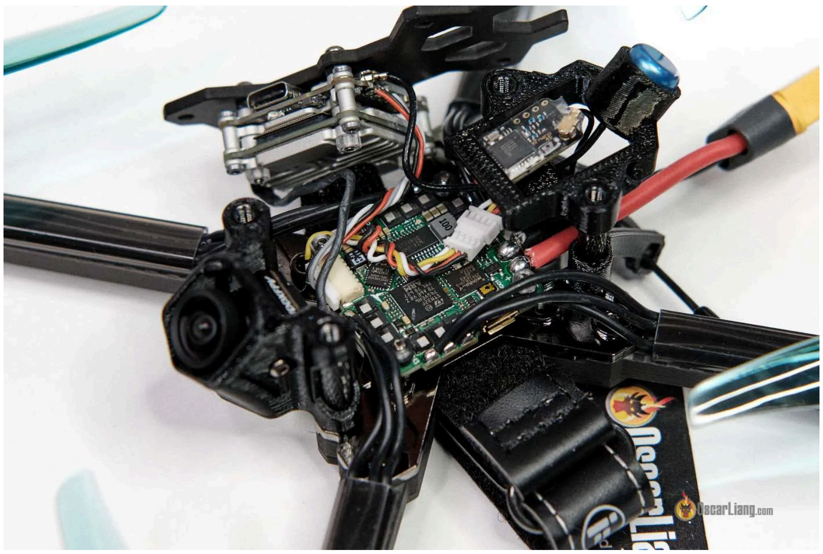
- Easier to replace or upgrade individual components.
- Can use higher-power ESCs for big motors.
- Better cooling and heat handling.

Cons:

- Bulkier and heavier (more boards and wires).
- Takes more space and is trickier to assemble.

AIO (ALL-IN-ONE) FC:

- **A single compact board that combines the FC + ESC**
  - All key components for controlling motors and sensors are built onto one board.
- **Use case:**
  - Common in small racing drones



Pros:

- Lightweight and compact.
- Simplifies wiring and assembly.
- Often cheaper for small builds.

Cons:

- If one part (like the ESC) burns out, you often have to replace the whole board.
- Usually handles less current, so less suitable for big drones with powerful motors.
- Repairs are harder.

https://oscarliang.com/flight-controller/#Flight-Controller-What-it-is-and-How-it-Works
https://oscarliang.com/flight-controller/#Flight-Controller-What-it-is-and-How-it-Works

<u>Electronic Speed Controller (ESC):</u>

electronic device used to control the speed, direction, and braking of an electric motor.

ESC's main operations are:

1. Takes the flight controller's commands.
2. Converts them into rapid electrical pulses.
3. Feeds the right amount of power to each motor, keeping the drone stable and responsive.

Components of ESC:

1. **MCU** – Reads signals and controls motor power.
2. **Gate Driver** – Strengthens signals for switching. *(works like an amplifier)*
3. **MOSFETs** – Switch power to the motor. *(kinda synthesises an AC power)*
4. **BEC** – Lowers battery voltage for electronics. *(extracts low voltages for electronics)*
5. **Current Sensor** – Tracks motor current.
6. **Temp Sensor** – Monitors ESC heat.
7. **Connectors/Wires** – Link battery, controller, and motor.

Next →

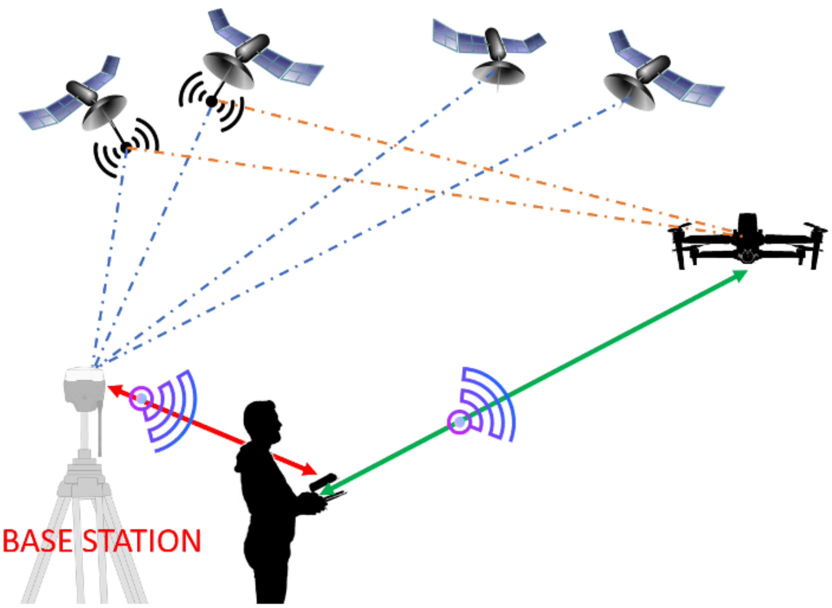
Global Positioning System (GPS):

The Global Positioning System (GPS) is a satellite-based navigation system that tells the drone its exact position on Earth.

Thus when a drone flies using GPS, it knows where it is relative to a 3D space, as long as it is connected to satellites and the base station.

How GPS Works

1. The drone's GPS receiver listens to signals from at least 4 satellites.
2. It calculates the distance to each satellite using the time it takes for signals to arrive.
3. By combining these distances, it finds the drone's latitude, longitude, altitude, and speed'



A **base station** is a fixed receiver placed on the ground at a known location.

1. The base station receives GPS signals from the same satellites as the drone.

2. Since its position is fixed and known, it can calculate any errors or signal delays in the GPS readings.

3. The base station sends correction data to the drone in real time.

4. The drone combines this correction with its own GPS data to determine its position with centimeter-level accuracy instead of the usual few meters.

The base station is a fixed ground unit that improves the GPS accuracy of the drone by sending correction signals.

Main Parts of GPS in a Drone

1. **GPS Receiver Module** – Captures signals from satellites.
2. **Antenna** – Boosts signal reception for better accuracy.
3. **Processor** – Calculates the drone's position from the signals.

Role in Drones

- Enables position hold (hovering in one spot).
- Allows autonomous navigation and waypoint missions.
- Provides Return-to-Home (RTH) functionality.
- Records flight paths for mapping or delivery tasks.

Pros:

- Self adjusts its errors, example: if a gust of wind blows the drone off-course; the drone can re-adjust.
- Cheap.

Cons:

- Needs to be outside to access satellites.
- Can produce faulty readings from large structures (like if too close to a building)

  This is where optical flow sensors come into consideration. (if no access to satellites)

Onboard Computer:

An onboard computer is a high-performance mini-computer mounted on the drone. It handles complex tasks that the flight controller alone cannot manage.

It works in coordination with the flight controller (FC):

- The **FC** manages real-time stabilization and motor control.
- The **onboard computer** handles advanced processing and decision-making tasks.

Main applications

- **Heavy Processing**: Runs advanced algorithms like computer vision, object detection, and SLAM (Simultaneous Localization and Mapping).
- **AI Tasks**: Recognizes objects, obstacles, or landing zones in real-time.(*Works well with NVIDEA Jetson*)
- **Sensor Fusion:** Combines data from LiDAR, cameras, GPS, etc., for better decision-making. This data can be used to create a 3D map.
- **Autonomous Control**: Supports self-flying, path planning, and obstacle avoidance.]

Common examples of some Onboard computers and their advantages:

- **NVIDIA Jetson –** popular for AI and vision-heavy tasks.
- **Raspberry Pi 4/5 –** good for lightweight processing or education.
- **Intel NUC –** used in larger drones for heavier processing.
- **Pixhawk Companion Computers –** designed to integrate tightly with flight controllers.

https://www.autopi.io/glossary/on-board-computer/

2.2 Sensors

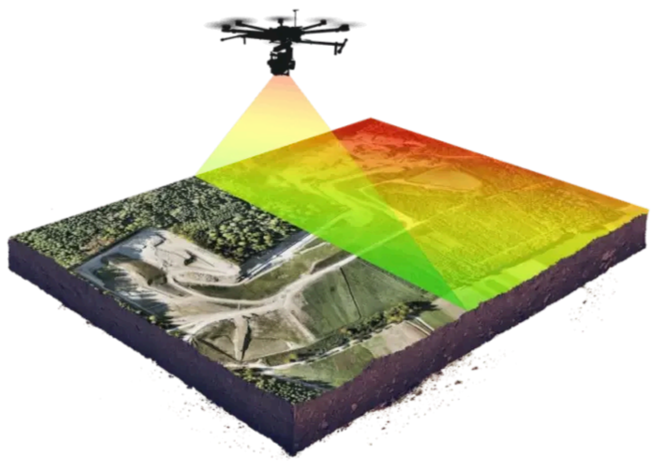
LiDARs

LiDAR stands for Light Detection and Ranging.

1. The LiDAR sensor emits rapid laser beams.
2. These beams hit objects and reflect back to the sensor.
3. By measuring the time of flight, the sensor calculates the distance to each object.

    a. **Distance = (Speed of Light × Time of Flight) / 2**

4. Collecting many such points creates a 3D map of the surroundings.



Lidar detection can be used in:

- Obstacle detection
- Altitude detection
- Mapping
- Navigation(by detecting obstacles)

Pros:

- High Accuracy: Measures distances with centimeter-level precision.
- Works in Low Light / Night: Since it uses its own laser light, it's not affected by ambient darkness.
- 3D Environmental Mapping: Creates rich point clouds for SLAM and autonomous flight.
- Fast Response: Good for real-time obstacle detection.

Cons:

- Higher Cost: More expensive than depth cameras or ultrasonic sensors.
- Shorter Range in Fog, Rain, or Dust: Particles scatter the laser beam, reducing effectiveness.
- Bulk & Weight: Larger LiDAR units can add weight to drones.
- Power Consumption: Continuous laser emission and data processing use more energy.

https://www.yellowscan.com/knowledge/how-does-lidar-work/

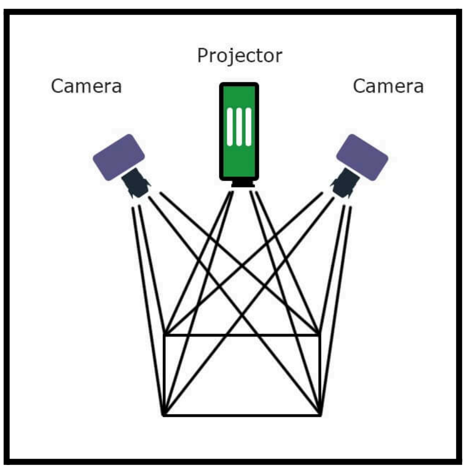
Depth Cameras

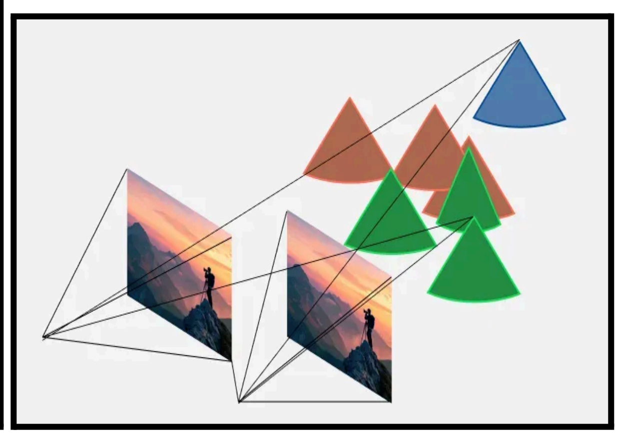
Depth cameras are not just normal feeds, but they have the ability to find the distance in realtime of each pixel(meaning they can in a way simulate the environment that they are recording.)

- Depth cameras make use of different methods to find these distances:

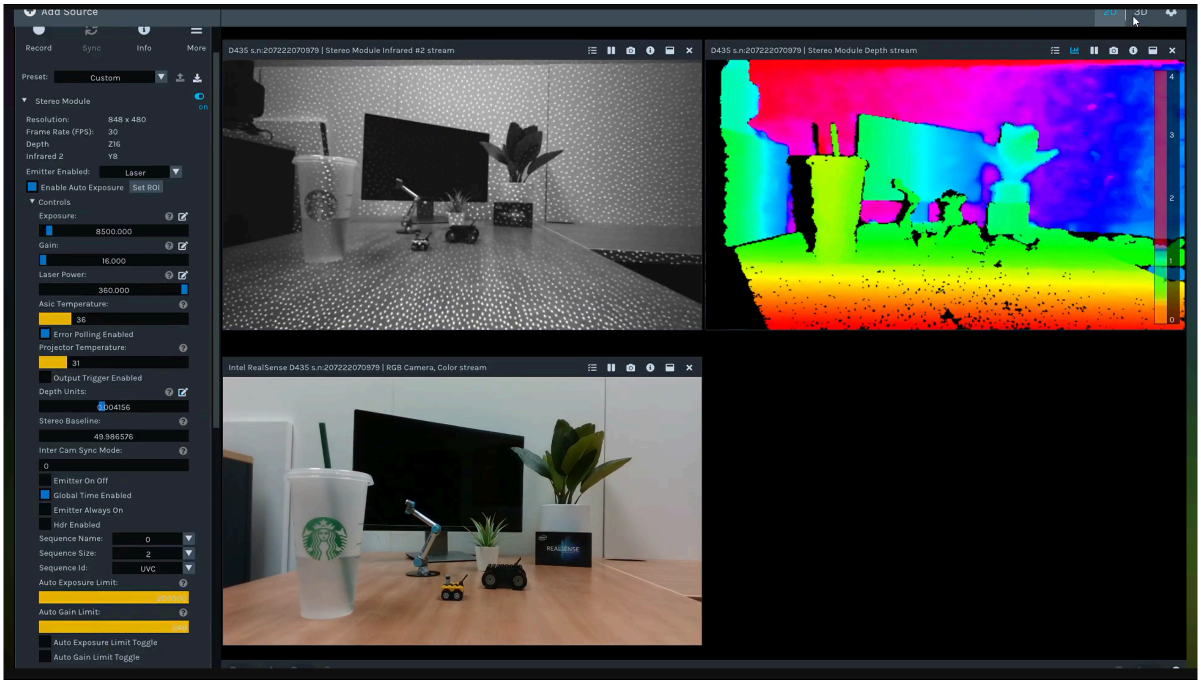
    Stereo vision -> (makes use of 2 cameras.)

    - It allows the perception of depth by identifying corresponding points in the images taken from each camera.
    - These 2 images can be analysed using Infrared projections or light patterns projected by the projector to figure out how far away each object is.
    - Using the information from these 2 cameras a depth map is created.





https://www.geeksforgeeks.org/computer-vision/stereo-vision-and-depth-estimation/



The image above shows the IR projections from a projector in the depth camera: intel realsense d435i.

- **Top left** shows the IR light projections, on the basis of which the distance will be found.
- Top right shows the distance of the objects, represented through a gradient of colors:
    - Near objects → usually red/yellow
    - Farther objects → green/blue/purple
- **Bottom** feed shows just a live feed, which makes use of both cameras.

Next →

Ref for both images: https://www.youtube.com/watch?v=KRZWev1N_uw

This is the final **depth map** created

Use case scenarios:

- **Obstacle Avoidance**
  - Detects nearby objects (trees, poles, walls) in real time.
  - Helps drones avoid collisions during flight.

- **Autonomous Navigation**
  - Enables drones to move safely in indoor or GPS-denied areas by sensing surroundings in 3D.

- **Precision Landing**
  - Measures exact distance to the ground

- **3D Mapping**
  - Captures detailed depth data for creating 3D maps of terrain

Optical flow sensor:

Used in conjunction with a height-detecting sensor.

An optical flow sensor does **not** know where it is in 3D space.

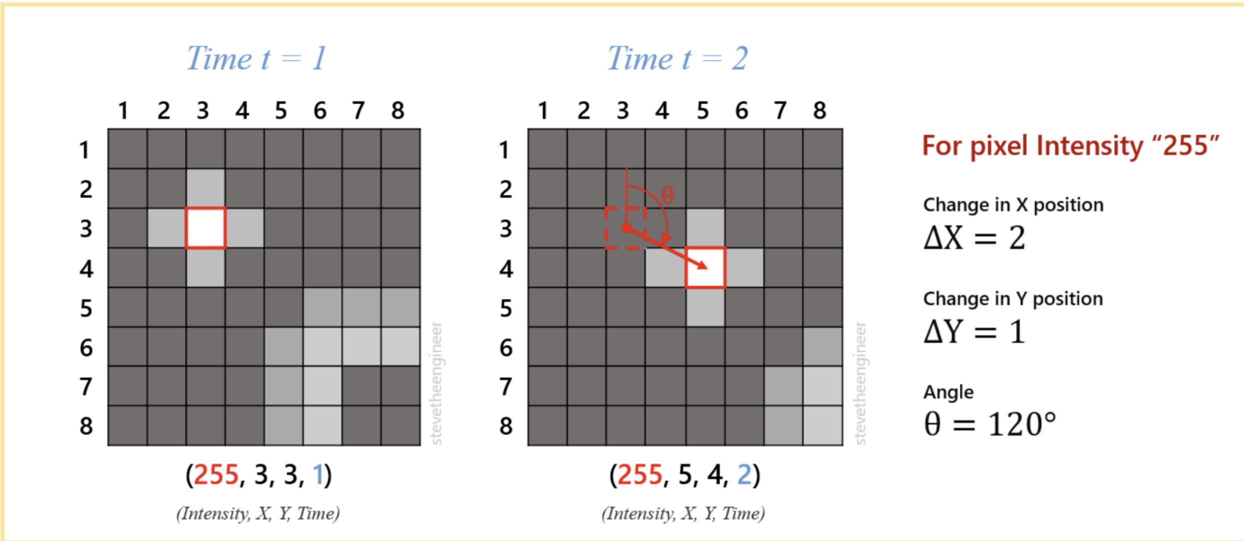
> **Analogy** ->*Imagine being blindfolded and feeling the carpet move beneath your feet. You sense your movement relative to the carpet but don't know your position in the room or how far you've gone.*

Main functioning of an optical flow sensor:

- Uses a camera (or an image sensor) that looks straight down at the ground.
- It tracks the apparent motion of ground patterns (like textures, lines, or speckles) between successive frames.
- By measuring how these patterns "flow" across the image, it infers the drone's horizontal movement (X-Y) relative to the ground.
- Optical flow alone can't tell you how far away the ground is — **it just detects motion *(hence a height detecting sensor is used in conjunction.)***

Only senses movement → the drone must keep track of the distance it has traveled to estimate its current position.

→ next



Ref = https://stevetheengineer.com/optical-flow/

This image shows how 2 pixels (1st at t=1, 2nd at t=2), would be analysed by an optical flow sensor.

- Thus the sensor can assume that we have moved 2 pixels right and 1 pixel down.
- Using this information, we can determine the velocity and direction of motion for each pixel. By repeating this process for all the pixels in the image, we can construct a rough 2D **velocity field** that represents the **optical flow**.

Optical Flow Sensor **Sonar Sensor(Height measurement)**

Ref = https://www.youtube.com/watch?v=mmeppFtjyng

Pros:

- Allows stable hovering indoors or in GPS-denied environments.
- High Precision at Low Altitude.
- Cheap.
- Lightweight and Compact **(especially helpful to keep under weight limit)**

Cons:

- Limited Altitude Range
- Needs Surface Texture, if surface texture is smooth, won't be able to find relative position.
- Accuracy drops in low light.
- Cannot provide absolute position(as opposed to GPS)

Next →

Additional Research

1. IR Sensor
2. Environmental Sensors (Wind, Barometer, IMU)

<u>Infrared Sensor (IR):</u>

- An infrared sensor detects objects and measures distance or temperature using infrared light

These sensors can be classified into 3 types:

1. **IR Distance Sensors:**
    - Emit infrared light and detect how much is reflected back.
    - Used for short-range obstacle detection (e.g., 10–80 cm).
    -
2. **IR Time-of-Flight (ToF) Sensors:**
    - Emit IR pulses and measure how long they take to return.
    - Provide more accurate distance measurements than basic proximity sensors.
3. **IR Thermal (Infrared Cameras):** ***(Not as relevant in navigation)***
    - Detects heat emitted by objects.
    - Used in search-and-rescue, surveillance, firefighting, or wildlife monitoring.

Why IR sensors can be useful in drones:

- Lightweight & Inexpensive: Ideal for small drones or basic obstacle avoidance.
- Works in Low Light: Does not rely on visible light.
- Good for Close-Range Tasks: Stable readings at short distances.

Cons

- Short Range: Typically effective only up to a few meters.
- Affected by Ambient Light & Reflective Surfaces: Bright sunlight or shiny objects can confuse the sensor.
- Limited Field of View: Covers a narrow detection cone compared to LiDAR or cameras.
- Lower Accuracy at Long Distances: Not suitable for detailed 3D mapping.

https://www.electronicsforu.com/technology-trends/learn-electronics/ir-led-infrared-sensor-basics

---

Environmental Sensors (Wind, Barometer, IMU)

- Environmental sensors don't directly detect obstacles, but they enhance flight safety, stability, and the performance of obstacle-detection systems by supplying vital information about the drone's surroundings.

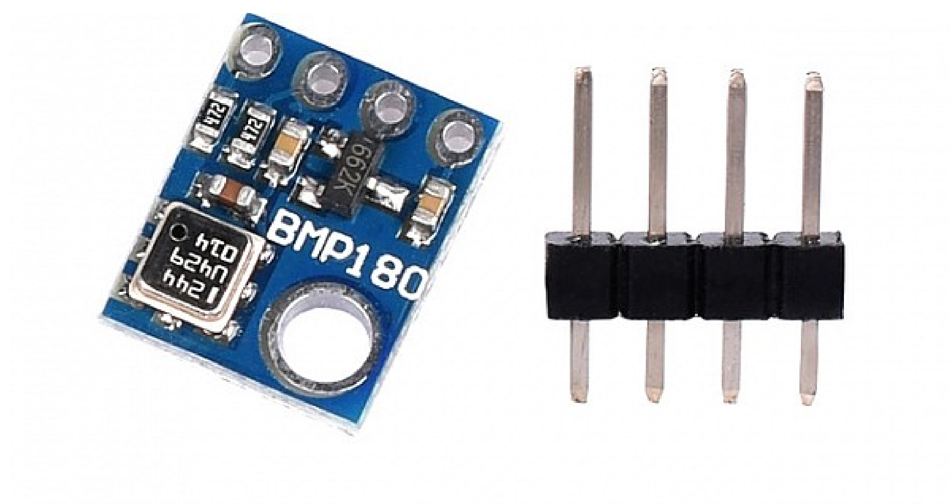
Wind Sensors (Anemometers)

Purpose: Measure wind speed and direction.

- **How it helps:**
  - Let the flight controller adjust thrust and attitude in gusty conditions.
  - Improves path-planning for stable hovering and precise landings.
  - Helps high-altitude / mapping drones plan energy-efficient routes.

Barometer (Barometric Pressure Sensor)

- **Purpose:** Measures air pressure to estimate altitude.



- **How it helps:**
  - Provides smoother altitude-hold than GPS, especially indoors or below 10m.
  - Used as a backup to laser/ToF altimeters during takeoff/landing.

- **Typical Specs:** Precision of ±10–20 cm in stable conditions.
- **Limitations:** Affected by rapid weather/temperature changes and prop wash.

IMU (Inertial Measurement Unit)

Combines accelerometers, gyroscopes (and sometimes magnetometers) to sense linear acceleration, angular velocity, and orientation.

- The measurement of motion, specifically, acceleration, rotation and velocity, is essential to understanding the orientation of an object.

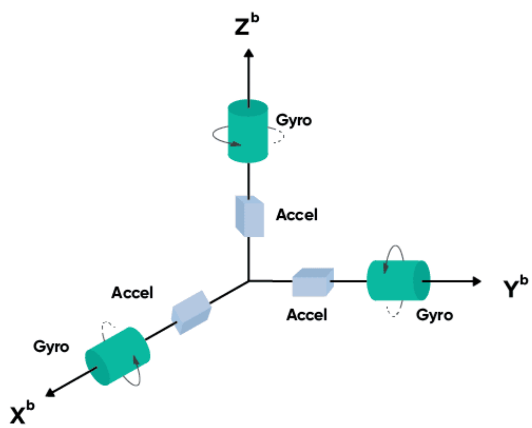


Image depicting the accelerometers and gyroscopes in the three axes of movement. Each accelerometer and gyroscope is positioned at 90 ° to the others (orthogonally). Accelerometers measure motion along each axis and each gyroscope measures angular velocity around each axis.

- **Accelerometers** are motion sensors that measure linear acceleration/rate of change in velocity of an object, relative to a local inertial reference frame.
- A **gyroscope** is a sensor that measures the rate of rotation (angular velocity) of an object around one or more axes.
- A **magnetometer** is used to detect and measure the strength and direction of the Earth’s magnetic fields in order to determine heading.

Role in Drones:

- Provides real-time data on attitude, orientation, and motion.
- Allows the flight controller to keep the drone stable and level.
- Enables accurate control during take-off, hovering, and maneuvering.

The IMU is the core motion-sensing unit — it tells the flight controller how the drone is moving, which is essential for balance and navigation.

https://landing.advancednavigation.com/tech-articles/inertial-measurement-unit-imu-an-introduction/

Sources:

ESC
https://www.tytorobotics.com/blogs/articles/what-is-an-esc-how-does-an-esc-work?srsltid=AfmBOopl_nbLYIx5ZuiQ8NOehxeJ-OGxUZ2jH6YUnvR4fXK-nKC-40RG

GPS:
https://www.youtube.com/watch?v=mmeppFtjyng
https://dronelife.com/2022/03/20/rtk-and-drone-mapping-do-you-need-it-is-it-worth-it/

OC:
https://www.autopi.io/glossary/on-board-computer/

LiDAR:
https://www.yellowscan.com/knowledge/how-does-lidar-work/

Depth Camera:
https://www.geeksforgeeks.org/computer-vision/stereo-vision-and-depth-estimation/
https://www.youtube.com/watch?v=KRZWev1N_uw

OFS:
https://stevetheengineer.com/optical-flow/
https://www.youtube.com/watch?v=mmeppFtjyng

Additional Research:
IR:
https://www.electronicsforu.com/technology-trends/learn-electronics/ir-led-infrared-sensor-basics

Wind sensor:
https://www.renkeer.com/wind-sensor-working-principle/

Barometer:
https://superiorsensors.com/what-does-a-barometric-pressure-sensor-do-2/

IMU:
https://landing.advancednavigation.com/tech-articles/inertial-measurement-unit-imu-an-introduction/